EFFECTIVE MANAGEMENT OF RADIOLOGICAL HAZARDS AT ABANDONED RADIOACTIVE MINE AND MILL SITES

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ABSTRACT

During the compilation of the National Park Service (NPS) inventory of abandoned mineral lands (AML), park managers in the Colorado Plateau physiographic province raised concern over the issue of radiation at abandoned uranium mine and mill sites. The Colorado Plateau has been mined for radioactive ores such as radium, vanadium, and uranium since 1900, and particularly from 1948-1970 when uranium procurement programs of the U.S. Atomic Energy Commission (AEC) were in effect. Other federal land management agencies, particularly the Bureau of Land Management and U. S. Forest Service, have many more radioactive AML sites than the NPS. These sites are potentially hazardous due to the possibility of elevated radioactive emissions. Currently there are no federal regulations addressing the management of AML sites for radioactive emissions or enhanced soil and water radiological constituents, but guidelines are available for each agency to establish its own regulations and policies. To manage these sites effectively and safely, land managers, and particularly human health and reclamation specialists, must be versed in the fundamental concepts of radioactivity, environmental characterization methods, data interpretation, risk characterization and assessment, and appropriate risk communication. Management and cleanup of radiologically elevated sites depends upon their planned use, the level of radioactivity present, and the typical duration of public exposure anticipated.

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INTRODUCTION

During the compilation of the National Park Service (NPS) inventory of abandoned mineral lands (AML), park managers of the Colorado Plateau region raised concern over the issue of radiological exposure at abandoned uranium mine and mill sites. Figure A shows the Colorado Plateau, a physiographic province centered on the "four corners" area of Utah, Colorado, New Mexico, and Arizona, which has been a major center of production for the nation's radioactive ores since 1900. Most of that production came from the Uravan Mining Belt in western Colorado and eastern Utah. Radium, used for medicinal purposes and in the production of luminescent dials, was the first commodity produced, followed by vanadium, used in steel production, especially during World Wars I and II. Beginning in 1943, uranium was produced for nuclear weapons, and by the mid-1960s that use switched to nuclear generation of electric power. Mining in the region peaked during the period from 1948-1970 when the U.S. Atomic Energy Commission conducted uranium procurement programs to build up national stockpiles, first for national defense, and later for nuclear power. Another brief uranium boom occurred in the Colorado Plateau from the late 1970s to early 1980s. This boom was cut short by overproduction, public rejection of nuclear power, and competitive domestic and foreign operations. Mining in the area has continued on a smaller scale since that time.

Radioactive ores of the Colorado Plateau occur most often as strata-bound deposits formed by groundwater flowing through flat-lying to moderately-tilted sedimentary rock units. The majority of these deposits occur in the Shinarump Conglomerate Member of the Chinle [pronounced, "chin-lee' ") Formation [Triassic geologic period, 225-190 present (mybp)] and in the Morrison Formation (Jurassic geologic period, 135-190 mybp). These are stream-laid sedimentary rock units with high concentrations of organic matter. After these sediments and others were deposited, volcanoes blanketed the area with radioactive volcanic ash during

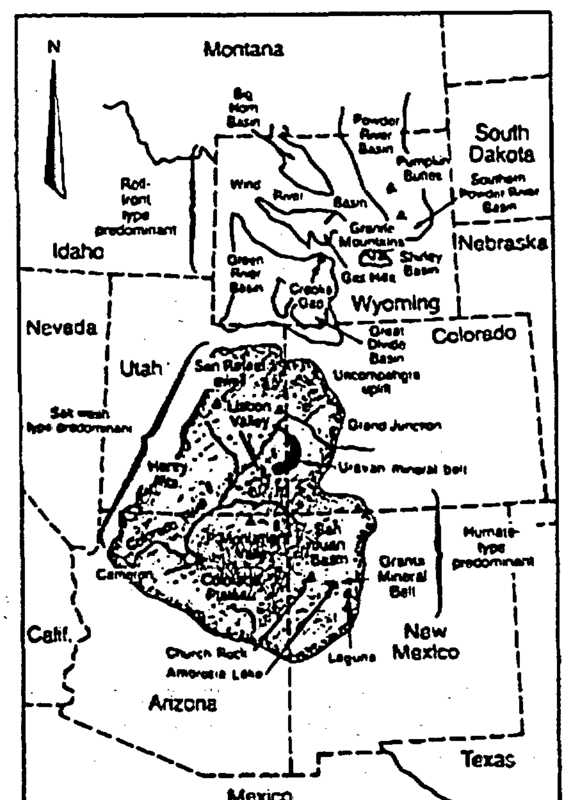


Figure A. Western states uranium deposits, Colorado Plateau shaded. (Guilbert, p. 911) the Tertiary geologic period (1.5-65 mybp). Through time groundwater leached radioactive elements such as uranium, along with other elements, from the ash into the subsurface strata. This groundwater tended to channelize and flow horizontally along buried paleo-stream channels. These channels are highly permeable because they are composed of various-sized rocks and cobbles in a sandy matrix. They also contain large amounts of organic material such as grasses, bones, tree limbs, or entire trees, which tend to reduce the acidity of the groundwater, causing its dissolved minerals to come out of solution. Uranium and associated minerals were therefore deposited in these channels, filling void spaces and replacing the organic material, resulting in sinuous ore deposits with localized high-grade zones where organic material was more prevalent. Many of the mines in the region are relatively small and arcuate in shape, and were originally log jams at curves in paleo-stream channels, in fact, petrified wood is very common to most of the Colorado Plateau's mine sites. Figure B is an idealized model of a paleo-stream channel uranium deposit typically found in the Colorado Plateau:

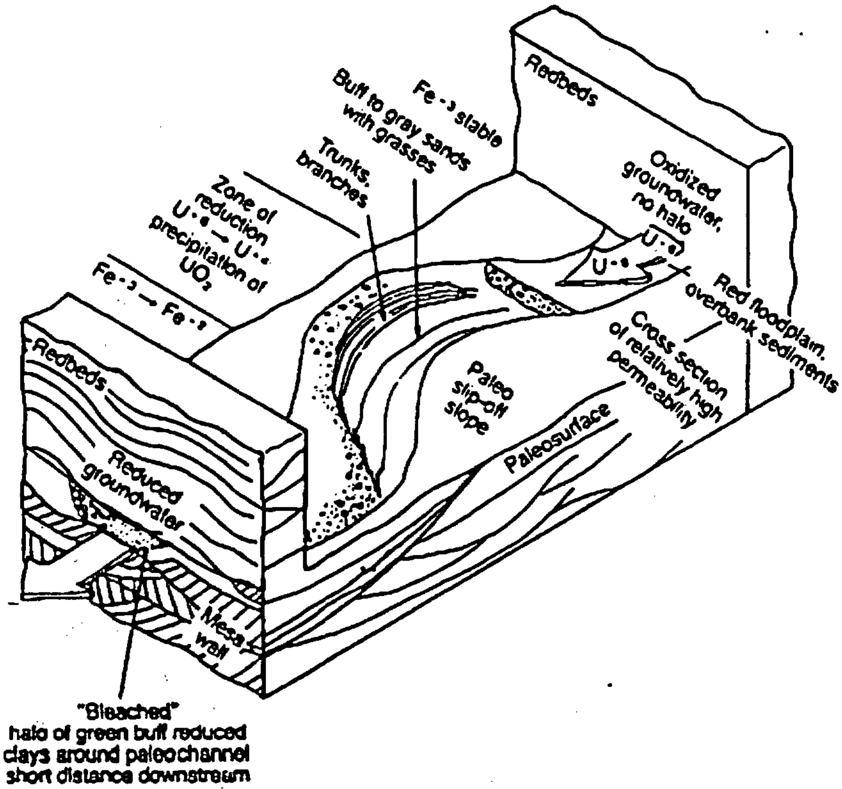


Figure B Cross-section of a typical paleo-stream channel uranium deposit. (Guilbert, p. 919)

There are currently no active mines on NPS lands in the Colorado Plateau, but the NPS inventory shows 44 abandoned radium or uranium sites in or immediately adjacent to NPS units. Numerous sites in the national park system were mined for other metallic commodities which had radioactive components in the ore that were not recovered. Other federal land management agencies, particularly the Bureau of Land Management and Forest Service, have many more radiologically hazardous AML sites than the NPS.

Vestiges of a time when the country was relatively unconcerned with environmental protection, many of these mine and ore-processing sites were abandoned without reclamation. Today the responsible parties are difficult or impossible to trace. Federal land managers are therefore faced with a problem: they are responsible for radioactive sites on their lands, but know little about radiation and the potential hazards these sites present. To manage these sites effectively and safely, land managers, and particularly human health and reclamation specialists, must be versed in the fundamental concepts of radioactivity, environmental characterization methods, and data interpretation. This will enable proper risk characterization, in which potential receptors (those being exposed) are identified, pathways of exposure are identified and quantified, and hazardous constituents causing radioactive emissions and contamination are identified and quantified. With that information, the risk of significant exposures can be reasonably assessed and effectively communicated to staff and the general public.

