4.3.13 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 in rocks, soil, and groundwater. 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 2016). An estimated 40 percent of the homes in Pennsylvania are believed to have elevated radon levels (Pennsylvania Department of Environmental Protection [PADEP] 2017c).

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

4.3.13.1 Location and Extent

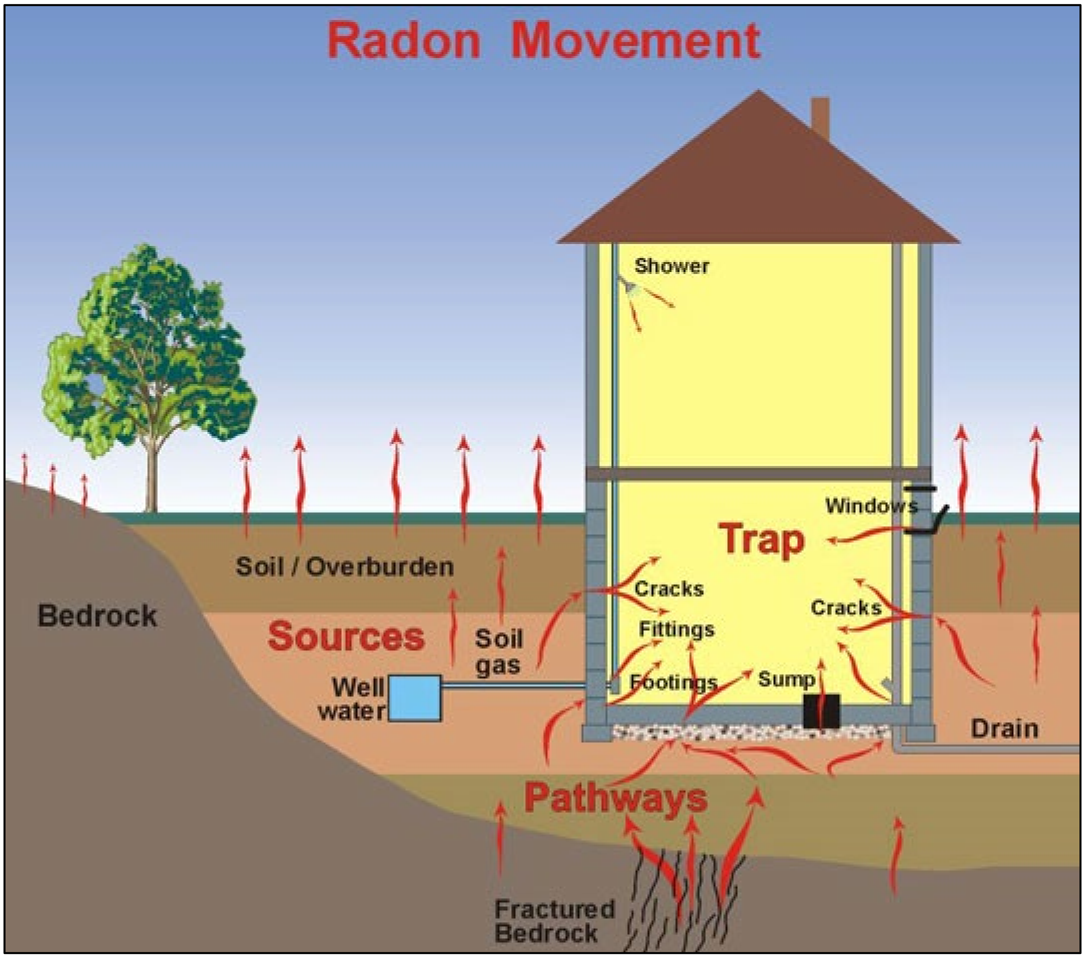
Radioactivity caused by airborne radon has been recognized for many years as an important component in the natural background radioactivity exposure of humans. However, it was not until the 1980s that the wide geographic distribution of elevated radon levels in houses and the possibility of extremely high radon concentrations in houses were recognized. In 1984, routine monitoring of employees leaving the Limerick nuclear power plant near Reading, PA, 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 this person 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 extents of feet or tens of feet. The following three sources of radon in residences 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 emanates from uranium-rich building materials (such as concrete blocks or gypsum wallboard); this source also is not known to be a problem in Pennsylvania (Pennsylvania Emergency Management Agency [PEMA] 2013).

Figure 4.3.13-1 illustrates radon entry points into a home.

