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Residential radon and lung cancer—detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14 208 persons without lung cancer from 13 epidemiologic studies in Europe

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had lived in a rural area for the whole of the 30-year period of interest had considerably higher radon concentrations than those who had lived for part of the time in an urban area (the mean TWA observed radon concentration being 123 Bq/m^3 for all rural and 67 Bq/m^3 for some urban).

Effect modification among lifelong nonsmokers according to the characteristics of the cases and controls

There was a significant association between the observed residential radon concentration and lung cancer risk when lifelong nonsmokers were considered separately (estimate of $\beta = 0.106$, 95% CI 0.003–0.280; X^2=4.15, 1 df; P=0.04) (table 18 and figure 3). When the cases and controls who were lifelong nonsmokers were subdivided according to age, sex, the smoking status of spouse, social status, proportion of time spent at home, whether or not they had spent some of the 30-year period of interest living in an urban area, or the position of the bedroom window at night, there was no evidence of any variation in the effect of residential radon on lung cancer risk (table 21). In contrast, when lifelong nonsmokers were subdivided according to whether or not they had been employed in an occupation known to be associated with an increased risk of lung

Table 21. Relationship between the relative risk of lung cancer and the observed residential radon concentration according to characteristics of the cases and controls among the lifelong nonsmokers. (β = the excess relative risk of lung cancer per 100 Bq/m^3 increase in the time-weighted average observed radon concentration, estimated after stratification by study, age, sex and region of residence; 95% CI = 95% confidence interval; df = degrees of freedom)

Characteristic	Lifelong nonmokers				Likelihood ratio test for heterogeneity or trend [a]		
	Cases (N)	Controls (N)	Estimate of β	95% CI for β	Chi-squared	df	P-value
Age							
<45 years	34	209	-0.329	<-0.329–1.557	0.46	1	0.50
45–54 years	101	735	-0.008	<-0.131–0.903			
55–64 years	262	1811	0.093	<-0.031–0.458			
65–74 years	348	2189	0.155	<-0.045–0.482			
≥75 years	139	474	0.071	<-0.078–0.890			
Sex							
Male	268	2888	0.320	0.014–1.118	1.74	1	0.19
Female	616	2530	0.060	-0.028–0.232			
Smoker as spouse							
Yes	389	1928	0.194	0.014–0.556	1.81	1	0.18
No	442	3225	0.044	-0.036–0.209			
Unknown	53	265	>5.000	0.031–>5.000			
Social status							
Higher	179	1133	0.025	<-0.101–0.477	2.54	1	0.11
Intermediate	260	1675	-0.014	-0.072–0.200			
Lower	297	1567	0.369	0.067–1.037			
Unknown	148	1043	0.105	<-0.031–0.580			
Employment in an occupation known to be associated with an increased risk of lung cancer							
None	769	4353	0.032	<-0.031–0.180	7.26	1	0.01
Some	51	589	2.859	0.272–>5.000			
Unknown	64	476	0.957	0.007–>5.000			
Proportion of time spent at home							
<50%	51	589	-0.009	<-0.031–0.752	0.95	1	0.33
50–75%	345	2461	0.012	<-0.046–0.235			
≥75%	144	1154	0.134	-0.022–0.557			
Unknown	344	1214	0.313	0.029–0.953			
Residence in urban or rural area							
All rural	528	3394	0.121	0.004–0.336	0.99	1	0.32
Some urban	268	1364	0.382	-0.022–1.526			
Unknown	88	660	-0.031	<-0.031–0.247			
Position of bedroom window at night							
Open	167	1151	-0.085	<-0.085–0.118	2.74	1	0.10
Closed	234	1396	0.216	-0.011–0.767			
Unknown	483	2871	0.145	0.000–0.439			

[a] For each characteristic, persons with unknown values for that characteristic were omitted from the likelihood ratio test.

cancer, there was evidence of a difference in the effect of residential radon on lung cancer (X^2=7.26, 1 df, P=0.01), with a larger increase in the relative risk per unit radon concentration for the cases and controls who had been exposed to an occupational risk than for those who had not (estimates of β were 2.859, 95% CI 0.272–>5.000, for those with occupational exposure and 0.032, 95% CI <-0.031–0.180, for those without). When the analysis of the modifying effect of occupational exposure was repeated separately for the men and women, the estimated effect of residential radon was greater for those with some occupational exposure among both the men and women, although only 12 women with lung cancer and 35 female controls were known to have had occupational exposure (table 22). When the analysis was repeated separately for occupational exposure to asbestos, radon, and other established risk factors, the modifying effect of asbestos and of other established risk factors was similar in size, although only 18 cases and 357 controls had occupational exposure to asbestos. Only 2 cases and 5 controls had occupational exposure to radon (table 22).

To gain further insight into the possible role of employment in an occupation known to be associated with an increased risk of lung cancer as an effect modifier of radon among the lifelong nonsmokers in this data set, the effect of such an occupation directly on lung cancer risk (ie, without radon being considered) was examined. It was found that lung cancer risks were, in fact, very similar for the cases and controls with and without employment in such an occupation (relative risk = 1.219, 95% CI 0.844–1.759; X^2=1.10, 1 df, P=0.30) (table 23). When the numbers of persons who were lifelong nonsmokers were tabulated by case–control status, the observed residential radon concentration and whether or not the persons had been employed in an occupation known to be associated with an increased risk of lung cancer, it was found that the modifying effect of employment was not primarily due to more cases than controls with occupational exposure to an established lung cancer risk having high observed radon concentrations, but rather due to a deficit of cases with low radon concentrations having such exposure. Among all of the lifelong nonsmokers, 51 cases and 589 controls had some employment in an occupation known to be associated with an increased risk of lung cancer. However, among the people with a TWA observed radon concentration of <25 Bq/m³, there was only 1 case compared with 45 controls.

Table 22. Relationship between the relative risk of lung cancer and the observed residential radon concentration according to sex and whether or not the person had been employed in an occupation known to be associated with an increased risk of lung cancer among the lifelong nonsmokers. (β = the excess relative risk of lung cancer per 100 Bq/m³ increase in the time-weighted average observed radon concentration, estimated after stratification by study, age, sex, and region of residence; 95% CI = 95% confidence interval; df = degrees of freedom)

Characteristic	Lifelong nonsmokers				Likelihood ratio test for heterogeneity of β [a]		
	Cases (N)	Controls (N)	Estimate of β	95% CI for β	Chi-squared	df	P-value
1. Employment in an occupation known to be associated with an increased risk of lung cancer							
Males							
None	213	2095	0.067	<-0.031–0.624	3.83	1	0.05
Some	39	554	2.714	<-0.126–>5.000			
Unknown	16	239	>5.000	> 5.000 [b]			
Females							
None	556	2258	0.028	<-0.046–0.190	2.86	1	0.09
Some	12	35	10.940	<-0.083–>5.000			
Unknown	48	237	0.239	<-0.045–>5.000			
2. Employment in an occupation with exposure to specific risks							
Asbestos							
None	802	4585	0.062	-0.028–0.224	3.33	1	0.07
Some	18	357	>5.000	0.003–>5.000			
Unknown	64	476	0.960	0.007–>5.000			
Radon							
None	818	4937	–				
Some	2	5	–				
Unknown	64	476	–				
Other							
None	783	4689	0.040	<-0.031–0.196	3.92	1	0.05
Some	37	253	1.697	<-0.083–>5.000			
Unknown	64	476	0.96	0.0071–>5.000			

[a] For each characteristic, persons with unknown values for that characteristic were omitted from the likelihood ratio test.
[b] Upper 95% confidence limit: numerical difficulties were experienced in the computation of the lower 95% confidence limit.

Table 23. Employment in an occupation known to be associated with an increased risk of lung cancer among the lifelong nonsmokers. (95% CI = 95% confidence interval, df = degrees of freedom)

Characteristic	Lifelong nonsmokers				Likelihood ratio test for difference		
	Cases (N)	Controls (N)	Relative risk [a]	95% CI for relative risk	Chi-squared	df	P-value
None	769	4353	1.000	–	1.10	1	0.30
Some	51	589	1.219	0.844–1.759			
Unknown	64	476	– [b]				

[a] Relative risks stratified by study, region of residence, age, sex, and smoking history.
[b] Estimate could not be obtained for persons with unknown values, as it could not be distinguished from the stratification variables.

