Estimating the Health Benefits of Progeny Extraction Units as a means of reducing Exposure to Radon

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Abstract

Radon exposure to the general public can be reduced by preventing entry of radon gas into buildings using a passive radon-proof membrane or an active sump and pump system. However, a significant majority of the radiation dose delivered is from the decay products of radon rather than from the gas itself. These decay products (also referred to as progeny) are present in indoor air, with an equilibrium factor – a measure of the ratio of progeny to radon gas – of between 0.4 to 0.5. As a result, systems which extract radon progeny from the air by filtering have been promoted as means of reducing exposure to the general population.

The European Community Radon Software (ECRS) offers a means of estimating lung-cancer risk associated with an individual's exposure to radon, and includes the possibility of estimating the health risk from different proportions of radon gas and its progeny by varying the value of the Equilibrium Factor. This software was used to estimate the health benefits associated with reduced decay products in differing concentrations of radon gas. The results were compared to health benefits expected if the risk was reduced by the standard method of reducing the radon gas concentration below the Action Level, which in the UK is 200 Bq·m^{-3} for domestic properties.

These calculations showed that there is the potential for efficient extraction units to provide the necessary dose and risk reduction where initial average radon gas concentrations are up to 800 Bq·m^{-3}. However, above 1000 Bq·m^{-3}, such systems cannot reduce the health risk sufficiently to reach levels comparable to those resulting from radon gas reduction to below the Action Level.

Introduction

The naturally-occurring radioactive gas, radon, is the second most significant risk for lung cancer after tobacco smoking. High levels of radon were first identified in uranium mines but, more recently, it has been established that significant levels are found in the built environment, and case-control studies have shown an associated increase in lung-cancer in the public from radon in their homes (BEIR VI 1999; Darby et al. 2005; AGIR 2009).

Radon decays into other radioactive elements, and two of these, Polonium-218 and Polonium-214, have been shown to deliver a significant proportion of the radiation dose received by occupants of domestic premises. In a sealed system, radon and its progeny exist in secular equilibrium. In the domestic environment, however, secular equilibrium is never maintained, because progeny are continuously being removed from indoor air by surface deposition and ventilation. The degree of disequilibrium between the radon gas and the progeny is represented by the Equilibrium Factor (EF), which is defined as the ratio of the potential alpha energy concentration (PAEC) of the actual progeny mixture to the PAEC of progeny in secular equilibrium with the radon gas. Thus EF is between 0 and 1, and within domestic buildings is typically in the range 0.4 to 0.5. Although they are intrinsically solid materials, radon progeny can exist in suspension in air, either unattached, or attached to aerosol particles. Porstendörfer (1984) has discussed these processes, including plate-out of particles and the influences on the ratio between radon and progeny.

Although technical solutions to the radon problem in domestic properties have been largely based on prevention of ingress of radon gas from the soil under the influence of the climatically-dependent pressure difference between the interior of the dwelling and the external environment, there has recently been renewed interest in the physical removal of radon progeny by direct filtering of the internal air, thereby reducing the equilibrium factor between radon gas and its solid progeny.

A number of studies by our own group (Marley et al. 1998) and others have confirmed that filters can indeed remove radon progeny from air (Ogorodnikov et al. 1962; Busigin et al. 1980) and their efficacy as respiratory filters in mining has been studied (Wake et al. 1992).

Offermann et al. (1985) reported that an air-cleaner used to control the indoor concentration of respirable particles and radon progeny, especially if fitted with a high efficiency particulate air filter (HEPA-filter), was effective in removing radon progeny, a finding confirmed by Li and Hopke (1991), who reported that air cleaners effectively reduce the median dose due to radon and its progeny, and that air-filtration is more effective than electronic air cleaning. However, while air cleaning can be effective in reducing total radon progeny, concentrations of unattached radon progeny, a dominant factor affecting the dose conversion factor, can increase with air-cleaning. Henschel (1994) reviewed techniques for the purpose of reducing indoor radon concentration, commenting that the effects of air-cleaners on health risk were unclear due to the increase in the unattached fraction. Tokonami et al. (2003) noted that use of an air-cleaner enhances the dose conversion factor critically, since the unattached fraction increases significantly due to aerosol removal. Most recently, Kranrod et al. (2009) showed experimentally that radon progeny dose reduction of the order of 50% was feasible by use of a well-configured air-cleaner.