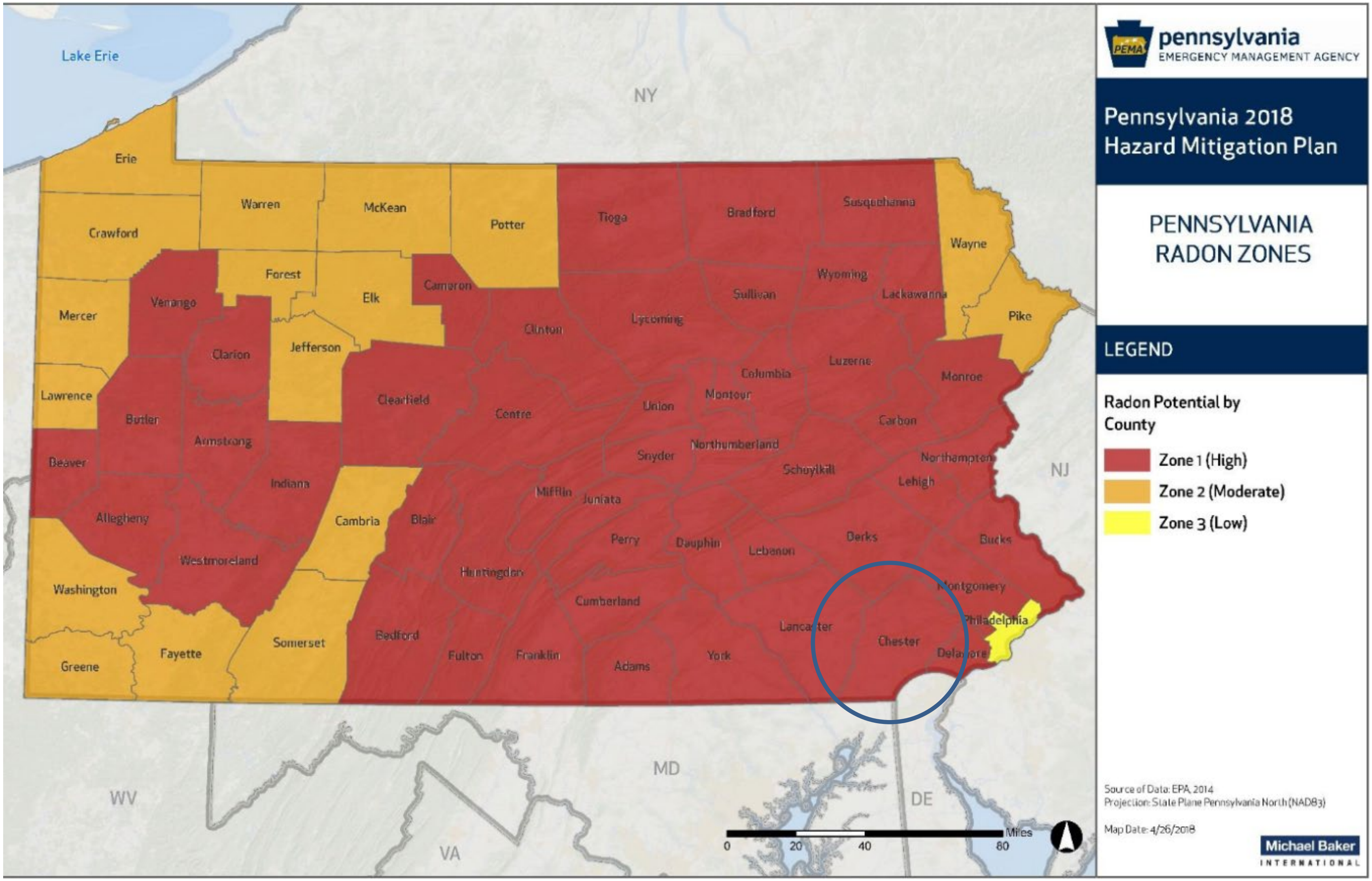
Figure 4.3.13-1. Sketch of Radon Entry Points into a House



Source: 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, however, is 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. Chester County is in Zone 1 – High Radon Potential, as noted on Figure 4.3.13-2 below.

Figure 4.3.13-2. Radon Hazard Zones in Pennsylvania



Source: EPA 2014 (Chester County is identified by the blue circle.)

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, 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 from the house 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 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 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.

Areas where houses have high levels of radon can be divided into the following 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 that have normal uranium content but properties that promote high radon levels in houses: This group is not completely understood at present. Relatively high soil permeability can lead to high radon concentrations; the clearest examples of this scenario are houses built on glacial eskers. Limestone-dolomite soils also appear to be predisposed for high radon levels in houses, perhaps because of the presence of 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 radon range of 0.5 to 5 ppm (PEMA 2013).

According to the Pennsylvania State 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 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 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).

4.3.13.2 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 2016). 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 4.3.13-1 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 cancer risks from other hazards for smokers and non-smokers, and (3) action thresholds.

