Original article

Scand J Work Environ Health 1984;10(1):25-34

doi:10.5271/sjweh.2366

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This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/6740274

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Scand j work environ health 10 (1984) 25—34

Radon in homes — A possible cause of lung cancer

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EDLING C, KLING H, AXELSON O. Radon in homes — A possible cause of lung cancer. *Scand j work environ health* 10 (1984) 25—34. An earlier case-referent study [*Scand j work environ & health* 5 (1979) 10—15] has indicated a possible relationship between lung cancer and exposure to radon and radon daughters in dwellings. Indoor radon concentrations seem to depend on both building material and leakage of radon from the ground. This new study, in a rural area, is a further attempt to elucidate the etiology of lung cancer, taking into consideration type of house and ground conditions, as well as smoking habits. Although the choice of a rural study population helped to eliminate various confounding exposures in the urban environment, it limited the size of the study because of the rareness of lung cancer in rural populations. Long-term residents, 30 years or more in the same houses, were studied, and again an association was found between lung cancer and estimated exposure to radon and radon daughters in homes. The data also seem to indicate the possibility of a multiplicative effect between smoking and exposure to radon and radon daughters in homes, but there was also some confounding between these factors in the data.

Key terms: case-referent, dwellings, epidemiologic study, homes, interaction, lung cancer, radon, smoking.

Lung cancer has become one of the predominating forms of malignant disorders in men of the industrialized world, and it is rapidly approaching this position also for women (37). The relations between lung cancer, or more precisely bronchial carcinoma, and smoking habits are generally recognized today (43), and there are suggestions of an association with passive smoking as well (15, 27, 46). However, some of the observations on the role of smoking in the causation of lung cancer are not quite consistent (and indicate that also other important factors are involved), and there have also been some more or less well-known challanges of the smoking theory from time to time (13, 22, 38).

A number of occupational factors has been associated with lung cancer (45), but they do not seem to account fully for the increased incidence in urban areas as compared to rural districts (47). Furthermore the urban-rural gradient of lung cancer incidence exists even after allowance has been made for smoking habits (24), ie, it has been found among nonsmokers and within the various smoking categories (16, 17, 18).

Quite recently interest has focused on another potential and widespread risk factor for lung cancer, namely, exposure to indoor levels of radon and radon daughters, as such exposure has presumably increased over past decades as central heating by radiators has replaced furnaces, etc, and a further increase is likely to result from efforts to save energy through the tightening of houses and decreasing ventilation (12, 19, 33, 42, 44).

Radon is a noble gas, originating from the decay of uranium through radium; it also decays itself by emitting alpha radiation into isotopes of lead, bismuth, and polonium, which are the so-called short-lived radon daughters, two of which emit alpha radiation. The occurrence of indoor radon and radon daughters is due to a leakage of radon from the ground, but building materials also contribute, especially if the foundation is on gravel or alum shale. Furthermore radon is given off from tap water if it originates from ground water. Since radon has proved to be a pulmonary carcinogen in studies of underground miners (3), it is of crucial interest to determine whether or not an effect of low levels in dwellings can be epidemiologically demonstrated.

In an earlier case-referent study on the possible impact of exposure to radon and its daughters in dwellings (5), we found an increased mortality from lung cancer among people in stone houses, where concentrations of radon and radon daughters tend to be higher (than in wooden houses) (28). In an American study measurements of radon concentrations in the homes of lung cancer cases were found to be higher than the levels in the homes of the referents

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(controls), the result being an odds ratio of slightly over 2 (Radford, personal communication). A correlation study from the state of Maine in the United States has shown a positive and significant correlation between lung cancer and presumably high radon levels in tap water, as related to high radon levels in well water (26). Another correlation study from the state of Iowa has also indicated a relationship between the levels of radium-226 in drinking water and incidence of cancer of the lung and bladder among males and of cancer of the lung and breast among females (11).

An additional study (41) on lung cancer rates and housing characteristics, ie, constructions and building materials, did not disclose significant findings of any such relations, but the rates were highest in the context of concrete houses and houses built on a concrete slab. In Sweden lung cancer incidences on a county level have been found to correlate with background gamma radiation, which in turn can be assumed to reflect the levels of radon daughters in dwellings reasonably well (21).