These uncertainties notwithstanding, there are several devices on the market specifically claiming to reduce the risk from radon[1,2]. However, the US Environmental Protection Agency (EPA) does not recommend radon remediation using filters (EPA 2010).

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[1] http://www.nrpltd.com/radon_gas_filter.php
[2] http://www.airpurifiersandfilters.com/radon-air-purifiers.php

Material and methods

The European Community Radon Software (ECRS) tool (Degrange et al., 2000) performs lung-cancer risk calculations specific to European populations for individual or collective radon exposure profiles. Specifically, the software is capable of generating a range of individual risk-related estimates, including reduced life expectancy and expected age at death, for subjects whose age, sex, smoking habits and domestic radon exposure are known, and can furthermore take into account the equilibrium factor applicable to the environment being investigated. ECRS has therefore been used in the present study to consider whether deploying EF-reducing filtration techniques in homes can produce a significant health benefit to occupants.

In addition to basic demographic, radon exposure and smoking status input parameters, ECRS permits user control of Equilibrium Factor and aerosol parameters. Two Equilibrium Factor tables are provided, attributable to ICRP 65 (ICRP, 1994) and the UK National Radiological Protection Board (NRPB) respectively. Whereas the ICRP parameters, the system default, do not vary with room type, the NRPB data addresses the possible impact of ventilation rate and air smoke content on the equilibrium factor. For the present study, a derivative of the ICRP dataset was used, with identical values of Equilibrium Factor being used throughout the house for each case modeled.

ECRS modeling addresses additional aerosol parameters, representing the overall radon progeny activity-size distribution by a sum of lognormal distributions (modes). For each of these modes, unattached progeny and three attached modes (nucleation, accumulation and coarse), values are given for fraction of total PAEC, dispersion (i.e. geometric standard deviation), and particle size in terms of Activity Median Aerodynamic Diameter (AMAD) for attached particles and Activity Median Thermodynamic Diameter (AMTD) for unattached particles. Two data models are provided, a default Generic House, where the parameters do not vary with room type, and a generalized model, which considers the possible impact of ventilation rate and air smoke content on the aerosol parameters and provides specific room-by-room data. The Generic House option was used in the present analysis.

For the present study, analysis was based on 40-year-old, Non-Smoking and Smoking Males and Females exposed to radon levels of 0, 200, 600 and 1000 Bq·m^{-3}, for Equilibrium Factors ranging from 1.0 down to 0.02. Using the results from this analysis, iso-risk plots were generated, identifying the effect of reduction of Equilibrium Factor on individual excess lung-cancer risk. The calculated risks of contracting lung cancer were then compared to the risk at a radon level of 200 Bq·m^{-3} (the UK domestic Action Level) with an Equilibrium Factor of 0.5.

Results

At all levels of Equilibrium Factor and for both sexes, excess lung-cancer risk is linearly proportional ($R^2 > 0.99$) to radon exposure over the range 0 - 1000 Bq·m^{-3} (five times the UK Action Level). Specific Risk factors (incremental risk attributable to 1 Bq·m^{-3} exposure) for 40-year-old Non-Smoking Males and Females are themselves linear in Equilibrium Factor (Figure 1), as is loss of life expectancy consequent on radon exposure (Figure 2).

