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LUNG CANCER RISK ATTRIBUTABLE TO INDOOR RADON IN A HIGH RADON POTENTIAL REGION OF FRANCE

O. Catelinois[a], F. Clinard[b], K. Aury[b-c], P. Pirard[a], L. Noury[d], A. Hochard[e], C. Tillier[b]

[a] *Institut de Veille Sanitaire - Saint Maurice*
[b] *Cire Centre-Est - Dijon*
[c] *Centre d'Epidémiologie de Population - Registre dijonnais des AVC - Dijon*
[d] *Direction Régionale des Affaires Sanitaires et Sociales de Franche-Comté - Besançon*
[e] *Observatoire Régional de la Santé de Franche-Comté - Besançon*

Abstract

Awareness of the health risks due to exposure to indoor radon has raised concern about its impact in the general population. Using all available epidemiologic results, our goal is to accurately estimate this risk based on data collected in a high radon potential region of France (Franche-Comté). For this study, we considered exposure (response relations derived from cohorts of miners and from joint analyses of residential case) from various control studies. The exposure data come from a representative measurement campaign conducted in Franche-Comté. The estimated number of lung cancer deaths attributable to indoor radon exposure in this region ranges from 72 to 139, depending on the model considered. The attributable risk is higher in granitic area (22 to 39% for 7 to 12 deaths) but the number of deaths is higher in sedimentary area (65 to 127 deaths for 13 to 26%). Although indoor radon concentrations are higher in granitic area, the public health impact is more important in sedimentary area because of higher population density.

Introduction

The French National Institute of Heath Survey (InVS) recently estimated that 1,000 to 3,000 lung cancer deaths a year may be attributable to radon exposure (Catelinois *et al.*, 2007). In the regions where radon is a potential issue, an accurate assessment of its health impact is important to inform, to sensitize the population and to target actions of risk prevention.

According to the French National Radon Measurement Campaign performed between 1984 and 1999, Franche-Comté is a French region particularly concerned with radon. But this nation-wide designed study, relying on measurements realized in volunteers' houses, may not be the best way to assess with accuracy the number of cancer deaths attributable to radon exposure. In fact, the National Campaign was designed to ensure a homogeneous geographic distribution of the measurements (the country was divided into grids of 40 km^2) with at least one measurement per grid. Grids that included municipalities with more than 1,500 inhabitants had a second measurement taken in a different location. Volunteers were mainly recruited through contacts in the local governments, which placed and collected the radon detectors. Therefore, data collected in Franche-Comté during this period were not very numerous and perhaps not representative of the various housing types. A more specific design developed for Franche-Comté could be more efficient to assess indoor radon exposure in the region.

Objective

The first goal of this study was to assess the lung cancer death risk due to indoor radon exposure in Franche-Comté, using a specific radon exposure assessment. A secondary objective was to compare the results of this assessment with those obtained using the French National Radon Measurement Campaign already available for all French regions.

Subjects and methods

Study setting

Franche-Comté is a mountainous region situated in NE France bordered to the East by Switzerland. The 16,202 Km² region has three towns which concentrated 50% of the population in 28% of the surface area with half of the region being wooded. Franche-Comté is divided in 4 administrative areas (*departments*): Doubs, Jura, Haute-Saône and Territoire de Belfort.

Identification of the population

According to the 1999 French National Institute of Statistics and Economics (INSEE, 2000) census, the total Franche-Comté population consisted of 1,117,257 people. The sex ratio was close to 1 ; 25% were younger than 20 years, 54% were 20–59 years, 14% were 60–74 years, and 7% were older than 75 years. Of this population, according to the French Institute of Health and Medical Research (INSERM; Paris, France), 512 people died of lung cancer (437 men and 75 women) in 1999.

Radon exposure assessment

Sample scheme

The study aimed to be based on a representative sampling of dwellings of the Franche-Comté region. This was achieve through the database of the French National Telecommunications Operator (*France-Telecom*) which allowed access to the address of most of the population for constructing the sampling frame (Until 2002, *France-Telecom* was the only operator in charge of dwelling connections to the telecommunication network in France). The designated sample size was 452 dwellings, equivalent to 1 detector per 1,000 homes. The sample was stratified by the geological structure (defined for each of the 1,786 districts of Franche-Comté according to geological maps – Genay, 2005) and by the type of housing (detached houses or blocks of flats). The distribution of the 452 dwellings selected is shown in Figure 1

Questionnaire development and interviewing procedures

Questionnaires were developed by the France-Comté Study staff using the experiences of the National Radon Measurement Campaign (IRSN, 2000) and the French Indoor Air Quality Observatory (OQAI, 2003). Up to 7 attempts were made to obtain an answered call for each sampled telephone number. Data were collected by 3 trained interviewers during face-to-face interviews in October and November 2005. Dwelling and household characteristics were collected using standardized questionnaires. The data provided information about demographic characteristics, residential and smoking habits, and technical characteristics of the dwelling like surface area, number of room, building materials and ventilation. Indoor radon measurements were carried out using 2 Kodalpha LR 115 detectors placed in a randomly selected bedroom and in the living-room for 2 months.