This paper is not intended to be a comprehensive technical guide for radiation specialists. Rather, it is aimed at equipping land managers with a general knowledge of the issues involved at radioactive AML sites, and at providing those responsible for safety and regulatory compliance at these sites with the necessary information to ensure public and employee protection. The reader should note that not all researchers concur on certain issues concerning ionizing radiation, particularly on the long-term health effects of low-level radiation exposures typically encountered in nature. Since theories of radioactivity and its effects on living organisms are still being developed and are subject to change, a consensus of the opinions which drive the current regulatory process is presented.

RADIOACTIVITY: AN OVERVIEW

Atomic Structure and Terminology - A very basic knowledge of atomic structure is essential in understanding the concepts of radioactivity. All **matter**, the material of which the universe is composed, is made up of **atoms**. (See attached glossary for definitions of terms used throughout this paper.) An atom consists of three fundamental particles: **neutrons**, **protons**, and **electrons**. Other subatomic particles have been identified, but these three particles will be the basis of our discussion. Neutrons and protons cluster in the center of the atom to form the **nucleus**, which is orbited by the electrons. Neutrons have an **atomic mass** of 1 and are neutral in charge. Protons also have an atomic mass of 1, but have a positive charge. Electrons have a negative charge and their mass is insignificant relative to the mass of neutrons and protons. The number of protons in a given atom, or its **atomic number**, is characteristic of each **element**. The **atomic mass** of a given element is equal to the sum of the neutrons and protons in its nucleus. For instance, the element, uranium, most often occurs in nature with a nucleus consisting of 92 protons and 146 neutrons, giving it an atomic number of 92 and an atomic mass of 238 (146 + 92). Uranium has other forms, or **isotopes**, which have the characteristic 92 protons, but different numbers of neutrons. Scientists commonly identify a specific isotope of an element by stating its name and atomic mass. For example, the isotope containing 92 protons and 146 neutrons is designated "Uranium-238" (abbreviated U238), as opposed to U235 and U234, which both have uranium's characteristic 92 protons, but only 143 and 142 neutrons, respectively. Another common scientific notation is to print the symbol for the element, immediately preceded by the atomic number in subscript and atomic mass in superscript, as with $^{238}_{92}U$.

Basic Radioactivity - **Radioactivity** can be defined as the spontaneous release of particles and energy by the nucleus of an inherently unstable atom. Certain atoms are inherently unstable because, although they may have been formed under incredible forces, it requires too much energy to keep them in that state in the natural environment.

Alpha radiation occurs when a radioactive atom spontaneously decays by releasing an **alpha (α) particle** from its nucleus. An alpha particle consists of two neutrons and two protons, and therefore has an atomic mass of 4. An atom undergoing alpha decomposition, therefore, experiences a corresponding drop in atomic mass, the **daughter** having an atomic mass of 4 less than its **parent**. Since two protons are lost in this process, the atomic number of an atom undergoing alpha decay is diminished by 2. Because it is the number of protons which distinguishes each element, the daughter is a different element from its parent. This process is demonstrated in Figure C, where Radium-226 decays into Radon-222 by ejecting an alpha particle from the atomic nucleus:

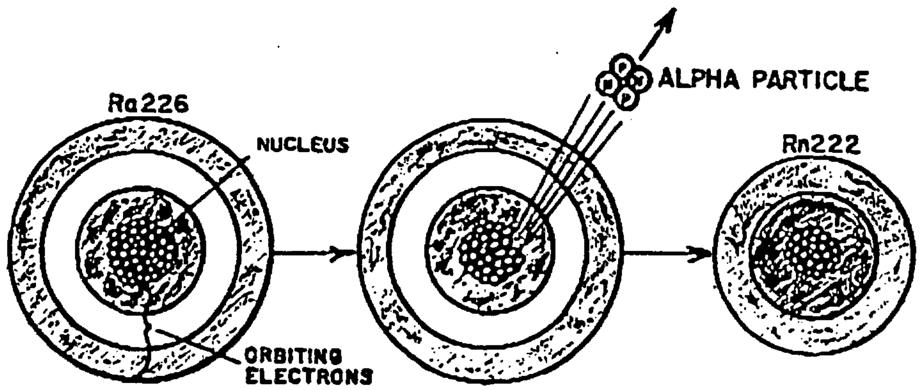


Figure C. Alpha decay of Radium-226 to Radon-222. (after Wiseman, p.326)

Radioactive elements may also decay into other elements of the same atomic mass through **beta decay**. This happens when a neutron spontaneously decays into a proton by ejecting an electron. This electron, or **beta (β) particle**, is not one of those orbiting the nucleus, nor did it previously exist in the nucleus. It is the product of the neutron transforming into a proton. Since the number of protons is increased by 1, a new element is produced, but since the overall number of protons and neutrons stays the same, the atomic mass is unchanged. This process is demonstrated in Figure D, where Bismuth-214 decays into Polonium-214 by ejecting a beta particle from the atomic nucleus as a neutron transforms into a proton:

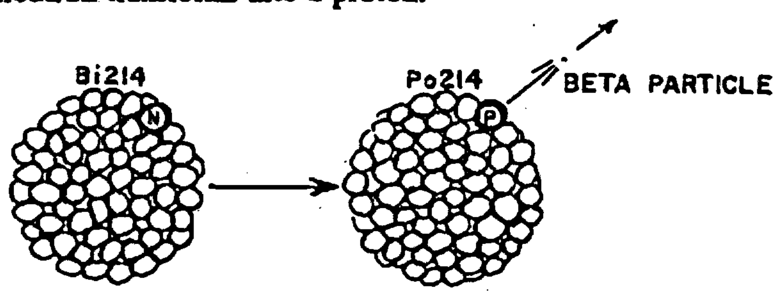


Figure D. Beta decay of Bismuth-214 to Polonium-214 (orbiting electrons not shown).

Gamma (γ) **rays** may be released in either of these processes. Like light and X-rays, these are energy rays, having no mass or electrical charge. Gamma rays have higher energy than X-rays, though, and are therefore more dangerous to living organisms.

The key to an element's radiological activity is its **half-life** the time required for half of the atoms of a radioactive element to decay (Figure E). Radioactive elements with long half-lives are said to be "less active" than those with short half-lives.

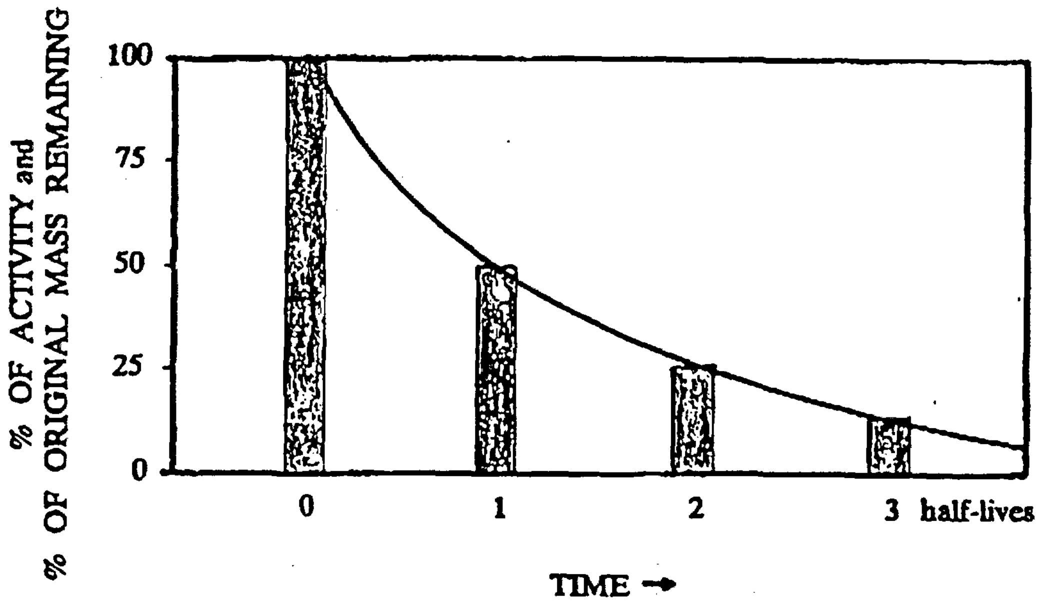


Figure E: Half-life of a radioactive element.

