OFFICE OF RADIATION AND INDOOR AIR
WASHINGTON, D.C. 20460

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MEMORANDUM

SUBJECT: Guidance -- Potential for Radiation Contamination Associated with Mineral and Resource Extraction

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TO: Regional SEMD Directors
Regional ARD Directors
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Office of Federal Facilities Restoration and Reuse
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Summary: This memo updates and informs Environmental Protection Agency (EPA) personnel of the potential for radioactive contamination associated with specific minerals and certain resource extraction, processing, or manufacturing industries. Some radioactivity may be associated with almost all minerals, rocks, ores, and water. Sites where the listed minerals or materials are found, processed, or stored may be subject to increased radiation and potential health and environmental hazards at sites where the listed minerals or materials occur or are processed and stored. This advisory includes ores and materials that may be obtained domestically, or are imported, and sites which are operating, on standby, or have been closed, or abandoned. The identification of listed minerals and materials at an inspection or investigation site (e.g., where the EPA is acting under statutory authority such as the Clean Air Act (CAA) or the Resource Conservation and Recovery Act (RCRA)) should serve as cause for EPA personnel to contact EPA regional radiation staff to help implement radiation safety measures and conduct radiation surveys as appropriate.

This memo updates the original dated April 15, 2003. Updates address the development of additional tools to characterize potential radiation hazards, such as the Superfund Preliminary Remediation Goal calculators. The updated memo also incorporates information related to the current national focus on critical minerals[1] and the radionuclides associated with them.

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[1] For example, Executive Order 13817, “A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals,” December 20, 2017; and Executive Order 14017, “America’s Supply Chains,” February 24, 2021.

Purpose

This guidance provides information for the EPA's inspectors, geological scientists, engineers, or environmental specialists to help them determine which extraction, processing, and or manufacturing operations have naturally occurring radionuclides in wastes, ores, or products. The presence of a mineral or material named in the lists in this document (see Appendices 2 and 3) does not imply that a site is radioactively contaminated, but instead should be considered as an advisory that radiation should be considered as a potential environmental hazard. The reference section lists documents that provide basic information on related radiation topics.

Potential Elevated TENORM Concentrations

Radioactive contaminants at mines or mineral processing/manufacturing facilities are often overlooked in site assessments, inspections, site investigations, environmental impact statements, or site cleanups. Such omissions may occur because the radioactivity is unexpected or because the principal mineral(s) being mined or processed were not suspected to be radioactive. However, the geological emplacement or geothermal phenomena which formed valuable minerals may have also concentrated radioactive minerals. In addition, the process of mining, beneficiation, and milling may have resulted in a concentration of the radioactive minerals in the waste. In some instances, the mineral(s) being mined may have radioactive elements as part of their molecular structure, resulting in radioactivity in the ore or even the finished product.

Appendix 2 of this document provides a listing of specific minerals (including many "Critical Minerals" as defined by the U.S. Geological Survey) and certain resource extraction, processing, or manufacturing industries with the potential for radioactive contamination. Appendix 3 provides an alphabetized list of the minerals and ores included in Appendix 2, which are known to be radioactive, or have the potential for radioactive contamination.

The EPA defines TENORM as: Material containing radionuclides that are present naturally in soil, rocks, water and minerals *and* whose radioactivity has been concentrated and/or exposed to the accessible environment as a result of human activities is referred to as Technologically Enhanced Naturally Occurring Radioactive Materials, or TENORM.

TENORM may be in other materials-ore, feedstocks, intermediate processing materials, emissions, discharges, spills, stored residues or wastes. TENORM may also be considered source or byproduct material under the Atomic Energy Act in certain instances (e.g., discrete manufactured radium sources, uranium mill tailings).

In many cases, the radioactive elements may be mobilized or leached from the waste or ore by normal environmental processes. Uranium is particularly soluble in acidic waters that would typically be associated with mine influenced waters, but it can also be mobilized in basic solutions. While radium is generally not soluble except in the presence of certain ionic solutions (e.g., barium), it can be swept along in water or wind to deposit in locations far from its source. Radioactive lead, a long-lived natural decay product of uranium, radium, and thorium, can be found in water and soils. Radioactivity can be harmful to human health, so public water systems are subject to strict regulations to limit its presence in drinking water.

