4.3.12 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. Radon 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), radon causes more than 20,000 lung cancer deaths per year, second only to smoking as the leading cause of lung cancer (EPA 2013). An estimated 40 percent of the homes in Pennsylvania are believed to have elevated radon levels (Pennsylvania Department of Environmental Protection [PADEP] 2019).

This section describes the location and extent, range of magnitude, past occurrence, future occurrence, and vulnerability assessment for the radon exposure hazard for the Dauphin County Hazard Mitigation Plan (HMP).

4.3.12.1 Location and Extent

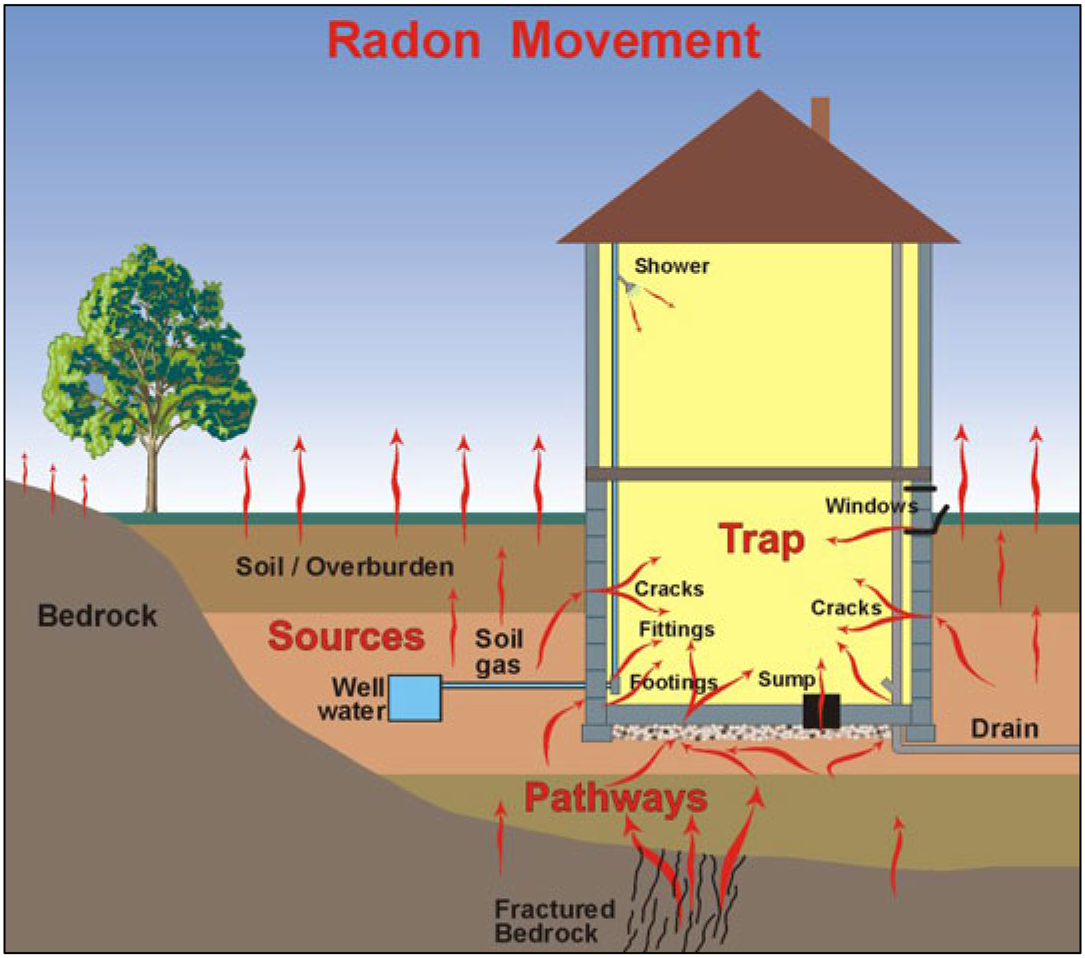
Radioactivity caused by airborne radon has been recognized for many years as an important component in the natural background radioactivity exposure of humans. However, it was not until the 1980s that the wide geographic distribution of elevated radon levels in houses was identified, and the possibility of extremely high radon concentrations in houses was 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, non-fission 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 of Pennsylvania (where the employee lived) became the focus of the first large-scale radon scare in the world.

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 feet or tens of feet. Three sources of radon in houses are now recognized:

- Radon in soil air 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 (PEMA 2013).

Figure 4.3.12-1 illustrates radon entry points into a home.