Fig. 1. Variation of excess risk per unit Bq.m^{-3} radon concentration, linear in radon over the range 0 – 1000 Bq.m^{-3}, with Equilibrium Factor for 40-year-old non-smoking Males and Females

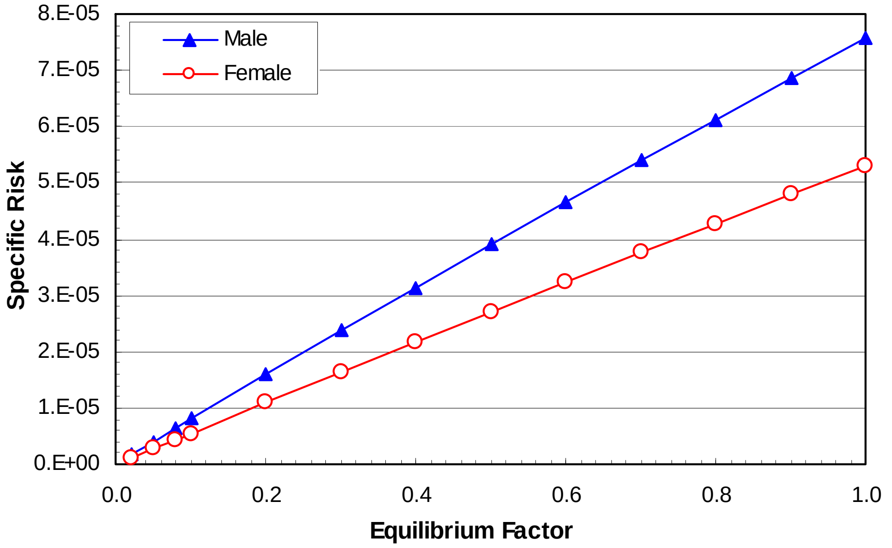
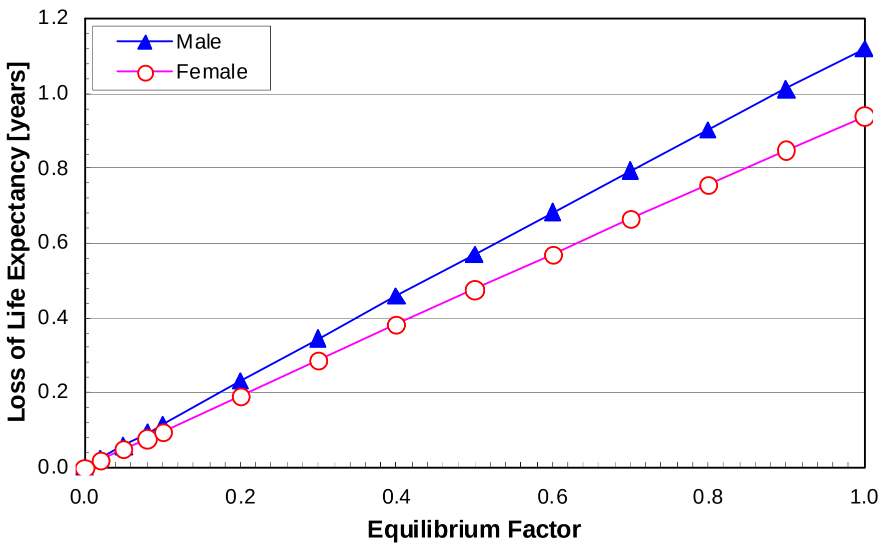