Process operations (e.g., acid or solvent extraction, electrowinning circuit unit operations, and furnace heating) first leach, then concentrate the radioactive materials in the product and waste streams. Industrial facilities which utilize large quantities of water may also inadvertently concentrate the naturally occurring radionuclides present in all water sources.

Radioactive mineral scales may accumulate in piping or filters at processing and manufacturing plants. Radionuclides may accumulate in process waste waters, sludges or ash, or be emitted in smokestack gases. Manufacturing facilities may accumulate radioactive wastes in liquid or solid forms.

Oil and gas production generates other fluids from the subsurface (i.e., brine) which may contain radium and its decay products. Not all oil and gas plays have TENORM accumulations, however. The radium (if present in produced water[2]), may form a mineral scale on production piping, tanks, and separators at the field site as a result of changes in pressure, temperature, and chemistry from deep underground to surface conditions. It may also be found in sludges and evaporite deposits in tanks, wastewater and mud pits on the site. Small amounts of radium and radon may continue to be found in the produced oil and gas. Isotopes of lead and polonium can be found in natural gas handling equipment as a thin film, and in pigging (pipe cleanout) wastes. TENORM contamination in refineries has also been reported. Radium-bearing scales in production pipes, metal tanks and separators may not have been completely removed before the metal is sold as scrap, resulting in possible contamination at scrap metal recycling facilities. Radium contaminated pipes have been used as structural members in houses and other buildings. Pipe yards where mineral scale has been removed may have radium contamination of soils at the site.

Underground mines of all kinds have the potential to accumulate and vent radon gas, whether they are active or inactive, placing EPA staff at risk. Mines with minerals listed in the Appendices to this memo may have an increased risk of higher levels of radon. Active mines should have large fans that pump underground gases laden with radon, diesel fumes and silica to the surface. Closed or abandoned mines can accumulate the gas in underground chambers or vent the gas through old openings or fractures overlying collapsed excavations. Because of its density, radon will accumulate in low areas. The greatest potential for radon concentrations comes from raw or processed mineral ores with known TENORM associations that are stored underground or in buildings.

Some of the minerals included in this guidance are gemstones, or stones used for jewelry, ornamental objects or mineral collections. Small stones or samples should not constitute an internal hazard, but prolonged exposure to external radiation and handling of the principal uranium and thorium minerals should be minimized. Larger concentrations or quantities could present an increased risk.

TENORM sands, gravels and waste rock, dusts, sludges and other liquids, ash, and scales may contaminate workplaces, wastes, piping, tanks and containers, storage drums and piles, vent stacks, and disposal sites. Concentrated raw or finished mineral products (including those in barrels or piles), and metal/ceramic molds that are coated with radioactive materials are also sources of exposure.

[2] Produced water is a combination of formation water, oil, gas, and water injected to develop the well. As the age of the well progresses, the ratio of water to product can be as high as 10:1.

Reclaimed and graded lands, including old mine or petroleum or other industrial locations, may not have been decontaminated and can be exposure sources emitting radiation and radon gas.

Exposures of EPA employees to radioactivity at a site may come from:

- Inhalation of dusts and gases (alpha, beta, and gamma).
- Direct radiation (gamma) from a radioactive source, as well as from radioactive dusts or soil or liquids. This includes radiation from contamination on clothing, hair, and skin. The radioactivity is readily detectable with survey instruments.

Background Radiation Levels

Radionuclides can be found in all soil, rock, and materials. In general, the levels of radiation in the ground tend to be slightly higher on average in the western U.S. than the east. Some geographic areas can have much higher background levels due to the mineral composition of their soils and bedrock. These levels may even be as high or higher than Nuclear Regulatory Commission (NRC) source materials thresholds, making determinations of background extremely important. As radiation program personnel identify sites with suspected contamination, they should design surveys that follow the procedures referenced below to determine statistically appropriate reference levels of natural soil background in areas of similar geology and that are uncontaminated by human activity. This information must be collected in order to establish the extent of any additive man-made contamination, determining site-related impacts, and assessing cleanup goals or requirements at or above background radiation levels (U.S. EPA et al., 2000; Eisenbud and Gesell, 1997; NCRP, 2009). Ambient background exposure rates range from about 5 – 20 microRoentgen per hour (μR/h).

