4.3.8 Radon Exposure

Radon is a cancer-causing natural radioactive gas that you can't see, smell, or taste. It is a large component of the natural radiation that humans are exposed to and can pose a serious threat to public health when it accumulates in poorly ventilated residential and occupation settings. According to the U.S. Environmental Protection Agency (EPA), radon is estimated to cause approximately 21,000 lung cancer deaths per year, second only to smoking as the leading cause of lung cancer (EPA 402-R-03-003: EPA Assessment…, 2003). An estimated 40% of the homes in Pennsylvania are believed to have elevated radon levels (Pennsylvania Department of Environmental Protection [PA DEP], 2009). This section provides a profile and vulnerability assessment for the radon exposure hazard.

4.3.8.1 Location and Extent

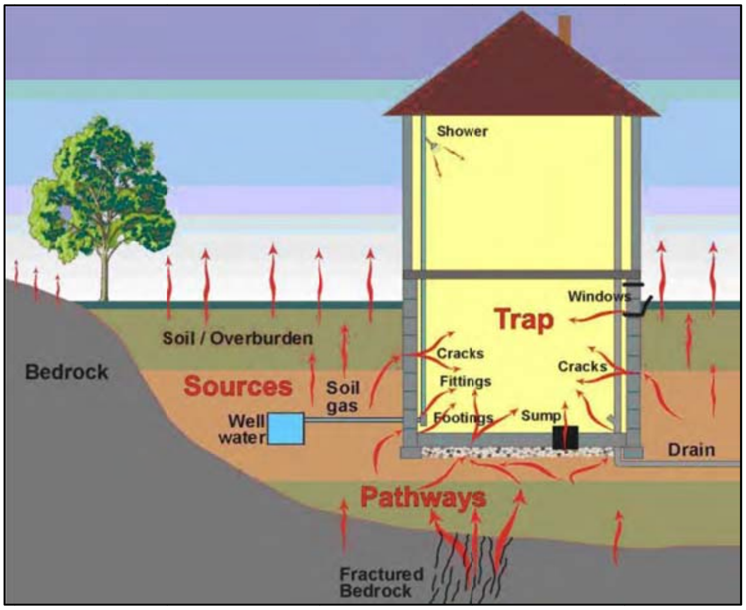
Radioactivity caused by airborne radon has been recognized for many years as an important component in the natural background radioactivity exposure of humans. It was not until the 1980s that the wide geographic distribution of elevated values in houses and the possibility of extremely high radon values in houses were recognized. In 1984, routine monitoring of employees leaving the Limerick nuclear power plant near Reading, PA, showed that readings on Mr. Stanley Watras frequently exceeded expected radiation levels, yet only natural, nonfission- product radioactivity was detected on him. Radon levels in his home were detected around 2,500 pico Curies per Liter (pCi/L), much higher than the 4 pCi/L guideline of the EPA or even the 67 pCi/L limit for uranium miners. As a result of this event, the Reading Prong section of Pennsylvania where Watras lived became the focus of the first large-scale radon scare in the world.

However, radon (i.e. 222Rn), which has a half-life of 3.8 days, is a widespread hazard. The distribution of radon is correlated with the distribution of radium (i.e. 226Ra), its immediate radioactive parent, and with uranium, its original ancestor. Due to the short half-life of radon, the distance that radon atoms can travel from their parent before decay is generally limited to distances of feet or tens of feet. Three sources of radon in houses are now recognized:

- Radon in soil air that flows into the house;
- Radon dissolved in water from private wells and exsolved during water usage; this is rarely a problem in Pennsylvania; and
- Radon emanating from uranium-rich building materials (e.g. concrete blocks or gypsum wallboard); this is not known to be a problem in Pennsylvania (PEMA, 2010).

Figure 4.3.8-1 illustrates radon entry points into a home.

