# Naturally-Occurring Radioactive Materials (NORM)

(*March 2009*)

- **Radioactive materials which occur naturally and expose people to radiation occur widely, and are known by the acronym 'NORM'.**
- **Exposure to NORM is often increased by human activities, eg burning coal, making and using fertilisers, oil and gas production.**
- **Radon in homes is one occurrence of NORM which may need to be controlled, by ventilation.**

NORM is an acronym for Naturally Occurring Radioactive Material, which includes all radioactive elements found in the environment. Long-lived radioactive elements such as uranium, thorium and potassium and any of their decay products, such as radium and radon are examples of NORM. These elements have always been present in the Earth's crust and within tissues of all living beings.

Many natural materials contain radioactive elements (radionuclides). The Earth's crust is radioactive and constantly leaks radon gas into our atmosphere. However, while the level of individual exposure from all this is usually trivial, some issues arise regarding regulation, and also perspective in relation to what is classified as radioactive waste.

Over the years there have been many occasions when it was asserted that coal-fired power stations emitted more radioactivity (from NORM) than was released anywhere in the nuclear fuel cycle. While having some basis in fact the claim is generally not correct now. Today the contention regarding NORM tends to be in relation to steel and other materials released from demolished industrial facilities, and whether the clearance level for this should be at or below naturally-occurring levels.

Another NORM issue relates to radon exposure in homes, particularly those built on granitic ground. Occupational health issues include the exposure of flight crew to higher levels of cosmic radiation, the exposure of tour guides to radon in caves, and exposure of miners generally and workers in the oil & gas and mineral sands industries to elevated radiation levels due to radionuclides in the Earth.

A characteristic of NORM is that because of their wide distribution from many sources, they give rise to a very much larger radiological effect to the public (by about four orders of magnitude) compared with that caused by the nuclear industry.

## Coal

Most coal contains uranium and thorium, as well as potassium-40, lead-210, and radium-226. The total levels are generally about the same as in other rocks of the Earth's crust. Most emerge from a power station in the light flyash, which is fused and chemically stable, or the bottom ash. Some 99% of flyash is typically retained in a modern power station (90% is some older ones), and this is buried in an ash dam.

The amounts of radionuclides involved are noteworthy. In Victoria, 65 million tonnes of brown coal is burned annually for electricity production. This contains about 1.6 ppm uranium and 3.0-3.5 ppm thorium, hence about 100 tonnes of uranium and 200 tonnes of thorium is buried in landfill each year in the Latrobe Valley. Australia exports 235 Mt/yr of coal with 1 to 2 ppm uranium and about 3.5 ppm thorium in it, hence up to 400 tonnes of uranium and about 800 tonnes of thorium could conceivably be added to published export figures.

Other coals are quoted as ranging up to 25 ppm U and 80 ppm Th. In the USA, ash from coal-fired power plants contains on average 1.3 ppm of uranium and 3.2 ppm of thorium, giving rise to 1200 tonnes of uranium and 3000 tonnes of thorium in ash each year (for 955 million tonnes of coal used for power generation). Applying these concentration figures to world coal consumption for power generation (7800 Mt/yr) gives 10,000 tonnes of uranium and 25,000 tonnes of thorium per year.

It is evident that even at 1 ppm U in coal there is more energy in the contained uranium (if it were to be used in a fast breeder reactor) than in the coal itself. At 25 ppm U and used simply in a conventional reactor it would be half as much as the coal.

The actual **radioactivity levels** are not great. UNSCEAR estimated that average concentrations in coal worldwide were 50 Bq/kg K-40 and 20 Bq/kg each U & Th, though CSIRO data quoted in Dale (1996) puts Australian figures at average 830 Bq/kg total radioactivity, related to 1.8 ppm U and 7 ppm Th in the coal, but contrasted with some 1400 Bq/kg average in the Earth's crust. US NCRP figures (in Gabbard 1993) give 174 Bq/kg average total radioactivity in US coal. Cooper (2003) gives 100-600 Bq/kg range for NSW coals and Misha (2004) 145 Bq/kg average in Indian coal.