The potential damage caused by alpha, gamma, and beta radiation is determined by the combined effect of their ability to penetrate and alter tissue. Figure F depicts the relative penetrating power of alpha, beta, and gamma radiation:

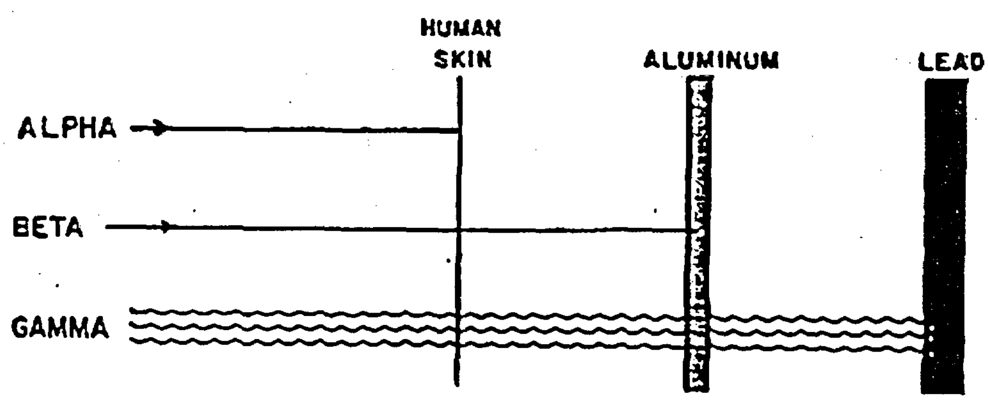
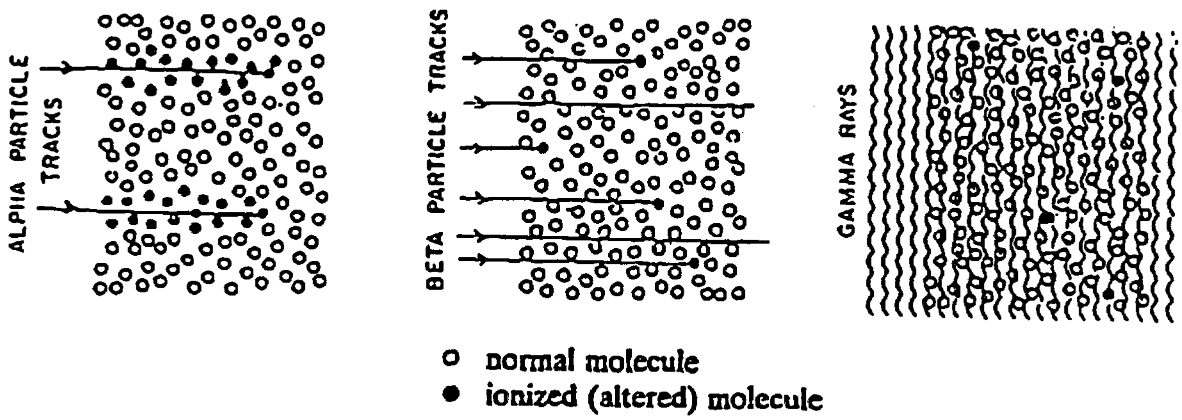


Figure F: Penetrating powers of alpha, beta, and gamma radiation.

The ability of radiation to alter molecules with which it comes into contact is termed **ionizing potential**. It is important to note that the ionizing potential of alpha radiation far exceeds that of beta and gamma. This is due to the size, electrical charge, and mass of individual alpha particles. The relative ionizing potential of alpha:beta:gamma is 100,000:100:1. Figure G illustrates the comparative effects of these three types of radiation:



<u>Figure G</u>: Ionizing potentials for alpha, beta, and gamma radiation.

In the natural environment, when the combined effects of penetration power and ionizing potential are considered, alpha and gamma are the most dangerous forms of radiation to living tissue. Beta radiation is relatively insignificant. This is not necessarily the case where certain radioactive materials have been technologically enhanced or refined. Since this study focuses on abandoned mine and mill sites where beta radiation should be relatively insignificant, it will not be discussed further.

The radioactive characteristics of elements are not affected by chemical or physical processes. For instance, if uranium is bound in the compound, uranium oxide (U_3O_8), the uranium atoms will decay at the same rate, in the same manner, and with the same energy as if they were in their elemental state not bound with oxygen in the compound. Similarly, variations in temperature and pressure will have no influence on the rate, manner, or energy released in radioactive decay.

<u>Uranium-238 Decay Series</u> - Figure H shows the Uranium-238 Decay Series, where unstable Uranium-238 (U238) undergoes a systematic decay process until it reaches a stable state as Lead-206 (Pb206). Alpha, beta, and gamma radiation are emitted in this process as indicated. There are similar decay series for other elements, most notably Thorium-232, but the vast majority of the radiation at most AML sites is typically caused by elements in the Uranium-238 series, so this decay series is the focus of our study.

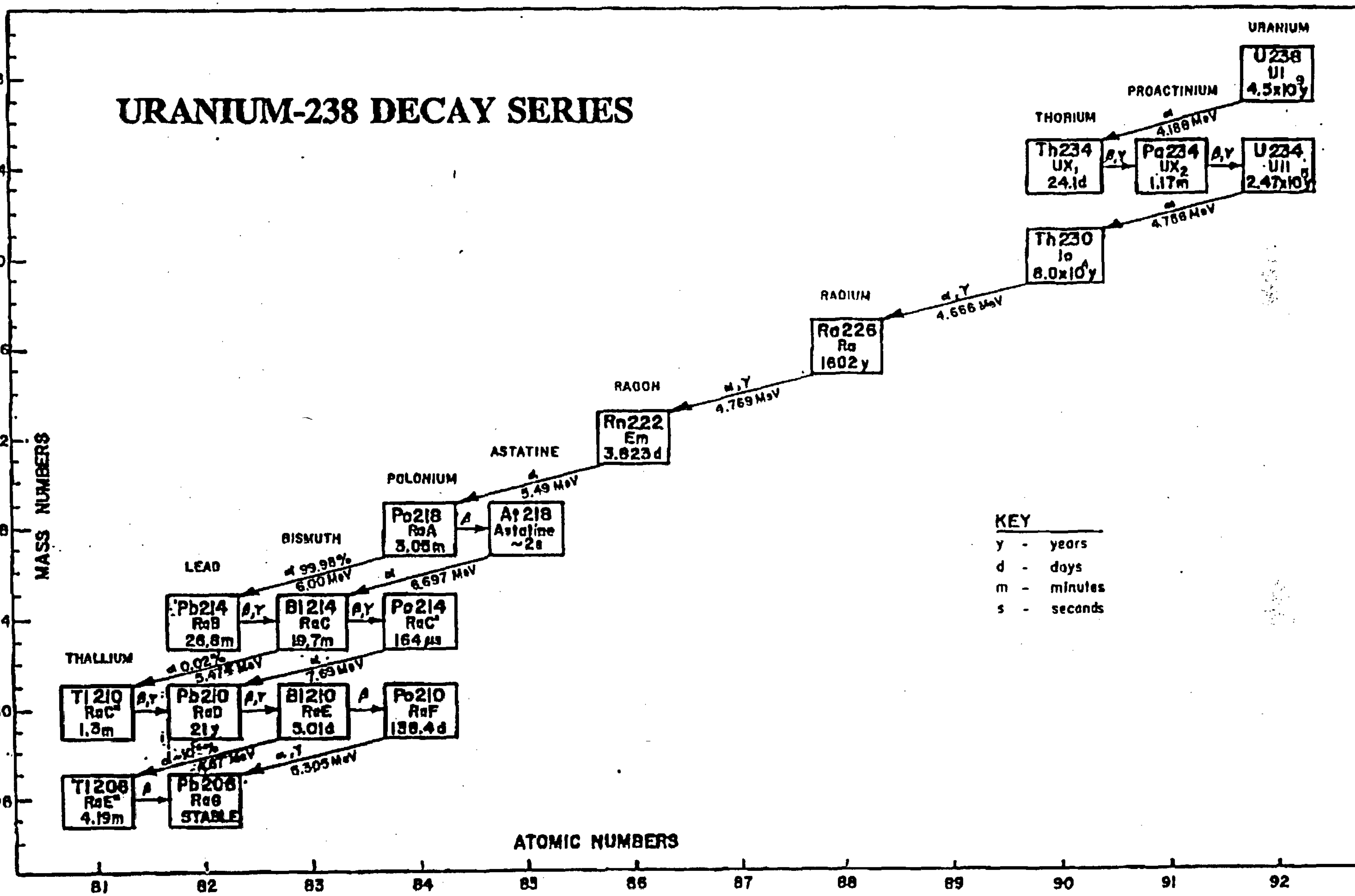

URANIUM-238 DECAY SERIES
URANIUM
U238
UI
PROACTINIUM
THORIUM
Th234
UX1
24.1d
Pa234
UX2
1.17m
U234
UII
Th230
Io
RADIUM
Ra226
Ra
1602 y
RADON
Rn222
Em
3.823d
ASTATINE
POLONIUM
Po218
RaA
3.05m
At218
Astatine
~2s
BISMUTH
LEAD
Pb214
RaB
26.8m
Bi214
RaC
19.7m
Po214
RaC'
164 μs
THALLIUM
Tl210
RaC''
1.3m
Pb210
RaD
21y
Bi210
RaE
5.01d
Po210
RaF
138.4d
Tl206
RaE''
4.19m
Pb206
RaG
STABLE
KEY
y - years
d - days
m - minutes
s - seconds
MASS NUMBERS
ATOMIC NUMBERS

