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Good paper

NORM IN MINERAL PROCESSING

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Two reports on naturally occurring radioactive material (NORM) have been published by the NORM Task Force (later the NORM Committee) of the Conference of State Radiation Control Program Directors (1,2). These reports described a number of mineral extraction industries where elevated levels of NORM had been found.

At the 11th Annual Conference in Oklahoma City, I presented information (3) discussing U.S. Environmental Protection Agency (EPA) studies which were underway to evaluate NORM in air emissions from some of these mineral extraction industries. The facilities to be studied were selected from among the agencies where one might expect to find enhanced levels of NORM. Information to be acquired in these studies was to be used in standard setting under the Clean Air Act, the Resource Conservation and Recovery Act, and the Uranium Mill Taings Radiation Control Act.

This paper will summarize some of the results from those EPA studies. It will also discuss NORM levels in baddeyelite processing and in facilities using chlorination processes. Finally the subject of "geogas" will reviewed.

The kinds of industries studied by EPA are shown in Table 1.

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TABLE 1

Mineral Extraction Industries Believed to Involve Enhanced Levels of NORM

Metallic		Nonmetallic
Aluminum*	Rare Earths	Clays*
Beryllium	Silver	Coal*
Columbium	Tantalum	Fluorspar*
Copper*	Thorium	Granite
Gold	Tin	Limestone*
Iron*	Titanium*	Phosphate*
Lead*	Uranium*	
Molybdenum	Zinc*	
Nickel	Zirconium*	

* USEPA field studies performed

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I'm going to exclude coal and uranium from my discussion since coal has been covered by the previous speaker and the uranium data has been previously presented at other meetings. Excluding coal and uranium about 30 facilities were studied. Selection for the study was, in part, based on size and on the potential to emit dosimetrically significant quantities of NORM to the atmosphere. The studies were performed by the EPA Office of Radiation Programs Las Vegas Facility staff and by EPA contractors. For a number of reasons it was not possible to carry out studies on all of the suspect industries. The studies were designed to obtain information on NORM leve's in air emissions, ores, process materials, and waste streams. Data on some of the studied facilities was published in EPA reports although data on thirteen facilities was not published but was placed in EPA open files.

Of the industries shown as not studied in Table 1, at least one beryllium plant has a uranium loop on its process stream. Columbium-tantalum ores, such as pyrochlore ore, are reported to contain over 3% uranium which would correspond to over 8,000 picocuries per gram of radium-226 if the uranium chain is in equilibrium. Gold is sometimes associated with uranium deposits. Gold mines were the source of some of the original radium ores in the form of pitchblend and produced some of the most radioactive ores found in this country. Molybdenum, nickel, and silver are all associated with some U.S. uranium deposits. Rare earths have been typically found in monazite sands which contain both uranium and thorium chain NORM. Much of the present rare earth production in the U.S. comes from a single bastnaesite deposit located in a high thorium area. Current U.S. thorium production is small to non-existent. The second NORM Committee report indicates levels of up to 26 picocuries per gram of radium-226 in tin smelter slag. Several uranium mills were included in the studies. Uranium mill data has been published in EPA reports. Some data on NORM levels in granite were reported in the first NORM report. Granite is elevated in potassium-40 and in both thorium and uranium chain radionuclides.

Table 2 shows the radium-226 levels in the ores in the industries studied by EPA. With minor exceptions, the uranium chain radionuclides are in near equilibrium. The thorium chain radionuclides for the facilities sampled are usually at slightly lower concentrations than the members of the uranium chain. Other investigators have reported higher levels of NORM in some of these minerals such as zirconium.

Table 3 lists the measured emission rates for polonium-210, lead-210, and radon-222. Most of the mineral extraction facilities use some sort of high temperature process which can range from dryers to electric arc furnaces. The elevated temperatures are usually high enough to cause volatilization and release of polonium and lead with respect to other radionuclides. The amount of release is determined by a combination of factors which includes NORM levels in the ore, tonnage of ore processed, process chemistry, process temperatures, and efficiency and proper functioning of air cleaning systems.

The radon releases shown are for the entire facility. The four largest releases listed as well as some of the smaller releases, are primarily from the mines associated with the individual facilities.