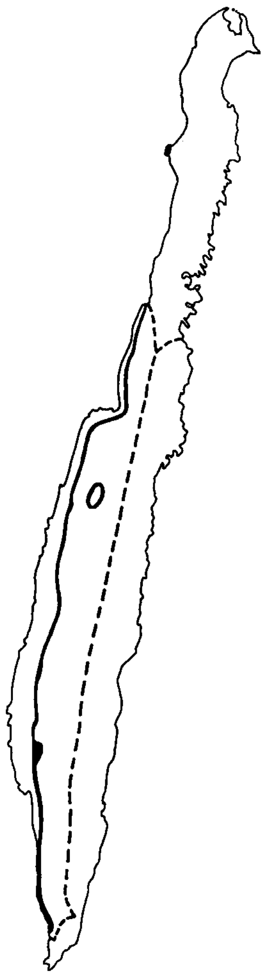

Figure 1. Map of Oeland, with the alum shale zone (in black) and the three parish areas (dotted lines).

These various observations have a more or less preliminary character, which calls for additional research in this field, and the present study was undertaken on the island of Oeland in the Baltic Sea to elucidate further a possible relation between indoor radon daughter exposure and lung cancer. Some preliminary results have already been presented (6), but, thanks to additional economic support, it has now been possible to obtain questionnaire information about the houses and to undertake radon daughter measurements. The smoking habits of the subjects have also been procured and a further check was made of medical records.

Material and methods

The island of Oeland, 140 km in length and up to 15 km in breadth, was chosen for the study because it is a rural area with particular geologic features, providing a rather unique study situation. The ground is limestone with uranium-containing alum shale underneath. But the layers of limestone and shale are slightly tilted towards the east, and the alum shale appears in the ground in a narrow strip (only some hundred metres in breadth) on the west side of the southern two-thirds of the island from a few hundred metres to about 2 km from the seashore (figure 1). This alum shale zone gives rise to an elevated level of gamma radiation exceeding 30 μR/h (77.4×10^{-10} C/kg · h), from the ground, and a somewhat increased leakage of radon into the air could be expected to occur. It is also very likely therefore that the indoor radon daughter levels in the houses on this particular ground are increased.

The population of the southern part of the island is peculiarly distributed, namely, in two strips, ie, part living along (within and outside) the alum shale zone on the western side and part residing on the eastern side of the island, whereas the inland of the island is sparsely populated (being a steppe-like area and forest land — this specific pattern is not followed in the northern third of the island, however). The total population of the island was about 20,000 individuals during the study period, 1960—1978, and there are three small towns with some 2,000—3,000 inhabitants each, all on the west coast.

As in other rural populations lung cancer was a relatively rare disease among the inhabitants, who made their living from farming, with associated services and tourism, or were employed (only a few hundred people) in small factories (cement and lightweight concrete production, sugar-beet refining and limestone quarrying). The plan was to undertake a case-referent study, but for economic reasons the study had to be built up step-by-step, evaluating the reasons and possibilities to proceed further. Thus a first analysis of the data was undertaken which showed a higher mortality from lung cancer in the western and northern parishes than in the eastern area (table 1). Since this difference could be related to the somewhat more urbanized structure of the west coast, but also was in accordance with the hypothesis of an increased lung cancer risk due to a higher background level of radon, the original plan of undertaking a case-referent study seemed necessary to evaluate the situation more definitively. Thereby it seemed reasonable to restrict the study to only that sector of the population which had been stable and had lived in the same houses for a very long time.

Selection of subjects

The official registers of deaths and burials in the 34 parishes of the island were merged and utilized as one single source register of subjects for this case-referent study. In all, 6,288 persons had died on the island during the 19-year study period, and, of these deaths, 69 were registered as due to lung cancer, all of persons 40 or more years of age. This registration was checked through a comparison with the medical files, and as cases those subjects were finally chosen who had died from malignant tumors of the lung [International Classification of Diseases (ICD) 162]. With the preliminary aim of attaining a one-to-six case-referent ratio, a random sample of 414 individuals was initially drawn as referents from the source register; thereby only those persons with noncancer diagnoses on their death certificates were enrolled.

