THE USE OF INDOOR RADON MEASUREMENTS AND GEOLOGICAL DATA IN ASSESSING THE RADON RISK OF SOIL AND ROCK IN CONSTRUCTION SITES IN TAMPERE

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ABSTRACT

We have developed a model which allows us to use indoor radon measurements in assessing the radon availability of soil and rock in construction sites. The effect of the geological nature of the construction site on indoor radon is distinguished from the construction effects of the house. The purpose is to divide the investigated area into more or less homogeneous subareas and calculate the percentages of houses exceeding 200 and 800 Bq/m^3 in future homes where no precautions have been taken against radon.

In this study we used 867 indoor radon measurements from the city of Tampere (population 171,000). They were two-month-average concentrations measured in winter. The soil and rock type for each house was determined on the basis of geological maps, the structure of the buildings according to questionnaire responses.

A radon prognosis was made for four different construction sites. For each group of contruction sites, Tampere was divided into 1-2 different subareas. Within each subarea, the assessments were also made for different foundation and rock types.

INTRODUCTION

In Finland, most indoor radon measurements are performed by the Finnish Centre for Radiation and Nuclear Safety (STUK). We keep the local authorities up to date and help them find affected areas. The means offered by the STUK are an alfa track measurement service, measurement plans and prognosis maps. We also collect information about houses where the radon level has been measured. To date we have collected a database of more than 23,000 indoor radon measurements in houses with known coordinates. Figure 1 shows the geographical distribution of indoor radon concentration in Finland.

We have constructed a model which allows us to use these measurements in assessing the radon availability of soil and rock in the contruction site. So far we have used this model for six regions. Tampere is an example of a location with wide range of indoor radon levels in a rather small area. The study area is shown in Figure 1.

MATERIALS

Since 1983 we have measured indoor radon concentrations in Tampere. Most of the measurements were made according to STUK's measurement plan. For this study we used data pertaining to 867 houses. All the measurements were performed in the lowest residential story of houses during a two-month period in winter. The measured radon concentrations were corrected to annual means (1).

Because the main purpose of our measurements was to determine which areas were affected most of the measurements were made in areas where we expected a high risk of radon. The most radon-critical areas in Finland are ususally eskers. They are long and narrow, steep-sided ridges formed by glacial rivers. Their composition of stratified sand and gravel makes them permeable to water and air. The esker running through the center of tampere has thus been investigated almost completely. We have made fewer measurements in other parts of Tampere, but we think that the findings represent the population distribution and different construction sites fairly well.

Data concerning the building stucture were collected from questionnaires filled out by the residents. The soil and rock types of the construction site were determined from maps of gravel and sand resources on a scale 1:20,000 and from other geological maps on a scale 1:100,000. Information about whether or not the house was built on rock was collected from the questionnaires. 14% of the houses were built on rock, 8% on moraine, 17% on clay and silt, 53% on eskers, and 8% on other sand and gravel formations.

