B. SOURCES OF BACKGROUND RADIOACTIVITY

B.1 Introduction

Background radioactivity can complicate the disposition decision for M&E. Background radioactivity may be the result of environmental radioactivity, inherent radioactivity, instrument noise, or some combination of the three. Special consideration is given to issues associated with technologically enhanced naturally occurring radioactive materials (TENORM) and orphan sources as contributors to background. The planning team should consider these potential sources of background activity and determine what effect, if any, they may have on the design of the disposition survey.

Information on background radioactivity can be obtained from many sources, including:

- The Nuclear Regulatory Commission (NRC) provides information concerning background radioactivity in *Background as a Residual Radioactivity Criterion for Decommissioning* NUREG-1501 (NRC 1994).
- The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has published a report on *Sources and Effects of Ionizing Radiation* (UNSCEAR 2000) and provides a searchable version of the report on the World Wide Web at www.unscear.org.
- The National Council on Radiation Protection and Measurements (NCRP) has published reports on *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94 (NCRP 1988a) and *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources*, NCRP Report No. 95 (NCRP 1988b).

B.2 Environmental Radioactivity

Environmental radioactivity is radioactivity from the environment where the M&E is located. There are three sources contributing to environmental radioactivity; terrestrial (Section B.2.1), manmade (Section B.2.2), and cosmic and cosmogenic (Section B.2.3). Although background radiation is present everywhere, the component radionuclide concentrations and distributions are not constant. Certain materials have higher concentrations of background radiation, and varying environmental and physical conditions can result in accumulations of background radiation. Information on environmental radioactivity is usually available from historic measurements identified during the initial assessment (IA).

If high levels of environmental radioactivity interfere with the disposition decision (e.g., action level less than environmental background, variability in environmental radioactivity determines level of survey effort), the planning team may consider moving the M&E being investigated to a location with less environmental radioactivity (see Sections 3.3.1.3 and 5.3). If the level of environmental radioactivity is unknown, it may be necessary to collect data during a preliminary survey (see Section 2.3) to provide this information.

B.2.1 Terrestrial Radioactivity

The naturally occurring forms of radioactive elements incorporated into the Earth during its formation that is still present are referred to as "terrestrial radionuclides." The most significant terrestrial radionuclides include the uranium and thorium decay series, potassium-40 and rubidium-87. Virtually all materials found in nature contain some concentration of terrestrial radionuclides. Table B.1 lists average and typical ranges of concentrations of terrestrial radionuclides. Although the ranges in the table are typical, larger variations exist in certain areas (e.g., Colorado).

Bulk materials containing elevated concentrations of terrestrial radionuclides as well as equipment used to handle or process these materials should be identified during the IA even if these materials and equipment were not impacted by site activities.

Radon is an element that occurs as a gas in nature. Isotopes of radon are members of both the uranium and thorium natural decay series. These radon isotopes decay to produce additional radioactive isotopes, which are collectively called radon progeny.

Table B.1 Typical Average Concentration Ranges of Terrestrial Radionuclides

Material	Radium-226 (Bq/kg)[a]	Uranium-238 (Bq/kg)[a]	Thorium-232 (Bq/kg)[a]	Potassium-40 (Bq/kg)[a]
Soil, U.S.	40 (8-160)[b]	35 (4-140)[b]	35 (4-130)[b]	370 (100-700)[b]
Phosphate Fertilizer	200[c] - 100,000[d]	200-1,500[b]	20[b]	--
Concrete	(19-89)[e]	(19-89)[f]	(15-120)[f]	(260-1,100)[f]
Concrete Block	(41-780)[e]	(41-780)[f]	(37-81)[f]	(290-1,100)[f]
Brick	(4-180)[e]	(4-180)[f]	(1-140)[f]	(7-1,200)[f]
Coal Tar Fly Ash-Bottom Ash	(100-300)[e] 200[e]	(100-300)[b] 200[b]	-- 200[b]	-- --
Coal, U.S.	--	18 (1-540)[g]	21 (2-320)[g]	52 (1-710)[g]
Tile	--	(550-810)[h]	650[h]	--
Porcelain, Glazed	--	(180-37,000)[h, i]		--
Ceramic, Glazed[b]	(79-1,200)[h, i]			

a To convert Bq/kg to pCi/g, multiply by 0.027.

