Environmental Health & Engineering, Inc.

Radon Exposures in a Granite Quarry

EXECUTIVE SUMMARY

Multiple studies have been published demonstrating that exposures to both radon and direct radiation from granite countertops are very low, and that this is not an issue of concern for homeowners (Allen et al., 2010; Chen et al., 2010; Myatt et al., 2010; Llope, 2011; Allen et al., 2013). Recently, the U.S. Environmental Protection Agency (EPA) presented an abstract that included some exploratory research pertaining to certain occupational exposure scenarios related to granite, namely quarry workers and fabricators. In this white paper, we sought to investigate this issue in-depth and conducted research to evaluate radon exposures in a granite quarry. Specifically, are quarry workers exposed to meaningful levels of radon, and do factors such as the depth of the quarry and the possible presence of temperature inversions lead to elevated quarry worker radon exposures?

KEY FINDINGS

Radon Exposures in a Granite Quarry

- According to the Mine Safety and Health Administration (MSHA) all active granite quarries in the U.S. are considered to be surface mines and therefore are naturally ventilated. MSHA reported that there were only 330 workers in dimension granite quarries.
- Air monitoring conducted as part of this study found that the radon concentrations measured at varying heights in a deep quarry in Vermont, selected to represent a ‘worst-case’ scenario because of the depth and high natural background radon, were all less than 0.3 picocuries per liter (pCi/L). This observed value is less than the average background radon concentration in the United States.
- If a temperature inversion occurs, it typically occurs at night during times when workers are not normally present in the quarry. Therefore, inversions would have little or no impact on workers' annual average exposure to radon.
- During air monitoring in a deep Vermont quarry, we observed one temperature inversion. This temperature inversion occurred at night when no workers were present in the quarry, and did not measurably impact the overall radon concentration measurements which were all less than the limit of detection.
- Occupational exposure to radon for granite quarry workers is insignificant, even when considering the potential for temperature inversions.

CONCLUSION

Based on EH&E's review of available data and radon measurements, occupational exposures and health risks related to radon for granite quarry workers are insignificant, i.e., below average background levels.

INTRODUCTION

Radon is a gas that comes from the natural decay of uranium in soil, rock, or water (EPA 2010). Radon is a very widespread pollutant, and can be detected in both outdoor air and inside of homes all across the United States. Radon is of concern because it is a known lung carcinogen, and the second leading cause of lung cancer in the United States (EPA 2003; Nuclear Regulatory Commission [NRC] 1999).

For quarry workers, occupational exposures to radon emanating from granite stones in the United States have not been extensively studied. This is most likely because granite quarries are not underground and are therefore naturally ventilated, and exposures to radon are presumed to be low. However, EPA has conducted exploratory research and raised the question regarding the impact of certain weather phenomena, known as temperature inversions, that could potentially occur that may increase a quarry worker's exposure to radon.

Normally, air temperature decreases with increasing height away from the earth's surface. Temperature inversions occur when the temperature of the air increases with increasing height away from the earth's surface. Therefore, temperatures near the earth's surface are cooler than temperature measured further away from the earth's surface. The presence of an inversion has many implications on the pollution in the area in which it is occurring. The temperature inversion acts as a "cap", and traps pollutants under the inversion layer. During these temperature inversion conditions, pollutants (such as radon gas) can be trapped and concentrations can increase as the pollutants do not mix with clean air, as they normally would. No studies could be found that report the frequency of of temperature inversions in granite quarries. A recent study has shown that temperature inversions occurred primarily between 6 PM and 6 AM, with only a few occurrences outside of those times (Fritz et al., 2008). Therefore, if an inversion does occur in a quarry, it is most likely to occur during periods when workers are not present.