Statistical analysis

The number of lung cancer deaths due to indoor radon exposure was estimated in a four-stage process: identification of the population, choice of the exposure-response relations, radon exposure assessment, and characterization of lung cancer risk. As described above, data on population and lung cancer deaths were provided respectively by the French National Institute of Statistics and

Economics and the French Institute of Health and Medical Research. Concerning the choice of exposure-response relations, we used results obtain through two major epidemiologic studies: the joint analysis of 11 cohorts of miners (BEIR 1999) and the joint analysis of 13 European case–control studies (Darby *et al.* 2005). They have been resumed in a recent paper (Catelinois *et al.*, 2006).

Because, indoor radon measurements vary with season (they are highest in winter and lowest in summer), corrections for seasonal variation was required for the 2-month measurements in order to estimate annual exposure. To obtain these seasonal correction factors, the model developed by Pinel *et al.* (1995) was applied to the French database of indoor radon measurements.

Application of the exposure–response relations mentioned above necessitates knowledge of the number of spontaneous deaths from lung cancer (*i.e.*, apart from radon exposure). It was assumed that most of the 512 lung cancer deaths observed in 1999 were probably due to smoking, with some attributed to indoor radon alone, while others to the interaction between smoking and indoor radon, and the remainder to such other risk factors as air pollution and occupational exposure (Darby *et al.* 2001). To estimate the number of lung cancer deaths attributable to indoor radon exposure, we applied the data described above to the following formula: $N_{r, a, d, s} = (RR_{r,a} \times N_{a, d, s})/(1 + RR_{r,a})$, where $N_{r, a, d, s}$ is the number of lung cancer deaths due to indoor radon exposure at age *a*, in district *d* and for sex *s*. $RR_{r,a}$ is the relative risk for age *a*, and radon exposure *r*. $N_{a, d, s}$ is the total number of lung cancer deaths at age *a* in district *d* and for sex *s*. Calculations were carried out by age, gender, and administrative areas (*departments*).

Results

The Franche-Comté radon measurement campaign

A total of 907 households were invited to participate. About 50% of those accepted with minor differences between strata (54.2% for the granitic dwelling stratum, 49.8% for detached houses and 47.7% for flats established on sedimentary geology). Few variables, both available in the Franche-Comté study and in the 1999 National French Census (INSEE, 1999), have been used to search a possible selection bias. Participants did not differ from the inhabitants of Franche-Comté in term of age, gender, social and occupational group (data not shown). The dwellings of the participant households were also comparable to the Franche-Comté dwelling park in term of age of construction, number of rooms in the dwellings and renter / landlord status of the occupants. Therefore, a post-stratification strategy, initially considered, was not performed.

Comparison between the National Radon Measurement Campaign and the Franche-Comté Study

Table 1 lists a comparison between Franche-Comté measurements extracted from the National Radon Measurement Campaign in France and the present Franche-Comté Study. In the former study, measurements were performed in three different types of room with a majority in the living-room. Although the place of measurement and the period of measurement differ in the two studies, distributions of radon concentration were quite similar. Indoor radon measurements were slightly lower in the Franche-Comté Study: arithmetic means were 138.2 and 134.0 Bq/m^3 respectively for the National Campaign and for the Franche-Comté Study, and geometric means were 88.3 and 79.6 Bq/m^3.

Estimates of lung cancer deaths attributable to indoor radon exposure in Franche-Comté

Table 2 shows the estimated number of lung cancer deaths attributable to indoor radon exposure using 2 datasets of indoor radon measurements (the French National Radon Measurement Campaign and the Franche-Comté Study) and 3 exposure-response relationships. Depending on the risk model used, the total number of lung cancer deaths ranged from 72 to 174. The calculations suggest that of the 512 lung cancer deaths in 1999 in Franche-Comté, 8% to 34% may be attributed to indoor radon exposure. The model obtain from the joint analysis of the European case-control studies (Darby, 2005), produced the fewest attributable deaths, the age-duration BEIR VI model the most. Although the proportion of lung cancer deaths varied from 13% to 26% in sedimentary areas (*vs.* 23% to 40% in granitic areas) depending to the risk model, 65 to 127 lung cancer deaths were expected *vs.* only 7 to 12 in granitic areas.