b UNSCEAR, Sources and Effects of Ionizing Radiation (UNSCEAR 2000).

c U.S. Environmental Protection Agency (EPA), 2000. *Evaluation of EPA's Guidelines for Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM).*

d National Academy of Sciences (NAS). 1999. *Evaluation of Guidelines for Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)*, Committee on Evaluation of EPA Guidelines for Exposure to Naturally Occurring Radioactive Materials Board on Radiation Effects Research Commission on Life Sciences National Research Council, National Academy Press, p. 72.

e ^{226}Ra is assumed to be in secular equilibrium with ^{238}U.

f Eicholz G.G., Clarke F.J., and Kahn, B., 1980. *Radiation Exposure From Building Materials*, in "Natural Radiation Environment III," U.S. Department of Energy CONF-780422.

g Beck H.L., Gogolak C.V., Miller K.M., and Lowder W.M., 1980. *Perturbations on the Natural Radiation Environment Due to the Utilization of Coal as an Energy Source*, in "Natural Radiation Environment III," U.S. Department of Energy CONF-780422.

h Hobbs T.G., 2000. *Radioactivity Measurements on Glazed Ceramic Surfaces*, J. Res. Natl. Inst. Stand. Technol. **105**, 275-283.

i Values reported as total radioactivity without identification of specific radionuclides.

Radon emissions vary significantly over time based on a wide variety of factors. For example, relatively small changes in the relative pressure between the source material and the atmosphere (indoor or outdoor) can result in large changes in radon concentrations in the air. Soil moisture content also has an affect on the radon emanation rate.

Radon progeny tend to become fixed to solid particles in the air. These particles can become attached to surfaces as a result of electrostatic charge or gravitational settling. Air flow through ventilation ducts can produce an electrostatic charge that will attract these particles. A decrease in atmospheric pressure often precedes a rainstorm, which increases the radon emanation rate. Immediately prior to an electrical storm, an electrostatic charge can build up on equipment resulting in elevated radiation levels from radon progeny. Rainfall acts to scavenge these particles from the air, potentially resulting in elevated dose rates and surface activities during and immediately following rainfall.

Pb-210 is a decay product of ^{222}Rn and ^{238}U. The 22-year half-life provides opportunities for buildup ^{210}Pb and progeny in sediments and low-lying areas. As mentioned previously, rain acts to scavenge radon progeny from the air. Areas where rain collects and concentrates can result in elevated levels of ^{210}Pb and progeny over time. In addition, lead is easily oxidized and can become fixed to surfaces through corrosion processes. Rust or oxide films on equipment can be indicators of locations with a potential for elevated background radioactivity.

B.2.2 Anthropogenic Radioactive Materials

Nuclear weapons testing and nuclear power reactors have produced large quantities of radionuclides through the fissioning of uranium and other heavy elements and the activation of various elements. Examples of anthropogenic radionuclides that could be in the environment are ^{137}Cs, ^{90}Sr, and various isotopes of plutonium.

