September 8, 2016

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Subject: **Analysis of Potential Radium/Radon Impacts – Vulcan Lexington, SC Quarry Schnabel Project 15619049.00**

Dear Mr. Hodge:

Schnabel Engineering LLC (Schnabel) has prepared this report in reply to questions that have been raised regarding the potential presence of naturally occurring radium in the groundwater and whether the planned quarry would have any effects upon radon gas transport that would reasonably be expected to affect receptors in the vicinity of the facility.

We reviewed geologic reports for the area, South Carolina Department of Natural Resources (DNR) ground water reports, and a number of technical reports examining radium/radon related to quarry operations other countries.

Radium and Radon

In a report on Groundwater Resources of Lexington County (2006), the South Carolina Department of Natural Resources identified naturally occurring radium as a potential health issue due to levels that exceeded the EPA Maximum Contaminant Levels (MCLs) in drinking water. DNR stated that,

> High levels were detected in the county as early as the mid-1970's. In a study by the Clemson University Water Resources Research Institute (1980), wells in and around the town of Batesburg/Leesville were tested for radionuclides over a 2-year period in the late 1970's. All of the wells in the town exceeded the maximum acceptable concentration for ^{226}Ra of 3.0 pCi/L1, and 12 of the 22 wells outside the town exceeded the EPA limit for ^{226}Ra. Consistently high ^{228}Ra levels caused all the wells in the town to contain 2 to 6 times the EPA limit for total radium in spite of the low levels of ^{226}Ra concentrations. Other ground-water data also confirmed the presence of dissolved ^{228}Ra in the Coastal Plain aquifers near the Fall Line from Georgia to New Jersey…
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> ^{226}Ra is a naturally occurring element in the earth's crust and is a progeny of Uranium-238 (^{238}U). ^{238}U has a relatively high solubility that contributes to its widespread distribution and, hence, to the widespread distribution of its daughter product, ^{226}Ra. In addition to its solubility, ^{226}Ra has a long half-life of 1,600 years. High concentrations of ^{226}Ra have been found in studies by the U.S. Geological Survey in aquifers along the Fall Line of the southeastern states from Georgia to New Jersey...The minerals containing these isotopes were derived from the crystalline rocks of the Blue Ridge and Piedmont provinces and emplaced as fluvial deposits...

^{228}Ra is the daughter product of Thorium-232 (^{232}Th). ^{232}Th is less soluble than ^{238}U, and ^{228}Ra has a shorter half-life (5.75 years) than ^{226}Ra. This isotope does not tend to migrate far from its source.

It is important to note that the proposed aggregate quarry will not be concentrating naturally occurring radium in the groundwater nor radon gas as a result of its operations. From a review of published literature regarding the potential for workers to be exposed to natural radioactivity in quarries, it is apparent that different geological materials emit varying levels of natural radioactivity. A study of workers in Italy concluded that individual workers were exposed to low doses of radioactivity, and that the so-called "effective doses" that were predicted using standard equations in models correlated well with observed personal dosimeter information. Volcanic materials such as basalts, tuffs, and lavas had the highest naturally occurring radionuclides content, while granites, sandstones, and marbles had lower levels of natural radioactivity, respectively.

In order to calculate exposure scenarios, the cosmic ray contribution dose must be subtracted from the overall does. In the study of workers in the stone industry, the data shows that most workers are exposed only to gamma background radiation. In addition, processing operations of quarried materials are not directly connected to the risks associated to radon exposure. The levels of radon in open quarries are very low and insufficient to adversely affect the health of workers.

In a well-known study of soil gas emissions near a quarry in Portugal, there were no significant changes in soil-gas radon concentrations associated with blasting. Radon gas was monitored in soil borings near the active front of the quarry, and the results varied greatly, even across a very short distance.

The Portuguese site is in a vastly different geological setting from the planned Lexington County quarry. Since the Portuguese study dealt with an area of active uranium mining, it could be viewed as an extreme example radon gas exposure. While the Lexington site is not comparable to the Portuguese quarry, the processes of transport for radon gas identified in the study provide an analogue to consider the effects of blasting and the ability of radon gas, if present, to migrate through faults and associated fractures.

Unlike the site of the proposed quarry in Lexington County, the Portuguese site was located on several active faults, and natural emissions of radon gas were higher along such faults than elsewhere. Such higher levels were attributed to variations in the stress field associated with such faults. There is not a similar stress field in Lexington County. The nearby shear zone, referred to as the Modoc Fault Zone has been inactive since the Carboniferous and thus there is not modern stress field that would be considered comparable to the Portuguese setting. The study area in Portugal also was affected by the presence of former uranium mining and the presence of the mineral uraninite that was associated with a late Hercinian orogenic pluton known as the Beiras batholith.

A potential pathway for migration of radium in groundwater and radon gas if present, is through fractures in the bedrock. Based on the analysis of rock cores from the proposed quarry site, the bedrock appears to lack significant fractures. It has been suggested that blasting or other quarry operations could create additional fractures in the bedrock that could exacerbate natural conditions. A review of calculations performed to investigate whether blasting would create additional pathways for the migration of radon gas indicated that blasting would create fractures in the bedrock of less than one foot in length away from the blast site. To propagate fractures longer than about a foot away from the blast site, would require high pressure hydraulic fracturing (personal communication Steve Brandon, PE, PG, CPG, Vice President, Schnabel Engineering). Normal blasting would not materially increase the migration of radon gas, if present, offsite. The facility is designed to have a buffer in excess of one thousand (1,000) feet from any residences in the area. Given limits of any predicted blast related fracturing of less than one foot, there is sufficient protection of migrating radon gas as a result of quarry related activities

In order to ensure that the high wall of the quarry has sufficient strength to avoid failure, it cannot be fractured or weakened by fractures that would compromise the structural integrity of the wall. Vulcan personnel expressed to this author that, in their analysis of this site, the lack of fracturing in the granitic deposit was a favorable factor in determining that the rock was suitable as an aggregate source, and that it also met geotechnical requirements necessary to ensure the integrity of planned quarry walls.

There is no evidence that the quarry development would lead to additional chemical weathering due to contact between the rock and groundwater. Weathering as a natural phenomenon occurs over hundreds of thousands of years. Dewatering should reduce the ability of groundwater to come in contact with the granite, thus minimizing the ability of chemical weathering to occur. We reviewed the literature regarding radium in the vicinity of Piedmont granite deposits. At another site, the mylonite rocks adjacent to granite were brittle and produced catalasite and gouge. These mylonites differ greatly from that observed in cores of the Lexington deposit. As such, it is our opinion that the mylonite rocks identified at the project site are not preferential pathways for the migration of groundwater or radon gas. The mylonites identified on site are not fractured, but they are indurated and not porous.

Conclusions

A literature review indicates there is no correlation between blasting or processing granite aggregate and radon emissions from aggregate mining activities. Vulcan's operations will not affect the physical or chemical characteristics of the subsurface in a manner that would reasonably be expected to increase the concentration of radium or radon (if they exist) at its facility. In addition, a buffer of 1,000 feet is more than sufficient to address any cracks or microfractures of less than one foot in length that might result from development of the quarry walls by blasting, or other processes.

We appreciate the opportunity to be of service for this project. Please contact the undersigned if clarification is needed for any aspect of this request.

Sincerely,
SCHNABEL ENGINEERING, LLC.

Raymond L. Knox, PG (SC#311)
Senior Vice President