4.3.14 Radon Exposure

Radon is a natural gas that cannot be seen, smelled, or tasted. It is a noble gas that originates from natural radioactive decay of uranium and thorium. It is a large component of the natural radiation to which humans are exposed, 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) (EPA 402-R-03-003: EPA Assessment), 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 2003). An estimated 40 percent of the homes in Pennsylvania are believed to have elevated radon levels (Pennsylvania Department of Environmental Protection [PADEP] 2014). This section provides a profile and vulnerability assessment of the radon exposure hazard.

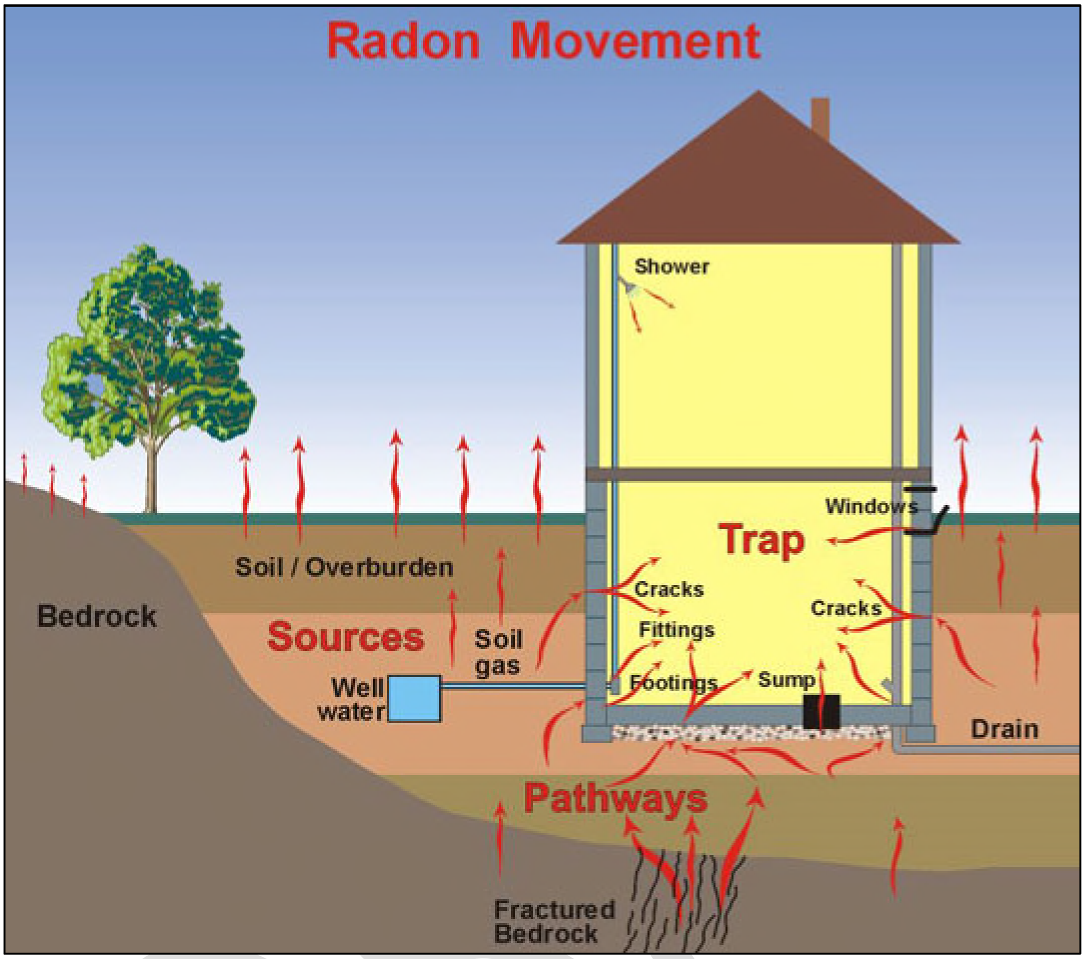
Location and Extent

Radioactivity caused by airborne radon has been recognized for many years as an important component in the natural background radioactivity exposure of humans. Not until the 1980s were the wide geographic distribution of elevated radon levels in houses and the possibility of extremely high radon concentrations in houses recognized. In 1984, routine monitoring of employees leaving the Limerick nuclear power plant near Reading, Pennsylvania, showed that readings from one employee 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 picoCuries per liter (pCi/L), much higher than the 4 pCi/L guideline set by EPA or even the 67 pCi/L limit for uranium miners. As a result of this event, the Reading Prong section, a physiographic province of Pennsylvania, where this person lived became the focus of the first large-scale radon scare in the world (PA HMP 2013).