Discussion

This is the first study in France providing radon concentration measurements based on a representative sampling of dwellings. This particular design allowed us to calculate with accuracy the number of lung cancer deaths attributable to indoor exposure in a high level indoor radon area. The results indicate that Franche-Comté is a high radon-emission area, even in the sedimentary zone. Using the risk assessment method proposed by the NRC (Covello and Merkho, 1993 ; NRC, 1983) we estimated the number of lung cancer deaths in France in 1999 attributable to indoor radon exposure. The consideration of several different exposure-response relations, which come from either cohorts of miners or residential case-control studies, allowed us to compare estimates of attributable deaths based on various exposure-response relations. We also considered the variability of indoor radon exposure between and within sedimentary and granitic areas of Franche-Comté.

Over the past two decades, many epidemiologic studies, mainly cohorts of miners and case–control studies in the general population, have estimated the lung cancer risk associated with radon exposure. Because miners are generally exposed to higher levels than the general population, using miners' data for assessing risks in general population clearly raises methodological issues, especially those related to the extrapolation of risk from high to low exposure and the transposition of risk estimates from miners to the general population (BEIR 1999). Although the radon hazard is no longer subject to debate, the use of risk models based on occupational exposure to assess the lung cancer risk attributable to indoor radon exposure is rightfully still considered a problem.

In this risk assessment, the number of lung cancer deaths due to indoor radon exposure is relatively stables regardless the exposure-response relation used. Nevertheless, as in the risk assessment performed for the entire of France, risk estimates obtained from miner studies appear conservative. Lung cancer deaths due to indoor radon exposure can be considered premature because approximately half occur before the age of 70 years. We did not calculate the number of years of lost life, but given the long life expectancy in France, this figure may be quite high; management of the risk due to radon is clearly a major public health issue in France.

Of the 512 lung cancer deaths in Franche-Comté during 1999, indoor radon probably caused 13-26% whereas 5-12% of lung cancer deaths were attributable to radon exposure in all of France. Our results must be interpreted according to the number of people in each geological category. Although 23 to 40% of lung cancer deaths were attributable to radon in granitic areas, granitic areas represent only 5% of the population and 9% of lung cancer deaths: most of lung cancer deaths attributable to radon will occur in sedimentary areas. Actions of risk prevention should not be only focused on granitic territories.

Conclusion

This study is the first lung cancer risk assessment associated with residential radon exposure in Franche-Comté. When we consider uncertainties related to the exposure–response relation and geographic variations in radon exposure, we find that the total number of lung cancer deaths in

1999 attributable to indoor radon exposure ranges from 72 to 140. Most of them will occur in sedimentary areas sometimes regarded as zones of low radon risk. Awareness and risk prevention campaigns against radon hazard could not be turn only to the most exposed people in granitic areas, but should rather concern the overall population of the Region.

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Figure 1: Sampling scheme of the Franche-Comté Study