Table 24. Relationship between the relative risk of lung cancer and the observed residential radon concentration according to histological type. (β = the excess relative risk of lung cancer per 100 Bq/m^3 increase in the time-weighted average observed radon concentration, estimated after stratification by study, age, sex, region of residence, and smoking history; 95% CI = 95% confidence interval; df = degrees of freedom)

Histological type	Cases (N)	Controls (N)	Estimate of β	95% CI for β	Test for heterogeneity of β		
					Chi-squared	df	P-value
1. Availability of microscopic confirmation in studies seeking clinical information regarding the diagnosis of lung cancer							
Microscopically confirmed lung cancer	6310	13 307	0.075	0.019–0.151	0.24	1	0.63
No microsopic evidence	484	13 307	0.039	< - 0.022–0.220			
2. Small-cell compared with other microscopically confirmed histological type							
Small-cell	1379	13 307	0.312	0.128–0.606	4.84	1	0.03
Other microscopically confirmed	4931	13 307	0.026	< - 0.031–0.102			
3. Histological type							
Small-cell	1379	13 307	0.312	0.128–0.606	7.07	3	0.07
Squamous-cell	2479	13 307	–0.014	< - 0.031–0.086			
Adenocarcinoma	1698	13 307	0.063	< - 0.031–0.202			
Other confirmed type	754	13 307	0.035	< - 0.031–0.235			

Differences in the effect of residential radon on different histological types of lung cancer

In the 11 studies that sought clinical information regarding the diagnosis of lung cancer, microscopic information confirming the diagnosis was available for all but 484 cases. The estimated value of β for those for whom no microscopic confirmation was available was somewhat lower than for the those for whom it was available (estimates 0.039 with 95% CI <-0.022–0.220 and 0.075 with 95% CI 0.019– 0.151, respectively), but the difference was not statistically significant (X^2=0.24 on 1 df, P=0.63). (See table 24.)

A steeper dose–response relationship for small-cell lung cancer than for other types has previously been reported among underground miners occupationally exposed to radon and, when the lung cancer cases for whom microscopic information was available were subdivided according to whether they had small-cell lung cancer or another histological type, the dose–response relationship in the two groups differed significantly (X^2=4.84 on 1 df, P=0.03). The estimated value of β for small-cell lung cancer was substantially higher than for other histological types (estimates of β were 0.312, 95% CI 0.128–0.606, for small-cell lung cancer and 0.026, 95% CI <-0.031–0.102, for other histological types) (table 24). For squamous cell carcinoma the estimated value of β was slightly negative, while for adenocarcinoma and for other confirmed histological types it was positive. However, in all these three groups the 95% confidence interval for β included zero (table 24). When the analysis by histological type was repeated separately for the men and women and for current cigarette smokers, ex-smokers and lifelong nonsmokers, the dose–response relationship for small-cell lung cancer was steeper than for other confirmed types in all five groups (table 25). Overall 21.8% (1379 of 6310) of the microscopically confirmed lung cancers were of the small-cell type (table 26). All 11 studies in which clinical information was sought on the diagnosis of lung cancer had persons with observed radon concentrations of <50 Bq/m^3, and, in this group, the proportion of microscopically confirmed lung cancers that were of the small-cell type was similar to the overall value, at 21.4% (508 of 2376). In contrast, among the cases and controls with observed radon of >800 Bq/m^3, 55.0% (11 of 20) of the microscopically confirmed lung cancers were of the small-cell type, and all five of those with observed radon concentrations of >1600 Bq/m^3 were small-cell lung cancers. The 11 persons with small-cell lung cancer who had observed residential radon concentrations of >800 Bq/m^3 came from seven different studies (Finland nationwide, Finland southern, France, Germany eastern, Spain, Sweden nationwide, and United Kingdom); 9 were male and 2 were female, while 4 were current cigarette smokers, 5 were ex-smokers, 1 was a lifelong nonsmoker, and 1 was an occasional smoker; their ages were 58, 61, 63, 66 (2 persons) 68, 69, 70, 71 (2 persons), and 80 years, respectively.

When the effect of residential radon on small-cell lung cancer was examined by categories of observed residential radon concentration, the relative risks compared with 0 Bq/m^3 in the categories <25, 25–49, 50–99, 100–199, 200–399, and ≥400 Bq/m^3 were 1.17 (95% CI 0.93–1.50), 1.15 (95% CI 1.00–1.31), 1.22 (95% CI 1.09–1.38), 1.27 (95% CI 1.06–1.53), 1.91 (95% CI 1.40–2.64), and 2.74 (95% CI 1.51–5.09), respectively (table 27 and figure 4). These values differed appreciably from those seen for other histological types of lung cancer, for which the relative risks compared with 0 Bq/m^3 in the same categories were 0.95 (95% CI 0.80–1.12), 1.03 (95% CI 0.94–1.13), 0.99 (95% CI 0.91–1.07), 1.17 (95% CI 1.04–1.32), 1.00 (95% CI 0.79–1.26), and 1.23 (95% CI 0.84–1.81), respectively.

Combined effect of smoking and radon exposure

The estimates of β for current cigarette smokers, ex-smokers, and lifelong nonsmokers were similar, at 0.070, 0.082 and 0.106, respectively, with no evidence of heterogeneity (table 18). It is therefore appropriate to assume that the overall estimate of β, at 0.084 (95% CI 0.030–0.158) is appropriate regardless of smoking status. Among the men, the risk of lung cancer for those smoking 15–24 cigarettes per day, relative to lifelong nonsmokers, was 25.8 for all of the studies

Table 25. Relationship between the risk of lung cancer and the observed residential radon concentration according to histological type, calculated separately for the men and women and for current cigarette smokers, ex-smokers, and lifelong nonsmokers. (95% CI = 95% confidence interval)

Histological type	Cases (N)	Estimate of $\beta^{a, b}$	95% CI for $\beta^{a, b}$
Men [c]			
Small-cell	1051	0.313	0.117–0.642
All other microscopically confirmed	3771	0.045	<-0.031–0.154
Squamous-cell	2134	0.003	<-0.031–0.124
Adenocarcinoma	1127	0.046	<-0.031–0.252
Other type	510	0.184	-0.014–0.561
Women [c]			
Small-cell	328	0.304	<-0.045–1.382
All other microscopically confirmed	1160	-0.002	-0.062–0.117
Squamous-cell	345	-0.069	<-0.045–0.138
Adenocarcinoma	571	0.079	-0.036–0.308
Other type	244	-0.069	<-0.045–0.048
Current cigarette smokers [d]			
Small-cell	829	0.150	<-0.045–0.512
All other microscopically confirmed	2308	0.046	<-0.066–0.235
Squamous-cell	1253	-0.028	<-0.066–0.163
Adenocarcinoma	718	0.129	<-0.066–0.636
Other type	337	0.278	<-0.066–1.094
Ex-smokers [d]			
Small-cell	416	0.344	0.078–0.876
All other microscopically confirmed	1758	0.013	<-0.082–0.146
Squamous-cell	997	0.018	<-0.082–0.201
Adenocarcinoma	508	-0.029	<-0.082–0.189
Other type	253	0.015	<-0.082–0.351
Lifelong nonsmokers [d]			
Small-cell	84	1.402	<-0.031–>5.000
All other microscopically confirmed	704	0.042	<-0.031–0.203
Squamous-cell	137	-0.031	<-0.031–0.279
Adenocarcinoma	438	0.108	<-0.031–0.359
Other type	129	-0.069	<-0.031–0.239

[a] β for the men and women was the excess relative risk of lung cancer per 100 Bq/m^3 increase in the time-weighted average observed radon concentration, estimated after stratification by study, age, region of residence, and smoking history.
[b] β for current smokers, ex-smokers, and lifelong nonsmokers was the excess relative risk of lung cancer per 100 Bq/m^3 increase in the time-weighted average observed radon concentration, estimated after stratification by study, age, sex, region of residence, and, for current and ex-smokers, detailed smoking history.
[c] Numbers of controls are 10 388 men and 3820 women.
[d] Numbers of controls are 3322 current cigarette smokers, 4930 ex-smokers, and 5418 lifelong nonsmokers.

Table 26. Numbers of persons with small-cell lung cancer and other microscopically confirmed types of lung cancer, by the time-weighted average observed radon concentration.