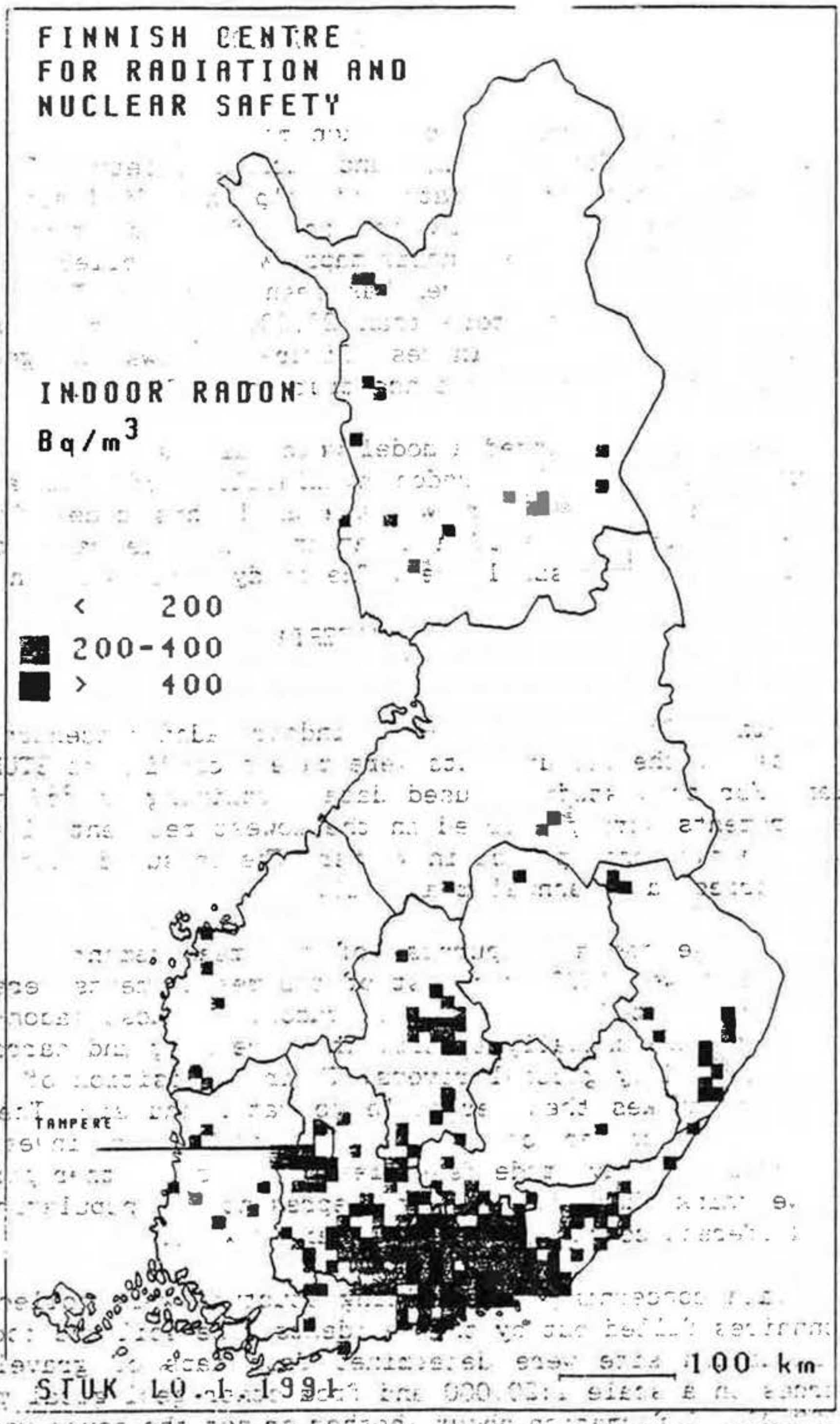

Figure 1. The indoor radon concentration has been measured in 23,000 dwellings in Finland. The square (10 x 10 km) on the map shows the arithmetic mean of the annual concentrations. The minimum is two measurements per square.

METHODS

The factors affecting the indoor radon concentration are: the uranium concentration of the ground, the permeability of the ground, the leakage of air from the soil through the building structure, and the ventilation rate. Because these factors were not measured, we replaced them by known class parameters. The factors were considered multiplicative and by logarithmizing them made it possible to use a linear model. To determine the influence of the building site on the indoor radon consentration, the effect of the building structure was adjusted for by means of a statistical model (2,3).

The resistance of the building structure to the leakage of soil air depends on the foundation type. The foundations of the houses under study were classified into four different groups. The type with the most leakage, which is also the most common type in Finland, is a slab-on-grade laid inside the foundation walls. Air from the soil can easily penetrate through the joints between the floor and the walls. The foundations which leak least are those in houses with a crawl space and those built on a slab with thickened edges. The latter is quite radon safe, because the slab usually has not joints or openings. The fourth foundation type is a house with a basement.

The year of construction is correlated, among other things, with the ventilation and with the type of construction. In modern houses, the air exchange rate is lowest and therefore the indoor radon concentration is highest. The year of construction is also associated with the type of foundation. The houses were divided into three classes: houses built before 1950, those built in 1950-1969 and those built in 1970 or after.