Radon (Rn-222), which has a half-life of 3.8 days, is a widespread hazard. The distribution of radon correlates with the distribution of radium (Ra-226), its immediate radioactive parent, and with uranium, its original ancestor. Because of the short half-life of radon, the distance radon atoms travel from their parent before they decay is generally limited to extents of feet or tens of feet (PA HMP 2013). Figure 4.3.10-1 illustrates radon entry points into a home. 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 source is rarely a problem in Pennsylvania.)
- Radon emanating from uranium-rich building materials, such as concrete blocks or gypsum wallboard (This source also is not known to be a problem in Pennsylvania) (PA HMP 2013).

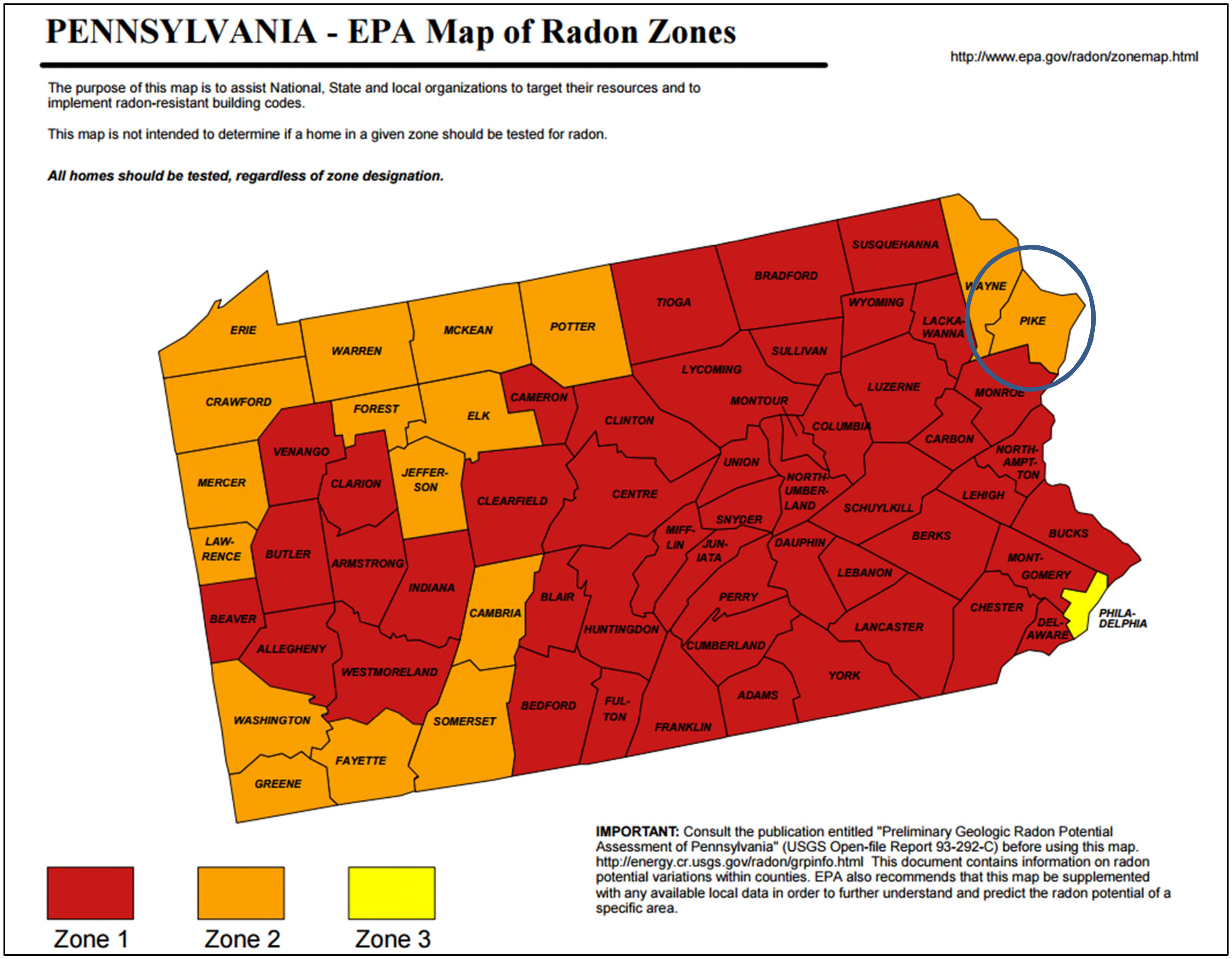
Figure 4.3.14-1. Sketch of Radon Entry Points into a House