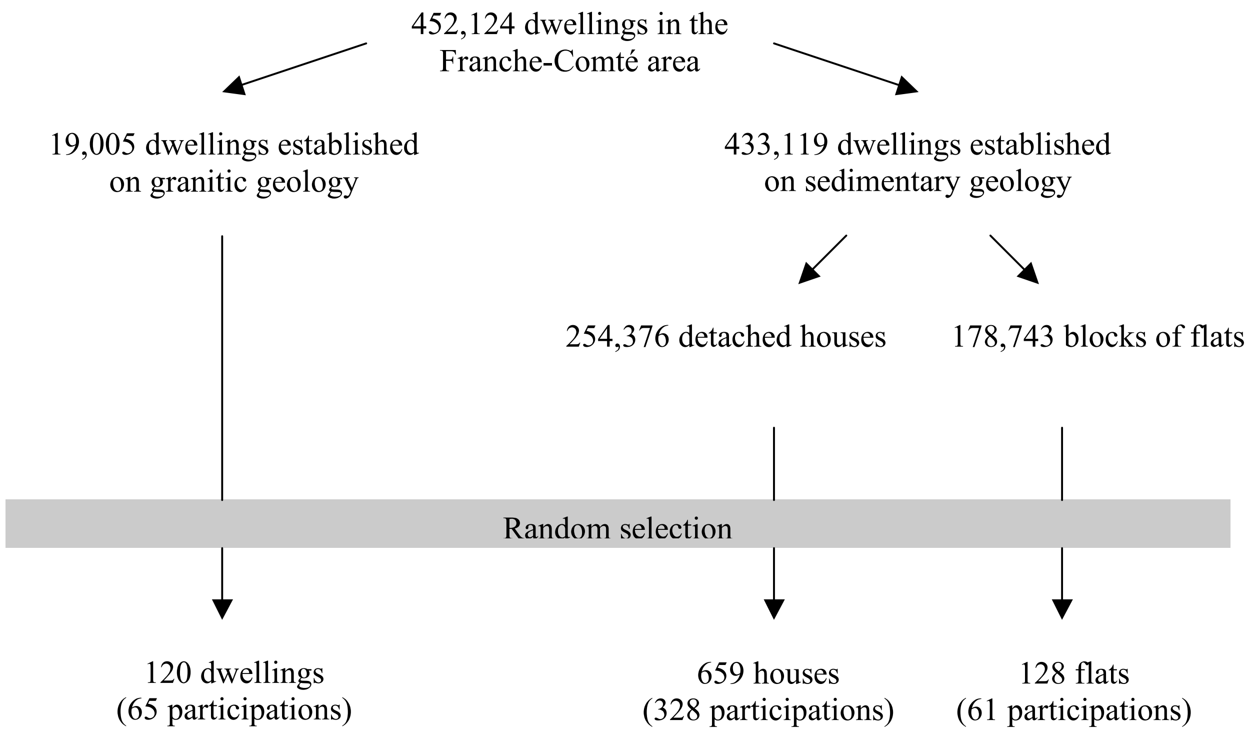

Table 1: Comparison of Franche-Comté measurements extracted from the National Radon Measurement Campaign and the Franche-Comté Study.

	National Radon Measurement Campaign (1984 – 1999) (volunteers)		Franche-Comté Study (oct. & nov. 2005) (random selection of dwellings)	
	N	(%) or [95%CI]	N	(%) or [95%CI]
No. of administrative areas	249		306	
No. of measurements	318		869	
No. of m. in a bedroom	27	(8.5%)	436	(50.2%)
No. of m. in a living-room	202	(63.5%)	433	(49.8%)
No. of m. in an other room	88	(27.7%)	0	(0.0%)
Arithmetic mean [95%CI]	138.2	[121.2 - 155.2]	134.0	[121.3 - 146.7]
Geometric mean [95%CI]	88.3	[81.0 - 96.2]	79.6	[74.7 - 84.8]
No. of m. upper than 200 Bq/m^3	52	(16.3%)	203	(23.4%)
No. of m. upper than 400 Bq/m^3	20	(6.3%)	79	(9.1%)
No. of m. upper than 1000 Bq/m^3	3	(0.9%)	12	(1.4%)

N: number of dwellings
95% CI: 95% confidence interval of the mean

Table 2: Comparison of the estimates of lung cancer deaths attributable to indoor exposure in Franche-Comté in the French National Radon Measurement Campaign and the Franche-Comté Study

	French National Radon Measurement Campaign			Franche-Comté Study		
	Male	Female	Total	Male	Female	Total
No of total lung cancer deaths (1999)	437	75	512	437	75	512
No of total lung cancers attributable to indoor radon exposure						
Study of miners						
EAD	147	27	174	93	17	110
EAC	126	23	149	118	21	139
Indoor study						
Darby				61	11	72
Proportion of lung cancers attributable to indoor radon exposure						
Study of miners						
EAD	34%	36%	34%	21%	23%	21%
EAC	29%	31%	29%	27%	29%	27%
Indoor study						
Darby				14%	14%	14%

EAD: Exposure-age-duration model BEIR VI (BEIR, 1999)
EAC: Exposure-age-concentration model BEIR VI (BEIR, 1999)
Darby: Raw risk model from the joint analysis of the13 European case-control studies (Darby, 2005)

Table 3: Estimates of lung cancer deaths attributable to indoor exposure in sedimentary and granitic areas of Franche-Comté. (Indoor radon measurements from the Franche-Comté study)

	Sedimentary structure	Granitic structure	Total
No of total lung cancer deaths (1999)	482	30	512
No of total lung cancers attributable to indoor radon exposure			
Study of miners			
EAD	100	10	110
EAC	127	12	139
Indoor study			
Darby	65	7	72
Proportion of lung cancers attributable to indoor radon exposure			
Study of miners			
EAD	21%	33%	21%
EAC	26%	40%	27%
Indoor study			
Darby	13%	23%	14%

EAD : Exposure-age-duration model BEIR VI (BEIR, 1999)
EAC : Exposure-age-concentration model BEIR VI (BEIR, 1999)
Darby : Raw risk model from the joint analysis of the13 European case-control studies (Darby, 2005)