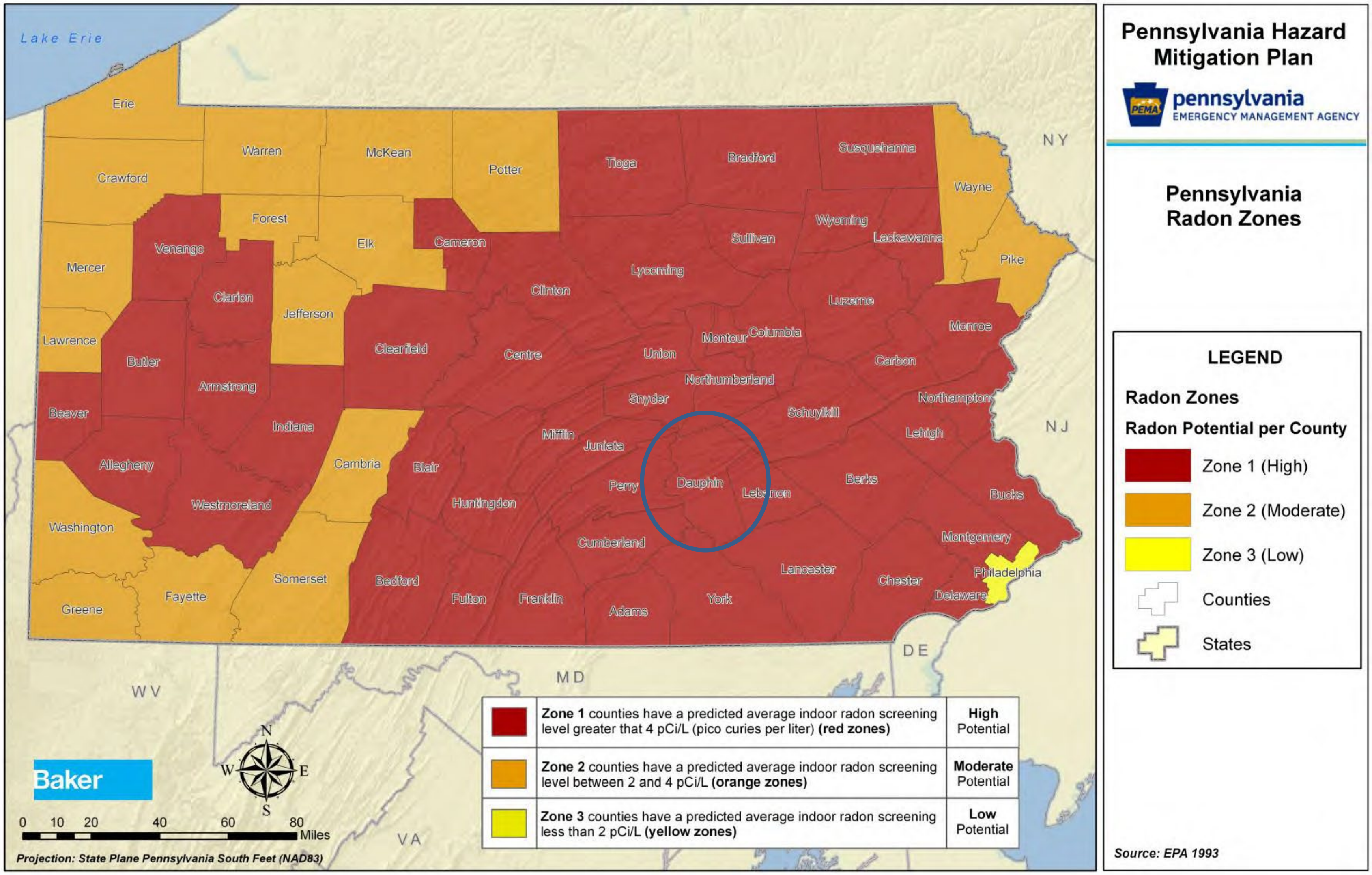
Figure 4.3.12-1. Sketch of Radon Entry Points into a House



Sources: PEMA 2013

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. Western Pennsylvania counties, however, are not completely immune from the threat of radon, as high potential for radon exposure exists within nine western counties. The average indoor radon screening level within high-exposure counties exceeds 4 pCi/L. Dauphin County is in Zone 1 – High Radon Potential, as noted on Figure 4.3.12-2 below.

Figure 4.3.12-2. Radon Hazard Zones in Pennsylvania



Sources: PEMA 2013
Note: Dauphin County is identified by the blue oval

High radon levels were initially thought to be exacerbated in tightly sealed houses, although it is now recognized that rates of airflow into and out of houses, as well as 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 from the house caused by a furnace, fan, thermal "chimney" effect, or wind effects. If the upper section of the house is sealed 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 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.