Protective Actions To Be Taken

If a site is suspected to have radioactive contamination above background levels as a result of human activities, it is recommended that EPA regional radiation personnel be contacted to determine next steps for site surveys, field sampling, and monitoring. Contact information for EPA regional radiation personnel is at https://www.epa.gov/radiation/regional-radiation-contacts.

If TENORM is suspected to be present, care should be taken to avoid worker exposure until radiation surveys can be conducted to characterize contamination at the site and determine any protective measures. If radioactive contamination is suspected at a site, EPA personnel should include radiation safety measures in the health and safety plan for their site visits. In addition, cleanup, waste management, and post-closure decisions must take into account radioactive contamination. If underground mines or ore storage areas (above or below ground) are to be inspected, it is prudent to consult regional radiation personnel in developing a sampling and monitoring plan to determine the presence and concentrations of radon gas.

In general, the radiation threshold for occupational radiation protection measures is higher than for exposure limits for members of the public. Long-term exposure to certain low levels of radiation below occupational limits may exceed the EPA's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance for radioactively contaminated site cleanup.

Ensure that the instrumentation used at the site are appropriate for the type of radioactivity being investigated. Gamma radiation surveys are the primary tool, but surface activity measurements need to be made on material and equipment. Instrumentation for emergency response purposes may not be appropriate for environmental surveys because they strip out background readings. Personal dosimetry may be recommended for some projects.

In a few cases, a state radiation authority, or other federal or state agency may have licensed or permitted a mine or other processing facility for production of uranium or thorium, even though it had been originally permitted to produce another type of mineral (e.g., gold, copper, phosphate). Do not assume a mine or processing facility produced only non-radioactive minerals; mine records may provide useful data. If the operation is closed or abandoned, EPA staff should be prepared to consult with appropriate federal or state agencies with jurisdictional responsibility to obtain information.

Site Surveys

Site investigation or monitoring procedures that regional radiation staff may use are outlined in documents such as the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), Revision 1[3] (U.S. EPA et al., 2000). MARSSIM was prepared specifically for site surveys involving radiological contaminants. The manual contains useful information on sampling procedures, field measurement methods and instrumentation, quality assurance and quality control procedures and interpretation of results. The information was developed as a consensus site closure approach by four federal agencies (EPA, Department of Energy, NRC and Department of Defense) to determine whether dose or risk-based release criteria for soils have been met. The MARSSIM-series documents and related informational tools can be obtained from the EPA's Radiation Protection Division website (https://www.epa.gov/radiation/multi-agency-radiation-survey-and-site-investigation-manual-marssim). In addition to MARSSIM, the Multi-Agency Radiological Laboratories Analytical Protocols Manual (MARLAP) (https://www.epa.gov/radiation/marlap-manual-and-supporting-documents) and, the Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME) (https://www.epa.gov/radiation/marsame-manual-and-resources) are also useful.

The EPA has developed a series of Preliminary Remediation Goals (PRG) calculators to assist in evaluating CERCLA sites (https://www.epa.gov/superfund/radiation-superfund-sites#models). This series of calculators apply to a variety of situations, including:

- PRG—Soil, Water, Air, Biota, Soil to Groundwater
- BPRG—Inside Buildings (Dust, Air, Fixed Contamination)
- SPRG—Outside Buildings (Dust, Air, Fixed Contamination)
- RVISL—Radon Vapor Intrusion (Air, Soil Gas, Groundwater)

In addition to Preliminary Remediation Goals, additional calculators are available that are useful for determining dose compliance concentration Applicable or Relevant and Appropriate Requirements (ARARs). Another useful guide, for surveying a site early in the remediation process is the "Soil Screening Guidance for Radionuclides," available at https://semspub.epa.gov/work/HQ/175428.pdf. Its Technical Background Document is available at https://semspub.epa.gov/work/HQ/175427.pdf.

[3] MARSSIM is under revision at the time of this document. Version 2 is anticipated to be published in 2024.

The guidance is intended to be used to screen out areas of sites, exposure pathways, or radionuclides of concern from further consideration, assuming certain conditions are present, or to determine that further study is warranted at a site. Its use may significantly reduce the time it takes to complete soil investigations and cleanup actions at some sites, as well as improve the consistency of these actions across the nation.