Sources: PEMA 2010; Arizona Geological Survey 2006

Each county in Pennsylvania is classified as having a low (Zone 3), moderate (Zone 2), or high (Zone 3) radon hazard potential (Refer to Figure 4.3.14-2). A majority of counties across the Commonwealth, particularly counties in eastern Pennsylvania, have a high hazard potential. According to the EPA map of radon zones, Pike County is located in Zone 2 (counties with predicted average indoor radon screening levels from 2 to 4 pCi/L).

Figure 4.3.14-2. EPA Radon Zones in Pennsylvania



Source: EPA 2016

Note: Pike County is identified by a blue circle. The figure indicates that Pike County is located in EPA Radon Zone 2 (moderate).

High radon levels were initially thought to be exacerbated in tightly sealed houses, although 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 affecting radon concentrations. Air must be drawn into a house to compensate for outflows of air caused by a furnace, fan, thermal "chimney" effect, or wind effects. If the upper part of the house is tight enough to impede influx of outdoor air (radon concentration generally below 0.1 pCi/L), 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 between 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 (PA HMP 2013).

Radon concentration in soil gas depends on a number of soil properties, the importance of which are 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. Fractured zones may supply air having radon concentrations similar to those in deep soil for houses built on bedrock (PA HMP 2013).

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

- Areas of very elevated uranium content (above 50 parts per million [ppm]) around uranium deposits and prospects: Although very high levels of radon can occur in these areas, the hazard normally is restricted to within a few hundred feet of the deposit. In Pennsylvania, these localities occupy an insignificant area.
- Areas of common rock having higher than average uranium content (5 to 50 ppm): In Pennsylvania, these rock types include granitic and felsic alkali igneous rocks and black shales. High uranium values in rock or soil and high radon levels in houses in the Reading Prong are associated with Precambrian granitic gneisses commonly containing 10 to 20 ppm uranium, but locally containing more than 500 ppm uranium. Elevated uranium occurs in black shales of the Devonian Marcellus Formation and possibly the Ordovician Martinsburg Formation in Pennsylvania. High radon values are locally present in areas underlain by these formations.
- Areas of soil or bedrock that have normal uranium content but properties that promote high radon levels in houses: This group is incompletely understood at present. Relatively high soil permeability can lead to high radon concentrations, 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 where 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 exceedance of 4 pCi/L in 93 percent of a sample of houses built on limestone-dolomite soils near State College, Centre County, and exceedance of 20 pCi/L in 21 percent of that sample of houses, even though uranium levels in the underlying bedrock are all within the normal range of 0.5 to 5 ppm (PA HMP 2013).

Range of Magnitude

Exposure to radon is the second leading cause of lung cancer after smoking. Radon exposure is the number one cause of lung cancer among nonsmokers. 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, no evidence indicates that children are at greater risk of lung cancer than adults. The main hazard is actually from the radon daughter products (polonium-218, lead-214, bismuth-214), which may become attached to lung tissue and induce lung cancer by their radioactive decay. Table 4.3.10-1 lists the following information for smokers and nonsmokers: (1) cancer risks from exposure to radon at various levels, (2) comparisons of lung cancer risks from radon exposure to comparable cancer risks from other hazards, and (3) action thresholds (PA HMP 2013).

Table 4.3.14-1. Radon Risk for Smokers and Nonsmokers

Radon Level (pCi/L)	Cancer Rate per 1,000 People with Lifetime Exposure	Comparative Cancer Risk of Radon Exposure	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	
8	About 120 people could get lung cancer	30 times the risk of dying in a fall	
4	About 62 people could get lung cancer	5 times the risk of dying in a car crash	
2	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing structure 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)	
NONSMOKERS			
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	
8	About 15 people could get lung cancer	4 times the risk of dying in a fall	
4	About 7 people could get lung cancer	The risk of dying in a car crash	
2	About 4 people could get lung cancer	The risk of dying from poison	Consider fixing structure 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 U.S. Environmental Protection Agency (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 2016

The worst-case scenario for radon exposure would be a large area of tightly sealed homes in Pike County provided residents high levels of exposure over a prolonged period of time without the resident being aware. This worst-case scenario exposure could then lead to a large number of people with cancer attributed to radon exposure. The most likely scenario is a single household exposed to a very low concentration of radon, with no adverse health effects.