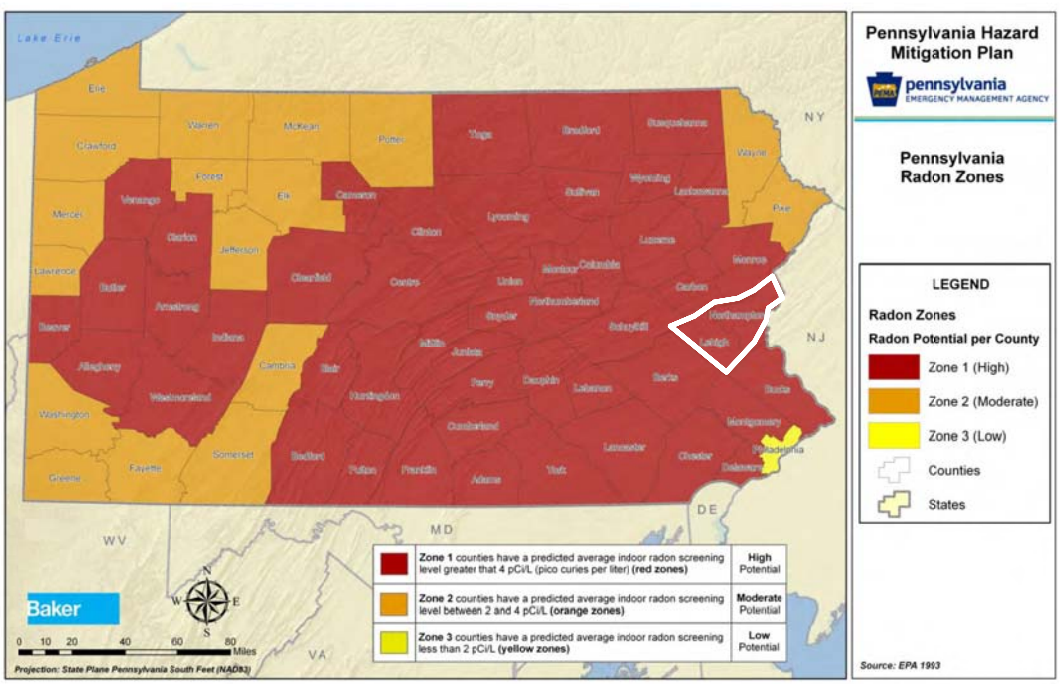
Figure 4.3.8-1: Sketch of Radon Entry Points into a House



Source: PEMA 2010, Arizona Geological Survey 2006

Each county in Pennsylvania is classified as having a low, moderate, or high radon hazard potential. A majority of counties across the Commonwealth, particularly counties in eastern Pennsylvania, have a high hazard potential. The average indoor radon screening level for these counties is greater than 4 pCi/L. Lehigh and Northampton Counties are both located in Zone 1 – High Radon Potential as noted in Figure 4.3.8-2 below.

Figure 4.3.8-2: Radon Hazard Zones in Pennsylvania



Source: PEMA 2010, EPA 1993 (white highlight added)

High radon levels were initially thought to be exacerbated in houses that are tightly sealed, but it is now recognized that rates of air flow into and out of houses, plus the location of air inflow and the radon content of air in the surrounding soil, are key factors in radon concentrations. Outflows of air from a house, caused by a furnace, fan, thermal "chimney" effect, or wind effects, require that air be drawn into the house to compensate. If the upper part of the house is tight enough to impede influx of outdoor air (radon concentration generally <0.1 pCi/L), then an appreciable fraction of the air may be drawn in from the soil or fractured bedrock through the foundation and slab beneath the house, or through cracks and openings for pipes, sumps, and similar features. Soil gas typically contains from a few hundred to a few thousand pCi/L of radon; therefore, even a small rate of soil gas inflow can lead to elevated radon concentrations in a house.

The radon concentration of soil gas depends upon a number of soil properties, the importance of which is still being evaluated. In general, 10 to 50 percent of newly formed radon atoms escape the host mineral of their parent radium and gain access to the air-filled pore space. The radon content of soil gas clearly tends to be higher in soils containing higher levels of radium and uranium, especially if the radium occupies a site on or near the surface of a grain from which the radon can easily escape. The amount of pore space in the soil and its permeability for air flow, including cracks and channels, are important factors determining radon concentration in soil gas and its rate of flow into a house. Soil depth and moisture content, mineral host and form for radium, and other soil properties may also be important. For houses built on bedrock, fractured zones may supply air having radon concentrations similar to those in deep soil.

Areas where houses have high levels of radon can be divided into three groups in terms of uranium content in rock and soil:

<u>Areas of very elevated uranium content (>50 parts per million [ppm]) around uranium deposits and prospects</u>: Although very high levels of radon can occur in such areas, the hazard normally is restricted to within a few hundred feet of the deposit. In Pennsylvania, such localities occupy an insignificant area.

<u>Areas of common rocks having higher than average uranium content (5 to 50 ppm)</u>: In Pennsylvania, such rock types include granitic and felsic alkali igneous rocks and black shales. In the Reading Prong, high uranium values in rock or soil and high radon levels in houses are associated with Precambrian granitic gneisses commonly containing 10 to 20 ppm uranium, but locally containing more than 500 ppm uranium. In Pennsylvania, elevated uranium occurs in black shales of the Devonian Marcellus Formation and possibly the Ordovician Martinsburg Formation. High radon values are locally present in areas underlain by these formations.

