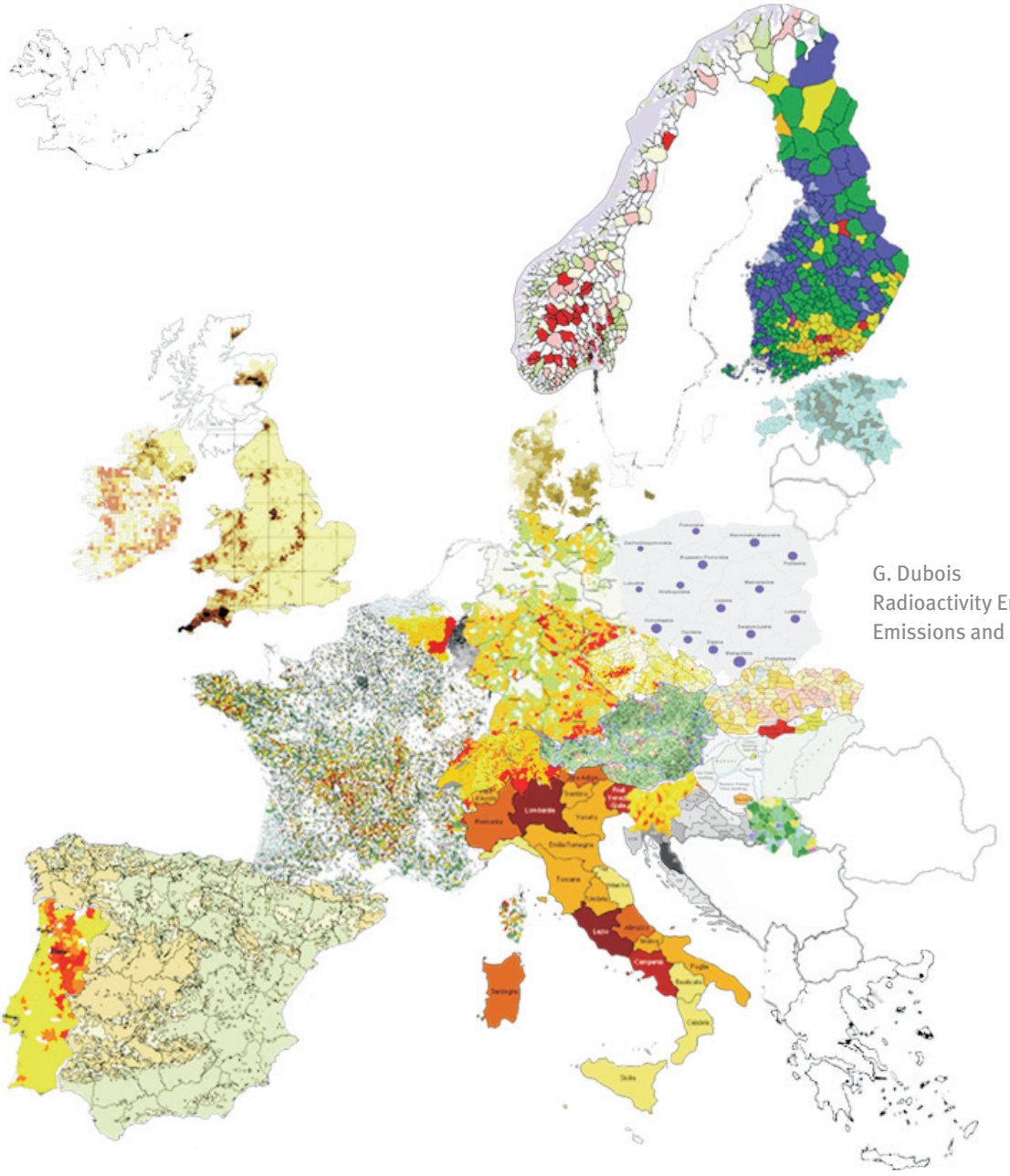
AN OVERVIEW

of

RADON SURVEYS IN EUROPE



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Joint Research Centre

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Preface

With the aim of preparing a European atlas of natural radiation, the Institute for Environment and Sustainability (IES) of the Directorate General Joint Research Centre (JRC) of the European Commission (EC) has conducted a European survey to assess the means and methods used by national authorities to describe radon levels in their countries.

Radon is a naturally radioactive gas that is, by far, the main contributor to the exposure received by the population from natural background radiation. It is also considered to be the main leading cause of lung cancer second to smoking, and most European countries have therefore adopted a number of regulations and made large efforts to identify radon-prone areas. Because indoor radon levels can fluctuate largely over short scale, establishing radon risk maps can become very difficult. It is the purpose of this report to explore the variety of the means and methods used in the European countries to measure and report radon levels.

By presenting the radon maps derived by the various authorities, this report should also help make its readers aware that part of their environment is also naturally radioactive.

Acknowledgements

This report was only possible thanks to the excellent collaboration of all the national authorities and contact persons whose names are indicated in the report. Our deepest gratitude also goes to the many researchers who provided useful advice, explanations, hints, addresses and references.

We would also like to thank our colleagues from the REM group and DG-TREN for their helpful suggestions.

Introduction

Radioactivity is everywhere in our environment and can thus be detected in the water we drink, in the food we ingest, in the air we breathe. Ionising radiation can have artificial or natural origins, and its relative contribution to the total dose we receive on the average per year is summarised in Table 1 [1]. By far, natural radiation is the main contributor to the total dose since less than 10% of the radiation we receive is man-made, from which 98% come from medical activities (diagnostics and therapy) (Figure 1).