**Radioactivity in Coal** (Bq/kg)

| source | | Total activity Bq/kg | Uranium series | Thorium series | K-40 |
|---|---|---|---|---|---|
| UNSCEAR | world | | 20 | 20 | 50 |
| CSIRO in Dale | Australia | 830 | | | |
| Gabbard | USA | 174 | | | |
| Cooper 2005 | NSW | | 8-50 | 20-70 | 70-500 |
| | Victoria | | 10-15 | 5-15 | 20-90 |
| | Queensland | | 10-20 | 10-20 | 10-40 |
| Misha | India | 145 | | | |
| Earth's crust | world | 1400 | | | |

UNSCEAR (1993) gives 3645 Bq/kg average in flyash. The above US data at 15% ash give 1200 Bq/kg in flyash. Dale (1996) quotes CSIRO figures of 2630 and 3200 Bq/kg from a high-ash NSW coal. Cooper (2003) gives up to 1500 Bq/kg for flyash and up to 570 Bq/kg for bottom ash in NSW. There are obvious implications for the use of flyash in concrete, and the data also may be compared with levels of 1.0 or 3.7 MBq/kg sometimes taken as threshold levels for classifying material as low-level radioactive waste, or with 25 MBq/kg for uranium metal.

**Radioactivity in Coal Ash** (Bq/kg)

| source | | Total activity | Pb-210 | Uranium series, Ra-226 | Thorium series | K-40 |
|---|---|---|---|---|---|---|
| UNSCEAR | world | 3645 | | | | |
| Gabbard | USA | 1200 | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CSIRO** | **Australia** | 2630 | | | | | |
| | **NSW** | 3200 | | | | | |
| **Cooper 2003** | **Australia** | up to 2070 | | | | | |
| **Cooper 2005** | **NSW** | | 130-200 | 80-150 | | 100-200 | 500-800 |
| | **Victoria** | | 15 | 20 | | 15 | 110 |
| | **Queensland** | | 40-100 | 70-120 | | 50-160 | 50-400 |
| **Earth's crust** | **world** | 1400 | | | | | |

With increased uranium prices the uranium in ash becomes significant economically.  In the 1960s and 1970s, some 1100 tU was recovered from coal ash in USA.  In 2007 China National Nuclear Corp commissioned Sparton Resources of Canada with the Beijing No.5 Testing Institute to undertake advanced trials on leaching uranium from coal ash out of the Xiaolongtang power station in central Yunnan.  It and two nearby power stations use lignite with high ash content (20-30%) and very high uranium content, from a single open-cut mine.  The coal uranium content varies from about 20 to 315 ppm and averages about 65 ppm.  The ash averages about 210 ppm U (0.021%U) - above the cut-off level for some uranium mines.  The power station ash heap contains over 1000 tU, with annual arisings of 190 tU.  (Recovery of this by acid leaching is about 70%.)  Sparton also has an agreement to extract uranium from coal ash following germanium recovery in the Bangmai and Mengwang basins in Yunnan.  This ash ranges from 150 to over 4000 ppm U (0.40 %U), averaging 250 ppm U (0.025%).  Then Sparton was commissioned by WildHorse Energy to assess the potential for recovering uranium from European coal ash having 80 - 135 ppm U.

## Mineral Sands

Mineral sands, mined chiefly for titanium minerals and zircon, often have a significant proportion of monazite, a rare earth mineral containing thorium and other elements of economic significance. The minerals in the sands are subject to gravity concentration, and some concentrates are significantly radioactive, up to 4000 Bq/kg. Dust control in the plants is the main means of limiting radiation doses to personnel.

