Draft

STRATEGIES FOR VALIDATING THE BLOCKSON RADON MODEL AND ADDRESSING STRATIFICATION ISSUES

Prepared by
John Mauro, SC&A, Inc.
1608 Spring Hill Road, Suite 400
Vienna, Virginia 22182

Revised September 9, 2009

INTRODUCTION

During the full Advisory Board meeting held in West Chester, Ohio, on July 27–29, 2009, there was some discussion regarding the radon model developed for the purpose of placing a plausible upper bound on the average annual radon concentrations that workers in Building 40 might have experienced during the covered period. Following those discussions, the Advisory Board voted on a motion to accept the model. The Board's vote was evenly divided with regard to this motion, thereby effectively resulting in non-acceptance of the model. It is SC&A's understanding that this was an important vote, because without an accepted method for addressing the radon issue, it might not be possible to move forward on the larger issue related to the Special Exposure Cohort (SEC) petition for the Blockson Chemical Company.

Based on the Board's discussions, it is SC&A's understanding that the primary issues related to the acceptance of the model are related to the fact that there are no radon measurements available for Building 40 for the time period of interest that could be used to validate the model, nor were any data or reports provided from other venues that might be useful in validating the model. In a related matter, one or more members of the Board also expressed concern that "stratification" was not explicitly taken into consideration in the model. The stratification issue has to do with the possibility that there might be locations within the building where the average annual radon concentrations were higher than the average annual radon concentrations derived for the overall building, as derived using the model. If this were, in fact, the case, then workers who might have occupied those locations could have experienced annual exposures to radon that were higher than those derived by the model.

SC&A would like to point out that, notwithstanding differences of opinion regarding the input parameter distributions employed in the model, the model was used by both NIOSH and SC&A to derive the upper 95th percentile concentration **of the average annual radon concentration in the building**. In performing these calculations, stratification was not explicitly taken into consideration. However, heuristic arguments were made by both SC&A and NIOSH that, given our understanding that workers were not at fixed locations, air flow patterns were complex and ever changing, and given that the upper 95th percentile concentration was selected for performing dose reconstructions, stratification is unlikely to have a significant impact on the dose reconstructions of individual workers. However, SC&A acknowledges that this perspective regarding the stratification issue is certainly a subjective judgment.

In order to help address issues related to model validation and stratification, the Board requested that both SC&A and NIOSH give some thought to lines of inquiry that might help to resolve these concerns. This report is provided in response to that request.

When addressing questions such as these, it is sometimes helpful to ask, *What information would answer these questions?* Under ideal circumstances, we would have access to data gathered from continuous radon monitors arranged in a 10 × 10 × 10 meter, 3-dimensional grid distributed over the entire volume of the building. Each location would be representative of the average radon concentration in a volume of 1,000 m^3. In this way, we would be able to estimate the average annual concentration of radon in each 1,000 m^3 volume within the building (which we estimate was between 17,321 and 23,983 m^3). We would then make some judgment regarding how much time each worker spent in each location in the building. Under worst-case conditions, we could assume workers spend all their time in the 1,000 m^3 volume with the highest average annual radon concentration. However, we don't have this information. If we did, we wouldn't need the model, but such data would be extremely useful in validating the model for use at other applications.

STRATIFICATION

There is little doubt that the radon concentration varied a great deal as a function of time and location within Building 40. The question is, however, did the average annual radon concentration at a given location differ significantly from the overall average radon concentration in the building? Given that such a gradient existed, and assuming that some workers occupied those locations for protracted periods of time, is it possible that the upper 95th percentile of the derived average annual concentration for the entire building would underestimate the annual radon exposures to some workers? We do not believe it is possible to provide a hard and fast answer to this question. However, there are certain lines of inquiry that might help to inform such judgments.

Strategy No. 1

One approach that might be used to address this question is to take advantage of what we know about Building 40. We believe that the most likely location from which radon would have been emitted into the atmosphere of Building 40 was at the surface of the digester tanks. We believe that when the crushed ore concentrate was dissolved in the sulfuric acid in the digesters, radon was also dissolved in the acid. The acid was stirred and was hot, and the digesters were open at the top. Hence, we believe that most of the radon that entered the atmosphere of Building 40 emerged from the surface of the digester tanks.

It is our understanding that these tanks were located on the upper level of the building and ran along the length of the building. Hence, it is likely that the location with the highest average annual radon concentration was the volume of air between the top surface of the digester tanks and the roof of the building. Given this conceptual model, one could calculate the concentration of radon in the air above the tanks as it rose vertically from the surface of the digesters and moved up toward the ceiling, where it exited the building via roof fans and/or vents. The rate at which the air left the building via this route can be estimated by using information that has been already developed regarding the air turnover rate for the building, and converting that rate (which is expressed in units of 1/hr) into a flow rate in units of m^3/hr. This can be accomplished by estimating the surface area of the ceiling above the digesters. Hence, atoms/sec of radon leaving the surface of the digester divided by cubic meters per second of air leaving the building via the roof vents yields atoms per cubic meter in the volume of air above the digester tanks. This would seem to be one simple and conservative method for assigning an upper bound to the average annual radon concentration within a segment of Building 40.

Strategy No. 2

One possible approach that can be used to explicitly address stratification is to assume that the concentration of radon in Building 40 has a 3-dimensional Gaussian distribution (i.e., has the profile of a normal distribution curve). In the simplest version of such an approach, it can be assumed that the distribution is spherically symmetrical. The average concentration of radon in the building can be assumed to be the same as that calculated by the existing model. However, the concentration at the building's boundary can be assumed to equal the outdoor ambient concentration of radon, i.e., the environmental background concentration. This assumption should place an upper bound on the concentration gradient in the building. When inserted into the existing Monte Carlo model, this will have no effect on the geometric mean, but will increase the spread of the calculated values. Such a calculation would produce an estimate of the maximum plausible value of the 95th percentile of the average annual concentration of radon anywhere in the building, which explicitly takes stratification into consideration. Since it is implausible that the concentration at the periphery of the building would be less than the outdoor concentration, we believe that the actual gradient cannot be steeper than the one derived by this procedure.