Prior to the 1963 Limited Test Ban Treaty, fallout from atmospheric nuclear tests distributed large quantities of anthropogenic radionuclides around the globe. Following the 1963 treaty most nuclear weapons tests were conducted underground, although China and France continued atmospheric testing of nuclear weapons into the late 1970s. In 1996 a Comprehensive Test Ban Treaty was negotiated with the help of the United Nations. The Comprehensive Test Ban Treaty has not been ratified by China or the United States and was broken by Pakistan and India in 1998. However, worldwide fallout concentrations have been declining since the mid 1960s.
In 1964 a Department of Defense weather satellite containing a radiation source failed to achieve orbit. The Space Nuclear Auxiliary Power (SNAP) 9-A Radioisotopic Thermoelectric Generator (RTG) burned up on re-entry and dispersed the nuclear inventory (primarily plutonium-238) into the atmosphere. Incidents involving Soviet satellites with radioisotopes or nuclear reactors occurred in 1969, 1973, 1978, and 1983. In April 1986 there was a non-nuclear steam explosion and fire at the number four reactor at the nuclear power plant in Chernobyl in north-central Ukraine. Large quantities of radioactive material were released into the environment as a result of the catastrophe. The radionuclides from these incidents have been inhomogenously deposited around the world.

Isolated pockets with elevated concentrations of anthropogenic radionuclides can still be found. For example, ventilation systems that were installed prior to 1963 collected fallout radionuclides. If these systems are still in use and the ducts have not been thoroughly cleaned, there is a potential for elevated background radiation. Another potential source of elevated background radiation from anthropogenic radionuclides is wood ash. Trees filter and store some airborne pollutants, including ^{137}Cs from fallout. When the wood is burned the ^{137}Cs is concentrated in the wood ash. Materials or equipment associated with the ash could have elevated levels of background radiation.

B.2.3 Cosmic Radiation and Cosmogenic Radionuclides

Cosmic radiation consists of highly energetic particles that are believed to originate from phenomena such as solar flares and supernova explosions. The Earth's atmosphere serves as a shield for these particles, although on rare occasions a solar flare is strong enough to produce a significant radiation dose in the lower reaches of the atmosphere.

Cosmic radiation is also responsible for the production of radioactive elements called cosmogenic radionuclides. These radionuclides are produced from collisions between the highly energetic cosmic radiation with stable elements in the atmosphere. Cosmogenic radionuclides include ^{3}H, ^{7}Be, ^{14}C, and ^{22}Na. Background concentrations of cosmic radiation and cosmogenic radionuclides generally do not impact disposition surveys.

B.3 Inherent Radioactivity

Inherent radioactivity, or intrinsic radioactivity, is radioactivity that is an integral part of the M&E being investigated. For example, concrete is made from materials that contain terrestrial radionuclides and is inherently radioactive. Some equipment is constructed from radioactive components, such as electron tubes or night vision goggles containing thorium components. Information on inherent radioactivity is usually obtained from process knowledge or historical measurements identified during the IA. Manufacturers of equipment that incorporates radioactive components can usually provide the radionuclide and the activity incorporated into the equipment. Information on radionuclides and activity levels for other types of equipment or bulk materials that are inherently radioactive is usually more generic. Table B.1 lists ranges of terrestrial radionuclide concentrations in some common materials (e.g., concrete, soil, brick). The wide range of radionuclide concentrations observed in these materials prevents establishing any general rules of thumb, so it is usually necessary to obtain project-specific information. For release scenarios, it is strongly recommended that all M&E be surveyed before it enters a controlled area. This provides project-specific information on inherent radioactivity and minimizes complications when designing the disposition survey. For interdiction scenarios, it is important to understand the types of M&E being investigated and the potential for inherent radioactivity. It may be necessary to establish an administrative action level that defines the upper end of acceptable inherent radioactivity for different types of M&E (see Section 3.2).

B.4 Instrument Background

Instrument background is a combination of radioactivity in the constituent materials of the detector, ancillary equipment, and shielding, and electronic noise contributing to the instrument response. Instruments designed to measure low levels of radioactivity generally are constructed from materials with very low levels of inherent radioactivity to minimize instrument background. The electronics in radiation instruments are also designed to minimize the signal-to-noise ratio, also reducing instrument background. Instrument background becomes the primary contributor to background only for radionuclide-specific measurements for radionuclides not contributing to environmental or inherent background (e.g., ^{60}Co in bulk soil measured by gamma spectroscopy). Note that radiation from M&E can interact with instrument shielding to produce secondary effects that may contribute to instrument background (e.g., Compton backscatter, generation of secondary photons and characteristic x rays, photoelectric absorption). Additional information on instrument background is available in Chapter 20 of *Radiation Detection and Measurement* (Knoll 1999).