The type of soil at the construction site describes the permeability of the ground. Esker (gravel and sand) is the most permeable and clay and unbroken rock are the least permeable.

The parameters correlating with the uranium concentration are the geographical area and the rock type. The rock types were classified into three groups on the basis of their uranium concentration and the measured indoor radon concentrations, group 1 being low, group 2 intermediate and group 3 high. Most of the rocks in Tampere belong to group 2, the intermediate group.

After testing several combinations of parameters, we found it practical to make three different models concerning houses built on rocks, eskers, and other soil types. To draw the boundaries of the subareas, the model was used to assess the construction factors. The adjusted concentrations were drawn on a map, and they were used to divide Tampere into more or less homogeneous subareas. When using an assumption of a lognormal distribution, the percentages of houses exceeding 200 and 800 Bq/m^3 in future homes where no precautions have been taken against radon can be assessed for each subarea.

RESULTS AND DISCUSSION

THE PARAMETER ESTIMATES OF THE MODELS

In the model concerning the houses built on rock, the subarea, the rock type, and the year of construction proved to be statistically significant. In the model concerning houses built on clay, silt, moraine, and sand and gravel formations other than eskers, the subarea, the foundation type, and the year of construction proved to be statistically significant. In the esker model, only the subarea and the foundation type proved to be statistically significant. The parameter estimates for the three models are shown in Table 1.

Application of the model and the parameters of Table 1 to a house with a slab with thickened edges built in the 1980s on clay in the lowest subarea 3 yields a geometric mean concentration of 1.26 x 1.00 x 0.62 x 139 Bq/m^3 = 109 Bq/m^3. Similarly, a house built in 1950s on aplite granite rock in subarea 2 results in a radon concentration of about 0.59 x 1.00 x 1.00 x 319 Bq/m^3 = 188 Bq/m^3.

RADON RISK OF SUBAREAS

The boundaries of subareas and the geographical distribution of measurements are shown in figures 2-5. It is worth noting that each subarea number indicates only a certain soil type in the area involved. Tables 2-4 show the assessments, made according to these models, for the percentages of houses exceeding 200 Bq/m^3 and 800 Bq/m^3.

The highest risk for radon in Tampere is on the top and on the upper slopes of the esker ridges. If conventional building structures were used there, about 90% of the houses would have an indoor air radon concentration above 200 Bq/m^3 and in over 50% of the houses it would exceed 800 Bq/m^3.

The lowest risk for radon occurs in houses built on rock in the central and northern parts of Tampere and in houses built on clay or silt in the center. In these areas and on these construction sites the estimates are that 10-30% would exceed 200 Bq/m^3, that radon levels exceeding 800 Bq/m^3 would be very rare (less than 0.1%).

The eskers in Tampere are perhaps the most radon-critical eskers in Finland. On the other hand, the radon risk on other construction sites in Tampere is only slightly higher than the average in Finland.

TABLE 1. PARAMETER ESTIMATES AND THEIR 95% CONFIDENCE LIMITS, THE MULTIPLE CORRELATION COEFFICIENT (R^2) AND THE GEOMETRIC DEVIATIONS (σ_g) FOR THREE DIFFERENT MODELS. MODEL 1 CONCERNS HOUSES BUILT ON ROCK, MODEL 2 HOUSES ON CLAY, SILT, MORAINE AND OTHER SAND FORMATIONS NOT ESKERS, AND MODEL 3 HOUSES ON ESKERS (GRAVEL AND SAND)