After the material was restricted to include only those cases and referents (men as well as women) who were above 39 years of age and who had lived in the same house for 30 years or more prior to death, and not including cases and referents who had lived in apartments, 23 cases and 202 referents were included in the analysis. Individuals living in apartments were not included because of the difficulties involved in assessing exposure categories in this context.

Assessment of exposure and smoking habits

The addresses of the cases and referents, as given in the source register of deaths and burials, were located on large-scale economic maps, which permitted the geographic identification of isolated houses. "Geo-Radiation maps," originally produced for uranium ore prospecting, were used to determine whether or not a house was situated on radiation ground.

The final assessment of exposure was then obtained in two ways, ie, ocular classification of the houses and measurements of radon daughters by alpha sensitive film. For the classification of the houses with regard to exposure, every house was visited and, from judgements of the outside, building material, type of house, and ground conditions were taken into account. This classification also involved photographing the houses, and it was undertaken without any consideration of whether or not the house had belonged to a case or a referent. Three categories were used: the reference (category 0) being wooden houses without a basement on normal ground; category 2 being wooden houses with a basement on radiation ground (the alum shale zone) or stone, brick and plaster houses with a basement on any ground (alternatively without a basement on radiation ground); and exposure category 1 comprising all other types of houses, ie, also wooden houses without a basement but on radiation ground.

Questionnaires were also administered blindly to the next-of-kin of the subjects or present house owners, and the collected data were used for supplementary information. For a few houses the original classification had to be slightly adjusted according to information obtained about the existence of basements. The questionnaires also referred to major renovations, major changes in ventilation, and the occupations and smoking habits of the subjects.

Measurements of radon daughter concentrations were undertaken together with the local public-health authorities, and were made in as many houses as possible, owners permitting (86 %). Kodak LR 115 type

Table 1. Number of cases of lung cancer, average background population, and lung cancer rates per 10^5 person-years (based on original 69 deaths) in the northern, western and eastern parishes (see figure 1) during 1960—1978, ie, during a 19-year time span. The average background population is based on the 1970 census.

Age (years)	Parish areas: North — Number of cases	North — Average background population	North — Lung cancer rates per 10^5 person-years	West — Number of cases	West — Average background population	West — Lung cancer rates per 10^5 person-years	East — Number of cases	East — Average background population	East — Lung cancer rates per 10^5 person-years
25—64									
Males	5	1,166	22.6	9	3,039	15.6	1	1,066	4.9
Females	3	956	16.5	0	3,023	—	0	934	—
≥65									
Males	4	402	52.4	30	1,006	157.0	3	462	34.2
Females	5	432	60.9	7	1,194	30.9	2	465	22.6

II cellulose nitrate film was placed about 1.5—2 m above the livingroom floor. Three films per house were exposed during one month in March—April and during three months around the period April—June. The films were analyzed by the Department of Radiophysics at the University of Lund, according to principles described elsewhere (40). These analyses were performed without any knowledge of whether the house had belonged to a case or a referent. Because the three months of measurements went into the summer season, a period with much better ventilation, the one-month measurements were regarded as reflecting the average exposure situation better and were therefore used in the analysis. (This was a suggestion made by the Department of Radiophysics before any evaluation had started.)

The categorization of the exposure levels was made with the fact in view that the average radon daughter concentration in Swedish houses seems to be about 50 Bq/m^3, but also with regard to the generally held belief that film measurements are uncertain at levels below 100 Bq/m^3. Furthermore there was a need to obtain a reasonable number of individuals at the highest exposure level to make the analysis meaningful. Thus the scale was set up as < 50 Bq/m^3, 50—149 Bq/m^3 and ≥ 150 Bq/m^3.

Information about smoking habits was obtained for the cases and referents through the aforementioned questionnaires. For a few subjects there was a supplementary telephone interview made by a local dean. People who had stopped smoking 15 years or more prior to death were considered nonsmokers.