Figure H

Note the long half-lives for most of the elements in the Uranium-238 decay series above Radium-226 (Ra226). Ra226 is a solid at standard temperature and pressure (STP), and is fairly immobile in the environment due to its low solubility. The daughters, or **progeny** of radium (those elements below Ra226 in the series) have relatively short half-lives. Although radium itself is not particularly active (half-life = 1,602 years), it is the direct parent of the most active constituents in the decay series. Concentration-based standards for radionuclides in water and soils are therefore keyed to radium due to the more active progeny it generates. If radium could be removed from the soil and water in an area, the most active portion of the series would essentially be cut off and the radiation hazard would quickly give way to thousands of years of acceptable low-level radiation. In an attempt to re-establish equilibrium (the state at which the radioactivity of consecutive elements in the decay series is neither increasing nor decreasing), the remaining Thorium-230 (Th230: half-life = 80,000 years) would require years to decompose and produce substantial increases in radiation levels. Radium content, therefore, is a major key or "marker" for radiological activity.

Radon gas (Rn222: half-life = 3.82 days) is the direct offspring of radium. The first four primary decay products of radon gas are referred to as the **short-lived daughters of radon**, commonly called **radon daughters** or **radon progeny**:

Daughter[1]	Formal name	Half-life	Emission(s)
Radium A (Ra A)	Polonium-218 (Po218)	3.05 minutes	alpha
Radium B (Ra B)	Lead-214 (Pb214)	26.8 minutes	beta, gamma
Radium C (Ra C)	Bismuth-214 (Bi214)	19.7 minutes	beta, gamma
Radium C′ (Ra C′)	Polonium-214 (Po214)	164 microseconds	alpha

Because of their short half-lives, these radon daughters are the most active part of the Uranium-238 decay series.

Specifics of Alpha Radiation - The primary alpha emitters of concern in nature are Radon-222 Radium A, and Radium C′. Radon daughters (Radium A, B, C, and C′) are solid at standard temperature and pressure. When they are produced from the decay of their respective parents, they quickly attach, or "plate out" on **condensation nuclei** such as dust particles or droplets of mist in the air. These particles and droplets can get lodged in lung tissue when inhaled. Although free daughters are less prevalent than attached daughters, they are still significant since once in the lungs, they are very likely to plate out on lung tissue. Because there is no "trapping mechanism" of this type for radon gas and it has a much longer half-life, it is typically exhaled

[1] Dual nomenclature for some members of the decay series is due to the original uncertainty of researchers when these members were discovered. In some cases researchers detected a presence, but were unsure what it was. This was the case with radon (Rn222), which was called "emanation" until it was better defined as a unique element with the atomic number 86. Similarly, for some members of the decay series, researchers were initially unsure whether they had discovered new elements or isotopes of known stable elements. Radium A through G were so-named as progeny of radium until researchers figured out that these were various isotopes of thallium, lead, bismuth, and polonium. The dual nomenclature is still used today, so both the historic and current names are used in this paper. The reader is likely to find either nomenclature in common usage.

before throwing off alpha particles, and is much less damaging to lung tissue. When trapped Radium A or Radium C′ atoms undergo radioactive decay in the lungs, they emit high-energy alpha particles which in turn collide with and damage cells of the lung tissue. With extreme or continued low-level exposure to radon and its progeny, lung cancer may develop.

Since alpha radiation is of primary concern when radionuclides are taken into the lungs, it is considered an internal radiation hazard. External alpha health hazards require unusually high levels of radiation that are not commonly encountered in nature. While skin cells may get damaged from alpha exposure, the effect is much less hazardous than typical sunburn damage, and the damaged cells are replaced with new, healthy cells. The external tissue most vulnerable to alpha radiation is the cornea of the eye, but again, this would not usually be of concern in a natural setting.

Radionuclides occur in varying proportions throughout nature. While radon and its progeny are certain to be present to some degree in abandoned uranium mines, they are certainly not limited to this occurrence. Radioactive elements are often associated with other metals in mineralized zones. Therefore mines for other commodities such as vanadium, gold, silver, copper, or cobalt are likely to have elevated levels of radioactivity, and may even have very high radiation levels.

Any confined airspace may host radiological activity, and the degree of activity is proportional, in part, to radionuclide concentrations in the area. In the case of alpha radiation, other factors may be involved such as the degree of dilution with fresh air sources and variations in atmospheric pressure. Movement of water through a mineralized zone in a mine may lead to elevated alpha radiation, since radon gas is highly soluble in water and tends to come out of solution when the water is exposed to the atmosphere. This phenomenon is enhanced as the water is heated or spread out over a broad area.

Since radon daughters are airborne and attach to dust particles, they are controlled in active mines by suppressing dust and by increasing fresh-air ventilation to dilute and disperse the contaminated air. Personal protection is achieved through the use of a dust- and mist-filtering respirator in low concentrations, or a supplied-air apparatus in high concentrations where radon gas concentration becomes a more significant factor.

When a mine is abandoned, ventilation systems are no longer operational and dust suppression measures are no longer taken. The resulting stagnant air inside the abandoned mine will be more highly contaminated than when the mine was operational. Alpha radiation levels will generally increase with distance into the mine, since air near the mine's portal is likely to mix with the fresh air outside. Alpha radiation levels outside the mine, even around the waste-rock pile or on a milled tailings pile, will be much less than inside the mine. This is because fresh, uncontaminated air is constantly diluting and removing contaminated air from the area. For this reason, unless considerable time is spent on-site, alpha radiation is not usually a concern outside the mine. Atmospheric pressure, thermal variations, and the layout of underground workings can cause mines to "breath," however. There may be instances where a mine "exhales" a significant quantity of highly-contaminated air, which in turn settles around the site or in nearby low areas.

A number of devices can be used to detect alpha radiation. These can be broken into two different categories: passive (no power required for operation) and active (power required). Passive devices include charcoal canisters, alpha-track detectors, charcoal liquid scintillation devices, and electret ion chamber detectors, all of which are commonly used in testing homes for low-level alpha. They are exposed to the air for a specified period of time and then sent to a laboratory for analysis. Short-term and long-term passive detectors are available, and they are relatively inexpensive. Active detectors include continuous radon or working level monitors, or systems which take grab samples of air and give point-in-time readouts of radon and/or its decay products. They are generally expensive and require operation by trained technicians. Although it might seem reasonable to assume that air in the area to be sampled is thoroughly mixed and homogenous, it is common practice to collect air samples for alpha from the "breathing zone" approximately 5 feet above the ground, since the primary concern is the radon daughters being inhaled.

Specifics of Gamma Radiation - The major gamma emitters in nature are Radium-226, Radium B, and Radium C. Unlike alpha radiation, gamma radiation is highly penetrating, essentially independent of air circulation, and decreases with the inverse square of the distance from a point source. One rarely encounters a point source in nature. Rather, particular rock units, or in the case at hand, waste rock and tailings piles, may contain varying concentrations of gamma emitters, in which case gamma radiation intensity will decrease more gradually with distance from the gamma-emitting surface.

Because of its high penetration power, personal protection from gamma radiation is virtually impossible except through complete avoidance. Workers who come into frequent contact with gamma should wear "dosimeters," often referred as "radiation badges," or "TLDs" (thermoluminescent dosimeters, a type of dosimeter commonly used). These sensors record cumulative gamma activity through time and are periodically read and discarded, or turned in to a laboratory for analysis. When cumulative exposure for a worker approaches a regulated limit, that individual must be re-assigned to other duties away from sources of exposure.

Various instruments are used to detect gamma radiation instantaneously. People are probably most familiar with hand-held "geiger counters." Gamma scintillation meters can also be used. Scintillation meters appear similar to geiger counters but operate on different principles. Since gamma decreases with distance from the source and the primary concern with gamma radiation is its effect on reproductive systems and the sensitive tissues of other organs (see below), gamma readings should be taken holding the meter at waist-level above the ground unless otherwise specified.

EFFECTS OF LOW-LEVEL RADIATION ON HUMAN HEALTH

Since Hiroshima and Chernobyl, the effects of acute, high-level radiation exposures from technologically-enhanced sources are hauntingly familiar to most people. Naturally occurring radioactive materials (NORM) which are the focus of this study, do not produce such effects. In fact, NORM will not produce noticeable symptoms at the time of exposure. The perplexing aspect of naturally-occurring low-level radiation, therefore, is that without instrumentation and specialized knowledge, an individual will probably be unaware that he or she is being exposed, and the deleterious effects of NORM will only be manifested much later when it is too late for preventative action.