<u>Areas of soil or bedrock that have normal uranium content but properties that promote high radon levels in houses</u>: This group is incompletely understood at present. Relatively high soil permeability can lead to high radon, the clearest example being houses built on glacial eskers. Limestone-dolomite soils also appear to be predisposed for high radon levels in houses, perhaps because of the deep clay-rich residuum in which radium is concentrated by weathering on iron oxide or clay surfaces, coupled with moderate porosity and permeability. The importance of carbonate soils is indicated by the fact that radon contents in 93 percent of a sample of houses built on limestone-dolomite soils near State College, Centre County, exceeded 4 pCi/L, and 21 percent exceeded 20 pCi/L, even though the uranium values in the underlying bedrock are all in the normal range of 0.5 to 5 ppm uranium (PEMA, 2010).

According to the state plan, radon tends to exist as a gas or as a dissolved atomic component in groundwater. In Pennsylvania, the most problematic source of radon in houses is radon in soil gas that flows into the house. Even a small rate of soil gas inflow can lead to elevated radon concentrations in a house. The state plan indicates that current data on the abundance and distribution of radon in

Pennsylvania homes is incomplete and biased, but the plan identifies general patterns. Values exceeding the Environmental Protection Agency's guidelines occur in all regions of the state. The highest proportion of elevated values includes a zone extending from central Pennsylvania to southeast Pennsylvania that appears to include the Lehigh Valley (LVHMP, 2006).

4.3.8.2 Range of Magnitude

Exposure to radon is the second leading cause of lung cancer after smoking. It is the number one cause of lung cancer among non-smokers. As stated earlier, radon is responsible for about 21,000 lung cancer deaths every year; approximately 2,900 of which occur among people who have never smoked. Lung cancer is the only known effect on human health from exposure to radon in air and thus far, there is no evidence that children are at greater risk of lung cancer than are adults (EPA, 2010). The main hazard is actually from the radon daughter products (218Po, 214Pb, 214Bi), which may become attached to lung tissue and induce lung cancer by their radioactive decay. Table 4.3.8-1 shows the relationship between various radon levels, probability of lung cancer, comparable risks from other hazards, and action thresholds.

Table 4.3.8-1. Radon Risk for Smokers and Non-Smokers

RADON LEVEL (pCi/L)	IF 1,000 PEOPLE WERE EXPOSED TO THIS LEVEL OVER A LIFETIME… *	RISK OF CANCER FROM RADON EXPOSURE COMPARES TO… **	ACTION THRESHOLD
SMOKERS			
20	About 260 people could get lung cancer	250 times the risk of drowning	Fix structure
10	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix structure
8	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix structure
4	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix structure
2	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3	About 20 people could get lung cancer	(Average indoor radon level)	Reducing radon levels below 2 pCi/L is difficult
0.4	About 3 people could get lung cancer	(Average outdoor radon level)	
NON-SMOKERS			
20	About 36 people could get lung cancer	35 times the risk of drowning	Fix structure
10	About 18 people could get lung cancer	20 times the risk of dying in a home fire	Fix structure
8	About 15 people could get lung cancer	4 times the risk of dying in a fall	Fix structure
4	About 7 people could get lung cancer	The risk of dying in a car crash	Fix structure
2	About 4 people could get lung cancer	The risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3	About 2 people could get lung cancer	(Average indoor radon level)	Reducing radon levels below 2 pCi/L is difficult
0.4		(Average outdoor radon level)	

NOTE: Risk may be lower for former smokers.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Source: EPA, 2010

