5. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.1 PRODUCTION

No information is available in the TRI database on facilities that manufacture or process radon because this chemical is not required to be reported under Section 313 of the Emergency Planning and Community Right-to-Know Act (Title III of the Superfund Amendments and Reauthorization Act of 1986) (EPA 1998).

Radon is a naturally occurring element; the isotope of primary health concern is ^{222}Rn. The largest source of radon in the environment is widely distributed uranium and its decay products in the soil (Buttafuoco et al. 2007; UNSCEAR 2000; Weast 1980). Radon is a decay product of radium and part of the uranium decay chain (see Figure 4-1) (Buttafuoco et al. 2007; O'Neil et al. 2006; UNSCEAR 2000). Every square mile of surface soil, to a depth of 6 inches, contains approximately 1 gram of radium, which slowly releases radon to the atmosphere (Weast 1980) when conditions of secular equilibrium exist.

The total production rate of radon in soil equates to the decay rate or concentration of radium present, which can range from 10 to 100 Bq/kg (270–2,700 pCi/kg) in the surface soil and from ~15 to ~50 Bq/kg (~400–~1,350 pCi/kg) in rock (Buttafuoco et al. 2007). The release of radon from the soil-gas or water to ambient air is affected by the soil porosity, meteorological factors, variations in atmospheric pressure, and concentration of radon in the soil-gas or water (WHO 1983). The concentration of radon in soil gas is affected by grain size, mineralogy, porosity, density permeability, and moisture, radium, and uranium content of the soil (Ericson and Pham 2001; Price et al. 1994; USNRC 1981). Meteorological factors, such as temperature and precipitation, may both enhance and inhibit transport of radon from the soil into other media. Radon progeny in the air can be removed by rainfall, soil moisture, and snow (UNSCEAR 2000). Alternatively, radon and its progeny may be temporarily increased at ground level after being brought to the surface by precipitation. If this is by rainfall, then the radon itself is rapidly released back into the atmosphere causing a spike in near-surface levels but leaving the particulate progeny behind in the water or on the surface. If this is by snowfall, then the progeny decay quickly, and any trapped radon builds up progeny toward equilibrium until snowmelt releases the remaining radon. Surface freezing can retard the radon emanation rate (Bunzl et al. 1998; Fujiyoshi et al. 2002). Vertical temperature gradients in which temperature decreases with elevation above the ground can help release radon from the soil, while temperature inversions inhibit this movement. The mechanism of radon transport in soil is described more fully in Section 6.3.1.

Outdoor radon levels vary significantly with geographic location. The ambient outdoor radon level goes through a daily cycle of concentrations ranging from approximately 0.03 to 3.50 pCi/L (Martin and Mills 1973) with the average level in the United States, based on a natural residential radon survey, being about 0.4 pCi L of outdoor air (EPA 2008b). Radon levels can be highly elevated in indoor spaces (UNSCEAR 2000). Indoor radon levels in the United States were found to range from approximately 0 to >80 pCi/L (3,000 Bq/m^3) (Fleischer 1986; Steck et a. 1999; White et al. 1992). EPA estimates that the average indoor radon level is 1.25 pCi/L in the United States (EPA 2003; Marcinowski et al. 1994).

The amount of naturally occurring radon released to the atmosphere is increased in areas with uranium and thorium ore deposits and granite formations, which have a high concentration of natural uranium. It is the presence of granite formations that has greatly increased radon concentrations in eastern Pennsylvania and parts of New York and New Jersey (EPA 2003; NAS 1999b; NCRP 1984a; Nero 1987), although elevated radon levels were also found in other parts of the country (map available at http://www.epa.gov/radon/zonemap.html) (EPA 2011a). Large granite outcroppings, such as the mountain in Stone Mountain, Georgia, are sources of additional airborne radon in that region. Sources of radon in the global atmosphere include natural emissions from radium in soil and water, tailings from metal mines (uranium, thorium, silver, tin, and phosphorus), agricultural lands utilizing phosphate fertilizers, and from construction materials and the burning of coal (EPA 2003; NAS 1999b; NCRP 1984a; Nero 1987). In a few locations, tailings have been used for yard fill, garden soil, sand for masonry work, or landfills and were subsequently built on, resulting in possible increased exposure to radon (Eichholz 1987). There is also an increased radon concentration in spring water due to the deposition of radium isotopes in the sinter areas around hot springs, where it is coprecipitated with calcium carbonate or silica (NCRP 1975). In groundwater, radon is present due to migration from rock and soil into surrounding groundwater (Hess et al. 1985; Lam et al. 1994).

Radon is not distributed commercially (Hwang et al. 2005). It has been produced commercially for use in radiation therapy, but for the most part, it has been replaced by radionuclides made in accelerators and nuclear reactors. Although no longer used, radiopharmaceutical companies and a few hospitals had pumped the radon from a radium source into tubes called “seeds” or “needles”, which may be implanted in patients (Cohen 1979). Due to the short half-life, research laboratories and universities typically produce radon in the laboratory for experimental studies (Hwang et al. 2005). Radon gas is collected by bubbling air through a radium salt solution (Hwang et al. 2005; Lewis 2001). The evolved gas containing radon, hydrogen, and oxygen is cooled to condense the radon and the gaseous hydrogen and oxygen are removed (Hwang et al. 2005).

5.2 IMPORT/EXPORT

Radon is not imported into or exported from the United States.