Type of lung cancer	Observed radon concentration (Bq/m^3)								Total number of persons
	<25	25–	50–	100–	200–	400–	800–	≥1600	
Small-cell lung cancer	123	385	518	235	94	13	6	5	1379
Other microscopically confirmed lung cancer	389	1479	1863	894	235	62	9	–	4931
Total	512	1864	2381	1129	329	75	15	5	6310

Table 27. Relative risk of lung cancer according to categories of observed residential radon concentration by histological type of lung cancer. (95% CI = 95% confidence interval)

Observed radon concentration [a]	Cases (N)	Controls (N)	Mean observed radon concentration (Bq/m³)	Relative risk [b]	95% CI [c]
Small-cell lung cancer					
<25 Bq/m³	123	1474	17	1.17	0.93–1.50
25–49 Bq/m³	385	3905	38	1.15	1.00–1.31
50–99 Bq/m³	518	5033	71	1.22	1.09–1.38
100–199 Bq/m³	235	2247	135	1.27	1.06–1.53
200–399 Bq/m³	94	936	275	1.91	1.40–2.64
≥400 Bq/m³	24	613	668	2.74	1.51–5.09
Total (Bq/m³)	1379	14 208	105	–	–
Other microscopically confirmed					
<25 Bq/m³	389	1474	17	0.95	0.80–1.12
25–49 Bq/m³	1479	3905	39	1.03	0.94–1.13
50–99 Bq/m³	1863	5033	71	0.99	0.91–1.07
100–199 Bq/m³	894	2247	136	1.17	1.04–1.32
200–399 Bq/m³	235	936	273	1.00	0.79–1.26
≥400 Bq/m³	71	613	651	1.23	0.84–1.81
Total (Bq/m³)	4931	14 208	100	–	–

[a] Observed radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there.
[b] Relative risks estimated after stratification by study, age, sex, region of residence, and, for current and ex-smokers, detailed smoking history. Risks scaled so that the relative risk was 1.00 at 0 Bq/m³ on the assumption of a linear relationship, see the Statistical Methods section for details.
[c] Confidence intervals calculated using the method of floated variances

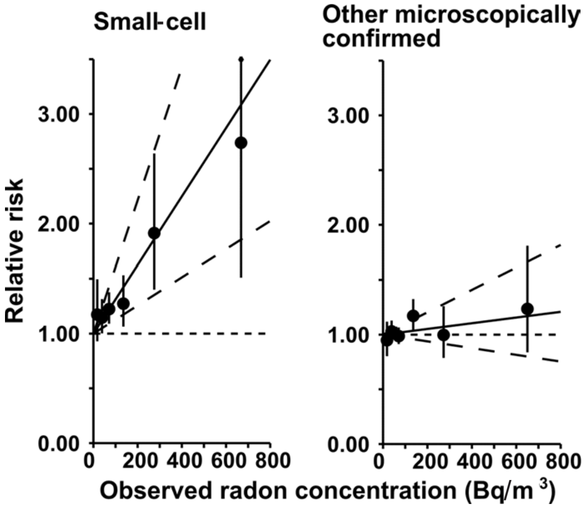

Figure 4. Risk of lung cancer according to the time-weighted average observed residential radon concentration by histological type. The risks were calculated after stratification by study, age, sex, region of residence, and, for current and ex-smokers, detailed smoking history. The relative risks and 95% confidence intervals are shown for the categorical analyses, as are the estimated linear relationships (solid lines) and 95% confidence intervals (dashed lines). The relative risks are equal to 1 at 0 Bq/m³. The lower confidence interval of the linear relationship for the "other microscopically confirmed" group was lower than that shown, but it could not be determined precisely.

combined, while for ex-smokers of <10 and ≥10 years' duration the risks relative to that of lifelong nonsmokers were 20.8 and 5.0, respectively (table 3). When these smoking-related risks are combined with the overall estimate of β, the result suggests that current smokers of 15–24 cigarettes per day have risks, relative to that of lifelong nonsmokers, varying from 25.8 to 43.1, as their observed radon concentration increases from 0 to 800 Bq/m³, while ex-smokers of <10 years' duration have risks varying from 20.8 to 34.8, as their observed radon concentration increases from 0 to 800 Bq/m³, and ex-smokers of ≥10 years' duration have risks increasing from 5.0 to 8.3, as their observed radon concentration increases from 0 to 800 Bq/m³ (table 28 and figure 5).

For lifelong nonsmokers with an observed radon concentration of 0 Bq/m³, the cumulative risk of death from lung cancer was estimated to be 0.42% by the age of 75 years, increasing to 0.81% by the age of 85 years. For lifelong nonsmokers with observed radon concentrations of >0 Bq/m³, the cumulative risks of death were somewhat greater, but, even at an observed radon concentration of 800 Bq/m³, the risk increased only to 0.71% (95% CI 0.43–0.95) by the age of 75 years and to 1.35% (95% CI 0.83–1.82) by the age of 85 years (table 29 and figure 6). For continuing smokers of 15–24 cigarettes per day, not only was the cumulative risk of death from lung cancer at an observed radon concentration of 0 Bq/m³ much higher, at 10.43% by the age of 75 years and increasing to 19.06% by the age of 85 years, but the increase in the cumulative risk with an increasing observed radon concentration was also substantially higher—by the age of 75 years the cumulative risks associated with observed radon concentrations of 100, 200, 400, and 800 Bq/m³ were 11.25% (95% CI 10.45–11.97), 12.07% (95% CI 10.48–13.49), 13.68% (95% CI 10.54–16.45), and 16.81% (95% CI 10.66–22.06), respectively. By the age of 85 years, these risks had risen substantially further, to 20.48% (95% CI 19.11–21.72), 21.88% (95% CI 19.16–24.29), 24.61% (95% CI 19.61–29.18), and 29.78% (95% CI 19.47–38.04), respectively. For those who gave up smoking, the relative risks during the first 10 years were about 80% of those of the continuing smokers (table 28). Hence the cumulative risks for ex-smokers would also be about 80% of those of continuing smokers. Thereafter they would be lower, but there were not enough persons in the present study who were ex-smokers of 10–19, 20–29, and so forth years' duration to calculate specific estimates of cumulative risk.

Table 28. Risk of lung cancer relative that of to lifelong nonsmokers with no radon exposure by observed radon concentration for various smoking categories. (95% CI = 95% confidence interval)

Observed radon concentration [a]	Relative risk [b]	95% CI
Current cigarette smokers (15–24 per day)		
0 Bq/m^3	25.8	–
100 Bq/m^3	27.9	26.5–29.8
200 Bq/m^3	30.1	27.3–33.9
400 Bq/m^3	34.4	28.9–42.1
800 Bq/m^3	43.1	32.0–58.3
Ex-smokers (<10 years)		
0 Bq/m^3	20.8	–
100 Bq/m^3	22.6	21.5–24.1
200 Bq/m^3	24.3	22.1–27.4
400 Bq/m^3	27.8	23.3–34.0
800 Bq/m^3	34.8	25.8–47.2
Ex-smokers (≥10 years)		
0 Bq/m^3	5.0	–
100 Bq/m^3	5.4	5.1–5.8
200 Bq/m^3	5.8	5.3–6.6
400 Bq/m^3	6.7	5.6–8.1
800 Bq/m^3	8.3	6.2–11.3
Lifelong nonsmokers		
0 Bq/m^3	1.0	–
100 Bq/m^3	1.1	1.0–1.2
200 Bq/m^3	1.2	1.1–1.3
400 Bq/m^3	1.3	1.1–1.6
800 Bq/m^3	1.7	1.2–2.3

[a] Observed radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there.

[b] Risk of lung cancer relative to lifelong nonsmokers with 0 Bq/m^3 radon concentration. Risks for smokers of 15–24 cigarettes per day, ex-smokers of <10, and ex-smokers of ≥10 years' duration relative to that of lifelong nonsmokers, assumed to be 25.8, 20.8 and 5.0, respectively (see table 3), regardless of the radon concentration. Relative risks of lung cancer assumed to increase by 0.084 (95% CI 0.033–0.158) per 100 Bq/m^3 regardless of smoking status.

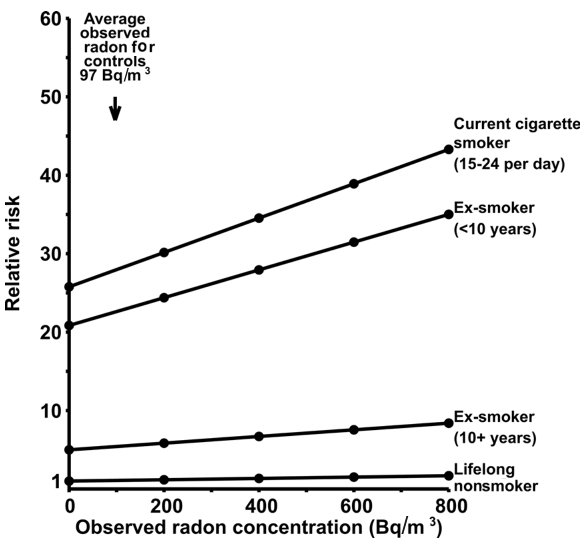

Figure 5. Risk of lung cancer relative to that of lifelong nonsmokers with no radon exposure by the observed radon concentration. See table 28 for the methodological details.