In most circumstances, the naturally radioactive gas called radon (Rn^{222} isotope with a half-life of 3.8 days) is the major contributor to the total dose. This gas is produced by the radioactive decay of uranium which is an element that is naturally present in the earth's crust. Radon transports radioactivity mainly by diffusion mechanisms through the ground, and its concentration in our environment thus depends mainly on geological factors, soil texture, soil water content, and the pressure difference between the gas in the soil and at the surface. Relatively heavier than air, radon shows low concentrations outdoor but tends to be trapped in basements and the lower floors of buildings. For the same reasons, it is often found at high concentrations in mining galleries.

Because radon is considered to be the main contributor to lung cancer second to smoking, the European Commission constantly makes efforts to inform the public about this natural hazard. Recent studies [2] have shown that radon in homes causes about 20,000 lung cancer deaths in the European Union (EU) each year. This is about 9% of the total lung cancer deaths in the EU and about 2% of cancer deaths overall.

Table 1. Worldwide average annual effective doses at year 2000 from natural and man-made sources of radiation in millisievert (mSv) [1].

Source of radiation	Dose (mSv)	%
Natural background (total, all sources)	2.4	46.07
Inhalation (mainly radon)	1.2	23.04
Terrestrial gamma rays	0.5	9.60
Cosmic rays	0.4	7.68
Ingestion	0.3	5.76
Medical diagnostics	0.4	7.68
Atmospheric nuclear testing	0.005	0.10
Chernobyl accident	0.002	0.04
Nuclear power production	0.002	0.04
Total doses / year	5.209	100.00

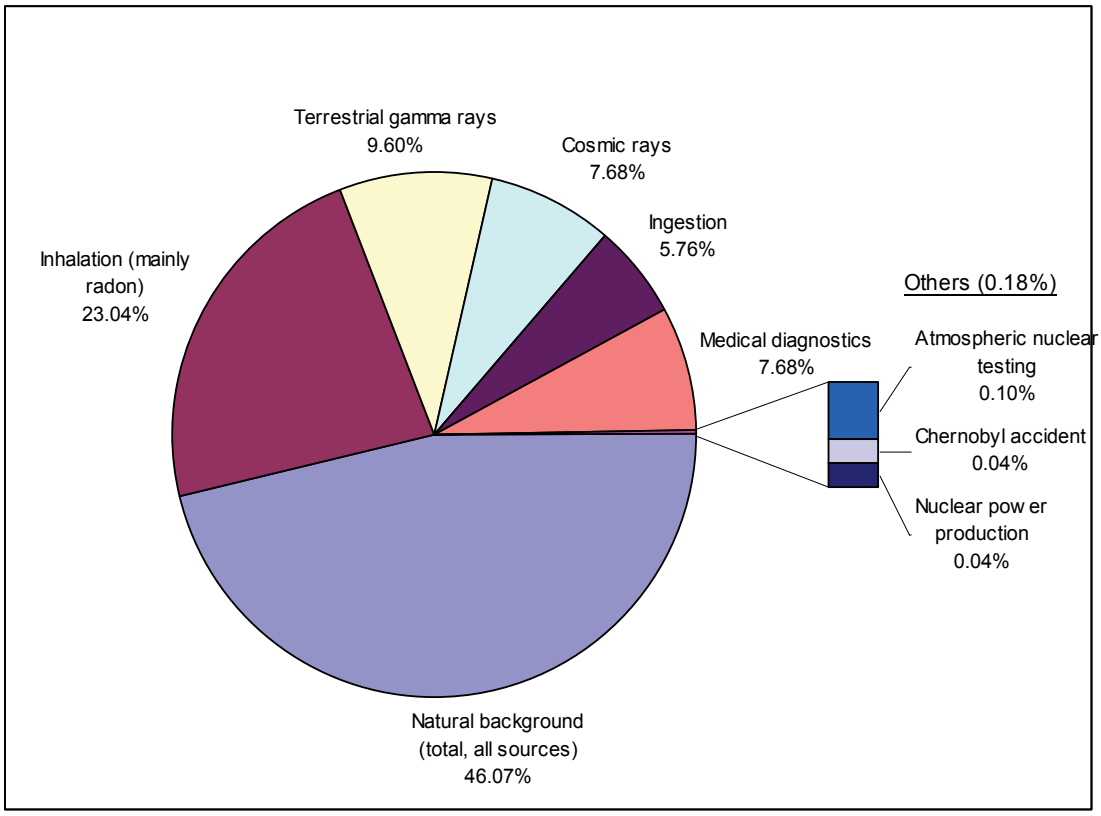

Figure 1. Pie chart showing the relative doses from natural and man-made sources of radiation. Derived from table 1 [1].

Exposure to radon in dwellings is also the subject of Commission Recommendation of 21 February 1990 on the protection of the public against indoor exposure to radon (90/143/Euratom) [3]. Indoor radon concentration levels of 200 and 400 Becquerel per cubic metre (Bq/m^3) are the reference concentrations above which mitigation measures should be taken in new and old buildings, respectively, to reduce exposure to radon. This can be done simply by improving the ventilation of the basements and/or by reducing the permeability of the foundations of the house to the gas.

To further identify regions that are susceptible to high radon levels, most European countries have organized large sampling campaigns, mainly by performing indoor and soil-gas measurements.

National radon surveys

To assess efforts made by European countries in identifying regions with increased radon levels, the JRC sent a questionnaire to national authorities, universities and research centres in the 25 Member States of the European Union, as well as Bulgaria, Romania, Croatia, Turkey, Norway, Switzerland, FYROM and Serbia-Montenegro. Addressed were the authorities that deal with ionizing radiations and the universities and research centres that have contributed to national radon surveys.