The goal of our study was to identify, evaluate and describe the factors impacting occupational radon exposures in a granite quarry. Factors investigated included the types of quarries present in the U.S., information on temperature inversions that could occur in quarries, measured radon concentrations in quarries, and the number of U.S. granite quarry workers likely to be impacted by radon. In addition, field measurements for radon were obtained at one of the deepest granite quarries in the U.S., in an area of the U.S. known to have high background radon concentrations (Vermont).

METHODS

Literature Review

A literature review of both the peer-reviewed and "grey" literature was conducted to search for information on the characteristics and sizes of granite quarries in the U.S., and information on the number of granite quarry workers in the U.S.

Quarry Sampling

We collected radon and temperature measurements in a quarry in Vermont in order to measure radon exposure concentrations and the vertical temperature profile of a representative U.S. granite quarry. We selected a quarry in Vermont due to the depth of the quarry, its accessibility, and the high natural background radon concentrations in the Northeastern U.S. The precise depth of the quarry is unknown; however, it was estimated by quarry employees and EH&E to be approximately 250 feet deep.

In order to measure radon concentrations and temperature at multiple heights throughout the quarry, six monitoring stations were set up and placed at varying heights throughout the quarry. Location 1 was placed at the very top of the quarry, while Location 6 was placed close to the bottom of the quarry where people were working. The other monitor locations were all placed at varying heights between these two monitors. Figure 1 depicts the location of the monitoring stations throughout the quarry. Figure 2 shows an example of the monitoring stations deployed in the quarry. At each of the monitoring stations, an outdoor HOBO Pro temperature data logger (Onset Corporation, Bourne, MA) and two RSSI Alpha-track Radon Detectors (RSSI, Morton Grove, IL) were deployed to measure temperature and radon, respectively. After approximately two weeks, the temperature data were collected and one set of radon detectors were removed from the quarry and analyzed along with two quality control samples in order to get a short-term radon measurement. The other set of radon detectors remained in the quarry in order to take a longer-term sample (ongoing as of the date of this report). During the initial visit, radon concentrations at each of the locations in the quarry were sampled in real-time using the RAD7 radon detector (Durridge, Billerica, MA). The detector was set to "sniff" mode, and radon concentrations were monitored over a period of 15 minutes.

Finally, to determine the radon flux from the stone mined from this quarry, a sample of this granite was analyzed to determine its radon flux. This flux measurement was conducted according to the methods outlined in a previous study measuring radon flux in multiple granite stones (Allen et al., 2010).

FIGURE 1. Aerial View of monitoring locations in the quarry

FIGURE 2. Photo of monitoring equipment deployed at the top of teh quarry (Location 1).

RESULTS

Literature Review Results

Quarry Types and Dimensions: In general, mines are typically defined as either surface or sub-surface (underground) mines, as these are the most common excavation methods. In a surface mine, the overburden (or the materials above the product of interest) are removed, leaving an open surface. For an underground mine, tunnels or shafts are dug down to where the products of interest are located. According to Mine Safety and Health Administration (MSHA) all active granite quarries in the U.S. are considered to be surface mines (MSHA 2012) and therefore are naturally ventilated.

Very little data were available regarding specific quarry dimensions in the U.S.. We were not able to find comprehensive, detailed information about the dimensions of the U.S. quarries. However, the E.L. Smith Quarry in Graniteville, VT, claims to be the world's largest deep-hole dimension granite quarry at approximately 600 feet deep (Rock of Ages, 2013).

Number of United States Quarry Workers: In a recent publication, the U.S. Geological Society (USGS) estimates that there are 1,500 workers employed in granite quarries and mills in the U.S. as of 2012, excluding office workers (USGS 2013). MSHA also collects data about the number of granite quarry workers in the US. MSHA reported that there were only 330 workers in dimension granite quarries (MSHA 2012).

QUARRY SAMPLING RESULTS

Radon Flux from the Granite Quarry: Previous studies have described radon emission rates (i.e., flux) from both U.S. and international sourced granite (Allen et al., 2010). However, the radon flux for the particular stone mined in the quarry studied was not previously measured. Therefore, a small chamber test was conducted and the flux from the quarried stone studied was measured. The average emission rate from this stone was low and determined to be 0.66 pCi/ft^2-hr for the "rough" side of the stone while the flux was 0.96 pCi/ft^2-hr for the "polished" side of the stone.