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 airflow, including cracks and channels, are important factors in 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 with radon concentrations similar to those in deep soil.

Areas where high levels of radon have been detected in homes 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 rocks 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 with normal uranium content but containing 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 (PEMA 2013).

According to the Pennsylvania HMP, radon tends to exist as a gas or as a dissolved atomic component in groundwater. The most problematic source of radon in houses in Pennsylvania 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 HMP indicates that current data on abundance and distribution of radon in Pennsylvania homes are incomplete and biased, but the plan identifies general patterns (PEMA 2013).

4.3.12.2 Range of Magnitude

Exposure to radon is the second-leading cause of lung cancer after smoking, and the leading cause of lung cancer among non-smokers. As stated earlier, radon is responsible for more than 20,000 lung cancer deaths every year. 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 (EPA 2013). The main hazard is actually from the radon daughter products (polonium-218, lead-214, and bismuth-214), which may become attached to lung tissue and induce lung cancer by their radioactive decay. Table 4.3.12-1 lists (1) cancer risks from exposure to radon at various levels for smokers and non-smokers, (2) lung cancer risks from radon exposure compared to risks of dying from other hazards for smokers and non-smokers, and (3) action thresholds.

Table 4.3.12-1. Radon Risk for Smokers and Non-Smokers

Radon Level (picoCuries per liter [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)	
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	
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 2pCi/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 2013

According to the EPA, the average radon concentration in the indoor air in homes in the United States is about 1.3 pCi/L. The EPA recommends that homes be repaired if the radon level is 4 pCi/L or more. However, the

EPA also recommends that Americans consider repairing or renovating their home if radon levels are between 2 and 4 pCi/L because there is no known safe level of exposure to radon. As listed in Table 4.3.12-1, a smoker exposed to radon has a much higher risk of lung cancer.

The worst-case scenario for radon exposure would be a large area of tightly sealed homes inducing high levels of exposure to residents over a prolonged period of time without awareness by the residents. This worst-case scenario exposure then could lead to a large number of people contracting cancer attributed to the radon exposure (PEMA 2013). The most likely scenario, however, is a single household exposed to a very low concentration of radon, with no adverse health effects on residents.

4.3.12.3 Past Occurrence

PADEP Bureau of Radiation Protection (Bureau) provides information for homeowners on how to test for radon in their houses. If results of a test reported to the Bureau exceed 4 pCi/L, the Bureau works to help the homeowner repair the house to mitigate high radon levels. The total number of tests reported to the Bureau since 1990 and test results by zip code are accessible on the Bureau's website. However, to best approximate the average for an area, information is provided only if more than 30 tests within that area were reported.

The Bureau collected the sufficient number of radon results from residences in 25 zip codes within Dauphin County to allow them to report the findings (summarized in Table 4.3.12-2). PADEP does not publish results unless a zip code has had at least 30 tests conducted. 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 test result within a zip code, many homes in that zip code may have elevated radon levels.

Table 4.3.12-2. Radon Level Tests and Results by Zip Codes

ZIP Code	Location	Area in Home	Number of Tests	Maximum Result (pCi/L)	Average Result (pCi/L)
17005	Berrysburg	Basement	Insufficient Data	Insufficient Data	Insufficient Data
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
17109	Colonial Park	Basement	3085	127.1	11.3
		First Floor	539	60.6	6.6
17018	Dauphin	Basement	550	91.9	10.8
		First Floor	104	41.1	5.6
17023	Elizabethville	Basement	285	92.5	11.4
		First Floor	46	50.3	8.5
17028	Grantville	Basement	307	565.3	12.3
		First Floor	55	34.1	5.0
17030	Gratz	Basement	57	78.4	11.2
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
17032	Halifax	Basement	982	416.3	30.3
		First Floor	148	138.6	10.5
17110	Harrisburg	Basement	3694	250.3	7.0
		First Floor	1034	66.0	3.1
17111	Harrisburg	Basement	5697	918.2	16.5
		First Floor	1185	102.2	8.8
17112	Harrisburg	Basement	7200	772.2	9.4
		First Floor	1171	90.8	5.5
17101	Harrisburg	Basement	205	81.3	6.6
		First Floor	60	12.3	1.3
17102	Harrisburg	Basement	554	508.0	6.7
		First Floor	252	8.1	1.1
17103	Harrisburg	Basement	398	147.8	7.4
		First Floor	113	40.5	2.8