Table 29. Cumulative risk of death from lung cancer by age for the lifelong nonsmokers and continuing smokers of 15–24 cigarettes per day at various levels of observed radon concentration. [a] (95% CI = 95% confindence interval)

Age	Lifelong nonsmokers		Continuing smokers of 15–24 cigarettes per day	
	Cumulative risk (%)	95% CI	Cumulative risk (%)	95% CI
Observed radon concentration of 0 Bq/m^3				
75 years	0.42	–	10.43	–
80 years	0.59	–	14.26	–
85 years	0.81	–	19.06	–
Observed radon concentration of 100 Bq/m^3				
75 years	0.46	0.42–0.49	11.25	10.45–11.97
80 years	0.64	0.59–0.68	15.36	14.30–16.32
85 years	0.88	0.81–0.94	20.48	19.11–21.72
Observed radon concentration of 200 Bq/m^3				
75 years	0.49	0.43–0.56	12.07	10.48–13.49
80 years	0.69	0.59–0.78	16.45	14.34–18.33
85 years	0.95	0.81–1.06	21.88	19.16–24.29
Observed radon concentration of 400 Bq/m^3				
75 years	0.56	0.43–0.69	13.68	10.54–16.45
80 years	0.79	0.60–0.96	18.58	14.42–22.21
85 years	1.08	0.82–1.32	24.61	19.26–29.18
Observed radon concentration of 800 Bq/m^3				
75 years	0.71	0.43–0.95	16.81	10.66–22.06
80 years	0.98	0.60–1.33	22.69	14.58–29.42
85 years	1.35	0.83–1.82	29.78	19.47–38.04

[a] Absolute risk of lung cancer for the lifelong nonsmokers taken from a prospective study of the American Cancer Society. The relative risk of lung cancer for continuing smokers of 15–24 cigarettes per day was assumed to be equal to the overall estimates in the present study (see table 3). The relative risk of lung cancer was assumed to increase by 0.084 (95% CI 0.030–0.158) per 100 Bq/m^3 increase in the time-weighted average observed radon concentration (see table 9).

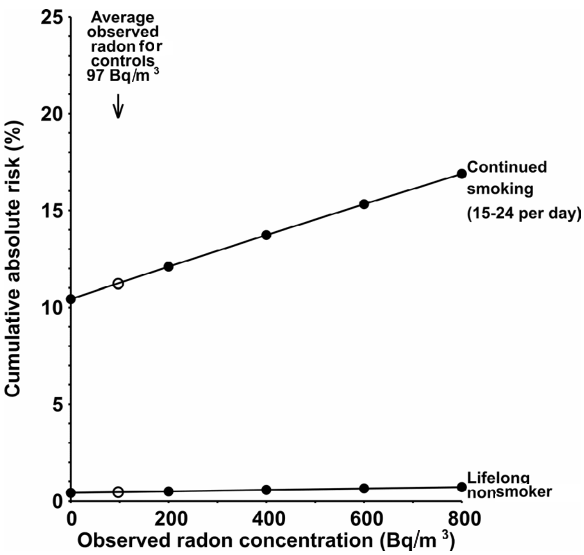

Figure 6. Cumulative risk of death from lung cancer by 75 years of age for various smoking histories by the observed radon concentration. (see table 29 for the methodological details.)

Analyses adjusted for the effect of random uncertainties in the assessment of radon concentration

The extent to which random uncertainties in the assessment of radon concentrations have affected the results presented in the previous sections is determined primarily by the variability of the repeated measurements of radon gas in the same dwelling in different years. No information about this variability is provided in the data presented in the preceding paragraphs. Therefore the laboratories that had performed the radon measurements for the 13 studies were contacted and requested to provide any information that they had available on the variability of repeated measurements of radon gas taken in the same dwelling on different occasions, in the same areas as the study and under approximately the same conditions as in the study. All of the information that could be obtained is summarized in table 30. There were substantial differences between the different countries in the amount of variation observed, from a variance on the log scale of 0.029 in Italy to one of 0.33 in Finland.

In table 30, in one of the two sets of data from Finland, the dwellings had specifically been selected to have small variability between repeated measurements, and the data from eastern Germany had been obtained

Table 30. Summary of the available information on the variability of repeated measurements of radon gas taken in the same dwelling on different occasions.

Location	Description of information	Type of dwelling	Typical duration of measurement period in each year	Occupier or building changes	Measurements always in same room	Main source of radon	Geometric mean (Bq/m³)	Variance on logarithmic scale	Coefficient of variation on linear scale
Czech Republic [a]	1920 measurements made in 960 dwellings in 1992 and repeat-in 1993 (J Hulka & L Tomášek, personal communication)	Mainly single family houses	1 year	None	Yes	Subsoil under dwelling	327	0.12	0.36
Finland	301 dwellings in Finland southern who had requested more than one measurement and who responded to a questionnaire (I Mäkeläinen, personal communication)	Mostly single family houses	Mostly 2 months during winter, but some 1 year	Same occupier; buildings with radon mitigation excluded	Not necessarily	Subsoil under dwelling	319	0.33	0.62
Finland [b]	337 measurements made in 80 dwellings in 18 different years; dwellings were selected to have small variability (I Mäkeläinen, personal communication)	Mostly single family houses	Mostly 1 year, but some 2 months during winter with seasonal correction	No occupier changes; building changes in 7 dwellings	Not necessarily	Subsoil under dwelling	196	0.12	0.36
Germany eastern [b]	110 measurements made in 11 dwellings in 5 different years [Heid et al (41)]	Mainly cellars of single family houses or laboratories	1 year	None	Yes	Subsoil under dwelling	~20 000	0.30	0.59
Italy	363 measurements made in 80 different dwellings in 3–5 consecutive years; each measurement is average of living and bedroom detectors [Bochicchio et al, personal communication]	Nine single family houses, remainder apartments	1 year (2 x 6 months consecutively)	Occupier changes in 1 dwelling; building changes in 1 dwelling	Yes	Probably both building material and subsoil	97	0.029 [c]	0.17 [c]
Sweden	860 measurements made in 44 dwellings in 13 different years (R Falk, personal communication)	Mostly single family houses [d]	3 months in winter	None	Yes	Subsoil under dwelling	178	0.14	0.39
United Kingdom	436 measurements made in 218 dwellings with time intervals of up to 10 years; each measurement is average of living and bedroom detectors [Darby et al (22), Lomas & Green (37)]	Mostly single family houses	Either 1 year (2 x 6 months consecutively) or 3 months with seasonal correction	Occupier changes in 148 dwellings; dwellings with radon mitigation omitted, but other building changes not ruled out	Not necessarily	Subsoil under dwelling	107	0.23	0.51
United Kingdom	576 measurements made in 96 dwellings in 6 different years; each measurement is average of living and bedroom detectors [Hunter et al (36)]	Mostly single family houses	3 months with seasonal correction	None	Not necessarily	Subsoil under dwelling	96	0.18	0.44

[a] Open detectors used in the Czech Republic and closed detectors used everywhere else.
[b] The data from Finland in which dwellings had been specifically selected to have small variability and the data from the Germany eastern study in which the dwellings considered had very high radon concentrations were not used in determining the values for the variation of repeated measurements made in the same dwelling on different occasions.
[c] All of the detectors were from same batch of material; therefore batch-to-batch variation was excluded.
[d] The variance estimate increases if the calculation is repeated after restriction to the three above-ground apartments.

from buildings with much higher radon concentrations than the dwellings included in the German epidemiologic studies. Therefore these two datasets were not used in determining the parameter values for the Collaborative Analysis. For the remaining datasets summarized in table 30, the estimated variances on the logarithmic scale were used to estimate the corresponding country-specific variances in the Collaborative Analysis, and for the United Kingdom the average of the two estimates given in table 30 was used. For studies carried out in countries in which there were no data available on the variability of repeated measurements, the median of the estimated values for the other countries was used (ie, 0.14). Additional details for the values of the parameters used in the analyses correcting for uncertainties in the assessment of radon concentrations are given in table D5 in appendix D.

When uncertainties in the assessment of the radon concentrations were taken into account using the method of integrated likelihood, the excess relative risk of lung cancer per 100 Bq/m^3 (ie, β) was estimated to be 0.16 (95% CI 0.05–0.31). As the variability of repeated measurements in the same dwellings on different occasions was not known precisely, this analysis was repeated using both higher and lower values (table 31). When the variability estimates were all decreased by 30%, the estimated value of β was 0.14 (95% CI 0.05–0.27), and, when the variability estimates were all increased by 30%, the estimated value of β was 0.19 (95% CI 0.06–0.41). All of the subsequent results presented in this report were calculated using the central estimates of the variability of the repeated measurements.