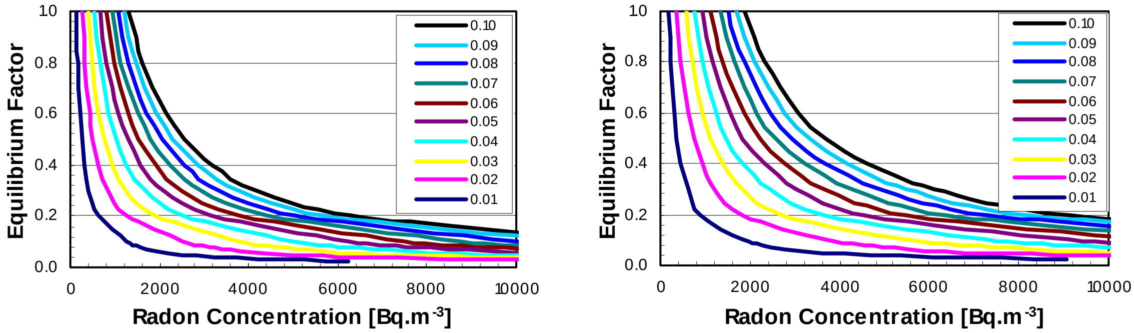
Fig. 2. Loss of Life Expectancy Attributable to Radon Exposure of 1000 Bq.m^{-3} for 40-year-old non-smoking Males and Females



Excess risk represents the additional risk of contracting lung-cancer directly attributable to radon exposure. This is a complex function of age, sex, radon exposure level and duration, equilibrium factor and smoking status. By way of example, Figure 3 shows the set of iso-risk plots in the exposure-level/equilibrium factor domain, generated for 40 year-old non-smoking males and females with whole-life exposure to the indicated radon concentration levels, spanning the range of excess risks from 0.01 to 0.1 (1% - 10%). Similar families of curves can be generated for individuals of other ages, of different smoking status, and with any desired combination of radon exposure and home occupancy. These all have the same rectangular hyperbolic analytical form, the product of radon concentration and equilibrium factor being constant for any given level of excess risk.

Fig. 3. Iso-Risk Plots for 40-year-old Non-Smokers, Excess Lung-Cancer Risk as parameter.

(a) Males **(b) Females**

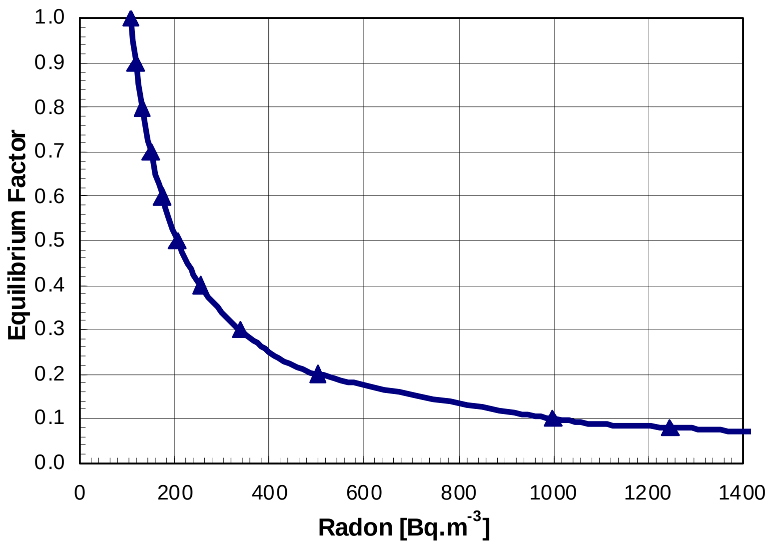


Discussion

At an exposure level of 200 Bq·m^{-3} with an Equilibrium Factor of 0.5, the current UK Action Level case, the excess risks of contracting lung-cancer are 0.008 and 0.0055 for Males and Females respectively. To facilitate further analysis and discussion, Figure 4 reports the 0.008 risk curve for Male subjects over the typically encountered range of domestic radon concentration levels. A similar curve can be generated for Females, in this case with a risk parameter of 0.0055.

As the figure shows, the iso-risk curves in the EF-radon domain take the analytical form of rectangular hyperbolæ (in this case, characterised by *EF•radon* = 106), a fact readily verified by inspection. Thus, if the Equilibrium Factor in a 200 Bq m^{-3} environment is reduced by a factor of 5 to 0.10, a reduced excess lung-cancer risk situation obtains at all radon levels from zero up to 1000 Bq m^{-3}.