Statistical methods

The calculation of chi-square values and the estimation of the overall odds ratios, equaling the incidence density ratios with the design applied (4), were based on the Mantel-Haenszel procedures (32). The requirement of minimum expected cell size, ie, that there be a potential variation of at least 5 on each side of the expected total across the tables for a particular cell entry, was determined with a method described by Mantel & Fleiss (31). Trends were tested by the Mantel extension of the Mantel-Haenszel test, scoring the exposure categories as 0, 1, and 2 (30). The principles applied for determining the standardized rate ratios have been outlined by Miettinen (34, 35), together with the method used for calculating the approximate (test-based) confidence interval of the rate ratios (36). Utilizing the GLIM (general linear interactive modeling) package (9), a logistic regression analysis was also applied, particularly for elucidating potential confounding and effect modification.

Results

As a result of the classification procedure (table 2), 10 of the 23 cases, or 43 %, and 125 of the 202 referents, or 62 %, were found to belong to exposure category 0 (reference category). Since seven of all the cases (30 %) had lived in houses in exposure category 2 versus 22 of the referents (11 %), the crude rate ratio was 4.0 and the Mantel-Haenszel point estimate 4.3, with a 90 % confidence interval of 1.7—10.6. Exposure category 1 comprised 6 of the cases (26 %) and 55 of the referents (27 %), ie, the crude odds ratio was 1.4 and the Mantel-Haenszel point estimate 1.2. The Mantel extension for trend resulted in a chi-square value of 5.34 ($p \leq 0.01$, one-tailed). A comparison of exposure categories 1 + 2 versus 0 resulted in a point estimate of 2.0 and a 90 % confidence interval of 0.95—4.2.

When smoking habits were allowed for, the material was reduced by one case (4 %) and 24 referents (12 %) due to missing information. Stratification on age, gender, and smoking (table 3) reduced the Mantel-Haenszel point estimates somewhat, ie, for exposure category 1 + 2 the rate ratio amounted to 1.8 with a 90 % confidence interval of 0.9—3.9 and for exposure category 2 it was 3.5 with a 90 % confidence interval of 1.3—9.2. The multivariate logistic analysis resulted in almost identical figures, ie, a rate ratio of 3.9 and a 90 % confidence interval of 1.5—10.0.

There was a slight positive confounding effect from smoking, 15 % of the referents who smoked belonging to exposure category 0 as compared to 27 % in exposure category 1 and 26 % in exposure category 2. When smoking was considered as the determinant of lung cancer and stratification was made on the basis of the various house categories, the risk ratio for smokers versus nonsmokers was 2.8 with a 90 % confidence interval of 0.9—5.5. From table 3 it was also possible to obtain some information about potential interaction between smoking and radon daughter exposure. A comparison of smokers in exposure categories 1 and 2 to nonsmokers in exposure category 0 revealed a rate ratio of 3.6 and 9.3, respectively, a result indicating a more than additive effect from these two factors. The same conclusion could be drawn from the multivariate logistic analysis showing a multiplicative effect between radon daughter exposure and smoking.

Measurements of radon daughter levels were made in all but 3 case (9 %) and 29 referent (14 %) houses. As shown in table 4, the measurements were in reasonably good agreement with the applied exposure classification. In the different exposure categories, 86 % of the houses in category 0 were measured, 84 % in category 1, and 90 % in category 2.

The results obtained from the alpha sensitive films have been used in assessing the exposure levels for those cases and referents with known smoking habits (table 5). Eight cases (42 %) and 102 referents (64 %) belonged to the lowest exposure level (reference level) and three cases (16 %) had lived in houses with the highest exposure level (≥ 150 Bq/m^3) versus seven referents (4 %). Consequently, the crude rate ratio was 4.9 and the Mantel-Haenszel point estimate 5.1 with a 90 % confidence interval of 1.4—18.5. The corresponding figure for all the exposure levels above 50 Bq/m^3 was 2.8 for the crude rate ratio, and the Mantel-Haenszel point estimate was 2.7 with a 90 % confidence interval of 1.1—6.4. The multivariate logistic analysis ended up in a rate ratio of 4.7 and a 90 % confidence interval of 1.2—18.5. The Mantel extension for trend resulted in a chi-square value of 4.73 ($p \leq 0.02$; one-tailed).