A TWA radon concentration correcting for uncertainties in the assessment of radon concentrations was calculated for each person. For the lung cancer cases, the mean value of the corrected radon concentrations was 90 Bq/m^3, somewhat lower than the mean of the observed values, which was 104 Bq/m^3. For the controls the weighted mean after correction was 86 Bq/m^3, compared with 97 Bq/m^3 before the correction. The estimated common difference between the corrected TWA radon concentration for the lung cancer cases and the controls was 3.4, with a standard error of 1.0 (P=0.0007) (table 32). Summaries of the distributions of the corrected radon concentrations in the individual studies are given in table D6 of appendix D.

For those with high values for their observed TWA radon concentration, the value after correction for uncertainties tended to be substantially lower. For example, for the 181 persons (66 lung cancer cases and 115 controls) with observed radon concentrations of >800 Bq/m^3, the mean observed radon concentration was 1204 Bq/m^3, while the mean corrected radon concentration was 678 Bq/m^3 (table 33). For those with low TWA observed radon concentrations, the corrected values tended to be somewhat increased—for the 2040 persons (566 lung cancer cases and 1474 controls) with observed radon concentrations of <25 Bq/m^3, the mean observed value was 17 Bq/m^3, while the mean corrected value was 21 Bq/m^3.

The linear relationship between the relative risk of lung cancer and TWA-corrected radon concentration, for which the estimated value of β was 0.16 per 100 Bq/m^3, is shown on the right in figure 7. Also shown on the right in figure 7 are the relative risks for the original categorical analysis (ie, for persons with *observed* radon concentrations in categories <25, 25–49, 50–99, 100–199, 200–399, 400–799, and ≥800 Bq/m^3), but these relative risks are now plotted against the mean *corrected* radon concentration for the

Table 31. Estimated linear relationship between the relative risk of lung cancer and the residential radon concentration correcting for uncertainties in the assessment of radon concentrations. (β = the excess relative risk of lung cancer per 100 Bq/m^3 increase in the time-weighted average radon concentration, estimated after stratification by study, age, sex, region of residence, and smoking history and correcting for uncertainties in the assessment of radon concentrations; 95% CI = 95% confidence interval)

Method of correction for uncertainties	Estimate of variability of repeated measurements in the same dwelling on different occasions	Estimate of β	95% CI for β
1. Integrated likelihood	Central estimate [a]	0.16	0.05–0.31
2. Integrated likelihood	Central estimate x 0.7	0.14	0.05–0.27
3. Integrated likelihood	Central estimate x 1.3	0.19	0.06–0.41
4. Regression calibration	Central estimate	0.16	0.05–0.3

[a] The central estimate uses the values of V_m given in table D5 in appendix D.

Table 32. Overall distribution of the time-weighted average of the residential radon concentration for the cases and controls after correction for uncertainties in the assessment of residential radon.[a]

Radon concentration	Cases		Controls	
	N	%	N	%
<25 Bq/m^3	403	5.6	1168	8.2
25–49 Bq/m^3	1985	27.8	4033	28.4
50–99 Bq/m^3	3096	43.3	5788	40.7
100–199 Bq/m^3	1207	16.9	2036	14.3
200–399 Bq/m^3	286	4.0	650	4.6
400–799 Bq/m^3	159	2.2	519	3.7
800–1599 Bq/m^3	11	0.2	14	0.1
≥1600 Bq/m^3	1	0.0	–	0.0
Total	7148	100.0	14 208	100.0

[a] The mean for the persons with lung cancer was 90 Bq/m^3. The estimated difference between the cases and controls was 3.4 Bq/m^3 (standard error 1.0 Bq/m^3), based on a linear model with separate effects for each study and a common difference between the cases and controls. The mean for the controls was 86 Bq/m^3 [weighted mean for the controls, with weights proportional to the study-specific numbers of cases].

Table 33. Mean observed and corrected radon concentrations by categories of observed radon concentration for the cases and controls.

Observed radon concentration [a]	Cases (N)	Controls (N)	Mean observed radon concentration [a] (Bq/m³)	Mean corrected radon concentration [b] (Bq/m³)
<25 Bq/m³	566	1 474	17	21
25–49 Bq/m³	1999	3 905	39	42
50–99 Bq/m³	2618	5 033	71	69
100–199 Bq/m³	1296	2 247	136	119
200–399 Bq/m³	434	936	273	236
400–799 Bq/m³	169	498	542	433
≥800 Bq/m³	66	115	1204	678
Total	7148	14 208	–	–

[a] Observed radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there.
[b] Corrected radon concentration after uncertainties in the assessment of the radon concentrations were taken into account.

persons in each category. The original analysis, based entirely on observed radon concentrations, and for which the estimated value of β was 0.084 per 100 Bq/m³, is shown on the left in figure 7 for comparison.

An additional analysis was carried out in which it was assumed that each person's TWA radon concentration was known precisely and was equal to his or her corrected value (ie, using the method of regression calibration). With this method, the estimated value of β was also 0.16 (95% CI 0.05–0.30), a value very similar to the estimated value of β using the method of integrated likelihood (table 31). Estimated values of β in the individual studies using the method of regression calibration are given in table D7 of appendix D. The analysis shown in table D7 was repeated omitting each study in turn, and the estimated value of β changed by <10% for 10 of the 13 studies. However, omitting either the Czech Republic or the Germany eastern study reduced the estimate of β by 11%, while omitting the United Kingdom study increased the estimate of β by 34%. Study-specific estimates based on a log-linear rather than a linear model are shown in table D8 of appendix D.

The analyses correcting for uncertainties in the assessment of radon concentrations were repeated separately for the cases and controls in different age groups, for the men and women, and for current cigarette smokers, ex-smokers, and lifelong nonsmokers (table 34). The estimates of β calculated using the method of regression calibration were similar to those calculated using the method of integrated likelihood throughout. As with the analysis based on the observed radon concentrations, there was no evidence of a trend in β with the age of the person, nor was there any evidence of differences in β between the men and women, or of heterogeneity in β between the three main categories of

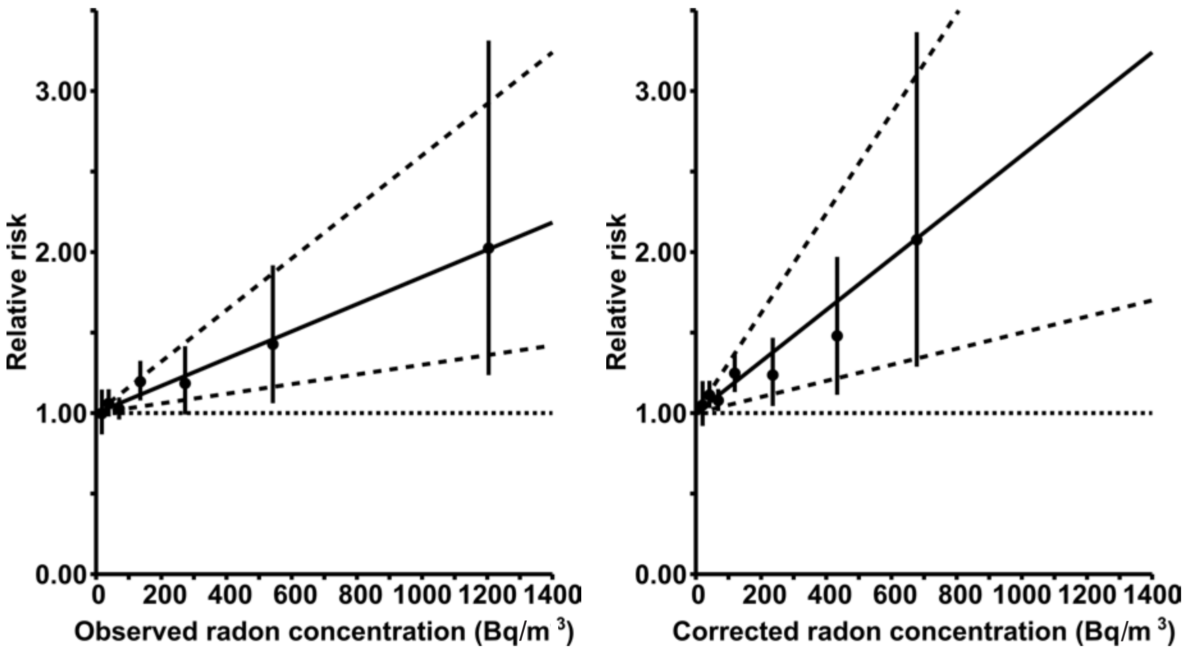

Figure 7. Relative risk of lung cancer according to the time-weighted average observed residential radon concentration (on the left) and the time-weighted average corrected residential radon concentration (on the right). The relative risks and 95% confidence intervals are shown for the categorical analyses, as are the estimated linear relationships (solid lines) with 95% confidence intervals (dashed lines). The risks were calculated after stratification by study, age, sex, region of residence, and smoking history. On the right, the estimated linear relationship was calculated using the method of integrated likelihood, and the relative risks from the categorical analysis based on categories of observed radon were plotted against the mean corrected radon concentration in each of these categories. In both figures, the relative risks are equal to 1 at 0 Bq/m³.