FACTOR	MODEL 1	MODEL 2	MODEL 3
R^2	0.37	0.34	0.29
σ_g	1.81	1.95	3.34
Constant (Bq/m^3)			
	319 (228,447)	139 (108,177)	183 (141,237)
Subareas:			
1	0.64 (0.50,0.83)		
2	1.00 -		
3		0.62 (0.49,0.78)	
4		0.97 (0.80,1.16)	
5		1.00 -	
6			4.77 (3.73,6.10)
7			1.00 -
Foundation types:			
A		1.64 (1.28,2.11)	
AB			1.00 (0.76,1.30)
B		1.26 (0.96,1.66)	
C		0.89 (0.52,1.51)	0.64 (0.45,0.92)
D		1.00 -	1.00 -
Rock groups:			
1	0.50 (0.30,0.82)		
2	0.61 (0.43,0.86)		
3	1.00 -		
Year of construction::			
<1950	0.62 (0.44,0.86)	0.85 (0.63,1.16)	
1950-1969	0.59 (0.44,0.80)	0.51 (0.40,0.64)	
>1969	1.00 -	1.00 -	

A = Slab-on-grade laid inside foundation walls
B = Slab with thickened edges
C = Crawl space
D = Basement
Rock group 1 = peridotite, amphibolite, tuffite, graywacke, uralite porphyrite and conglomerite.
Rock group 2 = granodiorite, granite, gabbro and veined mica gneiss.
Rock group 3 = phyllite, micaschist, acid tuffite, quartz-feldspar schist and aplite granite.

Figure 2: The boundaries of subareas 1 and 2 and the distribution of measurements made in houses built on rock.

Figure 3: The boundaries of subareas 3 and 4 and the distribution of measurement made in houses built on clay or silt.

Figure 4: The subarea 5 and the distribution of measurements made in houses built on moraine or sand formations other than eskers.