Table 4.3.13-1. 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	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 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)	Reducing radon levels below 2 pCi/L is difficult
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 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)	Reducing radon levels below 2pCi/L is difficult

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 2016

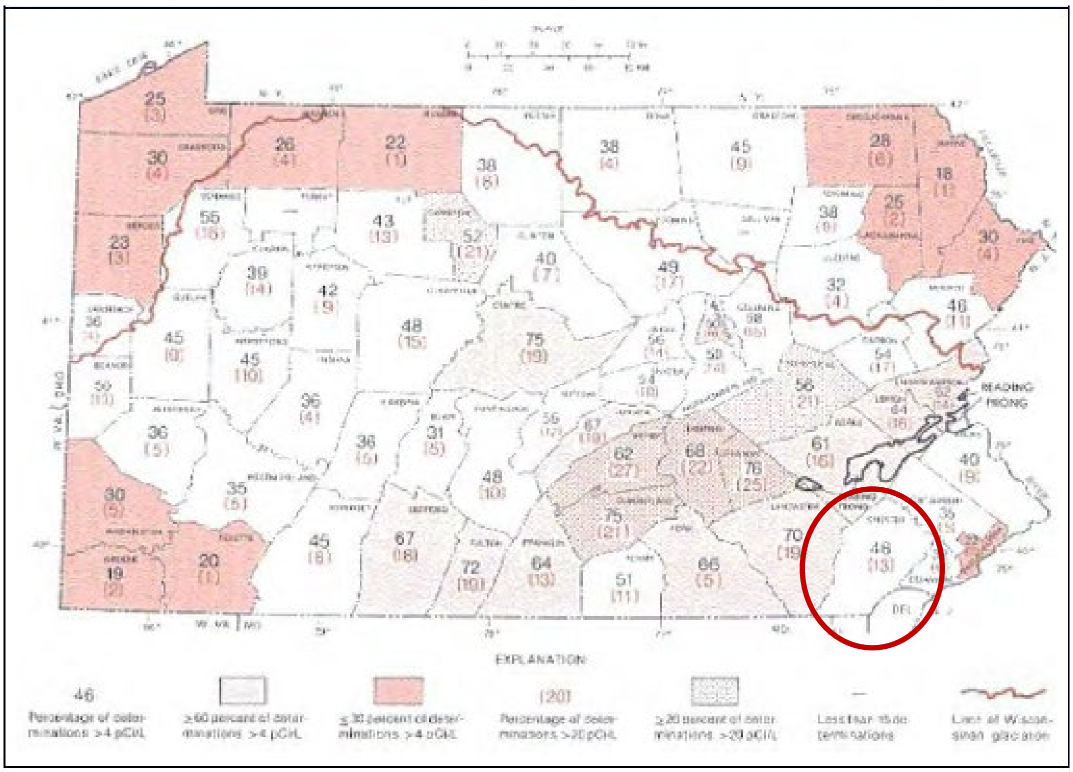
According to EPA, the average radon concentration in the indoor air in homes in the United States is about 1.3 pCi/L. EPA recommends that homes be repaired if the radon level is 4 pCi/L or more. However, EPA also recommends that Americans consider fixing their home if radon levels are between 2 and 4 pCi/L because there is no known safe level of exposure to radon. As listed in Table 4.3.13-1, a smoker exposed to radon has a much higher risk of lung cancer.

The worst-case scenario for radon exposure would be caused by a large area of tightly sealed homes inducing high levels of exposure to residents over a prolonged period of time, without awareness of this 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 2016). The most likely scenario is a single household exposed to a very low concentration of radon, with no adverse health effects.

4.3.13.3 Past Occurrence

Current data on abundance and distribution of radon in Pennsylvania houses are considered incomplete and potentially biased, but some general patterns are evident (as shown in Figure 4.3.13-3).

Figure 4.3.13-3. Percentage of Pennsylvania Homes with Radon Levels Exceeding 4 pCi/L



Source: PEMA 2013 (Chester County is identified by the red circle.)

PADEP Bureau of Radiation Protection (Bureau) provides homeowners with information 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 so as 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, this 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 36 zip codes within Chester County to allow them to report the findings (summarized in Table 4.3.13-2). 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 text result within a zip code, many homes in that zip code may have elevated radon levels.