Discussion

The results of this investigation are fairly well in accordance with those of an earlier study (5), and they strengthen the idea of a possible relationship between lung cancer and exposure to radon and radon daughters in dwellings. With regard to the number of cases that were obtainable, the size of the study is small, and the Mantel-Haenszel chi-square test was found to be somewhat suboptimal according to the evaluation suggested by Mantel & Fleiss (31), ie, when the single exposure categories were considered, but was acceptable for dichotomized data (ie, exposure categories 1 and 2 taken together). The results are also somewhat suggestive that a lung cancer hazard could exist already at exposure levels around or below 150 Bq/m^3, although the study is by no means conclusive in this respect.

The acquisition of cases and referents from the parish registers could perhaps be suspected of not

Table 2. Distribution of the cases of lung cancer (International Classification of Diseases 162) and referents, having lived 30 years or more at the same address, into exposure categories based on a housing classification. The estimated background population, correspondingly restricted, was taken from the 1970 census. (The study period is 1960—1978.)

Gender	Exposure category[a]				Estimated average population
	0	1	2	1 + 2	
40- to 69-year age group					
Males					
Cases	1	2	2	4	1,753
Referents	18	5	2	7	
Females					
Cases	0	0	1	1	2,289
Referents	9	4	3	7	
70- to 79-year age group					
Males					
Cases	2	2	2	4	440
Referents	18	12	5	17	
Females					
Cases	4	1	1	2	570
Referents	24	10	3	13	
≥80-year age group					
Males					
Cases	2	1	1	2	179
Referents	20	14	3	17	
Females					
Cases	1	0	0	0	225
Referents	36	10	6	16	
Total					
Males					
Cases	5	5	5	10	2,372
Referents	56	31	10	41	
Females					
Cases	5	1	2	3	3,084
Referents	69	24	12	36	
Crude rate ratio (odds ratio)	1.0	1.4	4.0	2.1	
Standardized mortality ratio	1.0	1.2	4.3	2.0	
Mantel-Haenszel rate ratio (odds ratio)					
Point estimate	1.0	1.2	4.3	2.0	
90 % confidence interval		0.5—3.1	1.7—10.6	0.95—4.2	
Mantel-extension $\chi_1^2 = 5.34$					

[a] 0 = wood houses without a basement on normal ground; 1 = all types of houses not included in category 0 or category 2; 2 = wooden houses with a basement on radiation ground or stone, brick and plaster houses with a basement on any type of ground (alternatively without a basement on radiation ground).

being entirely satisfactory owing to the incompleteness of such registers. However, the registers of deaths and burials in Sweden usually contain full information about the deaths as based on fairly complete diagnoses from the death certificates. However, when the diagnoses of the death certificates were compared with those in the medical files, there were five cases which could not finally be accepted as primary lung cancer and therefore the number of cases is fewer in this presentation than in the preliminary report of the same material (6). Nineteen additional referents have also been included that were

Table 3. Cases of lung cancer (International Classification of Diseases 162) and referents (various noncancer diagnoses) with known smoking habits and having lived ≥ 30 years at the same address.

Gender	Exposure category[a]			
	0	1	2	1 + 2
40- to 69-year age group				
Males				
Smokers				
Cases	1	1	1	2
Referents	7	3	2	5
Nonsmokers				
Cases	0	1	1	2
Referents	9	1	0	1
Females				
Smokers				
Cases	0	0	0	0
Referents	1	1	0	1
Nonsmokers				
Cases	0	0	1	1
Referents	7	3	2	5
70- to 79-year age group				
Males				
Smokers				
Cases	1	1	1	2
Referents	2	6	1	7
Nonsmokers				
Cases	1	1	1	2
Referents	13	6	4	10
Females				
Smokers				
Cases	0	0	0	0
Referents	0	0	0	0
Nonsmokers				
Cases	4	1	1	2
Referents	19	10	3	13
≥ 80-year age group				
Males				
Smokers				
Cases	1	1	1	2
Referents	5	1	2	3
Nonsmokers				
Cases	1	0	0	0
Referents	15	11	1	12
Females				
Smokers				
Cases	0	0	0	0
Referents	2	2	0	2
Nonsmokers				
Cases	0	0	0	0
Referents	30	5	4	9
Crude rate ratio (odds ratio)	1.0	1.3	4.0	2.0
Standardized mortality ratio	1.0	0.9	3.2	1.4
Mantel-Haenszel rate ratio (odds ratio)				
Point estimate	1.0	1.2	3.5	1.8
90 % confidence interval		0.5—3.0	1.3—9.2	0.9—3.9
Mantel-extension χ_1^2 = 3.88				