Past Occurrence

Current data on abundance and distribution of radon as it affects individual houses in the Commonwealth of Pennsylvania in general is considered incomplete and potentially biased (PA HMP 2013). Pike County is not an exception. The EPA has estimated that the national average indoor radon concentration is 1.3 pCi/L and the level for action is 4.0 pCi/L; however they have estimated that the average indoor concentration in Pennsylvania basements is about 7.1 pCi/L and 3.6 pCi/L on the first floor (PADEP 2016).

In 2015, a groundwater study was conducted by the USGS in collaboration with the Pike County Conservation District. The purpose of this study was to characterize the chemical quality of groundwater from shallow freshwater aquifers used by private residential homes and business supply wells in the County prior to gas drilling. As part of this study, 80 private wells were sampled in 2015 and analyzed for major ions, metals, dissolved gases, gross alpha- and gross-beta radioactivity, dissolved and suspended solids, oil and grease, total coliform, and determination of radon-222, dissolved nutrients, and additional major ions. As results become available from the Pike County Conservation District, they will be included in Pike County's HMP update.

The PADEP Bureau of Radiation Protection provides information for homeowners on how to test for radon in their houses. If a test results in radon concentrations over 4.0 pCi/L, then the Bureau works to help the homeowners make repairs to their houses to mitigate against high radon levels. The total number tests reported to the Bureau since 1990 and their results are provided by zip code on the Bureau's website and are summarized in Table 4.3.10-2 below for Pike County. However, this information is only provided if over 30 tests total were reported in order to best approximate the average for the area (PADEP 2016).

In Pike County, all zip codes had reported results from a sufficient number of tests to allow the Bureau to report the findings, which are shown in the table below. Please note that the PADEP does not post public results unless a zip code has had at least 30 tests conducted. The PADEP only publishes the average and maximum results for a zip code; it does not offer a range of results for a zip code, municipality, or region. The PADEP Radon Division recommends that all homeowners test for radon, regardless of test results within their respective zip codes. Despite a low average text result within a zip code, many homes in that zip code may have elevated radon levels.

Table 4.3.10-2. Radon Level Tests and Results by Pike County Zip Codes

ZIP Code	Location	Area in Home	Number of Tests	Maximum Result (pCi/L)	Average Result (pCi/L)
18336	Matamoras	Basement	188	44.4	4.1
		First Floor	63	11.4	1.6
18337	Milford	Basement	1,682	111.7	5.1
		First Floor	511	36.3	2.6
18428	Lords Valley (Blooming Grove Township)	Basement	1,816	89.0	4.6
		First Floor	739	40.1	2.5
18328	Delaware Township	Basement	1,106	70.7	4.6
		First Floor	491	23.1	2.2
18426	Greentown (Greene Township)	Basement	804	119.5	5.1
		First Floor	226	12.0	2.0
18428	Hawley (Lackawaxen Township)	Basement	1816	89.0	4.6
		First Floor	739	40.1	2.5
18324	Bushkill (Lehman Township)	Basement	1,195	456.0	5.5
		First Floor	437	73.2	2.8
18451	Paupack (Palmyra Township)	Basement	143	56.6	5.5
		First Floor	40	10.5	2.1
18458	Shohola Township	Basement	306	55.3	4.5
		First Floor	106	16.4	2.0

Source: PADEP 2016
Notes: pCi/L picoCuries per liter

Future Occurrence

Radon exposure is inevitable, given present soil, geologic, and geomorphic factors across Pennsylvania. Residents who live in developments within areas where radon levels previously have been found 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 by conducting proper testing within both existing and future developments, and implementing appropriate mitigation measures (PEMA 2013). As part of a 2014 initiative, EPA's "Test, Fix, Save a Life" radon action campaign strives to highlight radon testing and mitigation as a simple and affordable step to significantly reduce risk for lung cancer. Through this initiative, the "Test, Fix, Save a Life" mantra specifies activities and facts for the public regarding radon poisoning, as indicated below:

- Test: All homes with or without basements should be tested for radon. Affordable do-it-yourself radon test kits are available online and at home improvement and hardware stores, or you can hire a qualified radon tester.
- Fix: EPA recommends taking action to fix radon levels at or above 4.0 pCi/L and contacting a qualified radon-reduction contractor. In most cases, a system with a vent pipe and fan is used to reduce radon. Addressing high radon levels often costs the same as other minor home repairs.
- Save a Life: 21,000 Americans die from radon-related lung cancer each year. By decreasing elevated levels in a home, residents can help prevent lung cancer while creating a healthier home (EPA 2014).

Based on available data and the fact that radon is present across Pike County, future occurrences of radon exposure can be considered *highly likely* as defined by the Risk Factor Methodology probability criteria (further discussed in Section 4.4).

Vulnerability Assessment

To understand risk, a community must evaluate assets exposed or vulnerable within the identified hazard area. The following section discusses potential impacts of the radon exposure hazard on Pike County, including:

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

Overview of Vulnerability

Radon exposure is of particular concern in Pike County because of the County's location within EPA Radon Zone 2 (moderate potential). While structural factors (such as building construction and engineered mitigation measures) can influence the level of radon exposure, all residents and structures within Pike County are potentially vulnerable to radon.

Data and Methodology

The 2010 U.S. Census data for Pike County was referenced to support an evaluation of assets exposed to this hazard and potential impacts associated with this hazard. In accordance with the 2013 Pennsylvania State Hazard Mitigation Plan, an average radon mitigation system cost of $1,200 was applied to 20 percent of the building stock to evaluate economic vulnerability (PEMA 2013).

Impact on Life, Health, and Safety

For the purposes of this plan, the entire population of the County is assumed exposed to radon. 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, no evidence indicates that children are at greater risk of lung cancer than are adults (EPA 2010).

Impact on General Building Stock and Critical Facilities

While the entire general building stock and critical facility inventory in the County 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 in this section. The 2013 Pennsylvania State HMP notes that Pike County has 26 State critical facilities located in zip codes with average high radon test results (PEMA 2013).

Impact on the Economy

The EPA has concluded that an average radon mitigation system costs $1,200. EPA also states that current state surveys indicate one home in five has elevated radon levels. Based on this information, radon loss estimation is factored by assuming that 20 percent of the residential buildings within High Potential (Level 1) counties have elevated radon levels, and each would require a radon mitigation system installed at the EPA-estimated average of $1,200 (PEMA 2013). Therefore, within Pike County, estimated radon mitigation costs for residential structures could exceed $5.2 million. However, this costs could be higher based on the number of households in the County with radon levels exceeding 4 pCi/L.

Impact on the Environment

Radon exposure exerts minimal environmental impacts. Because of the relatively short half-life of radon, it tends to affect only living and breathing organisms such as humans or pets that are routinely within contained areas (basement or house) where the gas is released (PEMA 2013).

Future Growth and Development

Areas targeted for potential future growth and development within the next 5 years have been identified across the County (further discussed in Section 2.4 of this HMP). Any new land development will be exposed to this hazard. 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 than retrofitting existing structures to implement these measures.

Effect of Climate Change on Vulnerability

According to the EPA's *Climate Change and Indoor Air* Quality contractor report, the primary factors that influence radon entry into a home include: radon content of the soil; pressure differential between the interior of the home and the soil; the air exchange rate for the home; the moisture content surrounding the home; and the presence and size of entry pathways. These factors can be affected by climate change to different degrees. Climate change may also affect the depositional environment within the home resulting in changes to the delivered dose by radon decay products. Additionally, the EPA stated that the relative concentration of radon to its decay products, and the ability to deliver dose, is impacted by numerous factors including building ventilation rate, decay product attachment to aerosols, and particle deposition rate on surface. All these factors could be impacted by housing as well as behavioral changes driven directly or indirectly by climate change. For example, the increased use of ceiling fans could increase deposition of radon decay products and reduce the delivered radon-related doses to the lungs (EPA 2010).

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 Pike County. Because specific structural conditions affect human exposure to radon, direct radon measurements within facilities are necessary to properly assess the level of health risk and indicate the need for mitigation measures. Furthermore, EPA recommends consideration of radon exposure risk and installation of mitigation measures as appropriate during all new construction.