Radionuclides are present to some degree in all natural materials. The average concentration of radionuclides and their emissions over a broad area constitutes **background**. Background values are higher in some areas than others. Studies have shown that background radiation can actually have a beneficial effect on plants and animals. Our focus, however, is "hot spots" associated with mining which have elevated concentrations of radionuclides and radioactive emissions considerably in excess of background values.

Several commonly-held principles of radiation exposure should be clearly understood:

1. Laboratory experimentation supports the hypothesis that the effects of ionizing radiation are inherently stochastic (random) at the low levels encountered in nature. Because of this, the deleterious effects of low-level radiation are generally believed to increase linearly with exposure.

2. Also because the effects of radiation seem to be stochastic, most authorities believe that there is no threshold below which exposure to radiation does not pose some risk to health. Stated positively, most authorities believe that any exposure to radiation is potentially dangerous. This point is strongly debated by a relative few who purport the beneficial effects of low-level exposures to ionizing radiation. There has not been adequate research to support or refute this opinion, much less to determine acceptable or potentially beneficial levels. Most health specialists therefore err on the side of caution and assume that any exposure in excess of what the typical human receives in ordinary life is potentially dangerous.

3. Experiments with laboratory animals generally indicate that the effects per unit dose are less at low dose rates than at high dose rates. This means that exposure to low-level radiation over a long period of time is probably less damaging than infrequent high-level exposures.

4. The effects of many types of radiation are cumulative through one's lifetime, and their damage is usually irreversible.

There are two primary concerns regarding the effects of ionizing radiation on human health:

1. Somatic Effects - These are effects that impact the exposed individual directly. When living tissue is exposed to ionizing radiation, individual cells can be **mutated**, that is, altered to produce an inheritable change in the chromosomes. This process can stimulate **cancer**, the accelerated reproduction of mutated cells. Cancer may stay localized in one area or it may spread to other parts of the body. The risk of cancer increases with higher doses of radiation. It may result from exposure to penetrating radiation such as gamma, or from direct intake of radionuclides by ingestion or inhalation. Radiogenic cancers are indistinguishable from those associated with other causes, so determining whether a given incident of cancer is the result of radiological exposure or some other cause is often difficult or impossible.

   Included in the somatic category are the effects of radiation *in utero*. The unborn are generally more sensitive to radiation than adults because the rate of cell division in their developing organs is far greater, especially during the period from 8 weeks to 15 weeks after conception, and to a lesser degree, from 16 to 25 weeks. For this reason, women should take special precautions to avoid elevated radiological exposure during pregnancy. To a lesser degree, this is also true of minors, who are also undergoing major development until they reach adulthood.

Several types of cancer merit special note. One of the most hideous somatic effects of ionizing radiation is cancer in the blood-forming organs, or **leukemia**. Leukemia reduces the rate at which the components of blood are produced and alters the overall blood composition. In the 1920s a high incidence of bone cancer was noted in workers who applied radium to luminous dials on time pieces. Subsequently researchers discovered that ingested radium and other radioelements which are chemically similar to calcium tend to be incorporated into bones. As explained above, the lungs are particularly susceptible to cancer due to inhalation of radioelements. Literature contains numerous references to radiation inducing accelerated aging, but this has not been substantiated in studies on human populations or experimentation on laboratory animals. Rather, any shortening of life is usually explained by direct effects such as those mentioned above.

It is important to know that smoking and elevated concentrations of radon progeny have been shown to have compounding effects on their individual risks of contracting lung cancer. In other words, the risk of contracting lung cancer from smoking in high radon daughter concentrations is much greater than merely adding the cancer risks from radiation and smoking figured separately. This is because smoking generates particulates which are ideal condensation nuclei for unattached radon daughters. This contaminated smoke is then deliberately inhaled and the particulates can get lodged in the lungs. For this reason, smoking should be prohibited in areas of elevated radiation.

2. Genetic Effects - The essential characteristics of humans are passed from one generation to the next by **chromosomes** located in the nuclei of reproductive cells. Chromosomes are composed of **genes**, which are complex molecules that are strung together in bead-like fashion to form the chromosome. The 46 human chromosomes are composed of approximately 10,000 genes, and it is this combination of chromosomes and genes that passes on the physical and psychological characteristics from one generation to the next.

   Ionizing radiation can mutate the molecular structure of individual genes, break chromosomes, or rearrange chromosomes into a different configuration. If radiation mutates reproductive cells, these mutations are transmitted from the exposed individual to their descendants. The severity of genetic effects ranges from inconsequential to debilitating or fatal.

There are three basic principles for limiting exposure to ionizing radiation, thereby minimizing its effects:

TIME
DISTANCE
SHIELDING

Exposures are limited by minimizing the **time** of exposure, maximizing the **distance** between the receptor and the radiation source, and by **shielding** the receptor when exposure is unavoidable.

REGULATIONS, GUIDELINES, AND STANDARDS

Environmental policies generally define two categories of permissible limits: regulations and guidelines. A **regulation** is a rigid, enforceable policy promulgated by an agency. A **guideline** is an unenforceable recommendation which may be used as the basis for regulations. Regulations often contain **standards** for contaminants or other harmful agents, which are limiting values that must not be exceeded by the operations for which they were set.

To date, there are no specific regulations for radioactive substances or emissions at AML sites. This is not the case for active mines, mills, nuclear power plants, or other facilities which process and/or use radioactive materials, all of which are strictly regulated. Guidelines on radiation exposures to the general public are available from numerous sources. A review of these regulations and guidelines is helpful in understanding and properly managing radiological hazards at AML sites.

Various agencies are involved in establishing radiation regulations. For occupational standards, the Mine Safety and Health Administration (MSHA) is responsible for regulating and enforcing exposure limits and work procedures in active mines. This includes provisions and procedures for dealing with radioactive emissions at uranium mines, as well as mines producing other commodities which have associated radioactive elements in their ore. The Nuclear Regulatory Commission (NRC) and the U.S. Environmental Protection Agency (USEPA) regulate radiological emissions and concentrations of radionuclides involved in the transportation, processing, and waste disposal associated with radioactive ores once they leave the mine. The NRC also regulates nuclear power and reactor wastes. Issues concerning environmental and general public (nonoccupational) exposure are addressed by the USEPA, NRC, and DOE.

The USEPA and the National Institute of Occupational Safety and Health (NIOSH) generate **criteria documents** that become the foundation for new regulations and standards set by federal agencies. The recommendations of the USEPA and NIOSH are based on technical feasibility, and are subject to the approval of the Office of Management and Budget (OMB), which assesses the recommendations for their economic practicality. Numerous other national and international agencies have evolved through time to conduct research and make recommendations for the regulatory agencies, industry, and the general public. Several of these agencies are listed below:

ICRP	International Commission on Radiological Protection
IRPA	International Radiation Protection Administration
NCRP	National Council on Radiation Protection and Measurements
NAS-BEIR	National Academy of Science, Committee on the Biological Effects of Ionizing Radiation
NEA	Nuclear Energy Agency
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USERDA	United States Energy Research and Development Administration

Industrial Regulations - While the following discussion concerns regulations intended solely for active operations, many of these regulations have direct and indirect applicability to radiological issues at AML sites. A presidential document entitled "Radiation Protection Guidance to Federal Agencies for Occupational Exposure" was published in the Federal Register on January 27, 1987 (Vol. 52, No. 17, pp. 2821-2834). This document lists three basic principles that govern occupational radiation protection policy. These principles are foundational to all guidelines and regulations that have been developed to date:

1. Any activity involving occupational exposure should be determined to be sufficiently beneficial to society to warrant exposure of workers; i.e., it should be determined that the exposure is "justified."

2. Exposure of the work force should be as low as reasonably achievable, a principle commonly referred to by the acronym **ALARA**.

3. To provide an upper limit on risk to individual workers, "limitation" of the maximum allowed individual dose is required.

Current federal standards for radiation protection relative to the mining and processing of radioactive ores address two situations: occupational regulations concerning worker safety and health, and environmental regulations concerning waste disposal or storage. Regulations concerning workers are based on exposure, as opposed to dose. **Exposure** is the amount of radiation present in an environment, representing potential health danger to an individual. **Dose** is the actual amount of radiant energy absorbed by an individual.