Strategy No. 3

Although there are limited data on radon levels in phosphate production plants, it may be possible to assemble data on measurements taken inside a given facility within the same timeframe. These measurements could be used to construct a normalized frequency distribution. This distribution, which would be assigned a geometric mean of 1, would characterize the variability of radon levels at different locations. It would be a simple matter to include such a distribution in the current radon model. The geometric mean of the concentrations calculated by the Monte Carlo model would not change; however, the distribution of results would now explicitly include the gradient based on the variability of the actual measurements. The revised model would thus encompass the relative variability of the measurements, not the actual values of these measurements. It would combine the modeled concentrations, based on the specific characteristics of Building 40, with the gradient found in actual facilities. Because of the additional variable, the resulting concentrations would span a greater range, so the 95th percentile value would be somewhat larger than the values derived by SC&A and NIOSH.

This strategy has the advantage of being based on industrial facilities processing phosphate ore, and would better represent the concentration gradients than data on homes, offices, or other buildings where the radon enters from the surrounding soil (which is discussed next); the difficultly is finding data for facilities that can be reasonable surrogates for Building 40.

Strategy No. 4

There is a vast amount of data and literature on the variability of the concentration of radon in homes as a function of season and location within residences. One study[1] revealed that there is a several-fold difference in the radon concentration in residences between seasons and between the basement and the first and second floors in residences.

In addition, the EPA published a report in 1993 titled, *National Residential Radon Survey*. This was a survey of 5,600 residences in the United States, where short-term measurements of the radon concentrations were made in the basement, first floor, and second floor of each residence. The data reveal that the radon concentrations were 2 to 3 times higher in the basement than in the first and second floors. Similar data, but not as extensive, has been compiled for schools and large structures, such as apartment houses. These data were complied before a nationwide effort was implemented to reduce the concentration of radon in homes by the use of subslab ventilation systems and other construction techniques designed to mitigate the radon problem in the United States.

In the case of residences and other structures investigated by the EPA, the radon enters the structure primarily[2] through the floors and walls of the basement, and then moves vertically upward due to the stack/chimney effect, which is caused by the buoyancy of the warm indoor air compared with the cold (in winter) outdoor air. This effect is responsible for two mechanisms that inject and distribute radon; (1) the production of small, but persistent, air pressure differences across the foundation surfaces (that draw soil gas and radon into the building), and (2) the flow of outdoor air entering cracks and openings low on the building envelope, passing up through the building, and leaving through cracks and openings high on the building envelope. In addition, wind effects can also increase or reduce the extant air pressure differences, causing greater or lesser amounts of radon entry and altering air movement into and within the building. Hence, stratification resulting in a 2- to 3-fold difference in the average annual concentration of radon in different levels of residences is well established.

Certainly the physical setting and the source of the radon in Building 40 is different than in residences. In Building 40, the "radon pump" is the radon leaving the surface of the digester tanks located on the upper level of the building and moving up with the thermal plume created by the hot sulfuric acid. In a home, the radon pump is the radon that is entering the building from the basement due to cracks in the concrete floor and the pressure differential between the basement, and the radon in the pore space in the soil beneath and surrounding the basement. In addition, the different levels in residences are separated by the ceiling above each level in a home. We do not believe that these barriers are present in Building 40. In addition, if the radon moved relatively quickly from the surface of the digester tanks out of the building, there would

---

[1] Andreas C. George and Lawrence E. Hinchliffe, "Measurements of Radon Concentrations in Residential Buildings in the Eastern United States," in *Radon and Its Decay Products, Occurrence, Properties, and Health Effects*, Edited by Philip K. Hopke, ACS Symposium Series 331. American Chemical Society, Washington, DC, 1987.

[2] Radon also enters residences from ground water pumped into homes for domestic use, and from the surfaces of radium-bearing construction materials inside the building. However, these sources of radon are much smaller contributors to radon indoors than radon in the soil in the vicinity of the residences.

be little time for progeny in-growth. Reasonable arguments can be made that the gradient in occupied areas of a residence might be greater or less than that which might have existed in Building 40. Nevertheless, it might be possible to incorporate terms into the radon model that explicitly address the possibility of a gradient and use the radon data summarized above as the basis to assign a distribution to the gradient.

MODEL VALIDATION

Strategy 5

Investigate existing contaminant transport and dispersion models, such as the following:

- The applicability of models developed at national laboratories [Lawrence Berkeley National Laboratory (LBNL)] to study transport and mixing of contaminants within buildings (see examples – http://eetd.lbl.gov/IED/4.html). These studies were conducted in response to the potential threat of airborne biological and chemical attacks on a variety of U.S. buildings. They investigated the spread and dispersion of pollutants, and the identification of pollutant source locations. A review of the literature and discussions with the authors and scientists might indicate whether these models could be used to predict contaminant movement and accumulation in Building 40.

- The multi-zone airflow and contaminant transport analysis model, developed by the Indoor Air Quality and Ventilation Group at the National Institute of Standards and Technology (NIST) – CONTAM 2.4c (http://www.bfrl.nist.gov/IAQanalysis/). While the model is intended for multi-zone commercial and residential buildings, it may be possible to adapt it for the industrial conditions present in Building 40.