5.3 USE

While there are currently few significant technical uses for radon (Hwang et al. 2005), it does have several potentially useful applications. Medical uses of radon in the United States began as early as 1914. Treatments were primarily for malignant tumors. The radon was encapsulated in gold seeds and then implanted into the site of malignancy. During the period of 1930–1950, radon seeds were used for dermatological disorders, including acne. Radon therapy was still being studied and applied as recent as 1980 (Morken 1980).

Radium-223 (^{223}Ra), an isotope of radium that is a calcium surrogate and bone seeker, and which decays to ^{219}Rn, is being studied for possible use as a radiopharmaceutical in the treatment of skeletal metastases (NIST 2010). ^{223}Ra decays into ^{219}Rn, making this isotope a significant contributor to the radiation dose delivered to the tumor.

Water or air containing naturally high levels of ^{222}Rn has been used for therapeutic treatment of various diseases, such as arthritis (Becker 2003; Dobbin 1987; Pohl-Rüling and Fischer 1982). Small “radon mines” (caves with a high radon concentration in the air, such as abandoned mines) have been used as a health treatment (Cohen 1979). People would seek medical cures through exposure to radon gas for ailments ranging from arthritis, asthma, and allergies to diabetes and ulcers (Dobbin 1987), as well as for cancer treatment (Dobbin 1987; Lewis 2001). Radon “spas,” with their commensurately high radon levels, have been used in Europe for the treatment of hypertension and a number of other disorders. In the former Soviet Union., for example, radon baths were often prescribed by the National Health System (Uzunov et al. 1981).

Radon may be utilized in the prediction of earthquakes (Cothern 1987b). Large quantities of radon have been found to migrate to the atmosphere from the earth from active fault zones, varying with atmospheric conditions and potentially with seismic activity (Buttafuoco et al. 2007). The emission of radon from soil and the concentration measured in groundwater appear to be good indicators of crustal activity. Other uses of radon include the study of atmospheric transport, the exploration for petroleum or uranium (Cothern 1987b), as a tracer in leak detection, for flow-rate measurement, and in radiography. Radon is also used in chemical research (Lewis 2001) to initiate and influence reactions, as a label in surface study reactions, for radium and thorium determination, and in determining the behavior of filters (O'Neil et al. 2006).

As a tracer, radon can also be used in the identification and quantification of non-aqueous phase liquid (NAPL) contamination of the subsurface (Semprini et al. 2000). In the subsurface, naturally occurring ^{222}Rn exists as a dissolved gas in the saturated zone. While groundwater radon concentrations vary with the mineral composition of the substrate, they rapidly equilibrate in the absence of NAPL. The groundwater radon concentration, however, may be much less when NAPL is present due to its affinity for partitioning into NAPL. Reduced radon concentration correlates to the amount of NAPL in the subsurface pores. Scientists may then predict the location and saturation levels of NAPL by examining the distribution of radon in the subsurface (Semprini et al. 2000).

5.4 DISPOSAL

Disposal of radon would only be applicable to those facilities producing and/or using it for medical or experimental purposes where its release may be controlled. Regulations regarding the land disposal of radionuclides, as set forth in 10 CFR 61 (USNRC 2008), do not apply to radium, radon, or its daughters. Since radon is naturally occurring, it is not regulated by the U.S. Nuclear Regulatory Commission (USNRC) with the exception of emissions from uranium mill tailings. Uranium mill tailings contain radium, the precursor to radon. The Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) established programs to control the disposal and stabilization of uranium mill tailings to minimize public health hazards associated with the decay of radium within the tailings (EPA 1995). Any other regulation of radon is up to the individual states. The allowable release rate of radon from the surface is 20 pCi/m^2/second. See Chapter 8 for a listing of regulations concerning radon.

Radon emanation is not regulated under 10CFR20 for facilities operating under a USNRC license, but its flux or emanation rate is restricted by EPA regulation to 20 pCi/m^2/second (EPA 2011c). The two primary isotopes from natural sources have short half-lives and typically slow diffusion rates, so most ambient radon is produced in the top 30 cm or 1 foot of soil. Radon emanation rates from typical soil can be on the order of several pCi/m^2/second (Cember and Johnson 2009), but some mill tailings sites exceed the 20 pCi/m^2/second limit. In such cases, disposal involves moving the tailings or reducing the levels by adding a retarding layer over the tailings, such as a several foot thick layer of clay or shale soil (EPA 2008a). In small use facilities, radon may be compressed and stored in tanks until it decays or, if the quantity is small, it may be adsorbed on activated charcoal (Cember 1983). Particulate matter may be removed from the gas by a variety of different devices including detention chambers, adsorbent beds, and liquefaction columns. After filtration, the remaining radioactive particulates are discharged into the atmosphere for dispersion of the nonfilterable low levels of activity (Cember 1983).

Discharge via combustion stream from a natural gas incinerator power plant may contain high levels of radon when the natural gas is retrieved from an area with high concentrations of radium. Radon can be released to the environment from fossil-fueled power plants since radon cannot be scrubbed from the combustion stream by standard methods. The average concentration of radon in the combustion stream of a plant reported by Ericson and Pham (2001) was 370 pCi /L (13,700 Bq/m^3). Federal and State of California regulations do not control radioactive emissions such as these, which are considered to be “natural” emissions (Ericson and Pham 2001).