BASIS OF CONCERN: THE POSSIBLE LUNG CANCER RISK FROM RESIDENTIAL RADON

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INTRODUCTION

Our concern about the lung cancer risk from indoor radon arises from three issues. (1) The measured large variation range of the radon concentration in the indoor air of dwellings; (2) the rather high alpha dose to the critical bronchial cells from inhaled short-lived radon progeny; and (3) the clear evidence of an excess lung cancer risk, increasing with the exposure to radon progeny, which follows from epidemiological studies of Rn-exposed underground miners as well as from animal experiments. - On the basis of the latter findings, the International Agency for Research on Cancer has classified radon with its progeny as a carcinogenic agent to humans.

To quantify the possible lung cancer risk from indoor radon three different types of approaches can be taken into consideration: (1) Direct, well-designed epidemiological studies in population groups exposed residentially; (2) the transfer of exposure-risk models which follow from Rn-exposed miner's data, to the residential radon exposure of the general population; and finally (3) the so-called "dosimetrie approach" which proceeds from the observed excess risk of lung cancer among the atomic bomb survivors (Life Span Study), following a single, short-term dose to the lung by external radiation.

Starting with a summary of the population exposure to residential radon and its progeny, in the following the results and uncertainties of these risk approaches are outlined.

EXPOSURE TO RESIDENTIAL RADON

Survey measurements of the radon concentration in dwellings have been carried out in many countries. The results which are summarized in the UNSCEAR 1993 Report, yield a variation range from a few up to 200 000 Bq m^{-3}. The observed variation can be approximated by a log-normal distribution function with geometric standard variation in the range of 2-3. The cumulative distribution of the national mean values is shown in figure 1. The national arithmetic mean values cover a range from 10 to 110 Bq m^{-3}, compared with a mean value in outdoor air of about 10 Bq m^{-3}.

On the basis of these data UNSCEAR adopts for the world population a population - weighted, arithmetic mean value of the radon concentration in dwellings of 40 Bq m^{-3} (geometric mean 26 Bq m^{-3}). Taking into account a mean equilibrium factor F=0.4 for Rn progenies in indoor air this corresponds to a mean equilibrium - equivalent concentration c_{eq} of 16 Bq m^{-3}. Assuming a mean occupancy factor indoors of 0.8, it follows for the world

population a mean annual exposure indoors (exposure=concentration x residence time) to radon progeny of about $1.13 \cdot 10^5$ Bq h m^{-3}, expressed in terms of the equilibrium-equivalent exposure, or $6.28 \cdot 10^{-4}$ J h m^{-3}=0,177 WLM in terms of potential alpha energy exposure P_p. With a life expectancy of 65-85 years follows a lifetime exposure of 12-15 WLM.

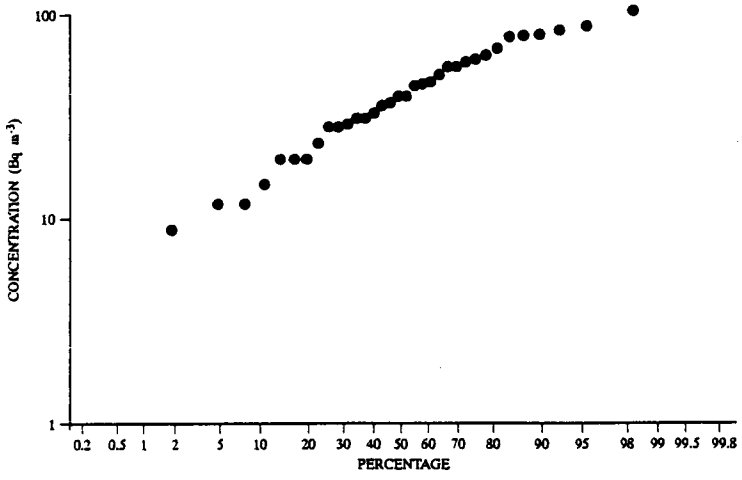

Fig.1. Population-weighted cumulative distribution of the mean radon concentration indoors which results from national surveys in 34 countries (UNSCEAR 1993).

From the observed variation of indoor radon it can be estimated that worldwide in about 2 % of dwellings the annual exposure might be more than a factor 5, and in about 0,2 % more than a factor 20 higher than the worldwide mean annual exposure value. - In this context it seems important to note that the epidemiological studies of Rn-exposed miners yield a statistical significant excess of lung cancer at cumulative occupational exposures above 50 WLM.