Design and interpretation of site surveys and laboratory radiological analyses of soil, sediment and water should be the responsibility of regional radiation personnel.

Radiation Site Cleanup Guidances

There are several EPA guidance documents that generally address the cleanup under CERCLA of sites with radium, thorium, and/or uranium contamination. Appendix 2 provides some detailed information on guidances that pertain to cleanup of TENORM and radiation contaminated sites. More detailed information may also be found on the EPA Superfund Radiation website at: https://www.epa.gov/superfund/radiation-superfund-sites.

Radiation protection guidances and waste disposal requirements for TENORM have been established in a number of states, predominantly for control of TENORM from oil and gas production. Some states may have published regulations for other sources of TENORM, or radiation in general. Such regulations should be consulted for their suitability in establishing ARARs for CERCLA sites with TENORM contamination.

Internet Information Sources

Other information on radiation basics, TENORM, and radiation site cleanup can be found at: http://www.epa.gov/radiation and https://www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm.

Contact

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U.S. Environmental Protection Agency (1998). *Use of Soil Cleanup Criteria in 40 CFR Part 192 as Remediation Goals for CERCLA Sites.* OSWER Directive 9200.4-25.

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APPENDIX 1
CERCLA GUIDANCES FOR RADIATION SITE CLEANUP

- OSWER Directive 9200.4-25, *Use of Soil Cleanup Criteria in 40 CFR Part 192 as Remediation Goals for CERCLA Sites*, dated February 12, 1998, provides general guidance regarding the potential status of the subsurface soil cleanup criteria in 40 CFR Part 192 as an applicable or relevant and appropriate requirement (ARAR) for radium or thorium in developing a response action under CERCLA.

- OSWER Directive 9200.4-35P, *Remediation Goals for Radioactively Contaminated CERCLA Sites Using the Benchmark Dose Cleanup Criteria in 10 CFR Part 40 Appendix A, I, Criterion 6(6)*, dated April 11, 2000, provides guidance regarding the potential status of the "benchmark dose" criteria in Criterion 6(6) as ARARs in developing a response action under CERCLA for sites with radium-226, radium-228, thorium-230, thorium-232, and uranium-234, and/or uranium-238 as contaminants of concern. Because of the interrelationship between the standards under 40 CFR Part 192 and those under Criterion 6(6), this memorandum should be used in conjunction with the OSWER Directive 9200.4-25 discussed above.

- OSWER Directive 9200.4-18, *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*, dated August 22, 1997, provides clarifying guidance for establishing protective cleanup levels for radioactive contamination at CERCLA sites. In particular, this memo discusses use of the risk range (generally 10^{-4} to 10^{-6} lifetime risk) for all carcinogens as established in the National Contingency Plan (NCP) for cleanup of radioactive contamination at CERCLA sites when ARARs are not available or are not sufficiently protective.

- OSWER Directive no. 9283.1-14, *Use of Uranium Drinking Water Standards under 40 CFR 141 and 40 CFR 192 as Remediation Goals for Groundwater at CERCLA Sites*, dated November 6, 2001, provides clarifying guidance on the EPA's cleanup standards for uranium contaminated ground waters at CERCLA sites that are current or potential sources of drinking water.

- "Radionuclide Preliminary Remediation Goals (PRGs) for Superfund" electronic calculator incorporates the EPA's risk assessment approach for establishing PRGs under CERCLA at the 1 x 10^{-6} cancer risk level. The PRG Calculator is available at: http://epa-prgs.ornl.gov/radionuclides/

APPENDIX 2
MINERALS AND INDUSTRIES KNOWN OR SUSPECTED TO HAVE RADIOACTIVE CONTAMINATION POTENTIAL

The following lists of minerals and materials with known radioactive associations is by no means exhaustive, and, in some cases, the generic name for a mineral is provided rather than the individual species. EPA staff undertaking inspections or investigations for regulatory programs[4] for mining, or mineral, or industrial processing/manufacturing sites should: conduct literature searches, review mining and assay reports, and substantiate mineral and trace mineral assemblages. The occurrence of radioactive minerals, or those known to occasionally include radioactive elements in their crystal lattice as intergrowths or impurities, raises the possibility that the site under investigation or inspection has TENORM occurrence.