ZIP Code	Location	Area in Home	Number of Tests	Maximum Result (pCi/L)	Average Result (pCi/L)
17104	Harrisburg	Basement	775	134.1	11.1
		First Floor	286	72.8	4.9
17120	Harrisburg	Basement	Insufficient Data	Insufficient Data	Insufficient Data
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
17033	Hershey	Basement	3923	140.2	7.6
		First Floor	1957	113.3	2.9
17034	Highspire	Basement	190	38.1	4.2
		First Floor	30	4.8	1.5
17036	Hummelstown	Basement	5898	435.5	13.4
		First Floor	969	224.0	7.4
17048	Lykens	Basement	140	77.9	12.9
		First Floor	30	32.2	4.0
17057	Middletown	Basement	1890	231.0	7.0
		First Floor	335	45.2	3.2
17061	Millersburg	Basement	540	115.5	13.2
		First Floor	106	46.7	6.4
17080	Pillow	Basement	Insufficient Data	Insufficient Data	Insufficient Data
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
17113	Steelton	Basement	626	126.7	13.4
		First Floor	146	439.6	13.5
17097	Wiconsico	Basement	Insufficient Data	Insufficient Data	Insufficient Data
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
17098	Williamstown	Basement	77	90.6	10.2
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data

Source: PADEP 2020

4.3.12.4 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 to be 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 2018). As part of a 2014 initiative to raise awareness, EPA implemented the "Test, Fix, Save a Life" radon action campaign to highlight radon testing and mitigation as a simple and affordable step to significantly reduce the risk of 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 corrective action to repair a home with radon levels at or above 4 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. Remediating high radon levels often costs the same as other minor home repairs.
- **Save a Life:** More than 20,000 Americans die from radon-related lung cancer each year. By decreasing elevated levels in the home, residents can help prevent lung cancer while creating a healthier home (EPA 2013).

Future occurrences of radon exposure can be considered *likely* as defined by the Risk Factor Methodology probability criteria (discussed in Section 4.4).

4.3.12.5 Vulnerability Assessment

To understand risk, a community must evaluate the assets that are exposed or vulnerable within the identified hazard area. This section evaluates and estimates the potential impact of the radon exposure hazard on Dauphin County in the following sections:

- 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
- Further data collections that will assist in understanding this hazard over time

Overview of Vulnerability

Radon exposure is of concern in Dauphin County because of the county's location within a High Potential (Level 1) EPA Radon Zone. While structural factors (such as building construction and engineered mitigation measures) can influence the level of radon exposure, all residents and structures within Dauphin County are vulnerable to radon exposure.

Data and Methodology

The 2018 U.S. Census data and the Hazards U.S. - Multi Hazard (HAZUS-MH) building inventory for Dauphin County were referenced to support an evaluation of assets exposed to this hazard and potential impacts associated with this hazard. Per the 2018 Pennsylvania HMP, an average radon mitigation system cost of $1,200 was applied to 20 percent of the building stock to evaluate economic vulnerability (PEMA 2019).

Impact on Life, Health, and Safety

For the purposes of this plan, the entire population of the county is assumed to the risk of radon exposure. Radon is responsible for more than 20,000 of lung cancer deaths every year. 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 2013).

As shown in Table 4.3.12-2 above, 21 out of 25 homes (84 percent) in Dauphin County have measured radon levels exceeding 4 pCi/L. Excess human cancer risk posed by radon exposure at this elevated level is identified in Table 4.3.12-1.

Impact on General Building Stock and Critical Facilities

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

Impact on the Economy

EPA has concluded that an average radon mitigation system costs $1,200. EPA also states that current Pennsylvania surveys indicate one home in five contains elevated levels of radon. Using 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, estimated radon mitigation costs for residential structures in Dauphin County could exceed $41 million. However, 4 percent of households in the county have measured radon-level average radon levels exceeding 4 pCi/L (shown in Table 4.3.12-2), indicating that the cost of radon mitigation may be higher than the estimate based on the above-cited information from EPA, whereby only 20 percent of structures are considered for mitigation.

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 2018).

Future Growth and Development

Because the entirety of Dauphin County has been determined to br at risk for the radon exposure hazard, any new development will be exposed to this 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 than retrofitting existing structures to implement these measures.

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 Dauphin County. Because specific structural conditions affect human exposure to radon, to properly assess the level of health risk and determine the need for mitigation measures, radon must be measured within individual facilities. Furthermore, EPA recommends consideration of radon exposure risk and installation of mitigation measures as appropriate during all new construction.