CALCULATION OF INDOOR EXTERNAL EXPOSURE DUE TO RADON AND ITS PROGENY

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INTRODUCTION

Radiation protection officials concerned with the potential health problems due to the presence of radon and its progeny inside buildings have devoted essentially all of their attention to exposures resulting from inhalation of these radionuclides. Little attention has been directed to the associated external exposures. The external exposure from the sources which are redistributed due to the emanation of radon within the walls and floors of a building, as well as the ground, and its subsequent escape into the air within the building, are considered. Estimated here, using a computer code, are the external exposure rates for each source distribution, taking into account the emanation of radon within the walls, its escape into the room air, and the plateout of radon progeny on the wall surfaces. Finally, the corresponding effective dose equivalents from these external sources are compared to those due to internal exposures from inhalation of radon and its progeny by the people within the room.

CALCULATIONS

The Monte Carlo code, REBEL-3, which was developed by L. Koblinger (Ko80), is used as an original program for our dose estimations. We obtained this code from the Radiation Shielding Information Center at the Oak Ridge National Laboratory. This code provides a methodology to calculate the specific indoor exposure rate and flux from the source uniformly distributed in the walls. However, the source distribution and source intensity in the original code have been modified in order to take account of the above-mentioned changes in the source distributions. Since Rn-222 emanation is all that is considered here, only the uranium series is dealt with as a source. Four kinds of source distributions are considered in the calculations. Source 1 relates to the non-liberated radon, its progeny and its precursor within the walls. They are assumed to have a uniform source distribution. Source 2 is assumed to have a non-uniform distribution within the walls, corresponding to the liberated radon and its progeny. Source 3 is assumed to be a uniform source, corresponding to the distribution of radon and its progeny within the air inside the building. Source 4 corresponds to the radon progeny as plated out on the wall surfaces from the indoor air.

ASSUMPTIONS

For representativeness in the calculations presented here, many parameters are chosen from the "standard" room in the work of L. Koblinger (Ko78). The following assumptions were made. That the room had a cross sectional area of 5mx4m; a height of 2.8m; that the walls and floors were made of SiO_2, with a density of 2.32g/cm^3 and a thickness of 20cm; and that the room had no windows or doors. The receptor was assumed to be located one meter above the floor in the center of the room.

Source 1 deals with the non-liberated radon and its progeny as well as its precursor within the walls. It is assumed that 90% of the radon was non-liberated. The liberated radon will move through the wall and form a non-uniform distribution of radon and its progeny within the walls. For source 2, the porosity and effective diffusion coefficient for the concrete walls were assumed to be 10% and 2.0E-5cm^2/s (Cu76), respectively. The distributions and concentrations of radon and its progeny within the walls were calculated using the equation for radon diffusion within walls of Moeller (Mo76). For source 3, the exposure rates were normalized for a unit concentration of Rn-222 (1 pCi/l) within the room air. The radionuclides assumed to be suspended in the air were Rn-222, RaA, RaB and RaC. Their relative activity ratios were estimated to be 1.00, 0.901, 0.537 and 0.359 based on an assumed air exchange rate of 1 per hour, and that the plateout rate for RaA was ten times greater than those for RaB and RaC. Based on these assumptions, the concentrations of RaB and RaC are then 0.537, and 0.359 pCi/l and the equilibrium factor is 0.51. The concentrations of RaD and Ra-226 in the room air were assumed to be zero. Using these values, the radionuclides suspended in the room air will have a source intensity of 0.910 photon per Rn-222 disintegration per liter. For source 4, the concentrations of RaA, RaB, RaC and RaD were estimated considering the mass balance of radon progeny in the room to be at steady state. Under these conditions, the concentrations of RaB and RaC would be 1.67, and 1.96 pCi/cm^2, respectively. The concentration of RaD is conservatively taken to be the same as that of RaC. The intensity for the source was 4.16 photons per Rn-222 disintegration per liter.

RESULTS AND DISCUSSION

The specific exposure rates for each of the sources considered in this study are given in Table 1. All the statistical uncertainties of the Monte Carlo results are within 5%. The values

Table 1. Specific Exposure (μR/h) (for a single room of 5mx4mx2.8m)

	uncollided	scattered	total
source 1*	1.78E 0	1.74E 0	3.52E 0
source 2*	4.10E-2	5.28E-2	9.39E-2
source 3**	1.05E-2	1.08E-3	1.16E-2
source 4**	5.63E-4	1.59E-4	7.22E-4

* Unit activity is pCi of Ra-226 per gram of concrete.
** Unit activity is pCi of Rn-222 per liter of air.

for source 1 are about 91% of those that would have been calculated without considering the emanation of radon within the walls (named "original result"). The exposure rates for source 2 are less than 3% of that for source 1. For sources 3 and 4, the uncollided photons are much more significant than the scattered photons. This is due to the fact that many photons reach the receptor before being collided since the absorber between the receptor and the source is only air. If the air within the room is assumed to have a Rn-222 concentration of 100 pCi/l, the exposure rates for sources 3 and 4 are estimated to be 1.2 and 0.07 μR/h, respectively. If the cross sectional area of the room is assumed to be increased up to 20mx20m, keeping the height at 2.8m, the volume of the room would increase to $1120m^3$ but the exposure rates for sources 1 and 2 would show no significant change. For source 3, the exposure rate increase gradually with room size and reach 193% of the "standard" room for a room with a cross sectional area of 20mx20m. For source 4, the exposure rates normalized for unit activity on the wall surfaces increase gradually to 158% of those for the "standard" room.

