Acta Physica Hungarica 59 (1—2), pp. 19—22 (1986)

MODELLING INDOOR EXPOSURE TO NATURAL RADIOACTIVE NUCLIDES

W. HOFMANN and F. DASCHIL
Division of Biophysics, University of Salzburg
A-5020 Salzburg, Austria

Radon enters buildings from several sources, principally building materials and the soil or rock that underlie or surround building foundations. The basic processes determining indoor concentrations are radioactive transmutations, attachment to aerosol particles, detachment by alpha particle recoil, plate-out on furniture and walls, and exchange with the outdoor air by natural or mechanical ventilation.

A multicompartment model has been developed which describes the fate of radon and attached or free radon decay products in a model room by a set of linear time-dependent differential equations. Time-dependent coefficients allow us to model temporal parameter changes, e.g. the opening of windows, or a sudden pressure drop leading to enhanced exhalation. While steady-state models have been used to study the effect of parameter changes on steady-state nuclide concentrations, our time-dependent models provide additional information on the time scale of these changes.

Introduction

In the past few years there has been growing concern over the indoor exposure to radon, thoron, and their short-lived decay products. Because of differences in construction materials, composition of soil, or ventilation conditions, these radionuclide concentrations exhibit large local variations. But even at a given site, significant temporal fluctuations have been observed [1]. Thus the simulation of the temporal behaviour of natural radionuclides in enclosed spaces may help us to interpret these experimental findings and to gain more detailed information on the physical processes governing indoor exposure.

Steady-state models have been used to study the effect of parameter variations on steady-state nuclide concentrations [2-7]. Our time-dependent model offers additional information on the time scale of these changes, i.e. the time after which the steady-state conditions are reached, which can vary between minutes and hours. In a preliminary version of our model, hybrid computational techniques were used [8] which are replaced here by digital simulation methods.

Basic processes determining indoor concentrations

In our current version of the model we assume that the indoor exposure in dwellings can be simulated by the radionuclide behaviour in a model room (box model), thus neglecting the exchange between the various rooms of a house .

The major sources of the noble gas radon are (1) exhalation from building materials (dominant in European structures), (2) diffusion and pressure-driven flow from the soil through cracks and openings in the foundation (the major radon source in U.S. buildings), and (3) radon released from domestic water supplies [9].

In the indoor atmosphere, a large fraction of the short-lived decay products is attached to aerosol particles, while a smaller fraction (typically in the order of 10% for ^{218}Po) remains unattached. Attached and unattached fractions are determined (1) by the attachment rate which is a function of the size distribution and the particle concentration of the natural aerosol, (2) the detachment rate, caused by alpha particle recoil after alpha decay, and (3) the plate-out rate for deposition on indoor surfaces, e.g. floor, walls and furniture, where deposition velocities for unattached nuclides are about two orders of magnitude higher than for attached nuclides [6].

The dominant particulate removal mechanisms indoors are (1) plate-out due to normal air motion, (2) plate-out due to forced convection, e.g. from mixing fans, and (3) air cleaning by filters or electrostatic precipitators [10].The basic ventilation processes, i.e. the exchange of indoor and outdoor air, are (1) infiltration, i.e. uncontrolled leakage of air through cracks and pores in the building envelope by wind and temperature differences (stack effect), (2) natural ventilation through open doors and windows, and (3) mechanical ventilation [11].

Mathematical realization of the box model

The kinetics of our box model can be described by an open multicompartmental system, in which the various nuclide concentrations, e.g. the concentration of unattached ^{218}Po-nuclides in room air, are represented by separate compartments [12]. A compartmental system can be described mathematically by a set of linear differential equations. In order to simulate short-time parameter variations, e.g. sudden changes of the ventilation rate caused by the opening and the subsequent closing of a door (simulated by two step functions), most transport rates in the model are represented by time-dependent coefficients in the differential equation system.

The differential equations describing our box model are so-called stiff differential equations, i.e. the solutions change rapidly in the neighbourhood of the initial conditions. This requires a step-wise integration procedure, with rather narrow integration intervals at the beginning. As initial conditions we assume in all our simulations that all indoor nuclide concentrations $C_i = 0$ at $t = 0$.

Results

In order to check our theoretical model, a simplified steady-state version has been used to compute the radon concentration for a given model room as a function of the ventilation rate, and to compare the calculated data with experimental results obtained by nuclear track detectors [13]. The fair agreement between theoretical and experimental data gives us some confidence that the major physical processes are described properly by our model.

For the simulation of the time- dependent model, all environmental parameters, e.g. the ^{222}Rn outdoor concentration, adopt constant values, and all indoor concentrations start from zero at t=0. The increase of the indoor concentrations as a function of time display the typical behaviour of an oscillatory system, i.e. approaching an equilibrium value with a characteristic time constant which depends on the actual parameter values as well as on the selected initial conditions.