This Appendix provides information on additional industries which use specific minerals listed in this guidance. However, information on whether radioactivity may be present or not in these industries is incomplete.

Appendix 3 is a combined alphabetical list of only the minerals and ores listed in this guidance.

Minerals and elements on the most recent 2022 USGS critical minerals list are noted with an asterisk (*). Several minerals that were included in the first USGS critical minerals list in 2018 were excluded in the 2022 list, and these are noted with a double asterisk (**). The U.S. Department of Energy also has its own list of "critical materials" for energy published in 2023 that adds to the USGS list.

Minerals Extracted for their Radionuclide Content

Uranium** minerals (principal or major minerals): Uraninite/pitchblende, carnotite, coffinite, davidite, autunite, pyrochlore, samarskite, torbanite, uranophane, and many other species.

Thorium minerals (principal or major minerals): thorite, monazite, thorianite, thorogummite.

[4] In addition to CERCLA, CAA and RCRA, relevant statutory authorities could include the Clean Water Act, Safe Drinking Water Act, or Toxic Substances Control Act.

Mineral Ores Known to Have TENORM Associated Wastes

Aluminum (bauxite)*	Niobium*
Beryllium*	Phosphate (phosphorous)
Carbonatite	Potassium (potash) **
Coal and coal ash/coal combustion residuals	Precious Metals (gold, silver)
Copper	Rare Earths*: bastnaesite, monazite, xenotime, apatite, euxenite, many others
Fluorospar/fluorite*	Tin*
Gypsum	Titanium:* leucoxene, ilmenite, rutile
Heavy Mineral Sands	Tungsten*
Lithium*	Vanadium*
Molybdenum	

Other Minerals with Radioactive Elements in Their Matrix

Allanite	Loparite
Alunite	Mosandrite
Apatite	Roscoelite
Baddeleyite	Spencite
Barite	Sphene/titanite
Cerite	Stillwellite
Cordylite	Vanadinite
Doverite	Wulfenite
Epidote	Xenotime
Karnasurtite	Yttrotantalite
Lead (galena)	Yttrotungstite

Some Minerals Known to Contain Uranium and Thorium as Intergrowths or Impurities

Adamite	Fluorite
Allophane	Limonite
Chrysocolla	Opal
Columbite	Pyromorphite

Cryotomelane	Scapolite
Evansite	Tantalite

Other Natural Resource Extraction Activities with TENORM Associated Wastes

- Oil and Gas Exploration, Production and Distribution
- Geothermal energy

Other Processing/Manufacturing Facilities with Known TENORM Associated Wastes

The following are known to have TENORM contamination potential:

- Water Treatment Facilities (radium scale and sludge contamination in wastes and filters)
- Paper and Pulp Facilities (radium scale and sludge contamination)
- Ceramics Manufacturing (zircon, uranium in wastes and molds)
- Paint and Pigment Manufacturing (thorium, uranium, radium in wastes from titanium ores)
- Metal Foundry Facilities (zircon contamination in molds for metal parts/machinery, thorium in welding rods)
- Optical Glass (thorium incorporated in glass)
- Fertilizer Plants (uranium, thorium, radium, radioactive potassium associated with fertilizer production, concentrations in wastes, filters, products, metal piping scales)
- Aircraft Manufacture (depleted uranium counterweights; in older facilities, radium dials, nickel-thorium alloys used in engine manufacture)
- Munitions and Armament Manufacture (depleted uranium in ammunition and armor)
- Scrap Metal Recycling (TENORM contaminated piping and metal)

The following list of minerals or elements are known to either be radioactive or are known to have the potential for radioactive contamination by inclusion of radionuclides in their molecular structure, or association with other radioactive minerals in their original ore body. A list of industries which use these minerals are included for information purposes (USGS, 1973; Kraus et al., 1959). Current information on resources, production, and uses of mineral commodities may be found at the USGS National Minerals Information Center. The inclusion of an industry in this listing does not necessarily mean that radioactivity may be present at any or all such sites.

Beryllium*	Used in electronics, aerospace, defense, medical, nuclear, and telecommunications industries. Light, strong alloys with high thermal conductivity, stiffness, and corrosion resistance.