Regulations for radiological contaminants and exposures can be found in the Code of Federal Regulations (CFR). These regulations are the basis for the ensuing discussion:

CFR Title 10: Nuclear Regulatory Commission
CFR Title 26: Department of Labor
CFR Title 30: Mine Safety and Health Administration (Department of Labor)
CFR Title 40: Environmental Protection Agency

Alpha radiation exposures are measured and regulated in **working levels (WL)**, **working level hours** (1 **WLH** = exposure at 1 WL for 1 hour), and **working level months** (1 **WLM** = 173 WLH). (Refer to the glossary for detailed definition of units.) A standard unit of measure for gamma radiation exposure has been the **roentgen equivalent man (rem)**, and gamma exposures are typically given in **millirems (mrem or mR)** per hour (1 mrem = 1×10^{-3} rem) or **microrems (μrem or μR)** per hour (1 μrem = 1×10^{-3} mrem = 1×10^{-6} rem). More recently, the **sievert (Sv)** is being used to express gamma radiation values, where 1 Sv = 100 rem.

Occupational levels of alpha and gamma radiation in underground uranium mines are regulated at 30 CFR, Part 57, Subpart D, which states that the yearly permissible exposure per individual worker shall not exceed 4 WLM alpha (30 CFR §57.5038) or 5 rem gamma (30 CFR §57.5047d). These limits are mutually exclusive. For example, a miner may have 3 WLM alpha and 4 rem gamma exposures and remain considerably below his annual allowance.

Alpha radiation carries several acute exposure limitations. MSHA-approved respirators are to be worn in all radon daughter concentrations between 1 WL and 10 WL (30 CFR §57.5005 and §5039). Above 10 WL (where the impact of radon gas begins to be significant) a supplied-air breathing apparatus or a face mask containing absorbent material capable of removing radon gas and its daughters is required (30 CFR §57.5046). Because of the compounding effects of smoking and radon daughter exposure on the risk of cancer, smoking is not permitted in mine workings exceeding 0.3 WL (30 CFR §57.5041). Occupational standards also require that inactive areas with radon daughter concentrations exceeding 1 WL should be posted against unauthorized entry and designated by signs requiring the use of approved respirators (30 CFR §57.5045).

There are no acute gamma exposure limitations specified for mines. This is because typical gamma exposures at a mine (or, for that matter, a mill tailings impoundment) should never approach levels where acute exposure is imminently hazardous. Background radiation values in the southwest, with a few noteworthy exceptions, are typically about 20 μR/hr. Many AML sites of the Colorado Plateau have gamma emissions falling in the range from 100 to 300 μR/hr. Gamma radiation in these ranges is not considered to be excessively high for short-term exposures. Values above this are characteristic only of sites where natural material has been concentrated by some technological means. For instance, sites operating under a license from the NRC (such as a nuclear power plant) require evacuation at 2 mR/hr (10 CFR, Subpart D, §20.1302). It is important to note that the NRC limits minors and pregnant women to 10% of the normal adult worker exposures (10 CFR §1207 and §1208). Although the CFR does not specifically address the issue, many active uranium mines and mill sites, in keeping with the principle of ALARA, restrict eating and smoking to designated areas where special precautions are taken to avoid contamination. The Department of Labor requires posting of radiation warning signs in "radiation areas," defined as any area where radiation exists at such levels that a major portion of the body could receive in any 1-hour, a dose in excess of 5 mR, or in any 5 consecutive days, a dose in excess of 100 mR. (26 CFR §1910.96)

Regulations applying to soil concentrations of radioactive elements are covered in 40 CFR §192, entitled, "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings." The waste-rock piles at abandoned mines are not subject to these regulations, as they have not been milled. These standards are predicated on a "residential use scenario," meaning that they are geared toward ensuring safe conditions for residential areas. Again, this is clearly not the case at remote AML sites, but data obtained from such sites can be compared to limits in these regulations to get a general idea how contaminated they actually are. The Code specifies at 40 CFR §192.12(a) that the concentration of Radium 226 in land averaged over an area of 100 square meters shall not exceed background (native concentrations of radioactivity or radioactive materials in the area prior to disturbance) by more than:

1. 5 pCi/g.[2] Ra averaged over the first 15 cm. of soil below the surface, and

2. 15 pCi/g. Ra averaged over 15 cm.-thick layers of soil more than 15 cm. below the surface.

The Code further stipulates at 40 CFR §192.12(b) that in any occupied or habitable building:

1. The objective of any remedial action, within reasonable means, should be to achieve an annual average (or equivalent) radon product concentration (including background) not to exceed 0.02 WL, and that in any case 0.03 WL should not be exceeded; and

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[2] The unit pCi/g (picocuries per gram) is the number of atomic decays per minute undergone by a radioactive species per unit mass of the sample. The decay rate of a sample, or its "degree of radioactivity," is directly proportional to the concentration of the radioactive constituent(s) being tested. For a pure radioactive substance, this value is constant; a distinguishing characteristic of the radioactive element termed specific activity.

2. Gamma radiation levels should not exceed 20 microroentgens per hour above background.

40 CFR §192.21 states that these standards are flexible in cases where:

a. remedial action would pose a threat to the health of workers performing the reclamation.

b. remedial action would "directly produce environmental harm that is clearly excessive compared to the health benefits to persons living on or near the site, now or in the future."

c. there is no likelihood of buildings being erected or people spending large amounts of time in the area. "Remedial action will generally not be necessary where residual radioactive materials have been placed semi-permanently in a location where site-specific factors limit their hazard and from which they are costly and difficult to remove, or where only minor quantities of residual radioactive materials are involved."

d. the cost of remedial action is clearly unreasonably high relative to the benefits.

e. there is no known remedial action.

f. radionuclides other than Radium-226 and its decay products are present in sufficient quantity to constitute a significant radiological hazard.

Regulations for effluents from active uranium, radium, and vanadium mines are cited in 40 CFR §440.32, which are listed in part in Figure G. The limit on uranium is related to its chemical toxicity, not its radioactivity.

Effluent Characteristic	Effluent Limitation	
	Maximum for any one day	Average of daily values for 30 consecutive days
Ra226 (dissolved)	10 pCi/l	3 pCi/l
Ra226 (total)	30 pCi/l	10 pCi/l
U (Uranium)	4 mg/l	2 mg/l

Figure G: Limits for concentration of pollutants discharged by underground uranium, radium, and vanadium mines.

NPS-14: Cave Radiation Safety and Occupational Health Management Guideline

The National Park Service manages many caves, some of which draw considerable visitation and require extensive underground time for NPS tour guides and scientists. When the harmful effects of radiation began to be understood and elevated levels of radiation were found in some of the major cave parks, NPS management realized the need to establish a safety policy for cave management. NPS-14 evolved from that realization. The stated purpose of this guideline is to "... establish protective administrative and operational procedures for addressing cave alpha radiation in order to minimize potential health hazards to employees, visitors, special use groups, and concessioners." NPS-14 acknowledges radon progeny as the principle radiological hazard underground, and limits employee exposure to 2 WLM per year. The currently-proposed revision of the document limits lifetime cumulative exposures to 60 WLM.

USEPA Federal Radiation Protection Guidance for Exposure of the General Public

It is a common practice, in the absence of regulations, to recommend 10 percent of occupational limits for the general public exposures, based on the assumption that individuals electing to work in hazardous environments knowingly accept a higher level of risk that would be appropriate for the public at large. Until recently, the NPS Geologic Resources Division has used this convention to advise parks on the relative hazard at various sites which have been tested.

On December 23, 1994, the USEPA published a notice in the Federal Register of a proposed Federal Radiation Protection Guidance for Exposure of the General Public (RPG). Although this RPG is not yet official, it will most likely soon be adopted. The purpose of this guidance is to provide a common framework for federal agencies in formulating regulations and conducting programs for protection of the general public from ionizing radiation. Limits recommended in the RPG are in keeping with the latest international research and theory on permissible radiological exposures, and represent a 5-fold increase in protection from limits in the previous recommendations which date back to 1960 and 1961.

The RPG applies to many normal sources of ionizing radiation that are created or influenced by human activity and can reasonably be controlled. Specifically mentioned are "mines, mills, and processors of uranium and thorium, ... [and] wastes from mineral ores, including ores which are mined for uses or purposes other than for their radioactive isotopes.... The RPG also address[es] most terrestrial sources of exposure arising from human activities (these principally involve naturally occurring radioactive materials), but not exposure due solely to background radiation or due to globally-dispersed effects of past activities or accidents." Cave exploration is mentioned as one activity which is specifically not covered in the RPG. The RPG does not apply to radiation exposure from background, medical treatments, results of nuclear accidents, or to exposures which are covered in other USEPA guidance or agency regulations such as occupational exposure and household radon gas and radon daughter exposures.

In the context of managing AML sites, the RPG is briefly summarized in the following seven recommendations:

1. There should be no exposure of the general public to ionizing radiation unless it is justified by the expectation of a net societal benefit from the activity causing the exposure, i.e., unless the resulting benefit to exposed individuals offsets the detriment the exposure causes. Justified activities may be allowed, provided exposure of the general public is limited in accordance with Recommendations 2-7.