Except for Albania, Bosnia-Herzegovina and Bulgaria, all the countries that were contacted replied to the questionnaire. Each one of them has carried

out radon surveys (see Table 2). As a consequence, the JRC could prepare short reports for these countries (see the Annex to this report)

For Albania the JRC found some relevant information in the scientific literature. At the time of printing this report, Turkey was finishing the analysis of its survey, and the JRC expects to publish these results in a later version of this report.

Outdoor radon concentrations are known to be low (the mean annual concentration is on the order of 10 Bq/m^3) and to have no major impact on health. Hence, all countries have concentrated their efforts on monitoring radon in dwellings or in soil-gas. The last approach is used to delineate radon-prone areas on the basis of physical, rather than mainly statistical and geographical, criteria (see Table 2).

Sampling strategies

Measurements are usually made on the ground floor of houses and buildings as radon is around nine times heavier than air. To assess doses received by inhabitants, measurements are usually made in bedrooms and living rooms. One can estimate the number of dwellings that have been investigated in Europe to between 1.5 and 2 million. The number of measurements can be multiplied by 2 since most surveys monitored several rooms in the same habitation.

Measurements of radon in soils, called soil-gas measurements, are made in all countries but systematically only in a few. These measurements are mainly used for identifying radon-prone areas. Given the large diversity in design and construction materials used to build houses, indoor measurements are usually made in addition to assess directly the exposure of the population in these areas.

Even if the countries have adopted various sampling strategies (systematic, preferential or random) and targeted various types of buildings (e.g. public places, hospitals, schools, multifamily and/or single family houses), one can consider that, overall, most radon-prone areas have been identified and delineated throughout Europe, with a lower resolution in the Balkans.

Measurement techniques

Measurements have been made using various types of detectors and for different time intervals. Most countries that have frequently organised very large monitoring campaigns used so-called alpha-track detectors as these are small enough to be sent by mail. These are then left in the main living area of the dwelling for a minimum of three months (winter time is usually preferred because exposure is highest due to lesser ventilation) but generally for a whole year.

Other measurements involving air pumps have also been made in a few countries, but these methods can run for a few days only and require the intervention of specialized personnel.

As a result of this variety in measurement techniques and sampling time (ranging from a few hours to more than a year), direct comparison between estimated levels measured in the different countries should be made with caution.

Table 2. National sampling efforts for monitoring radon.

Country	Population (x 10^6)	Number of dwellings monitored	Soil-gas campaign?
Albania	3.6	110	NA
Austria	8.2	16 000	60
Belgium	10.4	9 000	NA
Croatia	4.5	782	38
Cyprus	0.8	84	NA
Czech Republic	10.2	150 000	9 000
Denmark	5.4	3 120	NA
Estonia	1.3	515	566
Finland	5.2	73 074	400
France	60.7	12 261	230
FYROM	2.0	NA	NA
Germany	82.4	> 50 000	4 019
Greece	10.7	1 277	NA
Hungary	10.0	15 602	NA
Ireland	4.0	11 319	NA
Italy	58.1	5 361	NA
Latvia	2.3	300	NA
Lithuania	3.6	400	70
Luxembourg	0.5	2 619	NA
Malta	0.4	90	NA
Netherlands	16.4	1 846	475
Norway	4.6	51 925	NA
Poland	38.6	4 098	210
Portugal	10.6	3 317	NA
Romania	22.33	567	NA
Serbia-Montenegro*	10.8	968	NA
Slovakia	5.4	4 019	NA
Slovenia	2.0	2 512	NA
Spain	40.3	5 600	NA
Sweden	9.0	500 000	> 2000
Switzerland	7.5	55 000	NA
United Kingdom	60.4	450 000	NA

* *Province of Vojvodina only*
NA = Not Available.

Delineating and reporting radon levels

Most countries have used the European recommendation [3] on the annual mean indoor concentrations that should not be exceeded, that is 400 Bq/m^3 in existing buildings and 200 Bq/m^3 for new constructions, as reference for defining radon risk maps. As recommended by the UK, the criterion for identifying radon areas is frequently considered to be those where the number of dwellings with concentrations higher than 200 Bq/m^3 exceeds 1%.

Because radon-prone areas are sampled more than others, overall statistics are usually biased and not always meaningful. Hence, the summary information regarding average levels found in Europe are estimations based on statistics and or models and, here again, one should be careful when using the information summarized in Table 3.

Most national reports present their results in the form of a radon maps. Although this is obviously a powerful mean to delineate areas that are prone to radon, the mapping of radon levels is a task that is very difficult: radon levels between neighbouring houses can vary by a few orders or magnitude depending on the construction material used, the insulation used in the house and the living habits of the inhabitants. Because mapping usually involves some averaging step of the data collected, thus hiding a few areas that present higher levels, it is not a surprise to see that almost all countries adopted different mapping techniques and strategies.

Table 3. Some statistics for European radon surveys.