Copper	Manufacture of copper wire, nails, and copper sheeting, brass, bronze, electrical and electronic equipment, war munitions, chemical reagents.
Fluorspar* (fluorite)	A flux in the manufacture of steel, enamelware, opalescent glass, hydrofluoric acid, refining of antimony and lead. Also used in manufacture of vases, paper weights, dishes.
Gypsum	A flux in glass and porcelain manufacture, retarder in cement, filler in fertilizers. Alabaster used for statues vases, lamps, pedestals.
Molybdenum	Used in manufacture of steel and iron castings, and in high-speed tools.
Niobium*	Manufacture of stainless steel, high temperature alloys, jet engines and gas turbines.
Phosphate** (phosphorus)	Fertilizer manufacture, phosphoric acid for industrial and food, manufacturing uses, water softeners, manufacture of glass and ceramics.
Potassium** (potash)	Manufacture of glass, optical glass, incandescent light bulbs; (nitrate) gun powders, dyeing and tanning; (cyanide) solvent in gold extraction and photography.
Precious Metals (gold, silver)	Coinage and jewelry use, scientific and electronics instrument manufacture, photography, gold plating, lettering, dentistry.
Rare Earths*: (Lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, +/-scandium, yttrium)	High-strength magnets, electronics equipment, lasers, batteries, phosphors used in LEDs and electronic displays, glass polishing and additives, industrial processes.
Thorium	Electrodes, optical glass, refractory manufacture.
Tin*	Manufacture of tin plate or sheet tin, solder, bronze, tin amalgam, gun metal, type metal, speculum metal, pewter, also as a polishing powder.
Titanium* (leucoxene, ilmenite, rutile)	Steel additive, high-strength corrosion-resistant metal for airplanes and ships, welding rod coatings, use in carbide cutting tools; (dioxide) white pigment for paint manufacture,

	lacquer enamels and rayon, glass, highly opaque lightweight paper.
Tungsten*	Used in manufacture of x-ray tubes, filaments in incandescent lights, automobile engines.
Vanadium*	Used in manufacture of special steels and bronzes, high speed tools, ceramics, inks, silk dyeing.
Zirconium* (zircon)	Used to strengthen and increase corrosion resistance in specialty alloys of steel, brass, copper. Widely used in ceramics as a glaze, coating for ceramic and metal molds, refractory bricks, polishing powder, pyrotechnics, sandblasting powder. Used in manufacturing aircraft engines and parts, cutting tools, nuclear reactors, surgical tools, electric arc lamps, tanning and manufacture of textiles.

APPENDIX 3
ALPHABETIZED CHECK LIST OF MINERALS AND ORES WITH RADIOACTIVE CONTAMINATION POTENTIAL

Refer to the lists in Appendix 2 of this guidance to determine whether a mineral or ore listed below is naturally radioactive or is known to be found in association with radioactive minerals. Common names and mineral names are included in the list below.

Adamite
Allanite
Allophane
Aluminum
Alunite
Apatite
Autunite
Baddeleyite
Barite
Bastnaesite
Bauxite
Bertrandite
Beryl
Beryllium
Carnotite
Cerite
Chrysocolla
Coal (and coal combustion residuals)
Coffinite
Copper
Columbite
Cordylite
Cryptomelane
Davidite
Doverite
Epidote
Euxenite
Evansite
Fluorite/Fluorspar
Francolite
Gold
Gypsum
Ilmenite
Karnasurtite
Lanthanum
Lead
Leucoxene
Limonite
Lithium
Loparite
Molybdenum
Monazite
Mosandrite
Niobium
Opal
Phosphate
Phosphorite
Phosphorous
Potassium
Potash
Pitchblende
Pyrochlore
Pyromorphite
Rare Earths
Roscoelite
Rutile
Samarskite
Scapolite
Silver
Spencite
Sphene/titanite
Stillwellite
Tantalite
Thorite
Thorianite
Thorogummite
Tin
Titanium
Tobenite
Tungsten
Uraninite
Uranophane
Vanadinite
Vanadium
Yttrium
Wulfenite
Xenotime
Yttrotantalite
Yttrotungstite
Zircon
Zirconium