All of these industries process relatively large tonnages of ore. Quantities of waste generated by some of these industries are shown in Table 4 (4). Other industries handle quantities as small as a few tons of exotic ores. Some of these ores may contain NORM in levels approaching those of uranium ores. Custom smelters or custom refiners should be evaluated when possible.

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TABLE 2

Radium- 226 in Selected Mineral Ores

Commodity	Radium-226 (picocuries/gram)
Alumina- Bauxite	7.4
Clay - Facing brick	0.49, 0.77*
- Fireclay	1.4
Copper	0.81, 0.89, 1.0, 1.5**
Fluorspar	1.3
Iron	0.36, 0.81, 3.1**
Lead	0.65
Limestone	0.40
Phosphate - Elemental phosphorus	3.1, 26, 26, 50**
- Fertilizer	23, 28, 28, 32
Titanium - Ilmenite (pigment)	0.30
- Leucoxene (metal)	12
- Rutile (metal)	15
Zinc	0.11, 0.52, 0.81**
Zirconium	13

* One facility
** Multiple facilities
*** Two facilities

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One such industry not evaluated in the EPA studies processes baddeleyite ore from South Africa. The ore contains 97-99% zirconium oxide. The material is fused in an electric furnace, then crushed, ground, and classified into a final product. The final product is sold for use in sprayed thermal coatings and in refractory products. The ore contains both uranium and thorium chain radionuclides in about equal quantities. Radium-226 levels are shown in Table 5. This firm did not realize that it was processing radioactive ore until its finished product was returned by a customer because of the radioactive content of the product.

Note that there is some reduction in radium-226 in going from the ore to the finished product. The high temperature of the electric furnace volatilizes the polonium and lead as can be seen from the high lead-210 in the collector dust.

Annual gamma radiation exposure rates (for 2000 hours per year) were less than 100 mrem/year for about half the work areas in the processing and warehousing areas. About 40% of the work areas were in the 100-200 mrem/year range with about 10% of the areas in the 200-1,000 mrem/year range.

This is not the only U.S. company using South African baddeleyite. In 1980 it was being used for manufacture of abrasives, ceramic colors, and other uses.

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TABLE 3

Selected Radionuclide Emission Rates

Facility	Polonium-210 (millicuries/year)	Lead-210 (millicuries/year)	Radon -222 (millicuries/year)
Alumina reduction plant	9.3	7.8	2,800
Aluminum reduction plant	27	32	-
Facing brick plant	23	16	190
Fireclay mine & plant	0.04	0.005	17,000
Copper - smelter	15	13	2,500
- smelter	30	65	-
- UG mine & crusher	-	-	6,500
- crusher & hopper	2	1.9	1,900
Fluorspar UG mine & mill	0.01	0.01	1,400
Iron - mine & plant	97	63	2,900
- mine & pellet plant	3,400	154	72,000
Lead smelter	21	26	-
Limestone UG mine & crushers	0.50	0.38	720
Phosphate - elemental phosphorus	750	490	9,600
- elemental phosphorus	210	280	9,700
- elemental phosphorus	7,400	18*	-
- elemental phosphorus	21,000	600	-
- fertilizer plant	5-10	5-10	-
Titanium - metal	0.2	0.8	710
- pigment (sulfide)	0.56	2.2	-
Zinc - smelter	15	25	300
- UG mine & mill	2.2	1.6	230,000
Zirconium - metal	0.43	0.011	-
Phosphate - UG mine & Crushers	0.065	110	86,000

* Lead-210 may be low by up to a factor of five.

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A number of mineral processing industries use a chlorination stage as a part of their process. These industries should be more carefully evaluated. In the first NORM Task Force report and elsewhere, Oregon has described a zirconium extraction process using chlorination of zircon sands. This process produces residues containing relatively soluble radium chloride. Because of its solubility and ready leachability, the radium chloride presents a potential surface and groundwater contamination problem. From a zircon ore originally containing about 100 picocuries per gram of radium-226, process residues and sludges were found to contain up to

1,300 picocuries per gram. Water under a chlorinator residue pile measured up to 45,000 picocuries per liter of radium-226.

A different zirconium facility studied by EPA had radium-226 levels in the ore of 13 picocuries per gram increasing to 890 picocuries per gram in the chlorinator residue for an enhancement in radium level of almost 70 times.