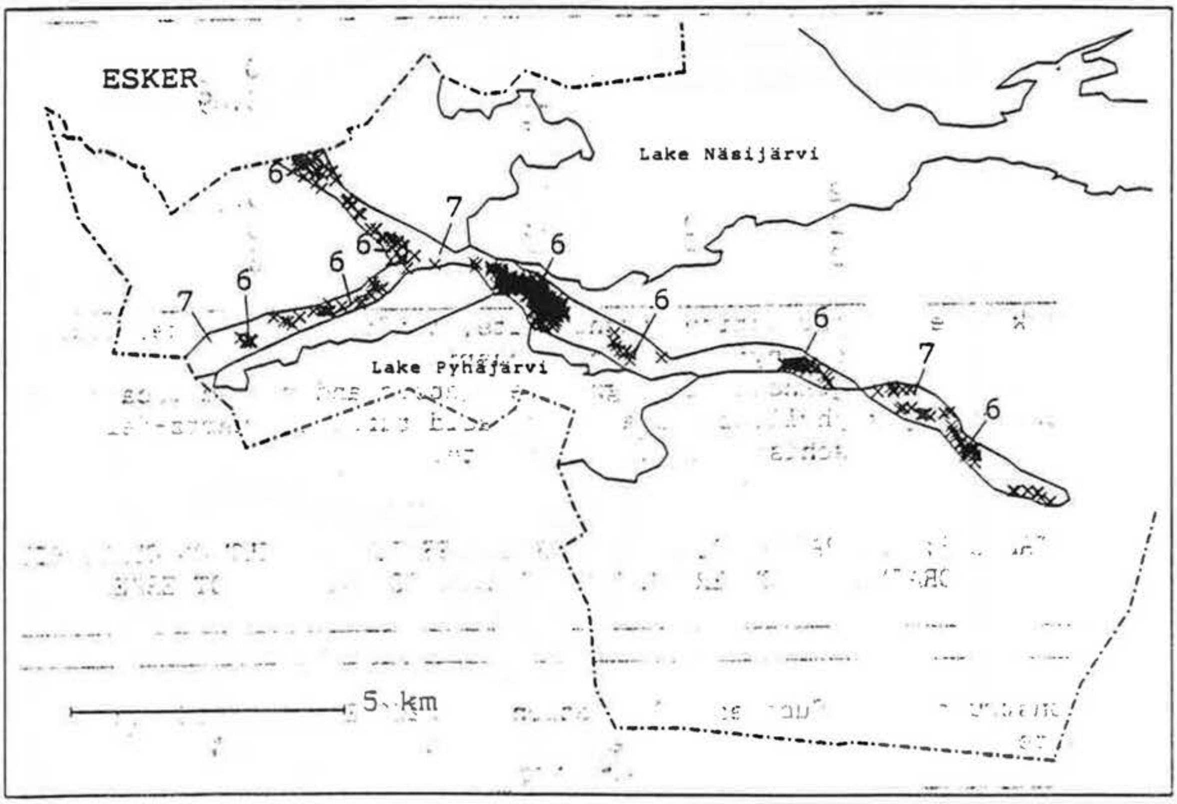

Figure 5: The boundaries of subareas 6 and 7 and the distribution of measurements made in houses built on gravel and sand in esker formations.

TABLE 2: THE RADON PROGNOSIS FOR HOUSES TO BE BUILT ON ROCK.

Construction site	Subarea	Rock type	>200 Bq/m^3 %	>800 Bq/m^3 %
Rock	1	1	13	0.03
	1	2	22	0.09
	1	3	55	1.4
	2	1	35	0.3
	2	2	48	0.9
	2	3	79	6.1

Rock type 1 = peridotite, amphibolite, tuffite, graywacke, uralite porphyrite and conglomerite.
Rock type 2 = granodiorite, granite, gabbro and veined mica gneiss.
Rock type 3 = phyllite, micaschist, acid tuffite, quartz-feldspar schist and aplite granite.

TABLE 3: THE RADON PROGNOSIS FOR HOUSES TO BE BUILT ON CLAY, SILT, MORAINE AND OTHER SAND AND GRAVEL FORMATIONS NOT ESKERS.

Construction site	Subarea	Foundation type	>200 Bq/m^3 %	>800 Bq/m^3 %
Clay and silt	3	A	30	0.5
	3	B	18	0.1
	3	D	10	0.04
	4	A	56	2.7
	4	B	40	1.0
	4	D	27	0.4
Moraine and other sand formations not eskers	5	A	58	3.0
	5	B	42	1.2
	5	D	29	0.4

A = Slab-on-grade laid inside foundation walls
B = Slab with thickened edges
D = Basement
Houses with a crawl space (only 7) are omitted.

TABLE 4: THE RADON-PROGNOSIS FOR HOUSES TO BE BUILT ON ESKERS.

Construction site	Subarea	Foundation type	>200 Bq/m³ %	>800 Bq/m³ %
Esker	6	A,B,D	89	53
	6	C	80	38
	7	A,B,D	47	11
	7	C	33	5.6

A = Slab-on-grade laid inside foundation walls
B = Slab with thickened edges
C = Crawl space
D = Basement

THE PRACTICE IN TAMPERE

The health authorities in Tampere received STUK's report a year ago (4). In addition to the radon prognosis, the report also included the boundaries of the affected areas and a plan for additional indoor radon measurements.

The only areas where the health and building authorities have required radon-safe constructions are the top and upper slopes of the eskers (subarea 6). Elsewhere they have notified individual builders, building companies and geotechnical planning companies of the radon risk of different subareas and construction sites. The authorities do not know whether or not precautions have been taken against radon in these areas. The health authorities are still considering whether they should require radon-safe constructions in some other subareas, too. In any case, the prognosis report, which contains a summary of all previous measurements, has proved useful.

COST-EFFECTIVENESS

The estimates of the radon availability of soil and rock in construction sites can be based on field measurements or previous indoor radon measurements. Although it may be easy to make accurate field measurements, the prediction of future indoor radon concentrations is uncertain.

Some 500-1,000 measurements are needed for the radon prognosis, which is based on indoor radon concentrations. The total cost, including compilation of the report and making all the measurements needed, is FIM 20,000-30,000 (USD 5,000-7,500). The cost of the field investigations for only one planning area may be as high. It would make good sence to compile radon prognosis reports for areas consisting of several municipalities.

CONCLUSIONS

The radon prognosis report is an easy way of getting information about the radon risk of future construction areas. The report is most reliable when it concerns construction near or within an existing settlement. The problem is that there is no general practice concerning which kind of radon-safe structures should be required in areas differing as to radon risk.

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