Country	Estimated annual mean levels (Bq/m^3)	% dwellings > 200 Bq/m^3 and <400 Bq/m^3	% dwellings > 400 Bq/m^3
Albania	NA	NA	NA
Austria	97	8	4
Belgium	48	1.7	0.3
Croatia	68	5.4	1.8
Cyprus	19	0	0
Czech Republic	140	10 - 15	2 - 3
Denmark	53	2.7	0.2
Estonia	60	2 – 2.5	0.3 – 0.5
Finland	120	8.7	3.6
France	63	6.5	2
FYROM	NA	NA	NA
Germany	50	2.5	< 1
Greece	55	2	1.1
Hungary	NA	5.1	0.8
Ireland	89	6	1.5
Italy	70	3.2	0.9
Latvia	NA	NA	NA
Lithuania	55	2.5	0.3
Luxembourg	115	NA	3
Malta	40	0	0
Netherlands	23	0.3	0
Norway	89	6	3
Poland	49	1.6	0.4
Portugal	NA	NA	NA
Romania	45	NA	NA
Serbia-Montenegro*	144	18	4
Slovakia	108	14	11
Slovenia	87	5.5	2
Spain	90	4	2
Sweden	108	6 - 7	3 - 4
Switzerland	77	10	7
United Kingdom	20	0.4	0.1

** Province of Vojvodina only*
NA: Not Available

To better illustrate these differences, a mosaic has been made from the national radon maps published in this report (see cover and Figure 2). One will realise that a majority of the countries has adopted

administrative boundaries to define local mean values while others have used a grid as a reference system to define these values. A few have used interpolation techniques, including advanced geostatistical techniques.

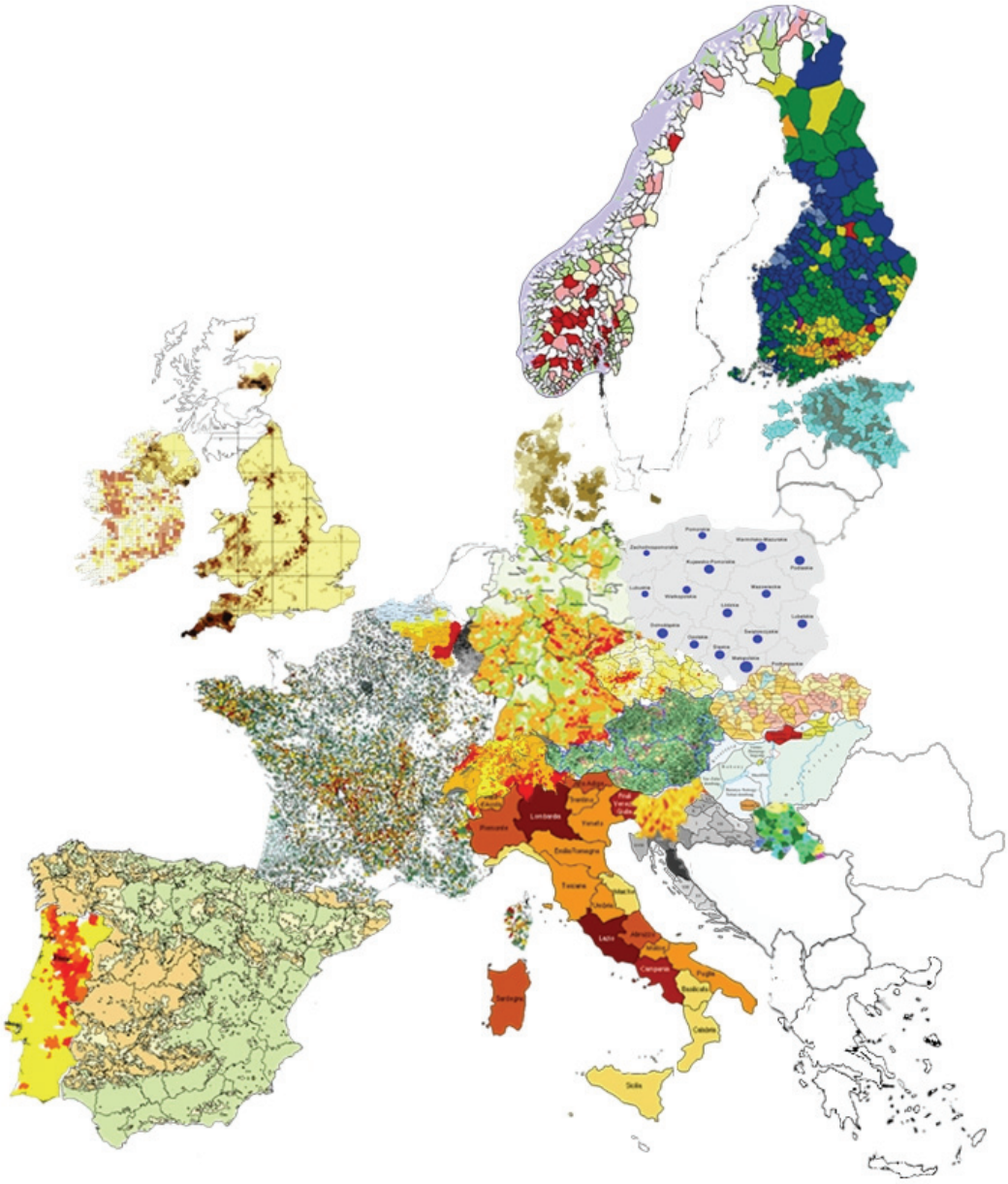

Figure 2. Mosaic of published European radon maps.

European maps of radon levels

The survey presented here could highlight large differences between the radon surveys. So far, no attempts have been made to harmonize data and maps at the continental level. As a consequence of these differences, it is difficult to compare maps and data between European countries. The Institute for Environment and Sustainability (IES) of the Joint Research Centre, in collaboration with the Directorate General for Transport and Energy (DG TREN) of the EC are exploring possibilities to harmonise such information with a view to obtain a better picture of the regions that are present elevated levels of radon. This should not only help everyone concerned, citizens and decision-makers alike, to assess better this natural threat to our health, but also to familiarize the population with the fact that their environment is naturally radioactive. More support and information from the European Commission regarding these issues can be found on the internet [4, 5].