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TABLE 4

Waste Generation (millions of metric tons)

Metals	1982 Mine Waste	Tailings	Leach Wastes	Total	1910 - 1981 Total
Copper	124	178	200	502	23,900
Gold	39	24	11	74	750
Iron	102	75		177	11,500
Lead	2	9		11	530
Molybdenum	24	6		30	870
Silver	20	6	1	26	80
Uranium	73	*		73	2,180**
Zinc	1	6		7	800
Other metals***	2	3		26	*
Subtotal	408	307	211	1,329	40,610
Nonmetals					
Phosphate rock	294	109		403	7,700
Totals	702	416	211	1,329	48,310

* Not reported

** Includes 180 million metric tons of tailings

*** Includes antimony, bauxite, beryllium, mercury, rare earths, tungsten, and vanadium.

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TABLE 5

Baddeleyite - Radium-226 Levels

Sample	Radium-226 (picocuries/gram)
Baddeleyite ore - SQ Grade (99% ZrO_2)	180, 290 *
Baddeleyite ore - N Grade (98% ZrO_2)	215, 290
Fused N Grade	200, 290
Ingot material	120, 250
Finished product (MZ-80)	120, 170
Dust - collector fines	400**, 330
Powder - Final product dust	1900

* All paired values are results of analyses performed by two different laboratories on samples collected four months apart.

** This sample contained 5,400 picocuries per gram of lead- 210.

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Table 6 shows radium-226 levels in industries known to use chlorination processes. With enhancement factors of perhaps 80 in going from ore to waste, waste concentrations can easily range from 100 to 2000 picocuries per gram and even higher. While waste volumes are not always readily available, some sites may have several hundred thousand tons of waste, especially titanium pigment plants. Many of these sites are located in areas such as New Jersey, Ohio, or Maryland where ground water is near the surface. Many of these sites may not be recognized as potentially NORM contaminated sites. A large percentage of these sites are probably no longer operational and older sites almost certainly have no engineered containment to protect groundwater. There are probably at least 30 rare earth sites that should be evaluated, at least 15-20 titanium sites, perhaps a half dozen columbium-tantalum sites, and probably more than a dozen zirconium facilities. If one counts landfills where wastes these operations have been placed, the number will undoubtedly grow. Several years ago we identified two counties in an East Coast state with almost 30 disposal sites containing zirconium wastes, titanium wastes, foundry sands, and slags. I strongly believe that the mineral extraction industries using chlorination should be more carefully evaluated. I would recommend a U.S. Geological Survey circular by Ed Landa to give you some perspective on the solubility and mobility of radium and the other NORM nuclides.(5)

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TABLE 6

Radium-226 in Mineral Industries
Using a Chlorination Process

Mineral	Radium-226 (picocuries/gram)
Columbium/Tantalum - Pyrochlore ore	8,700*
Columbium/tantalum - Euxenite ore	1,500*
Rare earths	?
Titanium - Metal/pigment - Rutile	15
- Leucoxene	12
- Ilmenite	0.3
Zirconium - Metal/oxide - Zircon sand	100, 13**
Refractories - Baddeleyite	290

* Estimated
** Different facilities

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Finally, I'd like to say a few words about "geogas". The Institute of Physics at Lund, Sweden together with the mineral prospecting department of the Boliden Group have developed, based on 10 years of research, a mineral prospecting method called the geogas technique (6). These researchers, while studying the long distance transport of radon through the overburden above ore bodies, found that radon was being transported about 10 times faster than could be accounted for by the accepted diffusion transport velocity. By long distance transport, they meant transport distances of up to 100 meters or more. This effect has also been observed by other investigators. The Swedish investigators concluded that diffusional transport could not be primarily responsible for the radon movement through the rock and proposed the concept of a carrier gas, which they called geogas, as the transport mechanism. They also hypothesized that the geogas might transport other elements in addition to the radon. The investigators have successfully used the geogas technique and a patented detector to prospect for arsenic, copper-nickel, and lead.

The long range transport of radon by carrier gas, while of obvious to mineral industry prospecting, may be of equal interest to those engaged in study of radon transport into structures.

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