[a] 0 = wood houses without a basement on normal ground, 1 = all types of houses not included in category 0 or category 2, 2 = wooden houses with a basement on radiation ground or stone, brick and plaster houses with a basement on any type of ground (alternatively without a basement on radiation ground).

not in the earlier presentation due to the new entries for identification that were obtained through the questionnaire information.

In the selection of referents, only those who had died of nonmalignant diseases were considered, since background radiation not only might cause the disease under study (lung cancer) but also other cancers (1), and the inclusion of cancer diagnoses among the referents could have given a false impression of the exposure frequency in the various categories of the study base. This might perhaps be the case particularly for persons of younger ages, judging from experiences indicating a relation between acute myeloid leukemia and background radiation (23), especially since a correlation of radon daughter exposure and exposure to gamma radiation can be expected. It needs be pointed out perhaps that the applied exclusion of cancer diagnoses largely explains the change of the case-referent ratio from the original one-to-six to one of almost one-to-nine, since people with cancer tend to die at relatively younger ages, the possibility to fulfill the inclusion criteria of having lived in the same house for 30 years or more prior to death thereby having been reduced.

The validity of the information about smoking habits, as obtained through interviews with next-of-kin, may be criticized with regard to a "memory bias." According to recent experiences, however, the assessment of exposure through interviews seems to be acceptable when interviews are compared to other sources as far as occupational exposures and smoking histories are concerned (25, 39). It is also known (14) that the number of smokers is generally low in rural areas, and in this study only 20 % of the referents were smokers. The exclusion of all cancers, some of them being related to smoking, would tend to give a lower frequency of smokers among the referents; such a procedure would have no impact on the main results of the study as long as this underfrequency is symmetrically related to the exposure categories however. This phenomenon might also be balanced by an overrepresentation of smokers with other specific diagnoses such as cardiovascular disease. Among the male cases, 60 % were smokers, but none of the female cases smoked. In the assessment of smoking habits, there was a dropout of 11 % of the total study population. Regarding only the referents, the relative dropouts were 12 % in exposure category 0, 11 % in category 1 and 14 % in category 2. In a reanalysis of the data under the assumption that all the referents with missing smoking information were nonsmokers whereas the missing case was a smoker, the crude rate ratio, as well as the Mantel-Haenszel point estimate, was certainly somewhat reduced, but there was still a numerically increased rate ratio for exposure category 2.

The alpha sensitive Kodak film (as well as other similar methods of measurement) has been criticized for insensitiveness and dispersion, but nevertheless it seems reasonable to believe that the method should be able to differentiate well enough between houses with low levels, formally taken as < 50 Bq/m^3 in this study, and houses with higher levels, or formally ≥ 150 Bq/m^3.

Lung cancer has been associated with exposure to pesticides (10) and, since farming is mainly of grain and vegetables in the southwest of the island, ie, along the alum shale strip, and the raising of livestock is more predominant in other areas, the possibility of confounding in this respect was also considered. To allow for this potential source of confounding but also for possible differences in smoking habits related to the more urbanized structure of the west coast or other "unknown" confounding factors as an explanation for the difference in lung cancer mortality between the eastern and western part of the island, an analysis was made also after restriction to the southwest only. The same relationship between lung cancer and the exposure categories was found, although for a limited number of individuals. Regarding occupations, the information from the questionnaires gave no indication of any association with lung cancer. By stratification according to wooden and nonwooden houses, the lung cancer risk was found to be higher on radiation ground (the crude rate ratio being 3.7); this finding is not surprising in view of the anticipated contribution of radon from the ground.