EPIDEMIOLOGICAL APPROACH FROM MINER'S DATA

Epidemiological studies of Rn-exposed miners in the USA, Canada, Europe, China and Australia give strong evidence for an the induction of lung cancer by inhaled radon progeny. Recently a joint analysis of the data from 11 cohort studies of male underground miners has been conducted (Lubin et al. 1994a). Figure 2 shows the excess relative risk (ERR) of lung cancer as function of the cumulative exposure P_p (in WLM units) to radon progeny which follows from the combined data of these studies. The analysis yields as best fit a linear relationship up to exposure levels of about 400 WLM with a slope ERR/P_p=0,005 WLM^{-1} (95 % confidence interval 0,002 - 0,010 WLM^{-1}). This relative risk coefficient is modified, however, by various factors. It decreases with attained age and declined with increasing time since exposure. Furthermore the data indicate an increase of the relative risk coefficient with decreasing exposure rate or with long duration of exposure (see figure 3). This inverse exposure-rate effect has been sometimes interpreted in terms of a reciprocal correlation. From an extended analysis of the data it has been recently concluded, however, that this effect decreases with decreasing cumulative exposure and obviously disappears at exposure levels below about 50 WLM which are of relevance for the population exposure (Lubin et al. 1995a).

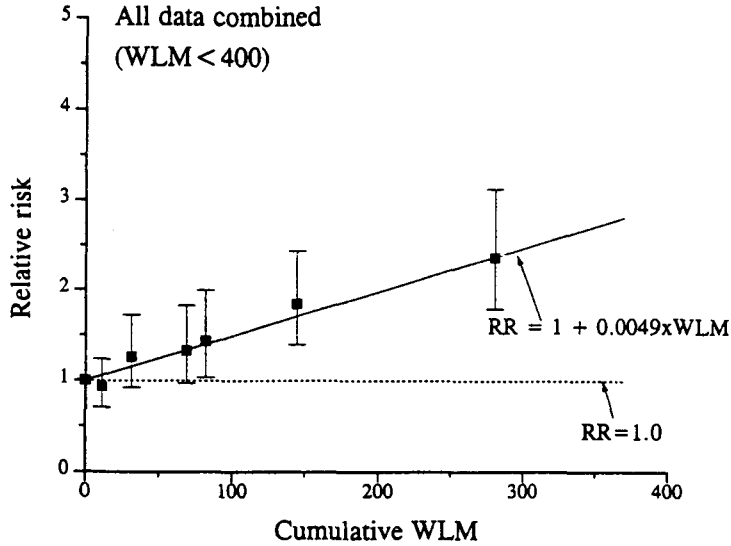

Fig.2. Relative lung cancer risk (RR) as function of the cumulative exposure (in WLM) to radon progeny which follows from the combined data of 11 cohort studies of underground miners. The mean values and their 95 % confidence interval are plotted at the mean exposure in each exposure category. The closed line indicates the best linear fit to the data (from Lubin et al. 1994a).

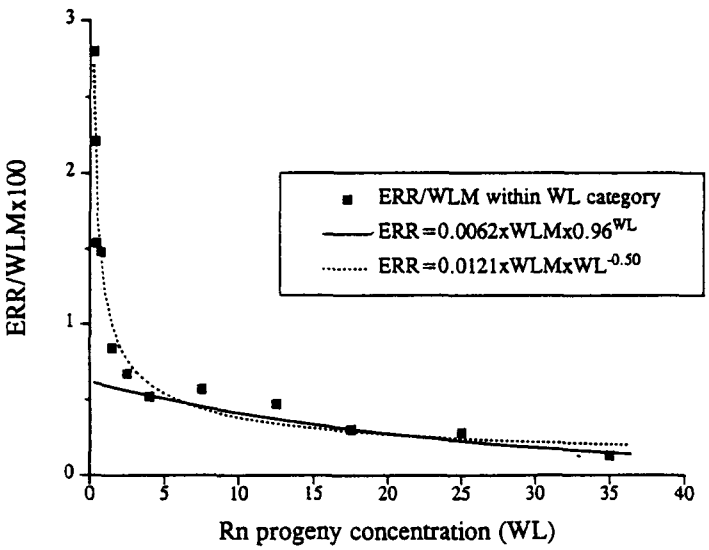

Fig.3. Estimated mean values of the relative risk coefficient ERR/P_p (WLM) within Working-Level (WL) categories as it follows from the joint analysis of 11 cohort studies of underground miners. The curves give the results of different models (from Lubin et al. 1994a).