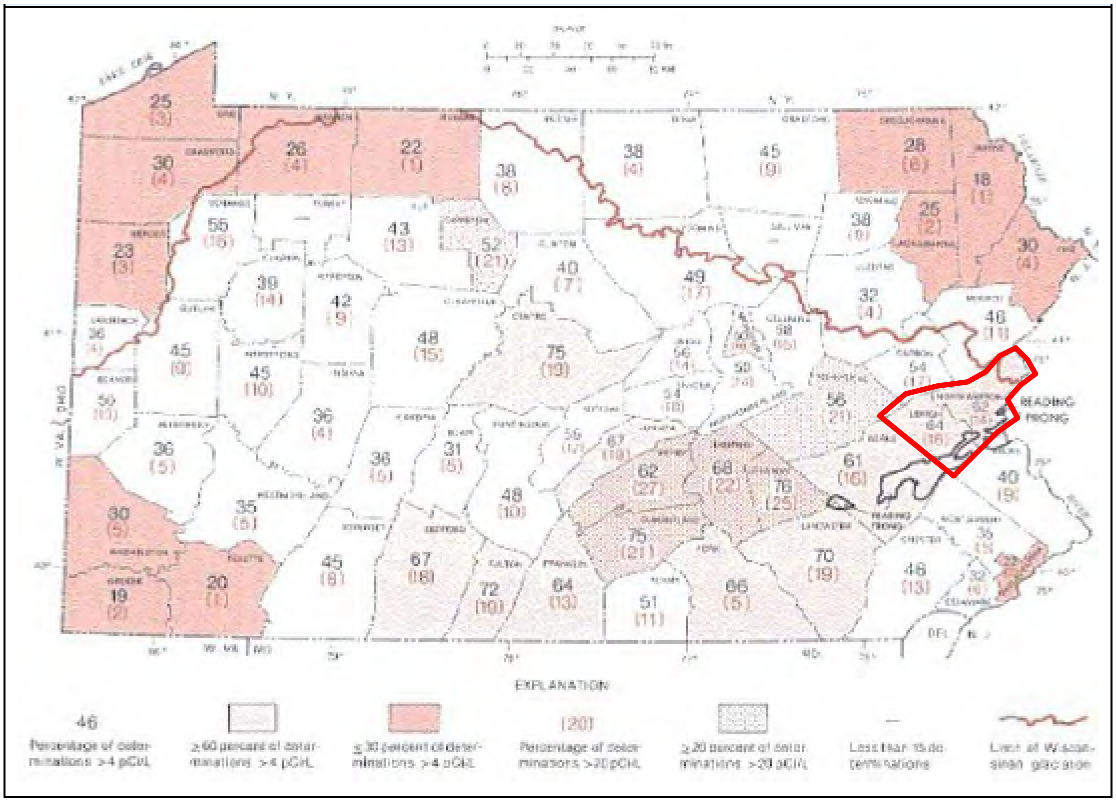
According to the EPA, the average radon concentration in the indoor air of U.S. homes is about 1.3 pCi/L. The EPA recommends homes be fixed if the radon level is 4 pCi/L or more. However, because there is no known safe level of exposure to radon, the EPA also recommends that Americans consider fixing their home for radon levels between 2 pCi/L and 4 pCi/L. As shown in Table 4.3.8-1, a smoker exposed to radon has a much higher risk of lung cancer.

The worst-case scenario for radon exposure would be that a large area of tightly sealed homes provided residents high levels of exposure over a prolonged period of time without the resident being aware. This worst-case scenario exposure then could lead to a large number of people with cancer attributed to the radon exposure (PEMA, 2010).

4.3.8.3 Past Occurrence

Current data on abundance and distribution of radon in Pennsylvania houses is considered incomplete and potentially biased, but some general patterns exist (see Figure 4.3.8-3).

Figure 4.3.8-3: Percentage of Pennsylvania homes having radon levels greater than 4 pCi/L



Source: PEMA 2010, PADER (now PADEP) 1989 (red highlight added)
Note: State-sponsored samples in the Reading Prong are not included

Values exceeding the EPA guideline of 4 pCi/L occur in all regions of the Commonwealth. The highest proportion of elevated radon values in the Commonwealth exist in a zone extending from central Pennsylvania to southeastern Pennsylvania, and in the Reading Prong which includes the Lehigh Valley. High values in the latter area are attributed to known uranium-rich granitic gneisses (Smith, 1976; Gunderson et al., 1988), accentuated by local factors such as shear zones, and include a surprising number of extremely high radon values (>200 pCi/L). Information on average radon levels by zip code in

Pennsylvania can be obtained from the DEP at: http://www.dep.state.pa.us/RadiationProtection_Apps/Radon/.0.4 (Average outdoor radon level) (PEMA 2010).

4.3.8.4 Future Occurrence

Radon exposure is inevitable given present soil, geologic, and geomorphic factors across Pennsylvania. Development in areas where previous radon levels have been significantly high will continue to be more susceptible to exposure. However, new incidents of concentrated exposure may occur with future development or deterioration of older structures. Exposure can be limited with proper testing for both past and future development, and appropriate mitigation measures (PEMA, 2010). The future occurrence of radon exposure can be considered *likely* as defined by the Risk Factor Methodology probability criteria (refer to Section 4.4).