Table 34. Relationship between the relative risk of lung cancer and the radon concentration according to age, sex, smoking status, and histological type, based on the observed radon concentration and also after correction for uncertainties in the assessment of the residential radon concentrations. (*b* = the excess relative risk of lung cancer per 100 Bq/m^3 increase in the time-weighted average radon concentration, estimated after stratification by study, age, sex, region of residence, and detailed smoking history; 95% CI = 95% confidence interval)

	Cases (N)	Controls (N)	Based on observed radon concentration		After correction for uncertainties in the assessment of radon concentration			
					Integrated likelihood method		Regression calibration method	
			Estimate of β	95% CI for β	Estimate of β	95% CI for β	Estimate of β	95% CI for β
Age								
<45 years	222	588	0.11	<-0.16–0.35	-0.15	<-0.08–0.69	-0.12	<-0.17–0.73
45–54 years	878	1994	-0.02	<-0.07–0.44	0.12	<-0.03–0.95	0.13	<-0.14–0.97
55–64 years	2506	4818	0.14	0.03–0.31	0.17	0.01–0.45	0.16	<-0.04–0.46
65–74 years	3051	5889	0.08	0.01–0.19	0.16	0.03–0.37	0.16	0.03–0.36
≥75 years	491	919	0.00	<-0.08–0.28	0.77	<-0.04–>5.00	0.57	<-0.14–4.54
P for trend			0.98		0.26		0.28	
Sex								
Men	5521	10388	0.11	0.04–0.21	0.25	0.09–0.49	0.25	0.09–0.48
Women	1627	3820	0.03	-0.04–0.14	0.04	<-0.03–0.23	0.04	-0.06–0.22
P for difference			0.19		0.26		0.08	
Smoking status								
Current cigarette smoker	3575	3322	0.07	-0.01–0.22	0.10	<-0.03–0.38	0.09	<-0.08–0.37
Ex-smoker	2465	4930	0.08	0.00–0.21	0.22	0.02–0.57	0.18	0.02–0.47
Lifelong nonsmoker	884	5418	0.11	0.00–0.28	0.20	0.02–0.52	0.20	0.02–0.53
P for heterogeneity			0.92		0.86		0.78	
Histological type of lung cancer								
Small-cell	1379	13 307	0.31	0.13–0.61	0.51	0.18–1.09	0.49	0.17–1.07
Other microscopically confirmed	4931	13 307	0.03	<-0.03–0.10	0.06	<-0.02–0.21	0.06	-0.04–0.21
P for difference			0.03		0.05		0.08	
All persons	7148	14 208	0.08	0.03–0.16	0.16	0.05–0.31	0.16	0.05–0.30
P for test of β=0			0.0007		0: 0.006		0: 0.0008	

smokers (table 34). With the method of integrated likelihood, the estimated value of β was 0.10 (95% CI -0.06–0.38) for current cigarette smokers, 0.22 (95% CI 0.02–0.57) for ex-smokers, and 0.20 (95% CI 0.02–0.52) for lifelong nonsmokers, and there was no evidence of heterogeneity (P=0.86). For persons with high observed radon concentrations, the corrected radon concentrations tended to be substantially lower, while, for people with low observed radon concentrations, the corrected values tended to be somewhat higher in all three smoking categories (table 35). The outcome of the analysis correcting for uncertainties in the three main smoking categories is summarized in the bottom half of figure 8, and the original analysis, based on the observed radon concentrations, is shown in the top half of the figure for comparison.

The correction for uncertainties had a proportionately greater effect on the estimated excess relative risks of the ex-smokers and lifelong nonsmokers than of the current smokers. To see whether this finding could be explained by the differing estimates of the variability between repeated measurements of radon gas in the different studies, the regression calibration analysis described in the previous paragraph was repeated on the assumption that, on the logarithmic scale, the variance between repeated radon measurements was the same in all of the studies and equal to 0.12. When this procedure was carried out, the differences between the three main smoking groups were smaller, and the estimated excess relative risks per 100 Bq/m^3 had values of 0.09 (95% CI -0.04–0.32), 0.14 (95% CI 0.01–0.35), and 0.16 (95% CI 0.00–0.42) for current cigarette smokers, ex-smokers, and lifelong nonsmokers, respectively.

The analyses correcting for uncertainty were also repeated considering only the persons with microscopically confirmed small-cell lung cancer, together with all of the controls, and considering only the persons with microscopically confirmed lung cancers of other types, together with all of the controls. For small-cell lung cancer, the estimated value of β using the method of integrated likelihood was 0.51 (95% CI 0.18–1.09), while for other microscopically confirmed lung cancers the estimated value of β was 0.06 (95% CI -0.04–0.21). Estimates derived using the method of regression calibration

Table 35. Mean observed and corrected radon concentrations by categories of observed radon concentration and smoking status.

Observed radon concentration [a]	Cases (N)	Controls (N)	Mean observed radon concentration [a] (Bq/m^3)	Mean corrected radon concentration [b] (Bq/m^3)
Current cigarette smokers				
<25 Bq/m^3	281	335	17	21
25–49 Bq/m^3	975	808	39	42
50–99 Bq/m^3	1304	1071	72	70
100–199 Bq/m^3	654	595	136	123
200–399 Bq/m^3	234	294	275	253
≥400 Bq/m^3	127	219	652	478
All concentrations	3575	3322	..	..
Ex-smokers				
<25 Bq/m^3	198	621	18	21
25–49 Bq/m^3	750	1515	38	42
50–99 Bq/m^3	898	1734	70	67
100–199 Bq/m^3	431	680	135	116
200–399 Bq/m^3	127	251	266	212
≥400 Bq/m^3	61	129	689	469
All concentrations	2465	4930	..	..

(continued)

Table 35. Continued.

Observed radon concentration [a]	Cases (N)	Controls (N)	Mean observed radon concentration [a] (Bq/m^3)	Mean corrected radon concentration [b] (Bq/m^3)
Lifelong nonsmokers				
<25 Bq/m^3	56	467	17	21
25–49 Bq/m^3	222	1443	38	42
50–99 Bq/m^3	332	2023	71	69
100–199 Bq/m^3	170	866	135	119
200–399 Bq/m^3	63	362	278	237
≥400 Bq/m^3	41	257	711	505
All concentrations	884	5418	..	..

[a] Observed radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there.
[b] Corrected radon concentration, after uncertainties in the assessment of radon concentrations were taken into account.

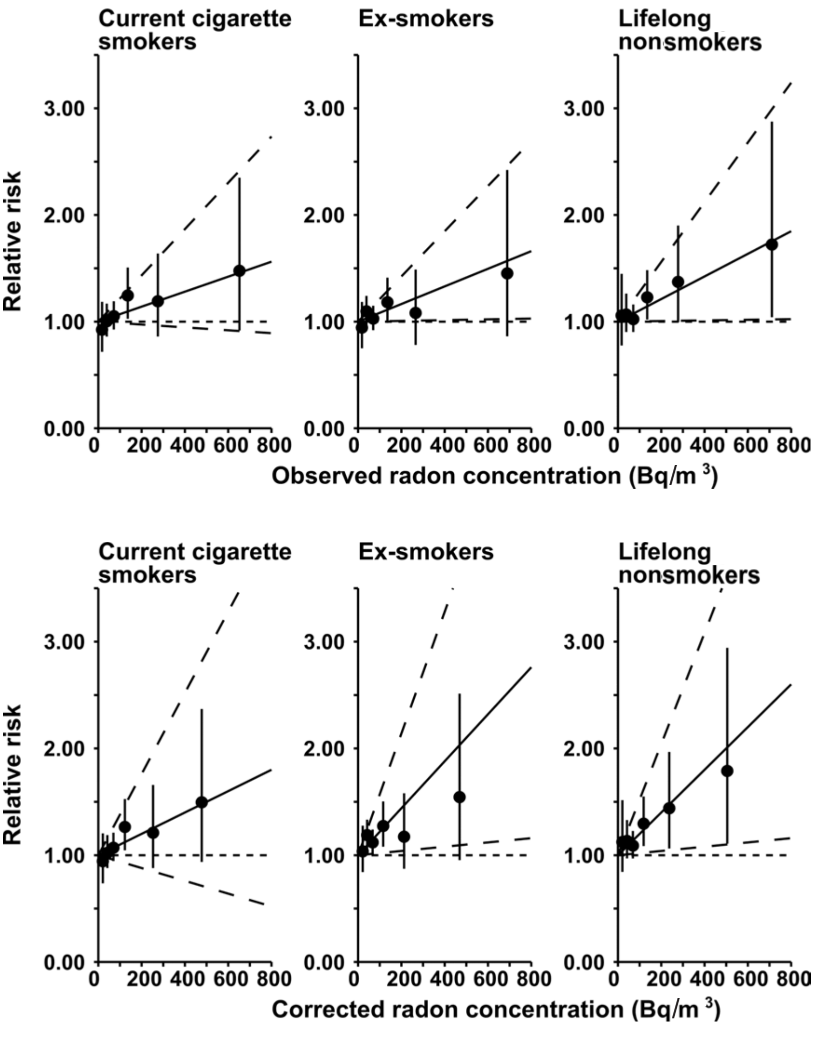

Figure 8. Relative risk of lung cancer according to the time-weighted average observed residential radon concentration (top) and the time-weighted average corrected residential radon concentration (bottom) by smoking status. The relative risks and 95% floated confidence intervals are shown for the categorical analyses, as are the estimated linear relationships (solid lines) and 95% confidence intervals (dashed lines). (See figure 7 for additional methodological details.)