Table 4.3.13-2. Radon Level Tests and Results by Zip Codes in Chester County

ZIP Code	Location	Area in Home	Number of Tests	Maximum Result (pCi/L)	Average Result (pCi/L)
19301	Paoli	Basement	2962	333.2	7.3
		First Floor	629	61.2	5.3
19310	Atglen	Basement	362	91.9	11.1
		First Floor	52	33.8	5.3
19311	Avondale	Basement	1043	47.4	3.0
		First Floor	96	23.5	2.6
19312	Tredyffrin	Basement	4636	359.6	6.4
		First Floor	1015	111.7	4.2
19320	Valley Township	Basement	9066	1669.0	10.6
		First Floor	1170	213.3	7.1
19330	Cochranville	Basement	721	574.3	11.6
		First Floor	98	31.4	4.6
19333	Devon	Basement	2141	165.1	5.7
		First Floor	589	100.8	3.4
19335	Downingtown	Basement	14785	357.6	6.7
		First Floor	2134	108.1	4.0
19341	Exton	Basement	4258	137.0	3.3
		First Floor	731	74.2	2.1
19343	Glenmore	Basement	2374	116.9	5.4
		First Floor	342	55.0	2.8
19344	Honey Brook	Basement	1344	193.0	6.0
		First Floor	169	34.5	2.9
19347	Kemblesville	Basement	41	34.5	3.5
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19348	Kennett Square	Basement	4604	322.8	3.9
		First Floor	723	92.0	2.3
19350	Landenberg	Basement	2326	50.3	3.3
		First Floor	324	22.1	1.9
19352	Lincoln University	Basement	1214	201.4	4.1
		First Floor	161	21.0	2.0
19353	Exton	Basement	34	81.0	7.8
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19355	Malvern	Basement	7454	250.0	6.8
		First Floor	1524	116.0	4.0
19360	New London	Basement	65	19.4	3.8
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19362	Nottingham	Basement	466	314.1	8.3
		First Floor	55	28.2	3.4
19363	Oxford	Basement	1994	181.6	4.9
		First Floor	212	50.3	2.6
19365	Parkesburg	Basement	1424	1530.0	23.1
		First Floor	180	577.2	15.0
19369	Sadsburyville	Basement	53	258.0	31.9
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19372	Downingtown	Basement	521	155.0	5.5
		First Floor	128	26.3	2.8
19374	Toughkenamon	Basement	33	10.3	3.9
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19375	Unionville	Basement	142	54.9	4.8
		First Floor	36	3.8	1.5
19382	West Chester	Basement	10805	1465.3	3.1
		First Floor	1983	71.3	1.9

ZIP Code	Location	Area in Home	Number of Tests	Maximum Result (pCi/L)	Average Result (pCi/L)
19390	West Grove	Basement	1585	113.0	3.3
		First Floor	231	21.5	1.9
19395	Westtown	Basement	91	32.1	2.7
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19421	Birchrunville	Basement	99	33.8	4.6
		First Floor	Insufficient Data	Insufficient Data	Insufficient Data
19425	Chester Springs	Basement	5126	287.4	5.3
		First Floor	632	76.7	3.3
19442	Kimberton	Basement	223	53.1	5.3
		First Floor	89	24.2	2.4
19460	Phenixville	Basement	9205	183.0	4.9
		First Floor	1502	42.5	2.4
19465	Pottsown	Basement	2305	224.3	5.5
		First Floor	249	60.9	3.3
19475	Spring City	Basement	1710	187.3	5.7
		First Floor	259	123.7	3.5
19481	Valley Forge	Basement	278	102.0	4.7
		First Floor	104	14.7	2.6
19520	Elverson	Basement	1021	182.9	6.6
		First Floor	133	90.1	3.9

Source: PADEP 2020

4.3.13.4 Future Occurrence

Radon exposure is inevitable given present soil, geologic, and geomorphic factors across Pennsylvania. Residents who live in housing 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 2016). 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 fix 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. Addressing 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).

4.3.13.5 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 Chester 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; and (4) the environment
- Future growth and development
- Further data collections that will assist in understanding this hazard over time
- Additional data and next steps

Overview of Vulnerability

Radon exposure is of concern in Chester 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 Chester 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 Chester County were referenced to support an evaluation of assets exposed to this hazard and potential impacts associated with this hazard. According to the 2018 Pennsylvania State HMP, an average radon mitigation system cost of $1,200 was applied to 20 percent of the building stock to evaluate economic vulnerability (EPA 2016).

Impact on Life, Health, and Safety

For the purposes of this plan, the entire population of the county is assumed to be at 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 adults (EPA 2016).

As shown in Figure 4.3.13-3 above, 89 percent of homes in Chester 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 4.3.13-1.

Impact on General Building Stock and Critical Facilities

While the entire general building stock and critical facility inventory in Chester 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 the following subsection.

Impact on the Economy

EPA has concluded that an average radon mitigation system costs $1,200. EPA also states that current state surveys indicate that 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 (EPA, 2016). Therefore, estimated radon mitigation costs for residential structures in Chester County could exceed $41 million. However, 72 percent of households in the county have measured average radon levels exceeding 4 pCi/L (shown on Figure 4.3.13-3), 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) near the source from which the gas is released (EPA, 2016).

Future Growth and Development

Because the entirety of Chester County has been determined at risk for the radon exposure hazard, any new construction 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 Chester 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 that new construction projects consider radon exposure risk and installation of mitigation measures as appropriate.