References

[1] M Charles (2001). UNSCEAR Report 2000: Sources and Effects of Ionizing Radiation. *Journal of Radiological Protection*, **21**(1): 83-85. http://www.iop.org/EJ/abstract/0952-4746/21/1/609

[2] S Darby, D Hill, A Auvinen, J M Barros-Dios, H Baysson, F Bochicchio, H Deo, R Falk, F Forastiere, M Hakama, I Heid, L Kreienbrock, M Kreuzer, F Lagarde, I Mäkeläinen, C Muirhead, W Oberaigner, G Pershagen, A Ruano-Ravina, E Ruosteenoja, A Schaffrath Rosario, M Tirmarche, L Tomásek, E Whitley, H-E Wichmann and R Doll. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies.
BMJ 2005;330:223-, doi:10.1136/bmj.38308.477650.63.
http://bmj.bmjjournals.com/cgi/reprint/330/7485/223.pdf

[3] Commission Recommendation of 21 February 1990 on the protection of the public against indoor exposure to radon (90/143/Euratom). Official Journal of the European Union, OJ L-80 of 27/03/90, page 26.
http://europa.eu.int/comm/energy/nuclear/radioprotection/doc/legislation/90143_en.pdf#search='90%2F143%2FEURATOM' en fr

[4] RadonNET. The objective of this network is to help radon stakeholders to communicate, share knowledge, identify problems and propose solutions to the various issues that arise. en
http://www.radonnet.eu.com/

[5] European Forum on Radon Mapping. This web site provides support to a European Forum for discussing methods for mapping radon levels. en
http://radonmapping.jrc.it/

ANNEX 1

SUMMARY REPORTS

Except when specified, all data and figures shown hereafter have been approved and authorised for publication by their respective national authorities or contact persons

TABLE OF CONTENTS

ALBANIA

The information below has been found in:

United Nations Environment Program, State of the Environment in Albania 1997-1998

Albania, indoor measurements

Web address of radon projects

- *NA*

Selected References:

- United Nations Environment Program, State of the Environment in Albania 1997-1998 : http://www.grida.no/enrin/htmls/albania/soe1998/eng/issues/waste/urbenimp.htm

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
< 1998	110	*NA*

Sampling strategy:

110 buildings, distributed in the whole area of the city of Tirana were tested. An average of 3 to 4 rooms was checked in each building. Priority has been given to ground floors, single-storey buildings and bedrooms.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
NA	2.6	*NA*	Ground floors, and bedrooms.

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
NA	2.6	*NA*	*NA*	*NA*

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
~350	134	*NA*	*NA*	0	5 690

Out of the 110 building that were studies, 4 (3.6%) had values ranging from 200 to 400 Bq/m^3 and 6 (5.4%) exceeded Bq/m^3 400.

Estimated mean annual radon levels in Albanian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
NA	*NA*	*NA*

Maps: *NA*

Albania, soil-gas measurements

NA

AUSTRIA

Contact point for indoor radon measurements:

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft Strahlenschutzabteilung V/7
Radetzkystrasse 2
A 1030 Vienna
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http://www.lebensministerium.at/

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http://www.boku.ac.at/

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Austria

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Fax.: +43 50550 6536
e-mail: franz-josef.maringer@boku.ac.at

Austria, indoor measurements

Web address of related project:

- http://www.univie.ac.at/Kernphysik/oenrap/onrap_e.htm

Selected References:

- Friedmann, H., C. Atzmüller, L. Breitenhuber, P. Brunner, K. Fink, K. Fritsche, W. Hofmann, H. Kaineder, P. Karacson, V. Karg *et al*. (2001). The Austrian radon project, *The Science of The Total Environment*, **272**(1-3): 211-212.
- Friedmann, H. (2005). Final Results of the Austrian Radon Project. Submitted to *Health Physics.*

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1991-2002	16 000	3

Sampling strategy:

Random selection of dwellings. Statistical methods were used to ensure that the selected homes were representative for all homes in Austria. The sampling frequency was proportional to the population density.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (SSNTD, system Karlsruhe 2)	90	Autumn - Spring	Living room and bedroom
E-PERM	90	Autumn - Spring	Living room and bedroom
Charcoal detectors with LSC measurements (Picorad)	3	Autumn - Spring	2 in the living room and 2 in the bedrooms

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (SSNTD, system Karlsruhe 2)	90	-	2	150
E-PERM	90	-	2	150
Charcoal detectors with LSC measurements (Picorad)	3	-	2	150

Statistics of the measurements

*Measurements statistics (units in Bq/m^3)**					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
40 000	97	61	-	< 5	8 325

