Reduction of the Radon Levels in the SNO Underground Laboratory: Internal Source from Emanated Radon excluding leakage of air into the utility room

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Introduction

On site radon (^{222}Rn) levels were mapped[1] at the INCO Creighton mine in order to select radon mitigation strategies for various purposes in the SNO Underground Laboratory. Based on these measurements a radon ingress model was developed[2] for the utility room at the underground location in order to identify the design criteria for reduction of the radon level.

In this simple model the sources of the radon activity in the room were taken to be the emanated radon from the surface area of the room and the radon activity from the make-up air introduced into the room for ventilation and air conditioning purposes. The losses from the total activity from these sources were taken to be arising from the decay of the radon with its characteristic 3.8 d half-life, and the activity carried out by the exhausted air vented from the room. The equilibrium activity A (pCi/l) was given by

$$A = (E \times S + A_i \times F_i) / (F_o + \lambda \times V) \qquad \dots 1$$

where E was the emanation rate (pCi/sft.min), S was the surface area (sft), F_i and F_o were the flow rates (cfm) of air into and out of the room of volume V (cft), and λ was the decay constant of ^{222}Rn (min^{-1}) with appropriate conversion factors between different units.

Emanation calculated from Radon ingress model

From the above equation it can be seen that the activity inside the room is zero when the introduced activity A_i is zero in the absence of activity from the emanation inside the room; i.e. A is zero when E and A_i are both zero.

Specifications for air handling units state only air flows for make-up air coming into the room and exhausted air vented out of the room which may be different from each other. At equilibrium the difference between these two flow rates implies a leakage rate of air into or out of the room which is not represented explicitly in the above model. Therefore, knowing all other variables a calculated value of E from the above equation will be an over estimate of the actual source term from emanated radon inside the room.

For the utility room of cross-section 20' x 20' and 200' in length, E may be calculated to be 1.6 pCi/sft.min with the activity in the air inside and outside the room at 3 pCi/l, and the make-up air coming in at 700 cfm and the exhausted air vented at 1000 cfm. Independent determinations of emanation rates[3-5] of radon from the typical surfaces in the SNO underground location as well as a typical rock[6] indicate that the measured value appears to be much smaller than the calculated value from the model.

Therefore, in order to account for hidden factors in the term E x S in the above equation, as a first approximation, it will be represented as the sum of two factors: 1. Activity entering the room via emanation of radon from the surface area of the room, and 2. Activity entering the room via leakage of outside air not accounted for by the make-up volume of air not specified by the specifications of the air handler unit.

Leakage into the room calculated from the model

The radon load (A_i x F_i) brought into the utility room from the activity in the incoming air is equal to 60 000 pCi/min. If the activity in the utility room is 3 pCi/l, then the combined radon load from leakage of air into the room and emanated sources may be calculated to be 26300 pCi/l. Neglecting contribution from emanated source, this load is approximately equal to a leakage of 300 cfm of outside air at the activity concentration of 3 pCi/l. This amount of air-flow due to leakage is in reality the difference in the flow rates of make-up air and exhaust air indicated by the air handler specifications.

The infiltration of outside air into residential and commercial buildings has been discussed in literature[7] in the context of ventilation and indoor radon levels. Data on leakiness characteristics of various enclosures[7,8] show that all radon mitigation measures for radon reduction will fail without getting a firm control of this entry path way. Performance characteristics reported in reference 8 are a prime example of the radon leakage problem into air tight enclosures.

Emanation calculated with leakage taken into account

Therefore, taking into account the activity entering the room due to leakage of external air at 300 cfm, the radon load from emanation of radon from the surface area of the room may be calculated to be 855 pCi/min which gives an emanation rate from the surface area of the room of 0.05 pCi/sft.min.

A measured value of 4.5×10^{-2} $pCi.m^{-2}.s^{-1}$ for radon emanation from a shotcrete/rock wall was reported by Bigu and Hallman[3], which is equal to 0.27 pCi/sft.min. This value is five times higher than the calculated value with leakage of air taken into taken into account.

However, the higher value reported by Bigu and Hallman may be consistent with the calculated value if a retardation factor is introduced for the epoxy coating put on top of the shotcrete/rock wall underground. A retardation factor of 5 for the high-build epoxy coating applied to the shotcrete/rock wall[9] will be consistent with reported values in literature[10] for industrial surface coatings.

Radon Load with zero ventilation if the utility room is totally sealed

The saturation concentration reached in room air from the internal source of emanated radon in a totally sealed utility room may be calculated from the following equation with $F_i = F_o = 0$, and L set equal to zero:

$$A = (E' \times S + A_i \times (L + F_i)) / (F_o + \lambda \times V) \quad \ldots 2$$

where E' is the emanation rate ascribed to the surface area of the room excluding contribution from the radon introduced into the room through infiltration of outside air at a leakage flow rate of L (cfm).

With the calculated value of 0.05 pCi/sft.min calculated above for E', the saturation concentration of radon in the sealed utility room may be estimated to be 2.8 pCi/l. This value is nearly the same as the radon concentration in the make-up air brought into the room, and reflects the concentration reached by the fresh air from the surface with a long residence time underground.

Effect of ventilation with radon free air

The air handling unit[11] (AHU) in the utility room serves four major purposes: 1. Brings in make-up air for oxygen requirements for human occupancy, 2. Maintains air temperature in the room by dissipating the heat load into the room from the surrounding rock, 3. Maintains the cleanliness of the air to the desired level of particle count by filtering the air, and 4. Maintains the humidity level. The operating parameters are set partly by the heat load and cleanliness considerations and partly by the regulatory agencies for the fresh-air requirements underground for human occupancy. Therefore, these cannot be readily changed.

The only parameter that can be changed is the radon concentration in the make-up air brought into the room by the AHU, and the air infiltration rate into the room by leakage through the entry door-way and other entry ports for pipes etc. If the leakage rate is totally eliminated then the flow rates F_i and F_o specified by the AHU must be changed to equal each other on the basis of equilibrium pressure considerations.

It can be calculated from equation 2 that the room air will be at a radon concentration of 0.01 pCi/l if the room is ventilated with radon-free air at the rate of 1000 cfm.

This concentration of radon is very small compared to the concentration of radon in the air outside the utility room. The difficulties in maintaining this low level of activity by supplying radon-free air to the ventilation system, and sealing the room may be appreciated by the radon build-up time reported in reference 8.

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