4.3.8.5 Vulnerability Assessment

To understand risk, a community must evaluate what assets are exposed or vulnerable in the identified hazard area. The following section discusses the potential impact of the radon exposure hazard on the Lehigh Valley including:

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact on: (1) life, health and safety, (2) general building stock and critical facilities, (3) economy, (4) environment and (5) future growth and development
- Further data collections that will assist understanding this hazard over time

4.3.8.5.1 Overview of Vulnerability

Radon exposure is of particular concern in the Lehigh Valley due to its location within a High Potential (Level 1) EPA Radon Zone. While structural factors (e.g. building construction and engineered mitigation measures) can influence the level of radon exposure, all residents and structures within the Lehigh Valley are vulnerable to radon exposure.

4.3.8.5.2 Data and Methodology

The 2010 U.S. Census data and the custom building inventory for the Lehigh Valley was used to support an evaluation of assets exposed to this hazard and the potential impacts associated with this hazard. Per the 2010 Pennsylvania State Hazard Mitigation Plan, an average radon mitigation system cost of $1200 was applied to 20% of the building stock to evaluate economic vulnerability.

4.3.8.5.3 Impact on Life, Health and Safety

For the purposes of this Plan, the entire population of the Lehigh Valley is exposed to the risk of radon exposure. Exposure to radon is the second leading cause of lung cancer after smoking. It is the number one cause of lung cancer among non-smokers. Radon is responsible for approximately 21,000 lung cancer deaths every year; approximately 2,900 of which occur among people who have never smoked.

Lung cancer is the only known effect on human health from exposure to radon in air and thus far, there is no evidence that children are at greater risk of lung cancer than are adults (USEPA, 2010).

Per Figure 4.3.8-3, 64% and 62% of homes in Lehigh and Northampton Counties, respectively, have measured radon levels exceeding 4 pCi/L, while 16% and 14% exceed 20 pCi/L in Lehigh and Northampton Counties, respectively. Excess human cancer risk due to radon exposure at these levels is identified in Table 4.3.8-1.

4.3.8.5.4 Impact on General Building Stock and Critical Facilities

While the entire general building stock and critical facility inventory in the Lehigh Valley is exposed to radon, radon does not result in direct damage to structures and facilities. Rather, engineering methods installed to mitigate human exposure to radon in structures results in economic costs described in the following subsection.

4.3.8.5.5 Impact on the Economy

Currently (2008), the EPA determines that an average radon mitigation system costs $1,200. The EPA also states that current state surveys show that one home in five has elevated radon levels. Using this methodology, radon loss estimation is factored by assuming that 20% of the buildings within the High Potential (Level 1) counties have elevated radon values and each would require a radon mitigation system installed at the EPA estimated average of $1,200.

According to this methodology, estimated radon mitigation costs for residential structures in the Lehigh Valley could exceed $60 million. Per Figure 4.3.8-3, 64% and 62% of homes in Lehigh and Northampton Counties, respectively, have measured radon levels exceeding 4 pCi/L, thus the estimated costs for radon mitigation in the Lehigh Valley may be significantly higher than that estimated using the EPA methodology where only 20% of structures are considered for mitigation.

4.3.8.5.6 Impact on the Environment

Radon exposure has minimal environmental impacts. Due to the relatively short half-life of radon, it tends to only affect living and breathing organisms such as humans or pets which are routinely in contained areas (i.e. basement or house) where the gas is released (PEMA, 2010).

4.3.8.5.7 Future Growth and Development

Areas targeted for potential future growth and development in the next five (5) to ten (10) years have been identified across the Lehigh Valley at the municipal level. Refer to the jurisdictional annexes in Volume II of this Plan. Table B.1 in each jurisdictional annex lists the location of the potential new development and its exposure (if any) to known hazard zones. For the radon exposure hazard, the Lehigh Valley in its entirety has been identified as the hazard area. Therefore, any new development will be exposed to such risk.

Measures to reduce human exposure to radon in structures are readily available, and can be incorporated during new construction at significantly lower cost and greater effectiveness as opposed to retrofitting existing structures.

4.3.8.5.8 Additional Data and Next Steps

The assessment above identifies human health and economic losses associated with this hazard of concern; however these estimates are based on national epidemiological statistics and generalized estimates of costs to mitigate structures in the Lehigh Valley. As specific structural conditions affect human exposure to radon, direct radon measurements within facilities are needed to properly assess the level of health risk, and indicate the need for mitigation measures. Further, a consideration of radon exposure risk, and installation of mitigation measures as appropriate are recommended by the EPA during all new construction.