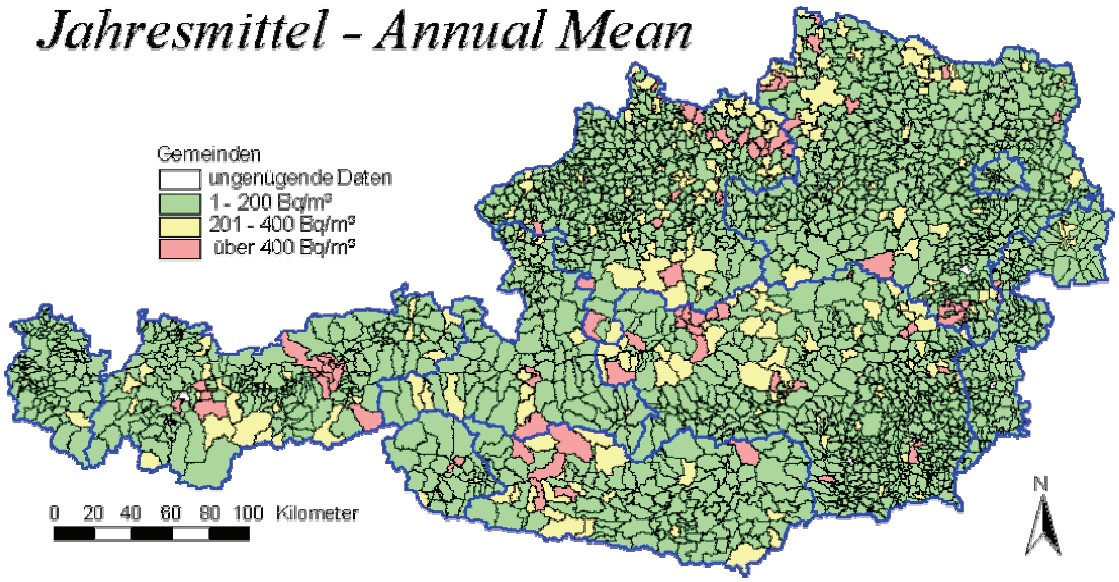
** The statistics shown above are of the values corrected for the season of exposure*

Estimated mean annual radon levels in Austrian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
97	8	4

Maps:

Method 1:

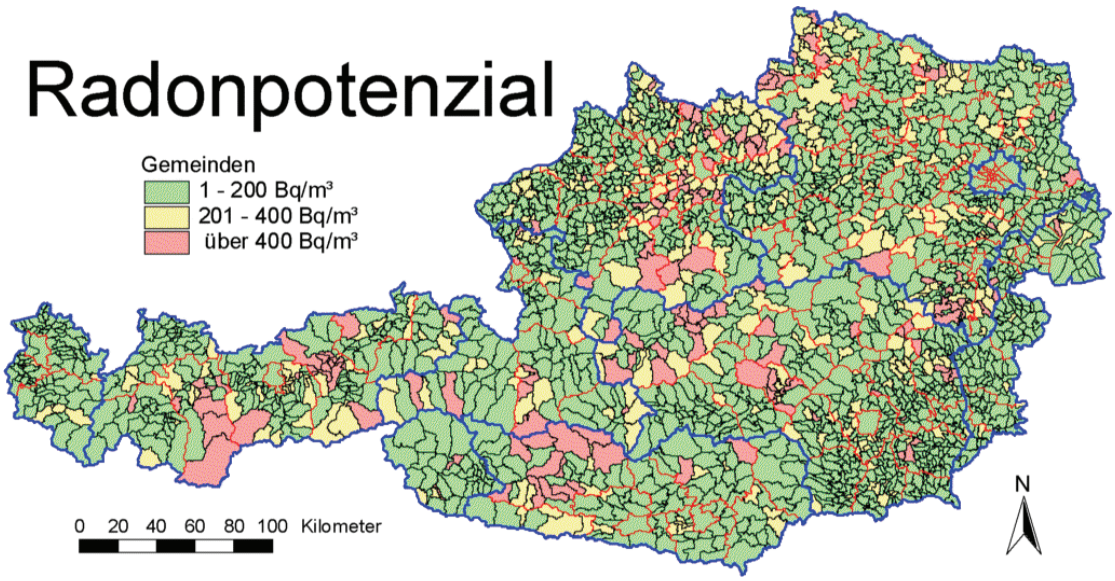
- Local annual mean radon concentration values were calculated at the municipal level. Annual mean radon levels are corrected for the season of exposure (taking a mean winter/summer ratio).



Local annual mean radon concentration values. Map reproduced with the kind courtesy of H. Friedmann © (2005). Web address: http://www.univie.ac.at/Kernphysik/oenrap/onrap_e.htm

Method 2:

- Map of radon potential. Measured radon data can be converted to a radon potential which was introduced to compare radon data measured under different conditions. This radon potential is defined mainly as the annual mean radon concentration in a commonly used living- or sleeping-room at the ground floor in a house without basement.



Austrian map of radon potential. Map reproduced with the kind courtesy of H. Friedmann © (2005).

Austria, soil-gas measurements

Selected References:

- Maringer, F.J., Heiss, G., Jung, M. (2000). Ermittlung des lokalen Radonpotentials aus geogenen Faktoren mittels eines geographischen Informationssystems und in-situ Bodenluftmessungen (ELORA). *Endbericht. Österr. Forschungs- und Prüfzentrum Arsenal GmbH, Wien*.
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- Gruber, V. (2004). Untersuchung und Evaluierung der geogenen Radon-Aktivitätskonzentration in eiszeitlich-glazialen Ablagerungen in Oberösterreich. *Diplomarbeit aus Technischer Physik. Techn. Univ. Wien*. 2004.

Campaign

Survey period	*Number of sample locations*
2000-2004	60

Sampling strategy:

Regions with expected high levels (crystalline rocks, glacial (ice-age) deposits were sampled.