Fig. 4. Iso-Risk Plot (Excess Risk = 0.008) for Males in 200 Bq.m^{-3}, EF = 0.5 Environment.



Curling et al. (1990a) developed an optimization model for filter thickness, solidity, and fibre diameter to minimize inhalation dose from radon decay products, based on modified forms of the Porstendorfer-Jacobi (Porstendorfer, 1984) room model and the Jacobi-Eisfeld (Jacobi and Eisfeld, 1980) lung-dose model. The resulting optimal design, a thin filter of low solidity and large fibre diameter, confirmed that significant reduction in the dose rate could be achieved using a filter system. While the theoretical model predicted 80% reduction in the dose rate, with the inherent assumption of movement of 230 room volumes per hour through the fan, initial experimental trials (Curling et al. 1990b) achieved 50% reduction.

Kranrod et al. (2009) confirmed by measurement that an air-cleaner equipped with an HEPA filter and a deodorizing activated carbon filter preferentially removed the attached fraction of radon progeny from the room air, reducing EF to around 71% of its un-filtered value. Because of the differing contributions to the risk from radon gas, attached progeny and unattached progeny, the 71% reduction in Equilibrium Factor achieved in this way again resulted in a 50% reduction in dose. In the case studied, the initial radon gas level was around 300 Bq·m^{-3} and the risk to occupants was reduced below that at the Action Level of 200 Bq·m^{-3}.

Examples in the literature of the Equilibrium Factors achieved in rooms where such filtration systems were operational are limited. Marley et al. (1998) measured F=0.17 in a UK hospital operating theatre, while Li and Hopke (1991) found F=0.134 in a US house. Reduction of the Equilibrium Factor to around this level in any room where the average radon gas level is below 800 Bq m^{-3} would reduce the risk to occupants sufficiently. If an equilibrium factor of 0.1 could be achieved, then the upper limit would be 1000 Bq m^{-3}, and so this could be regarded as an upper limit for such systems.

The performance of air-cleaners will depend on the air volume passing through the filter, and therefore will depend on the size of the room, the air throughput capability of the system and the characteristics of the filter. Thus it would be expected that an air-cleaner will not achieve as significant a reduction in progeny in a larger room. In addition, the movement of radon gas around the building needs to be considered. Additional units may be required in other rooms, if the radon gas moves slowly enough between rooms to decay and create new decay products, or if the source of radon gas and decay products is in another part of the building and reaches the living room and bedrooms independently.

For this reason, such units cannot be installed in any arbitrary room within a dwelling and be expected to achieve significant health benefits throughout the home. The performance of commercial units needs to be tested in standard conditions to ensure that a sufficient reduction in Equilibrium Factor is achieved. Furthermore, when deployed in a home, the performance needs to be checked. Standard track-etch devices only measure radon gas, and so there will be a need to develop simple assessment devices which measure both radon gas and progeny if these sort of units are to be deployed widely.

Conclusions

The theoretical calculations demonstrated in this paper demonstrate that air filtration units can reduce occupants' risk below the limit implied by the Action Level, provided that the radon gas level in the building is moderately raised above the Action Level. At increasing radon levels the air filtration units must be more efficient to achieve the required benefit, and above 1000 Bq·m^{-3}, the unit cannot reduce risk sufficiently to reach the target.

Thus such units may have their place in remediating homes with radon levels up to 800 $Bq{\cdot}m^{-3}$, and may also be of value in homes remediated by other means where the level has been brought down, but not below the Action Level. Kranrod et al. (2009) have confirmed that satisfactory performance of such units can be achieved, at least at 300 $Bq{\cdot}m^{-3}$.

Several practical issues remain before such units can be widely adopted. Firstly the performance of commercial units needs to be evaluated to assess how far they can reduce the Equilibrium Factor in a range of room sizes. Secondly, a simple monitoring system that can measure both radon gas, and progeny, and is comparable to the simplicity of the track etch systems for radon gas, must be developed, so that the health benefit from such units can be proven.

