TOWARDS A RADIATION PERFORMANCE INDEX FOR DWELLINGS IN THE NETHERLANDS

E R van der Graaf[1], L E J J Schaap[2], G Bosmans[3]

1) Nuclear Geophysics Division, Kernfysisch Versneller Instituut, University of Groningen, Zernikelaan 25, 9747 AA Groningen, The Netherlands
2) Lichtveld Buis & Partners, P.O. Box 156, 3500 AD Utrecht, The Netherlands
3) Intron BV, P.O. Box 5187, 6130 PD Sittard, The Netherlands

ABSTRACT

This paper describes the new approach to control radiation exposure from natural sources to inhabitants of dwellings that is presently being considered in the Netherlands. The goal of this approach is to uphold the current rather favourable situation (average annual effective dose due to indoor radon and external radiation in dwellings is approximately 1 mSv). To achieve this goal a model is foreseen to predict the potential effective dose an inhabitant may receive from a dwelling on basis of its building plan. A scheme to calculate this dose will be included in the Dutch Building Codes. In future, new to built houses will be evaluated by using this scheme and comparing the results with, yet to be posed, limits to the potential effective dose.

INTRODUCTION

The indoor-radon level (average 28 Bq m^{-3}) in new Dutch houses (period 1985-1994) is approximately 25% higher than the average for older houses. Air exchange measurements in these newer houses showed radon entry via the crawl space only contributes about 15% to the indoor-radon concentration, instead of the earlier estimate of 70% and consequently, building materials produce more radon[(1)]. This changed insight on the role of radon entry via the crawl space forced the Dutch government to redefine its policy on radon. Formerly, the main focus was on reduction of radon concentrations by taking measures to reduce entry via the crawl space. Recently, a new approach was launched in which a so-called ‘Radiation Performance Index (RPI)’ plays a central role. This is analogous to the already existing Dutch approach towards energy performance of buildings. The RPI should be calculated for new houses on basis of the building plan, ventilation and radiation aspects of building materials. Building permits are only issued if the RPI is below a limit value that has yet to be set by the government. After discussions between the government and representatives of the building industry it was decided that the RPI will be based on the annual average effective dose rate E (mSv a^{-1}) an inhabitant potentially receives from its dwelling.

CALCULATION SCHEME

In a joint project, LBP, NGD-KVI and Intron developed a scheme[(2)] to calculate the effective dose rate potentially received by an inhabitant due to gamma radiation from the building materials and due to indoor radon. In simplest approach this dose is given by equation 1.

$$E = C_h c_{dc} + E_\gamma \tag{1}$$

where: C_h (Bq m^{-3}) the annual radon concentration in the dwelling minus the annual average outdoor concentration; c_{dc} (mSv a^{-1} per Bq m^{-3}) the dose conversion factor; and E_γ (mSv a^{-1}) the effective dose rate due to gamma radiation of the building materials. The dose conversion factor is derived from ICRP 65 (0.021 mSv a^{-1} per Bq m^{-3}; radon gas, continuous exposure, equilibrium factor 0.4)(3). The expected radon concentration $C_{h,i}$ (Bq m^{-3}) in room i of a dwelling, is calculated as:

$$C_{h,i} = C_i - C_e = \frac{S_i + \sum_{j=1}^{n}((C_j - C_e)Q_{j\rightarrow i})}{n_i V_i} \tag{2}$$

where: $C_{h,i}$ = radon concentration in room i minus outdoor concentration (Bq m^{-3});
C_i, C_e = radon concentrations (Bq m^{-3}) in room i and outdoors, respectively;
C_j = radon concentration in room j (Bq m^{-3});
S_i = total radon production rate in room i (Bq s^{-1});
$Q_{j\text{-}i}$ = air flow from room j to i (m^3 s^{-1}) ;
n_i = ventilation rate (s^{-1}) of room i and
V_i = volume (m^3) of room i.

Values for the air flows between rooms and the ventilation rate and volume of the different rooms of the dwelling have to be derived from the designed ventilation characteristics and dimensions specified in the building plan. The radon production is obtained from the mass exhalation rates and amounts of building material used in each room. Radon entry from the crawl space is taken into account by an extra production term in equation 2 for the ground floor rooms. This term depends a.o. on floor surface area and air permeability. The air flow from the crawl space is usually very small and is neglected in the ventilation rate calculations. The dose contribution $E_{\gamma,i}$ (mSv a^{-1}) from gamma radiation is calculated for a certain room i from:

$$E_{\gamma,i} = k_{Ra}C_{Ra} + k_{Th}C_{Th} + k_K C_K \tag{3}$$

where: k_X are conversion factors from Bq kg^{-1} to mSv a^{-1} (X=Ra, Th or K) and C_X (Bq kg^{-1}) are average activity concentrations (X=Ra, Th or K) of the building materials in the room. In the present model the conversion factors k_X calculated by Koblinger(4) (20 cm thick walls; room dimensions 4x5x2.8 m^3; density 2.3 kg l^{-1}) are used. Corrections based on the average density of the walls are made but smaller influences as difference in room dimensions and chemical composition and thickness of the walls are not taken in to account.

INPUT VALUES

For both the mass exhalation rates S and the activity concentrations C_X of building materials, default values will probably be prescribed at the higher end of the range representative for the Dutch situation. Table 1 lists the presently proposed default values for the five most commonly used building materials in the Netherlands. These values are chosen such that 95% of the materials used in practice are below the default values (average plus two standard deviation). Use of such default values results in an overestimate of the real effective dose and thus of the RPI of the dwelling. However, lower values may be used if this can be justified by results of measurements according to standardized protocols. All default mass exhalation rates in Table 1 are identical due to the fact that average values for the different materials were not significantly different, consequently it was decided to attribute one unique value, being the grand average of all available measurements, to all materials.