were, once again, very similar to those calculated using the integrated likelihood method (table 34). As with the analyses already described, the corrected radon concentrations tended to be substantially lower than the observed ones for the persons with high observed concentrations, while, for persons with low observed concentrations, the corrected values were somewhat higher in both analyses (table 36). The outcome of the analyses correcting for uncertainties considering only the persons with small-cell lung cancer and considering only the persons with microscopically confirmed lung cancers of other types are summarized in the lower half of figure 9, and the original analyses, based on observed radon concentrations, are shown in the upper half of the figure for comparison.

As with the analyses based on the observed radon concentrations, there was no evidence of heterogeneity between the estimates of β in the three main smoking categories (table 34). The overall estimate of β obtained using the method of integrated likelihood (ie, 0.16, 95% CI 0.05–0.31) was therefore considered together with the risks of lung cancer relative to that of the lifelong nonsmokers for men, as given in table 3. This procedure suggested that, for lifelong nonsmokers, the risk of lung cancer increases by a factor of 2.3 (95% CI 1.4–3.5) as the corrected radon increases from 0 to 800 Bq/m^3. For current smokers of 15–24 cigarettes per day, the risks relative to that of lifelong nonsmokers were much higher, varying from 25.8 to 58.8, as the corrected radon concentration increased from 0 to 800 Bq/m^3, while, for ex-smokers of <10 years' duration, the risks varied from 20.8 to 47.5 as the corrected radon concentration increased from 0 to 800 Bq/m^3, and, for ex-smokers of ≥10 years' duration, the risks increased from 5.0 to 11.4 as the corrected radon concentration increased from 0 to 800 Bq/m^3 (table 37 and figure 10).

Using the methods described in "Combined Effect of Smoking History and Radon Exposure on Lung Cancer Risk" in the Statistical Methods section, the cumulative risk of death from lung cancer for lifelong nonsmokers with a corrected radon concentration of 0 Bq/m^3

Table 36. Mean observed and corrected radon concentrations by categories of observed radon concentration and histological type of lung cancer.

Observed radon concentration [a]	Cases (N)	Controls (N)	Mean observed radon concentration [a] (Bq/m^3)	Mean corrected radon concentration [b] (Bq/m^3)
Small-cell lung cancer				
<25 Bq/m^3	123	1 474	17	21
25–49 Bq/m^3	385	3 905	38	41
50–99 Bq/m^3	518	5 033	71	68
100–199 Bq/m^3	235	2 247	135	119
200–399 Bq/m^3	94	936	275	240
≥400 Bq/m^3	24	613	668	487
All concentrations	1 379	14 208	..	..
Other microscopically confirmed				
<25 Bq/m^3	389	1 474	17	21
25–49 Bq/m^3	1 479	3 905	39	42
50–99 Bq/m^3	1 863	5 033	71	68
100–199 Bq/m^3	894	2 247	136	119
200–399 Bq/m^3	235	936	273	235
≥400 Bq/m^3	71	613	651	473
All concentrations	4 931	14 208	..	..

[a] Observed radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there.
[b] Corrected radon concentration after uncertainties in the assessment of radon concentrations were taken into account.

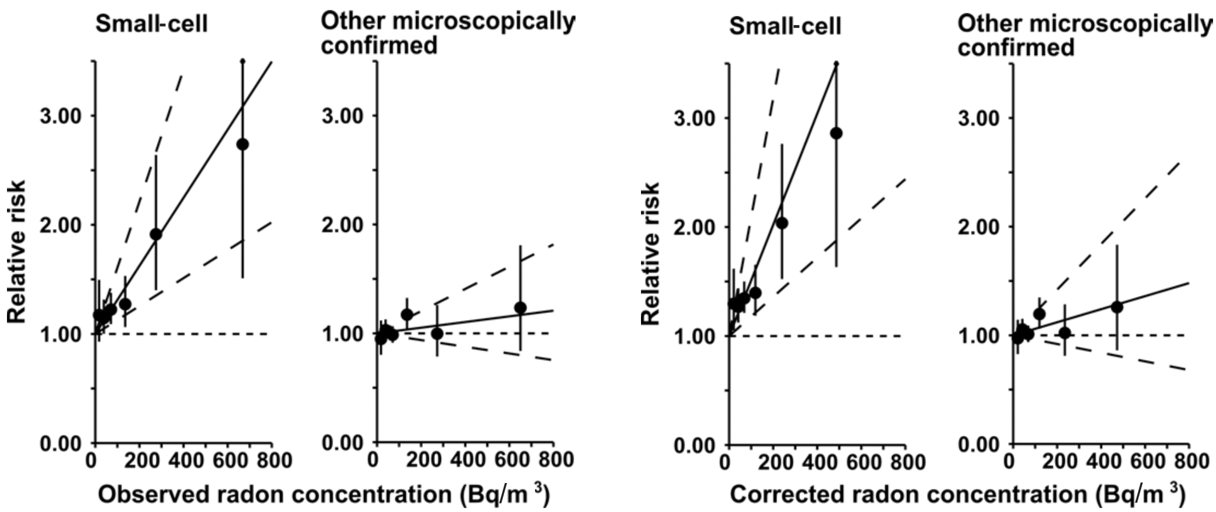

Figure 9. Relative risk of lung cancer according to the time-weighted average observed residential radon concentration (top) and the time-weighted average corrected residential radon concentration (bottom) by histological type. The relative risks and 95% floated confidence intervals are shown for the categorical analyses, as are the estimated linear relationships (solid lines) and 95% confidence intervals (dashed lines). (See figure 7 for additional methodological details.)

Table 37. Risk of lung cancer relative to lifelong nonsmokers with no radon exposure by corrected radon concentration for various smoking categories. (95% CI = 95% confidence interval)

Corrected radon concentration [a]	Relative risk[b]	95% CI
Current cigarette smokers (15–24 per day)		
0 Bq/m³	25.8	..
100 Bq/m³	29.9	27.1–33.8
200 Bq/m³	34.0	28.3–41.7
400 Bq/m³	42.3	30.9–39.3
800 Bq/m³	58.8	36.1–89.7
Ex-smokers (<10 years)		
0 Bq/m³	20.8	..
100 Bq/m³	24.2	21.9–27.3
200 Bq/m³	27.5	22.9–33.8
400 Bq/m³	34.2	25.0–46.7
800 Bq/m³	47.5	29.2–72.5
Ex-smokers (≥10 years)		
0 Bq/m³	5.0	..
100 Bq/m³	5.8	5.2–6.5
200 Bq/m³	6.6	5.5–8.1
400 Bq/m³	8.2	6.0–11.2
800 Bq/m³	11.4	7.0–17.4
Lifelong nonsmokers		
0 Bq/m³	1.0	..
100 Bq/m³	1.2	1.1–1.3
200 Bq/m³	1.3	1.1–1.6
400 Bq/m³	1.6	1.2–2.2
800 Bq/m³	2.3	1.4–3.5

[a] Radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there and corrected for uncertainties in the assessment of radon concentrations.
[b] Risk of lung cancer relative to that of lifelong nonsmokers with a 0 Bq/m³ radon concentration. Risks for smokers of 15–24 cigarettes per day, ex-smokers of <10 and ≥10 years' duration relative to that of lifelong nonsmokers assumed to be 25.8, 20.8, and 5.0, respectively (see table 3), regardless of the radon concentration. Relative risks of lung cancer assumed to increase by 0.16 (95% CI 0.05–0.30) per 100 Bq/m³ regardless of smoking status.