References

AGIR: Advisory Group on Ionising Radiation. Radon and Public Health. Documents of the Health Protection Agency, Report RCE-11, June 2009. ISBN 978-0-85951-644-0.

BEIR VI: Committee on Health Risks of Exposure to Radon, 1999. Health Effects of Exposure to Radon. National Academic Press, Washington DC, ISBN 0-309-05645-4.

Busigin A, van der Vooren AW, Phillips CR. Collection of radon daughters on filter media. Environmental Science and Technology 1980; 14 (5): 533-536.

Curling CA, Rudnick SN, Ryan PB, Moeller DW. Optimization of filtration for reduction of lung dose from Rn decay products: Part I - Theoretical. Health Phys. 1990a; 59(3):267-275.

Curling CA, Rudnick SN, Ryan PB, Moeller DW. Optimization of filtration for reduction of lung dose from Rn decay products: Part II- Experimental. Health Phys. 1990b; 59(3):277-285.

Darby S, Hill D, Auvinen A, Barros-Dios JM, Baysson H, Bochicchio F, et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case–control studies. Br. Med. J. 2005; 330: 223–227.

Degrange JP, Birchall A, Haylock R, Janssens A, Levy FP, Marsh J, Muirhead CA, European Commission software tool for radon risk calculation and evaluation of countermeasures, Proc. 10th International Congress of the International Radiation Protection Association, Hiroshima, Japan, 2000.

Environmental Protection Agency (EPA). Consumer's Guide to Radon Reduction : How to fix your home. Jan 2010. EPA 402/K-10/002

Henschel DB. Analysis of radon mitigation techniques used in existing US houses. Radiat. Prot. Dosim. 1994; 56: 21-27.

ICRP. ICRP 65, Protection against radon-222 at home and at work. 1994. ICRP Publication 65, Vol. 23, No.2, Pergamon Press.

Jacobi W, Eisfeld K. Dose to tissue and effective dose equivalent by inhalations of radon-222 and their short-lived daughters. 1980. GSF Report S-626, Springer-Verlag, Munich.

Kranrod C, Tokonami S, Ishikawa T, Sorimachi A, Janik M, Shingaki R, Furukawa M, Chanyotha S, Chankow N. Mitigation of the effective dose of radon decay products through the use of an air cleaner in a dwelling in Okinawa, Japan. Applied Radiation and Isotopes 2009; 67: 1127 1132.

Li C-S, Hopke PK. Efficacy of air cleaning systems in controlling indoor radon decay products. Health Physics 1991; 61(6): 785-789.

Marley F, Denman AR, Phillips PS. Studies of radon and radon progeny in air conditioned rooms in hospitals. Radiation Protection Dosimetry 1998; 76 (4): 273-276.

Offermann FJ, Sextro RG, Fisk WJ, Grimsrud DT, Nazaroff WW, Nero AV, Revzan KL, Yater J. Control of respirable particles in indoor air with portable air cleaners. Atmos. Environ. 1985; 19: 1761-1771.

Ogorodnikov BI, Kirichenko VN, Basmanov PI, Petryanov IV. The trapping of short-lived radon daughter products by FP fibrous filters. Atomic Energy 1963; 15 (3): 230-237.

Porstendörfer J. Behaviour of radon daughter products in indoor air. Radiation Protection Dosimetry 1984; 7 (1):107-113.

Tokonami S, Matsuzawa T, Ishikawa T, Iimoto T, Yonhara H, Yamada Y. Changes of indoor aerosol characteristics and their associated variation on the dose conversion factor due to radon progeny inhalation. Radioisotopes 2003; 52: 285-292.

Wake D, Brown RC, Trottier RA, Liu Y. Measurements of the efficiency of respirator filters and filtering facepieces against radon daughter aerosols. Ann. Occup. Hyg. 1992; 36 (6): 629-636.