Finally the interaction between smoking and radon daughter exposure should be somewhat further discussed. Thus the findings in this study are in accordance with some of the studies of mining populations, particularly from uranium mines (2), where also a

Table 4. Radon daughter concentrations with regard to radiation ground and exposure categorization; three films per house were exposed during one month.

	Radon daughter concentrations Bq/m^3 EER[a]	
	Arithmetical mean	Geometrical mean
Houses on radiation ground (N = 35)	142	86
Houses on normal ground (N = 158)	46	39
Houses in category 0 (N = 116)	42	36
Houses in category 1 (N = 51)	57	44
Houses in category 2 (N = 26)	170	109

[a] EER = equilibrium equivalent radon according to the International Commission on Radiological Protection (29); for conversion to WL (working level) divide by 3,700.

Table 5. Distribution of the cases of lung cancer (International Classification of Diseases 162) and the referents (having lived ≥ 30 years at the same address) into exposure levels as based on measurements of radon daughters by alpha sensitive film.

Gender	Exposure level (Bq/m³)			
	≤ 50	50—149	≥ 150	≥ 50
40- to 69-year age group				
Males				
Smokers				
Cases	1	1	1	2
Referents	6	4	1	5
Nonsmokers				
Cases	0	0	1	1
Referents	7	2	0	2
Females				
Smokers				
Cases	0	0	0	0
Referents	2	0	0	0
Nonsmokers				
Cases	0	1	0	1
Referents	8	2	1	3
70- to 79-year age group				
Males				
Smokers				
Cases	1	2	0	2
Referents	5	2	1	3
Nonsmokers				
Cases	1	1	1	2
Referents	15	7	1	8
Females				
Smokers				
Cases	0	0	0	0
Referents	0	0	0	0
Nonsmokers				
Cases	2	2	0	2
Referents	15	9	1	10
≥ 80-year age group				
Males				
Smokers				
Cases	2	1	0	1
Referents	4	1	0	1
Nonsmokers				
Cases	1	0	0	0
Referents	18	6	1	7
Females				
Smokers				
Cases	0	0	0	0
Referents	3	1	0	1
Nonsmokers				
Cases	0	0	0	0
Referents	19	16	1	17
Crude rate ratio (odds ratio)	1.0	2.4	4.9	2.8
Standardized mortality ratio	1.0	2.2	4.8	2.6
Mantel-Haenszel rate ratio (odds ratio)				
Point estimate	1.0	2.3	5.1	2.7
90 % confidence interval		0.9—5.8	1.4—18.5	1.1—6.4
Mantel-extension $\chi_1^2 = 4.73$				

more or less multiplicative effect has appeared. However, there is some inconsistancy with a couple of mining studies (7, 20), in which a merely additive effect of radon daughter exposure and smoking was found. The reason could be that ordinary people are not exposed to the same amount of dust and other irritants as miners, particularly in older mines, and that these irritants together with smoking tend to increase the thickness of the mucous sheath and thereby somewhat protect against the very short-ranging alpha radiation. [For a further discussion see the article by Axelson & Sundell (8).] Thus there is not necessarily any direct contradiction present between our results and the mining studies, especially as the induction-latency periods seem to be shorter for the smoking miners than for their nonsmoking colleagues (2, 7), a phenomenon which seems consistent with a promotive effect for smoking.

In conclusion, the findings presented in our present study, along with the results of the earlier study (5) and the general knowledge about the relationship between radon daughter exposure and lung cancer, seem to suggest that exposure to radon and radon daughters in dwellings may play an important etiologic role for lung cancer in the general population. Therefore, the risk estimates obtained for smoking might be influenced or modified, or even somewhat confounded by indoor radon daughter exposure, and this possibility might help explain some of the irregularities reported for the relationship between smoking and lung cancer

Acknowledgments

We thank Mr L Andersson and Dr Å Ringnér for their assistance and Ms A-L Björklinger for her secretarial help.

This study was supported by the Swedish Radon Commission and the County Council of Östergötland.

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Received for publication: 19 February 1983