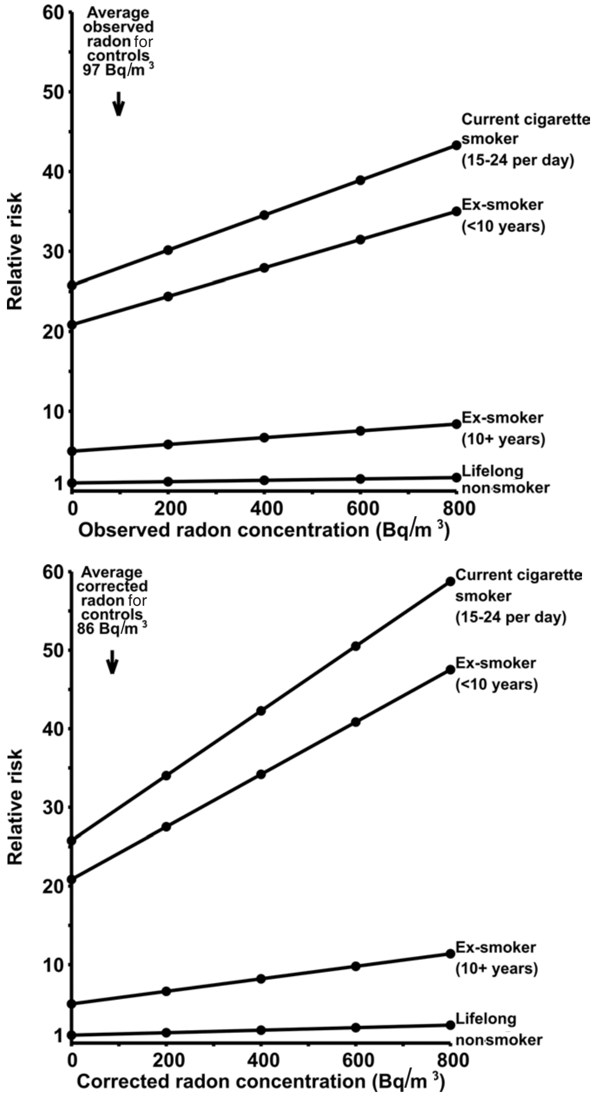

Figure 10. Risk of lung cancer relative to that of lifelong nonsmokers with no radon exposure by the observed radon concentration (top) and the corrected radon concentration (bottom).(See tables 28 and 37 for the methodological details.)

was estimated to be 0.41% by the age of 75 years, increasing to 0.78% by the age of 85 years. For lifelong nonsmokers with corrected radon concentrations of >0 Bq/m³, the cumulative risks of death were somewhat greater, but even at a corrected radon concentration of 800 Bq/m³, the risk rose only to 0.93% (95% CI 0.57–1.42) by the age of 75 years and to 1.78% (95% CI 1.10–2.70) by the age of 85 years (table 38 and figure 11). For continuing smokers of 15–24 cigarettes per day, not only was the cumulative risk of death from lung cancer at a corrected radon concentration of 0 Bq/m³ much higher, at 10.11% by the age of 75 years and increasing to 18.51% by the age of 85 years, but the increase in the cumulative risk with an increasing corrected radon concentration was also substantially higher—by the age of 75 years, the cumulative risks associated with corrected radon concentrations of 100, 200, 400, and 800 Bq/m³ were 11.63% (95% CI 10.59–13.03), 13.12% (95% CI 11.06–15.85), 16.03% (95% CI 12.00–21.23%), and 21.57% (95% CI 13.86–30.98), respectively. By the age of 85 years these values had risen substantially further, to 21.13% (95% CI 19.34–23.52), 23.67% (95% CI 20.16–28.22), 28.51% (95% CI 21.77–36.77), and 37.29% (95% CI 24.91–50.94), respectively. As with the analyses based on the observed radon concentration, for those who gave up smoking, the relative risks in the first 10 years were about 80% of those for continuing smokers (table 37). Therefore, the cumulative risks for the ex-smokers would also be about 80% of those for continuing smokers during the first 10 years after having stopped smoking. Beyond this time, they would be lower than the proportion of risks for

Table 38. Cumulative risk (%) of death from lung cancer by age for lifelong nonsmokers and continuing smokers of 15–24 cigarettes per day at various levels of radon concentration after correction for uncertainties in the assessment of radon concentrations.[a] (95% CI = 95% confidence interval)

Age	Lifelong nonsmokers		Continuing smokers of 15–24 cigarettes per day	
	Cumulative risk	95% CI	Cumulative risk	95% CI
No radon exposure				
75 years	0.41	..	10.11	..
80 years	0.57	..	13.84	..
85 years	0.78	..	18.51	..
Corrected radon concentration of 100 Bq/m³				
75 years	0.47	0.43–0.54	11.63	10.59–13.03
80 years	0.66	0.60–0.75	15.87	14.48–17.73
85 years	0.91	0.82–1.03	21.13	19.34–23.52
Corrected radon concentration of 200 Bq/m³				
75 years	0.54	0.45–0.66	13.12	11.06–15.85
80 years	0.75	0.63–0.92	17.85	15.11–21.44
85 years	1.03	0.86–1.27	23.67	20.16–28.22
Corrected radon concentration of 400 Bq/m³				
75 years	0.67	0.49–0.91	16.03	12.00–21.23
80 years	0.94	0.69–1.27	21.67	16.37–28.37
85 years	1.28	0.94–1.75	28.51	21.77–36.77
Corrected radon concentration of 800 Bq/m³				
75 years	0.93	0.57–1.42	21.57	13.86–30.98
80 years	1.30	0.80–1.97	28.79	18.82–40.45
85 years	1.78	1.10–2.70	37.29	24.91–50.94

[a] Absolute risk of lung cancer for lifelong nonsmokers taken from the prospective study of the American Cancer Society. Relative risk of lung cancer for continuing smokers of 15-24 cigarettes per day assumed equal to the overall estimates in the present study (see table 3). Relative risk of lung cancer assumed to increase by 0.16 (95% CI 0.05–0.31) per 100 Bq/m³ increase in the time-weighted average observed radon concentration (see table 31).

continuing smokers, but there were insufficient persons in the present study who were ex-smokers of 10–19, 20–29, and so forth years' duration to calculate specific estimates of cumulative risk.

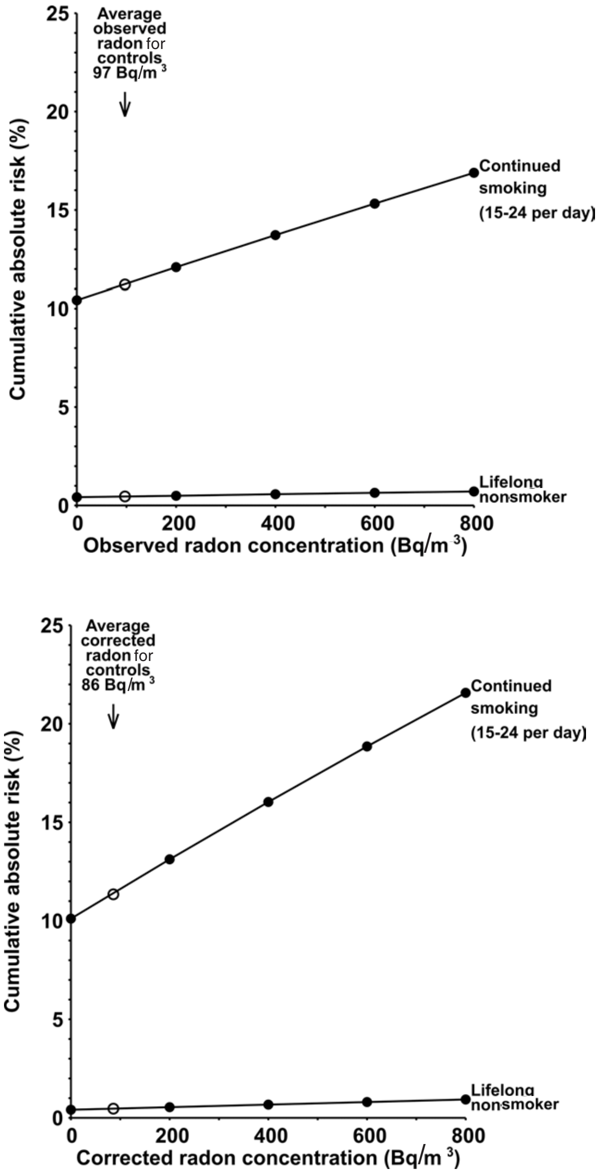

Figure 11. Cumulative risk of death from lung cancer by 75 years of age for various smoking histories by the observed radon concentration (on the left) and the corrected radon concentration (on the right). (See tables 29 and 38 for the methodological details.)