It would be extremely difficult to confirm the calculations presented here through direct measurements. For source 1, the estimates are 91% of "the original results." They are presumably correct because 90% of the radon and 100% of its precursor, Ra-226 which has 1.8% of the total gamma intensity of uranium series, were dealt with as sources and the dose contribution would be expected to be a little higher than 90% of "the original result." For source 2, further verification may be necessary. For sources 3 and 4, there are no direct experimental results that can be used for comparison or evaluation. Calculations for infinite conditions, therefore, have been performed to compare with the estimates found in papers. The infinite condition can be satisfied with a room, of which size is greater than 1000mx1000mx1000m, in our calculations. Since our radionuclide source is not mono-energetic, an average source energy was obtained for comparison with the estimates for a mono-energy source. For source 3, of which average source energy is 775 keV, the results for the infinite condition were consistent (within 12%) with the values reported by Dillman (Di74) for uncollided and scattered photon fluxes for the source of 0.8 MeV photons. For source 4, of which average source energy is 858 keV, the exposure rate for the infinite condition were again consistent (within 13%) with the results reported by French (Fr65) for the source of 0.85 MeV photons.

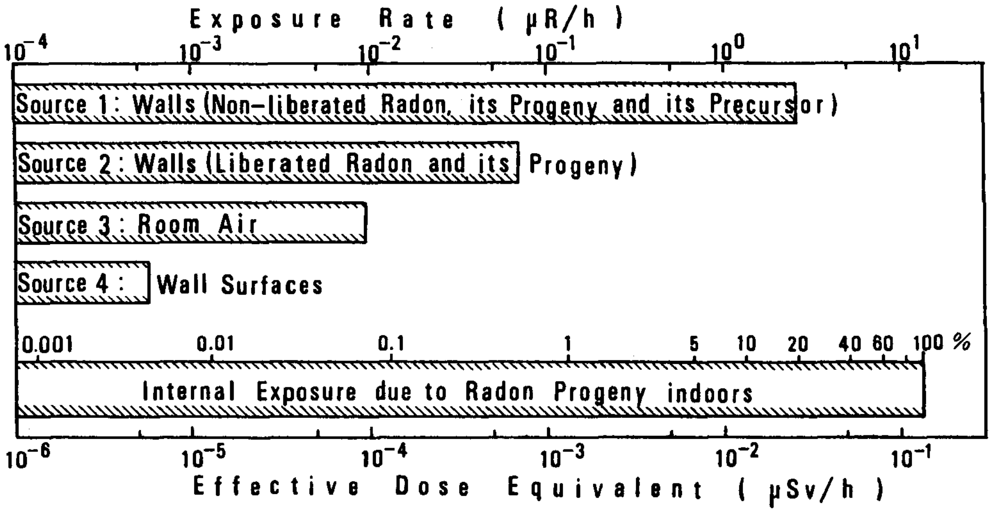

Fig. 1. Exposure Rates in "Normal" Condition in a Room of 5mx4mx2.8m.

Exposure rates for each source distribution for a "normal" situation are presented in Figure 1. "Normal" concentrations of Ra-226 in the concrete and Rn-222 in the air were assumed to be 0.75 pCi/g, and 0.81 pCi/l, respectively (UN82). Under these conditions, the contributions to the exposure rates from sources 3 and 4 are only 0.009 and 0.006 μR/h. Even in a very large room (cross sectional area of 20mx20m, and height of 2.8m), the exposure rates for sources 3 and 4 were only 0.02 and 0.002 μR/h, respectively. Most of the contribution to the external exposure rates arises through source 1. It must be acknowledged, however, that the exposure rates from this source are directly dependent upon the concentration of uranium and its decay products within the walls, including the rate at which radon is assumed to escape from the walls. Calculations based on the assumed conditions for source 2 show that most of the radon liberated within the walls escapes outside the walls. As a result, the exposure rates from source 2 are reduced to 25% of the total liberated radon and its progeny within the walls.

The effective dose equivalent from internal exposure due to inhalation of radon and its progeny by people who remain within the "normal" room, as described previously, would be 0.13 μSv/h. In the corresponding "normal" room, the effective dose equivalents due to external dose from sources 1, 2, 3, and 4 were estimated to be 20, 0.5, 0.07 and 0.004% of that from internal exposure (see Fig. 1).

CONCLUSIONS

A modified computer code has been developed which can be used to estimate indoor external exposure rates from the naturally occuring radionuclides in the walls and floor of a room which are redistributed due to the emanation of radon within the walls and floors of a building, as well as the ground. Accounted for in the code are also external exposures due to submersion within a radioactive "cloud" within the room as well as the plateout of radon progeny on the walls and floor. Applications of the code show that the relative contribution to external exposure rates from radionuclide sources arising through the emanation of radon within, and the escape of radon from, the walls of a room are quite small. The main contributors to external exposure rates are the radon and its progeny that remain within the walls of the room.

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