**Radioactivity in Australian mineral sands** (Bq/g)

| | **thorium** | **uranium** |
|---|---|---|
| **ore** | 0.02-0.03 | 0.03-0.12 |
| **concentrate** | 0.3-3.0 | 0-0.8 |
| **ilmenite, rutile** | 0.2-2.0 | 0-0.6 |
| **zircon** | 0.6-1.2 | 1-4 |
| **monazite** | 40-250 | 6-30 |

Cooper 2005.

See also Appendix.

## Tantalum concentrate

Tantalum ores, often derived from pegmatites, comprise a wide variety of more than a hundred minerals, some of which contain uranium and/or thorium. Hence the mined ore and its concentrate contain both these and their decay products in their crystal lattice. Concentration of the tantalum minerals is generally by gravity methods (as with mineral sands), so the lattice-bound radioisotope impurities if present will report with the concentrate.

While this has little radiological significance in the processing plant, concentrates shipped to customers sometimes exceed the Transport Code threshold of 10 kBq/kg, requiring declaration and some special documentation, labeling and handling procedures. Some reaches 75 kBq/kg.

## Phosphates

Phosphate rock used for fertiliser is a major NORM due to uranium and thorium. Australian phosphate rock contains up to 900 Bq/kg and that imported is about twice this, yielding about 1000 Bq/kg in phosphogypsum waste stream and up to 3000 Bq/kg in the superphosphate product. In the USA some 50 million tonnes per year are produced and state figures (UNSCEAR 1977) average up to 10,000 Bq/kg of total radioactivity. Processing this phosphate sometimes gives rise to measurable doses of radiation to people. Phosphate rocks containing up to 120 ppm U have been used as a source of uranium as byproduct – some 17,000 tU in USA, and are likely to be so again.

European fertiliser manufacturing gave rise to discharges of phophogypsum containing significant quantities of Ra-226, Pb-210 and Po-210 into the North Sea and North Atlantic. This has been overtaken as a source of radioactivity by offshore oil and gas production in Norwegian and UK waters releasing some 10 TBq/yr of Ra-226, Ra-228 & Pb-210. This means that they contribute 90% of the alpha-active discharges in those waters (two orders of magnitude more than the nuclear industry, and with this NORM having higher radiotoxicity).

## Oil and Gas production

In the oil and gas industry radium-226 and lead-210 are deposited as scale in pipes and equipment. If the scale has an activity of 30,000 Bq/kg it is 'contaminated' (Victorian regulations). This means that for Ra-226 scale (decay series of 9 progeny) the level of Ra-226 itself is 3300 Bq/kg. For Pb-210 scale (decay series of 3) the level is 10,000 Bq/kg. These figures refer to the scale, not the overall mass of pipes or other material (cf Recycling, below). Published data (quoted in Cooper 2003) show radionuclide concentrations in scales up to 300,000 Bq/kg for Pb-210, 250,000 Bq/kg for Ra-226 and 100,000 Bq/kg for Ra-228. In Cooper 2005, the latter two maxima are 100,000 and 40,000 respectively.

## Other solid NORM

Building materials can contain elevated levels of radionuclides including radium-226, thorium-232 and potassium-40, the last being most significant in published Australian data, ranging up to 4000 Bq/kg in natural stone and 1600 Bq/kg in clay bricks and concrete. Bricks can also contain up to 2200 Bq/kg of Ra-226 (Cooper 2005).

In smelting iron ore, lead-210 and polonium-210 accumulate in dust from smelter and sinter plant operations, in the latter case to 34,000 Bq/kg at Port Kembla in Australia.

Granite, widely used as a cladding on city buildings and also architecturally in homes, contains an average of 3 ppm (40 Bq/kg) uranium and 17 ppm (70 Bq/kg) thorium. Radiation measurements on granite surfaces can show levels similar to those from low-grade uranium mine tailings.