A further uncertainty concerns the influence of tobacco smoking. The available few data from miners give little quantitative information on this subject. In previous studies (ICRP 1987, BEIR IV-NRC 1988) a multiplicative model was assumed. This means that the relative risk coefficient ERR/P_p, would be equal for nonsmokers and smokers. The now available data from some groups of Rn-exposed miners indicate that the interaction between smoking and radon is somewhat less than multiplicative but more than additive. Lubin et al. (1994a) assumed in their smoking-adjusted model an ERR/P_p-value which is a factor 0,9 lower for smokers and a factor 3,0 higher for nonsmokers, compared with the average value derived from the miner's data. The uncertainty of this adjustment factor for nonsmokers is, however, quite large. A reanalyses of the data of the Colorado uranium miners yields an ERR/P_p-ratio between nonsmokers and smokers (20 cigarettes/day) of somewhat less than 2 (Moolgavkar et al. 1993).

In table 1 the central lifetime risk estimates of the attributable relative lung cancer risk (ARR) from residential radon exposure, averaged over males and females, are listed which should be expected on the basis of the approach from miner's data. In addition to the model of Lubin et al. (1994a) the results of previous estimates (ICRP 1987, BEIR IV-NRC 1988) are given. The ARR-values refer to a lifetime exposure to radon progeny at a constant rate of 0,18 WLM/year as it follows for a mean Rn-concentration indoors of 40 Bq m^{-3} like it was assumed by UNSCEAR.

Table 1. Attributable relative risk (ARR) of lung cancer from residential exposure to radon progeny at a constant mean level of 0.18 WLM per year; central estimates of different risk models derived from miner's data with dosimetric adjustment for indoor exposure.[a]

Relative risk model	Smoking influence	Population	ARR, in percent	
			nonsmokers	smokers
ICRP 50 (1987) const.RR-model	multi-plicative	Reference population[b]	6.8	6.4
BEIR IV (NRC 1988) TSE model	multi-plicative	USA	7.0	6.5
		Germany	6.0	5.7
Lubin et al. (1994a) TSE/AGE/WL-cat model	multi-plicative	USA	12.0	11.3
		Germany[c]	7.3	7.0
	submulti-plicative	USA	28.5	10.3
		Germany[c]	18.8	6.5

a) Dosimetric adjustment factor K for indoor exposure:
0.8 for age < 10 y; 0.7 for age ≥10 y (NRC 1991);
b) refering to a population with a life expectancy of 70 y for males and 75 y for females.
c) estimate for the population in West-Germany, taking into account mortality data 1985-89 Steindorf et al., 1995).

The ARR-values given in table 1 are averaged over females and males. Assuming a multiplicative influence of smoking the attributable risk which follows from the new joint analysis of 11 miner's studies (Lubin et al. 1994), is about a factor 1.7 (US population) or 1.2 (German population), respectively, higher than the values resulting from the BEIR IV-model (NRC 1988). As it should be expected the values, adjusted for a submultiplicative influence of smokers, lead to considerably higher ARR-values for nonsmokers. It must be kept in mind, however, that this risk approach from miner's data involves large uncertainties. The statistical 95 % confidence interval of the input data covers a range given by a factor from about 0.3 to 2.5. Additional systematic uncertainties concern mainly the assessment of miner's exposure, the exposure-rate effect, the influence of smoking, and, last not least, the simplifying assumptions made for the transfer of the risk models from underground miners to the residential exposure of the general population, particularly to females and children.

DIRECT RESIDENTIAL RADON STUDIES

Direct well-designed, epidemiological studies on the carcinogenie effect of radon progeny in indoor air are desirable. Two different types of studies have been conducted: (1) So-called "geographie" or "ecological" studies which look for a correlation between the lung cancer rate in certain geographical areas and the mean radon exposure in these areas; and (2) case-control or cohort studies in which individual radon exposures of lung cancer cases are estimated and compared with those of appropriate controls.

The available results of geographic studies are summarised and reviewed in reports of Stidley and Samet (1993) and of UNSCEAR (1994). A further comprehensive study in which data from 1601 US counties are compared, has been published recently (Cohen 1995). - Summarising, 9 of these studies indicate a positive correlation, 6 studies show no correlation and 5 studies yield a negative association between lung cancer frequency and estimated radon exposure. Taking into regard the general methodological problems and limitations of these studies, the value of such geographical studies is questionable (Stidley et al. 1993, IARC 1995). An exception might be studies which compare the lung cancer frequency in areas with strongly different concentrations of indoor radon, like the study in Umhausen/Tirol in Austria (Ennemoser et al. 1994).