Radon Concentration Sampling: Two types of radon measurements were made in the quarry. Real-time radon measurements were taken at each of the six sampling locations with the RAD7 monitor. Each of those measurements were below the limit of detection of the instrument in its "sniff" mode. Therefore, no elevated levels of radon were observed in the quarry using the real-time monitor during the day the field team deployed the longer term monitoring equipment.

Radon concentrations measured over 15 days in the quarry were all below the method limit of detection; blank corrected radon concentrations were all below 0.3 pCi/L. For comparison, the average outdoor radon concentration in the US is 0.4 pCi/L and EPA's action level for indoor air in homes is 4.0 pCi/L (National Council on Radiation Protection and Measurements [NCRP] 1987). Table 1 presents the results of the short-term, 15-day radon sample conducted in the quarry.

TABLE 1 Radon Concetratioons Observed in the Quarry after Approximately Two Weeks

Monitor Location	Radon Concentration (pCi/L)
Site 1	<0.3
Site 2	<0.3
Site 3	<0.3
Site 4	<0.3
Site 5	<0.3
Site 6	<0.3

Testing for the Presence of Temperature Inversions: Temperature data were collected after 15 days of sampling, and the results were analyzed to look for the presence of temperature inversions that may be occurring in the quarry. Figure 3 depicts the observed temperatures for both the highest (Location 1) and lowest (Location 6) elevation monitoring locations, over the entire sampling period. In general, the temperature profiles at the sampling locations both at the bottom and the top of the quarry track well with one another. The temperature at the bottom of the quarry was often slightly warmer than the temperature at the top of the quarry.

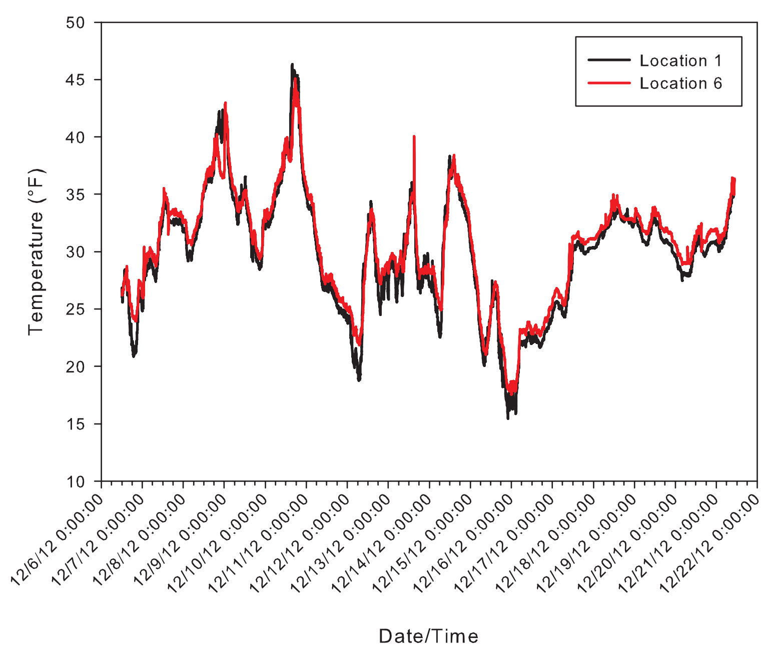

FIGURE 3. Temperature trend over time for both the highest (Location 1) and lowest (Location 6) elevation monitoring stations in the quarry over the entire study period.

Looking at the data in Figure 3, over the 15 days monitored there seems to be one instance of a temperature inversion that occurred at night on December 8, 2012, and lasted into the early morning of December 9, 2012. Figure 4 depicts the temperature profile of that evening in greater detail.