## Radon

Radium-226 is one of the decay products of uranium-238, which is widespread in most rocks and soils. When this radium decays it produces radon-222, an inert gas with a half life of almost 4 days. (Radium-224 is a decay product of thorium, and it decays to radon-220, also known as thoron, with a 54-second half-life.) Because radon is so short-lived, and alpha-decays to a number of daughter products which are solid and very short-lived, there is a high probability of its decay when breathed in, or when radon daughter products in dust are breathed in. Alpha particles in the lung are hazardous.

Radon levels in the air range from about 4 to 20 Bq/m 3. Indoor radon levels have attracted a lot of interest since the 1970s and in USA they average about 55 Bq/m 3, with an EPA action level of 150 Bq/m 3. Levels in Scandinavian homes are about double the US average, and those in Australian homes average one fifth of those in USA. Levels up to 100,000 Bq/m 3 have been measured in US homes. In caves open to the public, levels of up to 25,000 Bq/m 3 have been measured.

Radon also occurs in natural gas at up to 37,000 Bq/m 3, but by the time it gets to consumers the radon has largely decayed. However, the solid decay products then contaminate gas processing plants, and this manifestation of NORM is an occupational health issue.

## Recycling and NORM

Scrap steel from gas plants may be recycled if it has less than 500,000 Bq/kg (0.5 MBq/kg) radioactivity (the exemption level). This level however is one thousand times higher than the clearance level for recycled material (both seel and concrete) from the nuclear industry! Anything above 500 Bq/kg may not be cleared from regulatory control for recycling.

Decommissioning experts are increasingly concerned about double standards developing in Europe which allow 30 times the dose rate from non-nuclear recycled materials than from those out of the nuclear industry. Norway and Holland are the only countries with consistent standards. Elsewhere, 0.3 to 1.0 mSv/yr individual dose constraint is applied to oil and gas recyclables, and 0.01 mSv/yr for release of materials with the same kind of radiation from the nuclear industry.

The main radionuclide in scrap from the oil and gas industry is radium-226, with a half-life of 1600 years as it decays to radon. Those in nuclear industry scrap are cobalt-60 and caesium-137, with much shorter half-lives. Application of a 0.3 mSv/yr dose limit results in a clearance level for Ra-226 of 500 Bq/kg, compared with 10 Bq/kg for nuclear material.

The concern arises because of the very large amounts of Tenorm (technologically-enhanced NORM) needing recycling or disposal from many sources. The largest Tenorm waste stream is coal ash, with 280 million tonnes arising globally each year, and carrying uranium-238 and all its non-gaseous decay products, as well as thorium-232 and its progeny. This is usually just buried. However, the double standard means that the same radionuclide, at the same concentration, can either be sent to deep disposal or released for use in building materials, depending on where it comes from. The 0.3 mSv/yr dose limit is still only one tenth of most natural background levels, and two orders of magnitude lower than those experienced naturally by many people, who suffer no apparent ill effects.

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# Mineral Sands

## Naturally-Occurring Radioactive Material Appendix 1

*(Updated September 2010)*

- **Australia and Africa are major producers of mineral sands containing titanium minerals and zircon.**
- **A minor constituent of many mineral sands deposits is monazite, which is the main source of thorium.**
- **As thorium is radioactive, occupational health provisions are required for handling materials containing thorium.**

Australia and Africa have extensive deposits of mineral sands which comprise:

- Titanium minerals: rutile – $TiO_2$ with up to 10% iron; ilmenite – $FeTiO_3$ with some manganese and magnesium; and leucoxene – hydrothermally altered ilmenite.
- Zircon (zirconium silicate, $ZrSiO_4$), which may have traces of uranium & thorium (up to 500 ppm) in the crystal structure, along with hafnium.
- Monazite – a rare earth phosphate containing a variety of rare earth minerals (particularly cerium and lanthanum) and 5-12% (typically about 7%) thorium.
- Xenotime – yttrium phosphate with traces of uranium and thorium.

These mineral sands are in placer deposits which have been naturally concentrated by gravity. They have been mined since 1934 and Australia has a major share of the world market for both titanium minerals and zircon. In the mining plant they are concentrated by gravity (in spiral sluices) and magnetically (for ilmenite).