Material	S (µBq kg^{-1}s^{-1})	C_{Ra} (Bq kg^{-1})	C_{Th} (Bq kg^{-1})	C_K (Bq kg^{-1})
Concrete	6.6	32	25	166
Cellular concrete	6.6	13	9	228
Brick	6.6	81	88	713
Gypsum	6.6	11	2	16
Sandy lime stone	6.6	21	16	275

Table 1: Default values for mass radon exhalation rates S and activity concentrations C_X (X=Ra, Th or K) for the five most commonly used building materials in the Netherlands

TEST OF CALCULATION SCHEME

The scheme was tested on a reference dwelling (taken from a real design) typical for recent Dutch building practice. This dwelling is a terraced three-storeyed single-family house. Living room and (open) kitchen (total area 35.5 m^{-2}) are at the ground level. In the entrance hall (7.3 m^2) a staircase leads to the first floor where three bedrooms (15 m^2, 11 m^2, 7 m^2) and a bathroom (5 m^2) are situated. The second floor consist of an attic. Floors and walls between dwellings are made of concrete, front and back are cavity walls made of brick (outside) and sandy lime stone (inner side).

Room	Radon concentration in (Bq m^{-3}) with radon exhalation rate *Default*	 *Average*
Living/Kitchen	22.8	16.3
Bedroom 1	13.2	7.4
Bedroom 2	14.1	7.9
Bedroom 3	11.5	6.4

Table 2: Radon concentrations in various rooms of the test dwelling on basis of default and average mass radon exhalation rates.

In the test, values were used for mass exhalation rates corresponding to the default (high) and to average values. Furthermore ventilation was included by using the actually designed ventilation strategy of the dwelling which consisted of air supply through ventilation openings in walls and windows and mechanical air removal in kitchen, batchroom and toilet. As experience shows that inhabitants adjust ventilation systems to lower than designed values to reduce noise and energy consumption, the designed ventilation rates were reduced with a factor 0.5 to compensate for this occupant influence.

The radon concentration in the living room of this dwelling calculated on basis of either default or average radon exhalation rates (Table 2) underestimates the national average living room concentration minus the outdoor concentration (28-4=24 Bq m^{-3}). For the bedrooms, where measurements showed similar radon concentrations as in the living room, this is even more evident. The most likely reason for this underestimate is that the influence of occupants is still larger than modelled. The reference dwelling was also used in an analysis of the sensitivity of the RPI on the input values for the activity concentrations. Using default values from Table 1 resulted in a dose rate of 0.36 mSv a^{-1} for both living room and bedrooms. Figure 1 presents the relative change in effective dose from gamma radiation (E_γ) due to changing the values of the activity concentrations C_X (X= ^{226}Ra, ^{232}Th, ^{40}K) in the building materials with a factor α relative to values for the reference dwelling C_X(ref) with default values for the activity concentrations. The figure shows that this dose component depends linearly on the activitity concentrations and that changes in ^{226}Ra and ^{232}Th concentration have relatively a larger effect than changes in the ^{40}K concentration. Using average values for the activity concentrations resulted in a dose rate of 0.30 mSv a^{-1} consistent with the dose rate range (0.18-0.61 mSv a^{-1}) estimated from measurements.

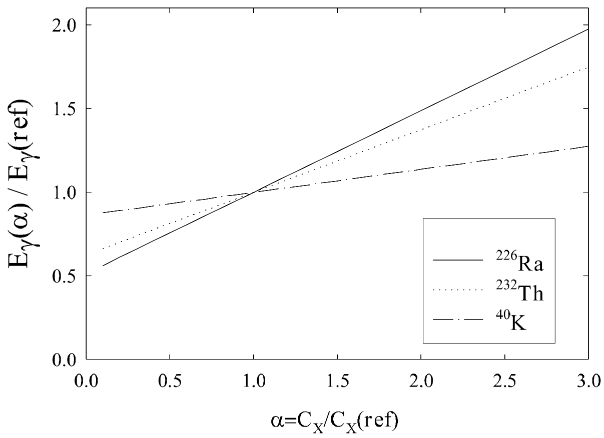

Figure 1: *Sensitivity of effective dose due to gamma radiation on activity concentrations in building materials in single-family reference dwelling.*

CONCLUSION AND OUTLOOK

An important feature of the presently proposed RPI-calculation scheme is the summing of two dose contributions, namely radon and external radiation. For the RPI to be an unbiased instrument, not favouring dose contributions due to either radon release or external radiation, the estimates of both contributions should be of the correct magnitude. The present version of the RPI-scheme seems to underestimate the radon component of the dose. Consequently, future developments concerning the RPI will involve a more extended validation of the approximations used and a standardization of the calculation schema. The RPI is intended to be implemented in Dutch building codes in the year 2002.

REFERENCES

[1] Stoop, P., Glastra P., Hiemstra, Y., de Vries, L. & Lembrechts, J. Results of the second Dutch national survey on radon in dwellings, RIVM report 610058006 (1998).

[2] Schaap, L.E.J.J., Van der Graaf, E.R. & Bosmans, G. Stralingsprestatienorm (Radiation Performance Index), In Dutch, LPB report R43 111AO.LS (1998)

[3] ICRP 23, Protection against radon-222 at home and at work. ICRP Publication 65, *Ann. ICRP* **23**, Pergamon, Oxford (1994).

[4] Koblinger, L. Mathematical models of external gamma radiation and congruence of measurements. *Radiat. Prot. Dosim*. **7**, 227-234 (1984).