2. A sustained effort should be made to ensure that doses to individuals and to populations are maintained as low as reasonably achievable (ALARA). This concept, also designated as "optimization" of radiation protection, involves balancing public health against the

economic constraints involved in protecting it.

3. The combined radiation doses incurred in any single year from all sources of exposure covered under the RPG should not normally exceed an effective dose equivalent of 1 mSv (100 mrem) for any individual.[3] Realizing that in some unusual situations this level of protection may not be achievable, i.e., temporary situations that are not anticipated to recur chronically, an effective equivalent dose of 5 mSv (500 mrem) is permissible. Continued exposure near or at these levels over substantial portions of an individual's life should be avoided. The normal limit represents a five-fold reduction from the previous recommendation limiting all individuals to 0.5 mSv. The stricter limit takes into account the long-term effects of certain radionuclides which, if inhaled or ingested, may remain in and continue to irradiate the body for many years, and considers that the average American is exposed annually to 3 mSv from natural background, two thirds of which comes from radon in homes.

4. Authorized limits on doses received from individual sites should be established, and limited to a fraction of the RPG or ALARA, whichever is less. Although in the past the USEPA has suggested up to 25 mrem (0.25 mSv) as a source-specific limit, it is currently recommending 10 mrem (0.1 mSv) at individual sites (10% of the RPG).

5. Risks associated with potential radiation exposures at a site should be communicated to the general public. The degree of detail and type of information made available should be appropriate to the potential radiation exposures involved.

6. Sites where radioactive emissions are possible should be competently assessed for their potential impact on affected populations. This includes radiometric surveys of the site and a reasonable analysis of likely exposures to the public, taking into account how the site is used.

7. Exceptions to Recommendation 3 should be made only for highly unusual circumstances, and only when the federal agency having jurisdiction has carefully considered the reasons for making them in light of Recommendations 1-6.

[3] Previous guidance on general public exposures (1960 and 1961) consisted of separate limits on dose for the whole body and for specified organs. The RPG replaces that system with a risk-weighted dose limitation introduced by the ICRP in 1977, which uses the concept of **effective dose equivalent (EDE)**. A limit in terms of EDE reflects the exposure, and somatic and hereditary cancer sensitivities, of all organs and tissues of the body. It does not differentiate between exposures from internal and external sources, but includes both. The standard unit of measure is the sievert (Sv), To integrate the contribution of alpha radiation as described above, an alpha dose of 1 WLM can be very roughly equated to 10 mSv (1 rem).

APPLICATION

The NPS Geologic Resources Division has adopted the new RPG in advising units of the National Park System on management of AML sites. Sites suspected of elevated radiological activity should be characterized so that intelligent decisions can be made on their proper management. A realistic estimate of the typical visitor or employee exposure at each site should then be made. For instance, suppose a reclaimed mine site might reasonably be expected to draw a backpacker for one night once in a year with an estimated exposure duration of 15 hours per visit. Perhaps an abandoned mill site beside the trail typically draws a visitor for two hours. A district ranger might be in charge of monitoring a hazardous mine site, involving 3 hours on-site once per month. Or perhaps a designated campsite in the Chinle Formation is found to have elevated background radiation values and the typical camper spends up to 5 days there. Once the length of a typical visit is established and hard data on exposure levels are known, the cumulative exposure to the typical site visitor can be calculated and compared to specifications in the RPG. Sites should be evaluated and managed using a worst-case scenario, i.e., using the site visitor most likely to spend the most time on-site.

Employees often represent a special use group worthy of separate consideration. For instance, with the current effort in BLM to generate an AML inventory, a natural resource specialist may be detailed to conduct inventory work for all of the mines in a particular mining district. This individual should receive adequate safety training, be equipped with proper instrumentation and wear a dosimeter, and should be reassigned if he or she begins to approach a cumulative annual exposure limit. Since working in elevated radiation areas is not a normal part of this employee's job responsibilities, his or her exposure should probably be limited according to guidelines for the general public, i.e., 100 mrem/year (1 mSv/year), rather than using occupational limits.

Mitigation of radiologically-elevated sites may include administrative measures such as policy statements, printed handouts, road and trail closures, or signs posted at the site. A sign developed for use at NPS AML sites is shown in Figure I.

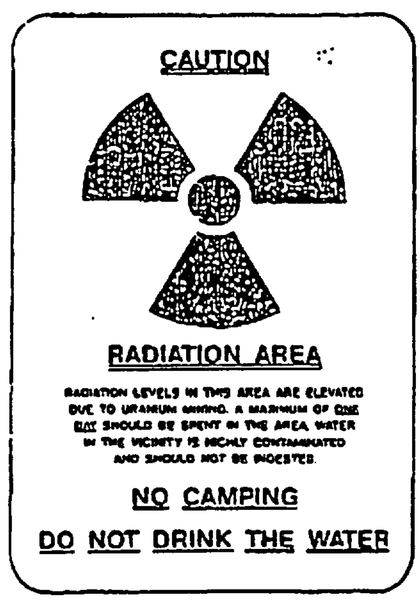

Figure I: Radiation Warning Sign

If excessive exposure is unavoidable, more drastic measures may be appropriate such as bulkheading mine openings, waste rock and tailings burial or removal, up to and including total site reclamation.

Land management offices that have frequent dealings with radiologically-elevated sites should obtain (or have ready access to) proper instrumentation for radiological characterization. First and foremost, this is essential to ensure employee safety and safety of the general public which may come in contact with these sites. In the case of offices managing mine reclamation projects, these instruments can be used in project design by identifying "hotter" material that should be isolated by burial, or in extreem cases, by removal to a designated disposal site. Instruments should also be used to monitor exposures to on-site supervisors and work crews implementing these reclamation projects.

For more information, radiation specialists in the agencies mentioned above are excellent sources of technical assistance. Other agencies which deal regularly with these issues are also very helpful. The U.S. Bureau of Mines (USBM) Ionizing Radiation Program has been engaged in research, consulting, site monitoring, and site mitigation. Unfortunately, the USBM is being closed at this time, but a contingent from this group, its laboratory, and equipment is slated for a transfer to the Colorado School of Mines in Golden, Colorado. The U.S. Department of Energy [DOE, formerly the Atomic Energy Commission (AEC)] is integrally involved in nuclear power plants and nuclear fuel processing facilities. DOE is often involved in the cleanup of USEPA Superfund sites, and is also reclaiming a number of its own AML sites which were mined on special AEC lease tracts. (These tracts were withdrawn from the public domain between 1948 and 1954 to develop a source of domestic uranium ores for national defense purposes.) The author can also be contacted at National Park Service - GRD, P.O. Box 25287, Denver, CO, 80225-0287, by telephone at (303) 969-2099, by FAX at (303) 969-2822, or over the internet at john_burghardt@nps.gov.

GLOSSARY[4]

ALARA - Acronym for the overall guiding principle of radiation safety: that exposures to ionizing radiation should be kept as low as reasonably achievable. Even in situations where anticipated exposures are well below regulated limits, ALARA, also referred to as "optimization of radiological protection," should be the overriding policy for exposure.

Alpha (α) energy - Alpha particles are emitted from atomic nuclei with varying degrees of energy, but the energy from any radionuclide is characteristic and consistent. For example, Ra A emits a characteristic 6.0 MeV alpha particle and Ra C′ emits a characteristic 7.7 MeV alpha particle.

Atom - The smallest unit into which a chemical element can be divided and still retain its characteristic properties.

Alpha (α) particle - A positively charged particle composed of two neutrons and two protons released by some atoms undergoing radioactive decay. The alpha particle is identical to the nucleus of a helium atom.

Atomic mass - The sum of the number of protons and neutrons in the nucleus of an atom.

Atomic number - The number of protons in the nucleus of an atom. The atomic number is the distinguishing characteristic of a given element.

Background - The radioactivity which is inherent in the environment. Where specific radiation measurements exclusive of the general environment are desired, the background radiation must first be determined and then subtracted from the total count.

Beta (β) particle - An electron emitted from the atomic nucleus as a neutron spontaneously decays to a proton. Beta particles are more penetrating but less ionizing than alpha particles.

Cancer - The accelerated reproduction of mutated cells in living tissue.

Cell - A very small, complex unit of protoplasm, usually with a nucleus, cytoplasm, and an enclosing membrane. All plants and animals are made up of one or more cells, usually very many.

Chromosome - One of the bodies in the cell nucleus composed of genes strung together in bead-like fashion.

Condensation nuclei - The small dust and aerosol particles in the atmosphere to which the atomic-sized radon daughters readily attach. The size of condensation nuclei are generally in the 0.2- to 0.3-micron range.

Curie (Ci) - A quantitative measure of radioactivity. One curie equals 2.22×10^{12} disintegrations per minute (dpm).