While the main products of mineral sands mining are titanium oxide and zircon, monazite is also a significant component. In some deposits xenotime also occurs. Monazite and xenotime may be processed to recover rare earth oxides[a], which are used in electronics and other specialist fields, but the presence of thorium[b] makes them commercially unattractive. Monazite is thus normally returned to the mine with the tailings.

Western Australian mineral sands deposits contain up to 10% heavy minerals, of which 1-3% is monazite. This in turn typically contains 5-7% of radioactive thorium and 0.1-0.3% of uranium, which is barely radioactive. However, if decay products of either are present in the minerals, the radioactivity levels may be significant when the monazite is concentrated.

### Radioactivity

The occupational health issue of specific relevance to the mineral sands industry is radiation. In ore or general heavy mineral concentrate, the radiation levels are too low for radioactive classifications. However, when the radioactive material is concentrated in the process of separation and production of monazite, the radiation levels are increased, creating the need for special controls to protect some designated employees in dry separation plants.

The most significant potential radiation problem is alpha radiation arising from thorium in airborne dust dust, which may be inhaled. Dust control is therefore the most important objective in radiation safety for the titanium minerals industry. This contrasts with other industries where the focus for radiation protection has been direct gamma radiation from materials in rock. Exposure to gamma radiation still needs to be controlled in the mineral sands industry, due principally to uranium and thorium in zircon.

Australian radiation protection standards

In Australia, the more precise identification of airborne radiation in mineral sands dry separation plants led to the introduction of voluntary codes of practice in 1980. These codes were incorporated into protective legislation in 1982. The method of calculating permissible exposure levels was changed in 1984 and again in 1986. The result was an effective six-fold reduction in radiation exposure limits.

The industry responded with two major initiatives:

- Engineering programs to reduce airborne dust in the dry separation plant.
- Research programs to improve industry and community knowledge about airborne radiation.

Collectively, the titanium minerals mining companies in Western Australia[c] have spent more than $30 million on engineering programs to improve dust control measures. As a result, average radiation levels have been reduced by more than 70%. Protective masks are no longer required for most plant operators. All new plant is designed to incorporate efficient dust control equipment.

Titanium minerals production is managed under the *Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing*[1]. The current occupational exposure radiation levels are well below the Code limit of 20 millisieverts per year (mSv/yr)[d].

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## Further Information

### Notes

a. 'Rare earths' (scandium, yttrium, and the fifteen lanthanides), while valuable, are not particularly rare and preferred sources do not have thorium present. For example, lanthanum and cerium now come from ionic clays in China, which do not have thorium present. [Back]

b. Thorium oxide is used in refractories, lamp mantles, specialised glass and welding electrodes. However, the potential supply as a by-product of mineral sands mining vastly exceeds demand. [Back]

c. Most of Australia's mineral sands occur on the east coast of Australia between Sydney and Fraser Island or on the southern section of the west coast. New South Wales and Queensland producers are required to meet the same standards as Western Australian miners. However, the limited monazite content of most east coast deposits means that radiation levels in New South Wales and Queensland dry plants have always been well below occupational health limits. [Back]

d. Australian occupational exposure limits correspond to those set by the ICRP (International

Commission for Radiological Protection). These are given in paragraph 166 of the ICRP 1990 Recommendations, *ICRP Publication 60*: "A limit on effective dose of 20 mSv per year, averaged over five years (100 mSv in five years), with the further provision that the effective dose should not exceed 50 mSv in any single year." [Back]

## References

1. Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005), Radiation Protection Series No. 9, Australian Radiation Protection and Nuclear Safety Agency (August 2005) [Back]

## General sources

Titanium Fact Sheet on the Australian Atlas of Mineral Resources, Mines, and Processing Centres website (www.australianminesatlas.gov.au)

Greg Baker, Thorium in Australia, Research Paper no. 11 2007-08, Parliament of Australia (September 2007)