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
Pulsed ionisation chamber (Alpha Guard, Germany)	30 minutes	150

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
200	75 000	60 000	30 000	40 000	600 000

Maps: *NA*

BELGIUM

Contact point for indoor radon measurements:

Federal Agency for Nuclear Control (FANC)
Ravensteinstraat 36
B-1000 Brussels
Belgium

http://www.fanc.fgov.be/

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Fax.: (+32 2) 2892106
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Belgium, indoor measurements

Web address of radon projects

- http://www.fanc.fgov.be/nl/radnat.htm (Flemish version)
  http://www.fanc.fgov.be/fr/radnat.htm (French version)

Selected References:

- Poffijn, A., G. Eggermont, S. Hallez, and P. Cohilis (1994). Radon in Belgium: Mapping and Mitigation in the Affected Area of Visé. *Radiation Protection Dosimetry*, **56**(1-4): 77-80.
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- Zhu, H. -C., J. M. Charlet and F. Tondeur (1998). Geological controls to the indoor radon distribution in southern Belgium. *The Science of The Total Environment*, **220**(2-3): 195-214.
- Zhu, H. -C., J. M. Charlet and A. Poffijn (2001). Radon risk mapping in southern Belgium: an application of geostatistical and GIS techniques. *The Science of The Total Environment,* **272**(1-3): 203-210.
- Vanmarcke, H., Mol, H., Paridaens, J. and G. Eggermont (2004). *Exposure of the Belgian Population to Ionizing Radiation*. In: Proceedings of the IRPA-11 Congress. Madrid, May, 2004.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1995-1999	9 000	1

Sampling strategy:

The national radon survey was mainly conducted to find areas with increased indoor radon values. Small-scale surveys allowed to focus on provinces with radon prone areas and, as expected, higher radon values were found in the southern part of Belgium (Walloon region) that was later on preferentially sampled and investigated.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (Makrofol)	90	February-April	Mainly living room or kitchen

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (Makrofol)	90	*NA*	60	180

Statistics of the measurements

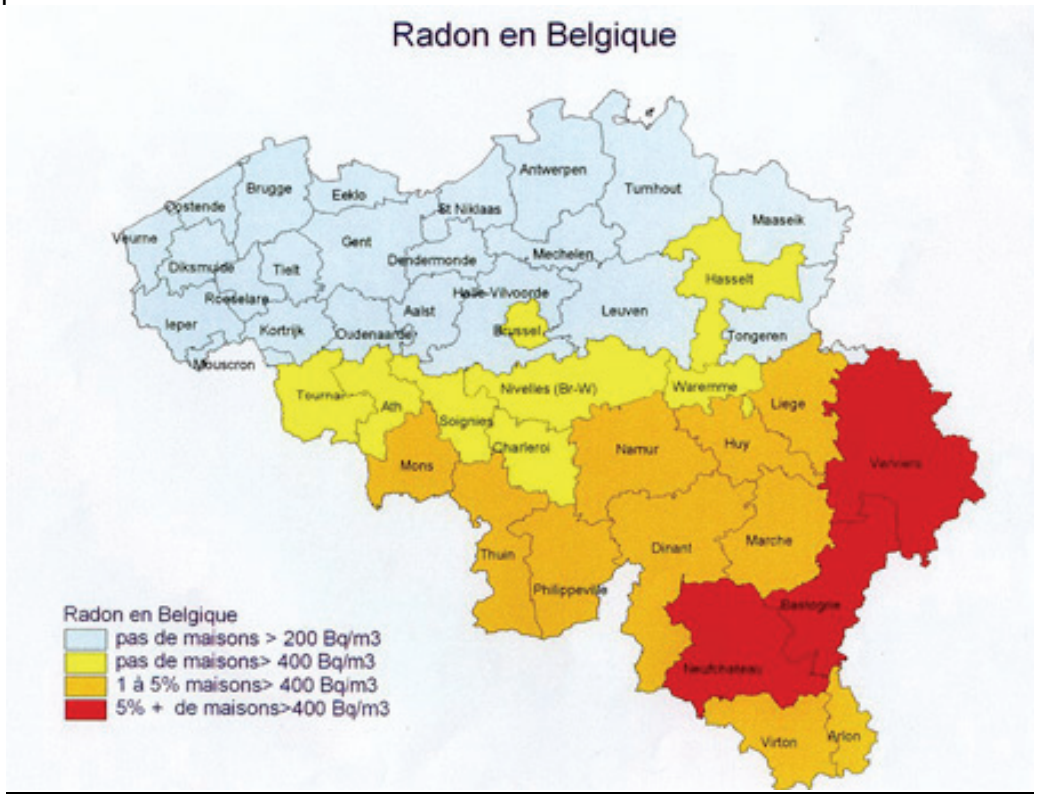
	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
9 500	93	77	*NA*	10	4 100

Estimated mean annual radon levels in Belgian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
48	1.7	0.3

Seasonal variations have been followed in many houses in different parts of southern Belgium. It appeared that the three months time periods September-November or February-April were the closest one to yearly values.

Maps:

Administrative boundaries were used to calculate percentages of houses expected to exceed defined threshold values.



Percentage of houses exceeding 200 and 400 Bq/m^3. Map reproduced with the kind courtesy of FANC © (2005). Reference: http://www.fanc.fgov.be/fr/radnat.htm#carte

Belgium, soil-gas measurements

No survey made at the national level or on a large scale. Local campaigns of indoor measurements are still ongoing and combined with information provided by soil-gas measurements.