B.5 Technologically Enhanced Naturally Occurring Radioactive Material

Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) is any naturally occurring material not subject to regulation under the Atomic Energy Act whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities (NAS 1999). Some industrial processes involving natural resources concentrate naturally occurring radionuclides, producing TENORM. Much TENORM contains only trace amounts of radioactivity and is part of our everyday landscape. Some TENORM, however, contains very high concentrations of radionuclides. The majority of radionuclides in TENORM are found in the uranium and thorium natural decay series. Potassium-40 is also associated with TENORM. Radium and radon typically are measured as indicators for TENORM in the environment. TENORM is found in many industrial waste streams (e.g., scrap metal, sludges, slags, fluids) and is being discovered in industries traditionally not thought of as being affected by radiation. Examples of products and processes affected by TENORM include:

- Uranium overburden and mine spoils,
- Phosphate industrial wastes,
- Phosphate fertilizers and potash,
- Coal ash, slag, cinders,
- Oil and gas production scale and sludge,
- Sludge and other waste materials from treatment of drinking water and waste water,
- Metal mining and processing waste,
- Geothermal energy production waste,
- Paper and pulp,
- Scrap metal recycling,
- Slag from industrial processes (metal and non-metal),
- Abrasive mineral sands, and
- Cement production.

Radon and radon progeny are concerns when dealing with TENORM. Radon-222 is a decay product of ^{238}U. The 3.8-day half-life means that ^{222}Rn is capable of migrating through several decimeters of soil or building materials and reaching the atmosphere before it decays. The radioactive progeny of unsupported ^{222}Rn have short half-lives (e.g., 27 minutes for ^{214}Pb) and usually decay to background levels within a few hours. ^{220}Rn, which has a 55-second half-life, is a decay product of ^{232}Th. The short half-life limits the mobility of ^{220}Rn since it decays before it can migrate to the atmosphere. However, ^{232}Th activity that is located on or very near the surface can produce significant quantities of ^{220}Rn in the air. The radioactive progeny of unsupported ^{220}Rn can result in elevated levels of surface radioactivity for materials and equipment used or stored in these areas. The 10.6-hour half-life of ^{212}Pb means that this surface radioactivity could take a week or longer to decay to background levels.

B.6 Orphan Sources

Radiation sources are found in certain types of specialized industrial devices, such as those used for measuring the moisture content of soil and for measuring density or thickness of materials. Usually, a small quantity of the radioactive material is sealed in a metal casing and enclosed in a housing that prevents the escape of radiation. These sources present no health risk from radioactivity as long as the sources remain sealed, the housing remains intact, and the devices are handled and used properly.

If equipment containing a sealed source is disposed of improperly or sent for recycling as scrap metal, the sealed source may be “lost” and end up in a metal recycling facility or in the possession of someone who is not licensed to handle the source. Specially licensed sources bear identifying markings that can be used to trace these sources to their original owners. However, some sources do not have these markings or the markings become obliterated. In these cases, the sources are referred to as “orphan sources” because no known owner can be identified. They are one of the most frequently encountered sources of radioactivity in shipments received by scrap metal facilities.

Scrap yards and disposal sites attempt to detect orphan sources and other contaminated metals by screening incoming materials with sensitive radiation detectors before they can enter the processing stream and cause contamination. Housings that make the sources safe also make detection difficult. Further, if the source is buried in a load of steel, the steel acts as further shielding and thus these sources may elude detection. Consequently, there is always a potential for sources to become mixed within and impact scrap metal.