Case-control studies are more appropriate than geographical studies. The results of 12 published case-control studies are summarized and reviewed in the UNSCEAR 1994 Report and in papers of Lubin et al. (1994b; 1996 in press). Most of these studies involve, however, only a relative small number of lung cancer cases, which leads to large statistical uncertainties. This is demonstrated in figure 4 (from Lubin et al. 1994b) where for 7 of these studies the observed relative lung cancer risk is plotted as function of the radon concentration indoors. The three larger studies are the nationwide Swedish study (Pershagen et al. 1994), the study in Winnipeg/Canada (Letournean et al. 1994) and the study in New Jersey/USA (Schoenberg et al. 1990). The Swedish study (1360 cases, 2847 controls) yields for the concentration cohort from 140-400 Bq m^{-3} a mean excess relative risk of 0.3 (95 % CI: 0.1-0.6), compared with the cohort below 140 Bq m^{-3}. The study in Winnipeg (750 cases, 750 controls) shows no significant correlation between lung cancer and indoor radon exposure. The New Jersey-Study (433 cases, 402 controls) indicates a poitive trend after adjusting for smoking and age, but there are only a few cases with higher radon exposure in this study.

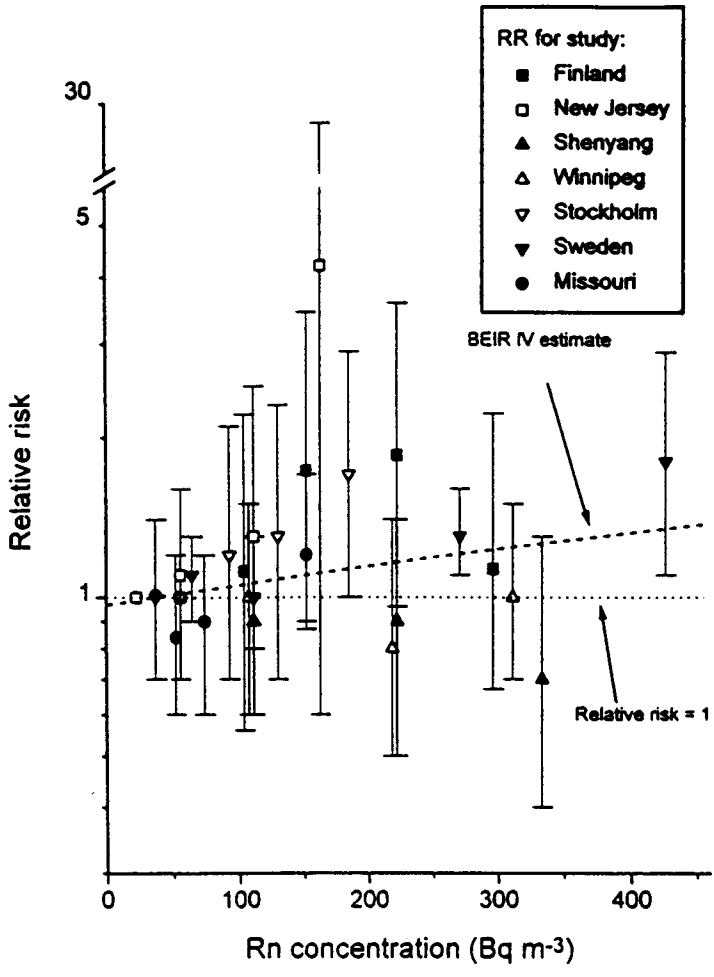

Fig.4. Relative lung cancer risk in different intervals of indoor radon concentration (mean values and 95 % conficence intervals) resulting from 7 residential case-control studies (from Lubin 1994b, 1996). The dashed line shows the increase which should be expected on the basis of the BEIR IV-model derived from miner's data, refering to a residential exposure from age 35-65.

However, all of the available case-control studies have limitations that hinder a clear interpretation of their results. This concerns particularly the assessment of the individual lifetime exposure, taking into regard the residential mobility, and the assessment of the individual smoking habits. It should be kept in mind that in these studies the radon exposure of most lung cancer cases was relatively low and therefore the attributable risk from radon will be small compared with the lung cancer risk from smoking. To illustrate the influence of errors in exposure assessment, Lubin et al. (1995b, 1996 in press) have simulated case-control studies. The results reveal the substantial contribution of these errors in explaining the inconsisteney of the present case-control studies. Lubin concludes: "These simulations imply that it is unlikely that case-control studies alone will be able to determine precise estimates of risk from indoor radon. Also implied is that even future efforts at pooling epidemiological studies may not adequately adress issues of risk from residential radon exposure" (Lubin 1995b).

FINAL CONCLUSIONS

Without doubt ionizing radiation is a carcinogenic agent for humans. This general statement is also valid for the induction of lung cancer from inhaled radon with its progeny. The problem is to quantify the risk from residential radon exposure. The available direct geographical and case-control studies are inconsistent and enable no conclusion. Like in the past risk estimates for residential radon must therefore continue to be based on the approach from epidemiological data of Rn-exposed miners. In spite all uncertainties this approach indicates that, apart from smoking, inhalation of radon with its progeny in dwellings seems to be the most important cause of lung cancer in the general population.

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