With the aid of our compartment model we have investigated problems such as: influence of ventilation conditions, surface to volume ratio, effect of plate-out, and influence of meteorological parameters on the exhalation rate (in particular barometric pressure drop).

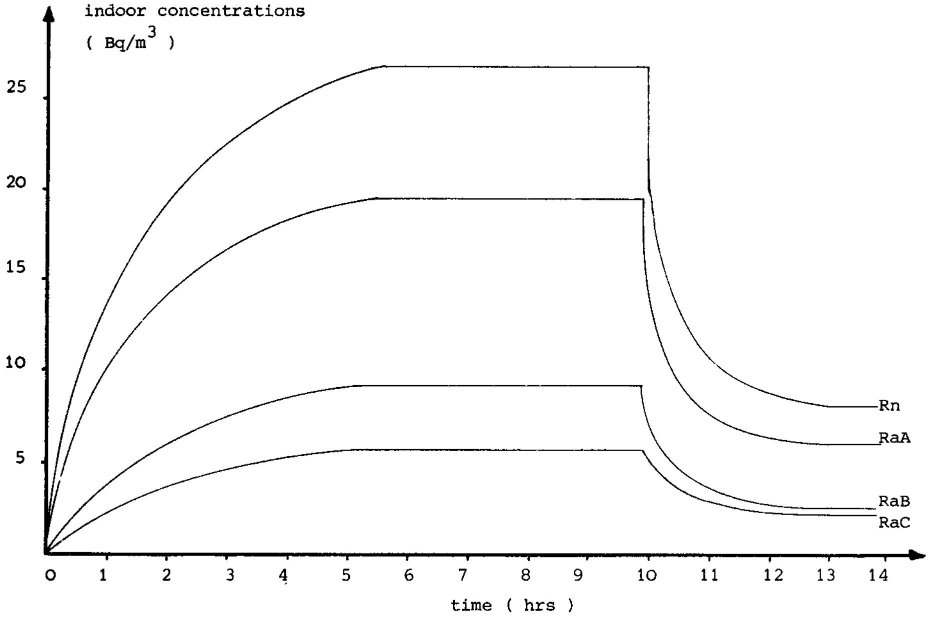

Fig. 1. Effect of a sudden change of the ventilation rate from 0.5 to 6.0 hrs^{-1} on radon and radon progeny concentrations in indoor air

As an illustrative example of those simulation runs, the effect of a sudden change of the ventilation rate on indoor air concentrations is shown in Fig. 1. Dependent on the parameter values selected for this particular simulation, it takes approximately 5 hours to reach equilibrium conditions (starting from t = 0 with $C_i^n = 0$). After 10 hours, a sudden drop of the ventilation rate from 0.5 to 6 hrs^{-1}, simulated by a step function, leads to a significant reduction of the indoor concentrations, reaching the new equilibrium values after approximately 2 hours. This behaviour emphasizes the importance of knowing the ventilation conditions prior to measurements of the indoor concentrations in order to obtain reliable information on the natural exposure in a given flat or dwelling.

Conclusions

The computer model described in this paper enables us to investigate the effect of time - dependent variations of parameter values on indoor concentrations. A critical test of our model predictions would require detailed experimental data which are not yet available. It is planned to extend the single room-model to a house - model, consisting of three rooms, in order to study transport processes between different rooms.

Acknowledgements: This work was supported by the Austrian Bundesministerium für Bauten und Technik, Wohnbauforschung, F 874/1-V-31/82.

References

1. F. Steinhäusler, W. Hofmann, E. Pohl and J. Pohl-Rüling, in Proc. Natural Radiation Environment III, eds. T.F. Gesell and W.M. Lowder, Technical Information Center, U.S. Department of Energy, 1978, p. 1145.
2 W. Jacobi, Health Phys., 22, 441, 1972.
3. J. Porstendörfer, A. Wicke and A. Schraub, Health Phys., 34,465,1978,
4. E.O. Knutson, A.C. George, J.J. Frey and B.R. Koh, Health Phys., 45, 445, 1983.
5. R.C. Bruno, Health Phys., 45, 471, 1983.
6 J. Porstendörfer, Radiat. Prot. Dosim., 7, 107, 1984.
7. T. Kusuda, S. Silberstein and P.E. McNall, JAPCA,30, 1201, 1980.
8. W. Hofmann, in Simulation of Control Systems, ed. I.Troch, North-Holland Publishing Company, Amsterdam, 1978, p.239.
9 A.V. Nero, Health Phys., 45, 303, 1983.
10 S.N. Rudnick, W.C. Hinds, E.F. Maher and M.W. First,Health Phys.,45,463, 1983.
11. S.M. Doyle, W.W. Nazaroff and A.V. Nero, Health Phys., 47, 579, 1984.
12. J.A. Jacquez, Compartmental Analysis in Biology and Medicine, Elsevier Publishing Company, Amsterdam, 1972.
13. F. Edl, B. Kunsch, F. Reumann and J. Rupp, OEFZS BER.No A0596, PH-398/84, 1984.