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[4] This glossary was adapted from a glossary found in "Radiation Monitoring," a handbook prepared by the U.S. Department of Labor, Mine Safety and Health Administration (MSHA), 1979. Information in that glossary was edited and expanded upon to suit the purposes of this study.

Daughter - That which remains when a radioactive element releases an alpha or beta particle.

Decay series - The consecutive members of radioactive family of elements. A complete series commences with a long-lived parent which decays through a defined sequence of steps until it becomes a stable element, such as Uranium-238 decaying to stable Lead-206, or Thorium-232 decaying to stable Lead-208.

Disintegrations per minute (dpm) - The radioactive decay rate, determined from the count rate on the instrument divided by the gross counting efficiency of the instrument.

Dose - The amount of absorbed radiant energy. Usually given in rems or rads.

Effective Dose Equivalent (EDE) - The sum of all internal and external doses of radiation which takes into account the somatic and hereditary cancer sensitivities of all organs and tissues of the body.

Electrons - The orbital, negatively-charged particles surrounding the nucleus of an atom.

Electron volt (eV) - The amount of energy required to move one electron through a difference in potential of one volt. The unit is equal to 1.6×10^{-12} erg.

Element - A pure substance which cannot be decomposed into any simpler pure substance.

Equilibrium - The state at which the radioactivity of consecutive elements within a radioactive series is neither increasing nor decreasing.

Exposure - The amount of radiation present in an environment, not necessarily indicative of absorbed energy, but representative of potential health damage to the individual present.

Gamma (γ) radiation - A true ray of energy, in contrast to beta and alpha radiation which are particulate. The properties of gamma rays are similar to X-rays and other electromagnetic waves. Gamma radiation is highly penetrating, but relatively low in ionizing potential.

Gene - A complex molecule which forms a small section of a chromosome in the nucleus of a cell. Genes pass on physical and psychological characteristics from one generation to the next.

Guideline - An unenforceable recommendation which may be used as the basis for regulations.

Half-life - The time required for half of the atoms of a radioactive element to undergo decay.

Ionization - The breakdown of a molecule or atom into unstable charged components. This breakdown can be caused in several ways, one of which is by exposure to ionizing radiation.

Ionizing radiation - Radiation capable of providing sufficient energy to ionize or break down molecules.

Isotopes - Variant forms of an element, each of which contain the same number of protons, but different numbers of neutrons.

Leukemia - A cancer of the blood-forming organs.

Matter - The material of which the universe is composed, i.e., anything that occupies space and has mass.

Mutation - An inheritable change in the chromosomes of a cell.

Neutron - An electrically-neutral particle in the nucleus of an atom, having an atomic mass of 1.

NORM - Acronym for naturally occurring radioactive material, as opposed to material that has been technologically enhanced through some means of isolation and refinement.

Nucleus (atomic) - The center portion of an atom containing protons and neutrons.

Nucleus (cell) - A body present in most cell types containing chromosomes and nucleoli in a matrix of nucleoplasm, enclosed in an external nuclear membrane.

Parent - A radioactive element which will, in time, undergo radioactive decay to become a new element.

Picocurie (pCi) - A quantitative measure of radioactivity equal to 1×10^{-12} curie or 2.22 dpm.

Proton - A positively-charged particle in the atomic nucleus, having an atomic mass of 1. The number of protons in an atom its "atomic number," which is the distinguishing characteristic of a given element.

Protoplasm - A semifluid, viscous, translucent colloid, the essential living matter of all animal and plant cells. It consists largely of water, proteins, lipoids, carbohydrates, and inorganic salts and is differentiated into nucleoplasm (within the cell's nucleus) and cytoplasm (outside the cell's nucleus).

Progeny - The offspring of a radioactive element resulting from its decay through alpha and beta particle emissions.

Radiation Absorbed Dose (rad) - The unit denoting absorption of 100 ergs of radiant energy per gram of absorbing material.

Radioactivity - Spontaneous release of particles and energy by the nucleus of an inherently unstable atom.

Radionuclide - A radioactive atom.

Radium - Generally refers to Ra226, the parent of radon gas in the Uranium-238 decay series.

Radium A - Polonium-218 (Po218), the first daughter of Rn-222. It emits a 6.0 MeV alpha particle and has a half-life of approximately 3 minutes.

Radium B - Lead-214 (Pb214), the second daughter of Rn-222. It emits beta and gamma radiation and has a half-life of about 27 minutes.

Radium C - Bismuth-214 (Bi214), the third daughter of Rn-222. It emits a beta particle and a strong gamma ray and has a half-life of about 20 minutes.

Radium C' - Polonium-214 (Po214), the fourth daughter of Rn-222. It emits a 7.7 MeV alpha particle and has a half-life of only 164 microseconds. Because of its extremely short half-life, very few atoms of Ra C' can be present and its activity is always equal to the activity of Ra C.

Radium D - Lead-210 (Pb210), is technically not considered one of the short-lived daughters of Rn-222 because of the relatively long half-life of 22 years. The long half-life prevents RaD and successive decay members from contributing much activity over short periods of time.

Radon - Normally the noble gaseous element (Rn-222) in the U-238 decay series, the immediate parent of Po-218 (Ra A).

Radon daughters - The four short-lived elements which succeed radon in the U-238 decay series. These include Po-218 (Ra A), Pb-214 (Ra B), Bi-214 (Ra C), and Po-214 (Ra C').

Regulation - A rigid, enforceable policy promulgated by an agency.

Roentgen - A primary unit of radiation exposure. Technically, it is defined as that quantity of X-ray or gamma radiation that produces one electrostatic unit of electrical charge per 0.001293 gram of air.

Roentgen Equivalent Man (rem) - The amount of ionizing radiation that when absorbed by a person is equivalent to one roentgen of X-ray or gamma radiation.

Sievert (Sv) - An SI (International System of Units) unit equivalent to 100 rem.

Standard - A limiting value that must not be exceeded by operations for which they were set.

Thoron - Also known as Radon-220 (Rn-220), this is a noble gaseous element in the Thorium-232 decay series, and the immediate parent of Po-216 (Th A).

Uranium - Refers normally to U-238, although about 0.7 percent or naturally-occurring uranium is actually U-235, the fissionable component in nuclear fuels.

Uranium series - The 15 radioactive elements commencing with U-238 and culminating in stable Pb-206.

Working level (WL) - An atmospheric concentration of radon (Rn-222) daughters which will deliver 1.3×10^5 MeV of alpha energy per liter of air in decaying through Ra C' (Po-214).

Working level hour (WLH) - An exposure equivalent to one working level of radon daughters for 1 hour.

Working level month (WLM) - An exposure equivalent to one working level of radon daughters for 173 hours.

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	Dr. Robert Holub	Physicist, Ionizing Radiation Program
	Mr. Robert Droullard	Geophysicist, Ionizing Radiation Program USBM Denver Research Center, Colorado
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NPS	Mr. Robert Carson	Air Quality Specialist, WASO Air Resources Division Denver, Colorado (detailed to Mammoth Cave National Park, Kentucky)
	Ms. Allyson Mathis	Geologist, Capitol Reef National Park Torrey, Utah

REFERENCES

Chenoweth, William L., 1990, A History of Uranium Production in Utah, Utah Geological Association Publication 18, pp. 113-124.

Curtis, Helena, 1968, Biology, Worth Publishers, Inc., New York, NY, 854 pp.

Fischer, R.P., 1968, The Uranium and Vanadium Deposits of the Colorado Plateau Region, taken from Ore Deposits of the United States, 1933-1967, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, NY, Vol.1, Part 6, Ch. 35, pp. 735-746.

Guilbert, John M. and Charles F. Park, Jr., 1986, The Geology of Ore Deposits, W. H. Freeman and Company, New York, NY, 985 pp.

Eisenbud, Merril, 1987, Environmental Radioactivity from Natural, Industrial, and Military Sources, 3rd ed.: Academic Press, Inc., San Diego, CA, 475 pp.

Rock, R. L. and Robert T. Beckman, Radiation Monitoring: U.S.Department of Labor, Mine Safety and Health Administration, 1979, 50 pp.

U.S. Environmental Protection Agency, 1992, A Citizen's Guide to Radon, 2nd ed.: Air and Radiation Pamphlet ANR-464, 15 pp.

U.S. Department of Health and Human Services, National Institute of Occupational Safety and Health, 1987, A Recommended Standard for Occupational Exposure to Radon Progeny in Underground Mines: 215 pp.

Wheeler, Gerald F., Larry D. Kirkpatrick, 1983, Physics: Building a World View, Prentice-Hall, Inc., Englewood Cliffs, NJ, 556 pp.

Wiseman, Frank L., 1985, Chemistry in the Modern World: Concepts and Application, McGraw-Hill, Inc., New York, NY, 495 pp.