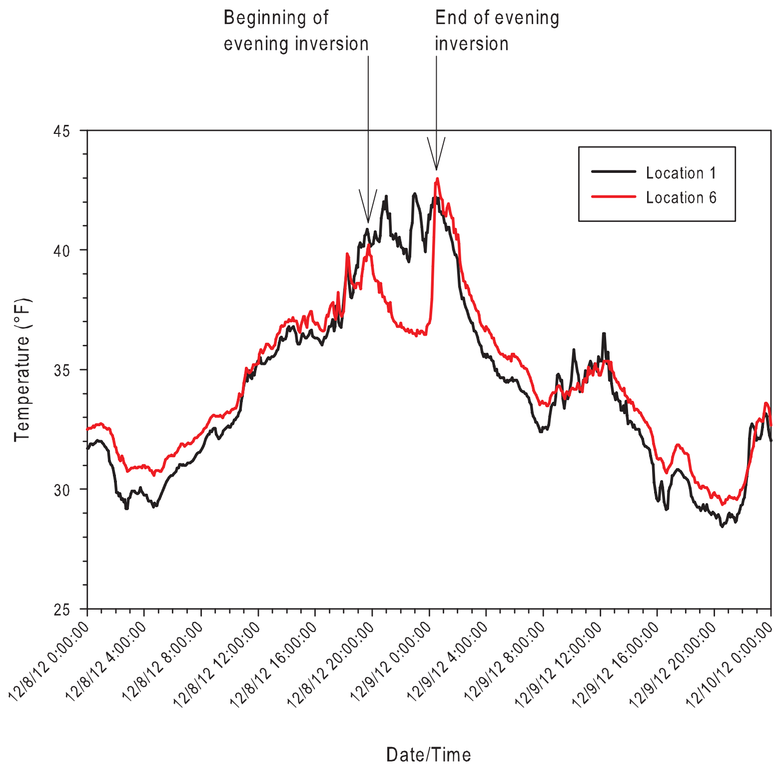

FIGURE 4. Temperature trend over time for both the highest (Location 1) and lowest (Location 6) elevation monitoring stations on December 8, 2012, and December 9, 2012.

Looking at Figure 4, starting at approximately 8 PM on December 8, 2012, a temperature inversion occurred. The inversion lasted for approximately five hours, and was the only prolonged temperature inversion observed during the 15-day monitoring period. The inversion occurred at night, and no workers were working during that time period. This analysis agrees with our understanding of temperature inversions in general, which typically occur at night or in the early morning, during calm wind conditions.

CONCLUSIONS

Our literature review found that all of the granite quarries in the U.S. are surface mines, and that there are no underground granite quarries in the U.S. Also, the deepest granite quarry in the U.S. is approximately 600 feet deep, much of which is filled with water an inaccessible. Using MSHA data, it was determined that there are relatively few active granite quarry workers in the U.S.

Air sampling results from the 15-day study inside a quarry in Vermont demonstrated that the radon concentrations measured at varying heights in an approximate 250 feet-deep quarry were less than 0.3 pCi/L. This observed radon concentration is less than the average background radon concentration in the U.S. Real-time radon measurements were also taken in the quarry, and did not detect any measurable amounts of radon gas at each of the six sampling locations.

Our temperature measurement data indicated that there was a singular temperature inversion that occurred during one of the nights included in the study. There were no daytime temperature inversions observed during our study, so no workers would have been present in the quarry during this temperature inversion. This finding is consistent with studies reported in the peer-reviewed literature which find that most inversions occur overnight and into the early morning, in the winter months. Even in the presence of this inversion, observed radon concentrations in this study were still very low.

In conclusion, based on EH&E's review of available data and radon measurements, occupational exposures and health risks related to radon for granite quarry workers are insignificant, i.e., below average background concentrations, even when considering the potential for temperature inversions.

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