CROATIA

Contact point for indoor radon measurements:

University of Osijek, Department of Physics
P.O.Box 125, Gajev trg 6
31000 Osijek
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Croatia

http://www.ffos.hr/radon

Reporting contact point:

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Croatia, indoor measurements

Web address of related project:

- http://www.ffos.hr/radon

Selected References:

- Planinic, J., Z. Faj, V. Radolic, G. Smit, and D. Faj (1999). Indoor radon dose assessment for Osijek. *Journal of Environmental Radioactivity*, **44**(1): 97-106.
- Radolić, V.., B. Vuković, D. Stanić, M. Katić, Z. Faj, B. Šuveljak, I. Lukačević, D. Faj, M. Lukić, J. Planinić (2005) National survey of indoor radon levels in Croatia (submitted to *Journal of Environmental Radioactivity*).

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
2003-2005	782	1 diffusion mode (+1 open mode)

Sampling strategy:

Random selection of dwellings. The sampling frequency was proportional to the population density.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector (LR-115)	382.4	Whole year	Living rooms

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (LR-115)	382.4	24.6	249	508

Indoor radon levels

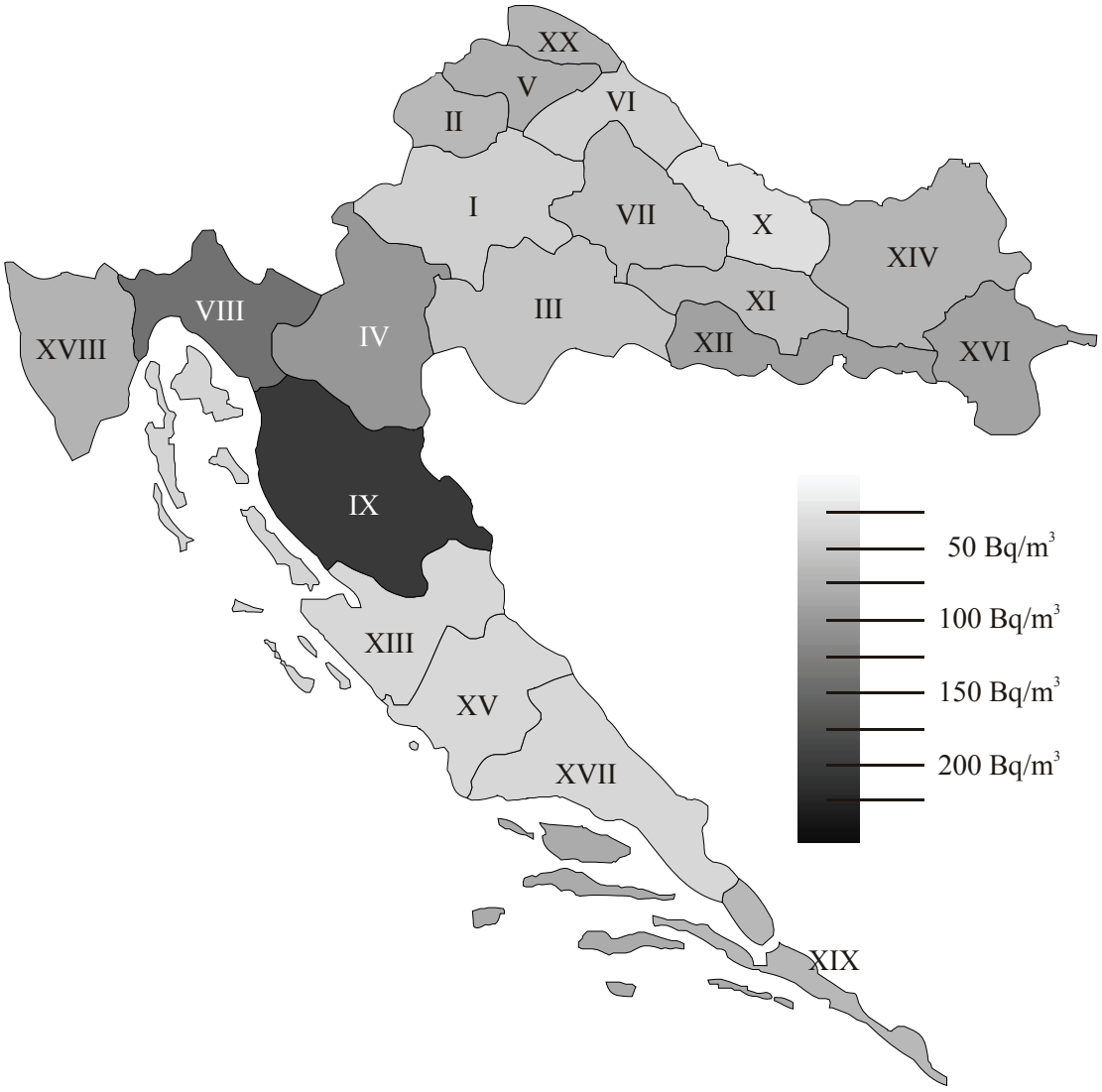
	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
782	68	50	85	4	751

Estimated mean annual radon levels in Croatian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
68	5.4	1.8

Maps:

Method:

- Local averages were calculated on the basis of administrative boundaries



Annual mean indoor radon concentrations in Bq/m^3 shown on a regional level. Map reproduced with the kind courtesy of the J. Planinić. © (2005) Reference: http://www.ffos.hr/radon

Croatia, soil-gas measurements

Selected References:

- Planinić, J., V. Radolić, Z. Faj, D. Stanić i B. Vuković, *Radon risk mapping in Osijek*, *Proceedings of Sixth International Workshop on the Geological Aspects of Radon Risk Mapping*, Prague 2002, 71-77.
- Planinić, J., V. Radolić., B. Vuković (2004). Radon as an earthquake precursor, *Nuclear Instruments and Methods in Physics Research, Section A,* **530**(3): 568-574.

Campaign

Survey period	*Sample locations*	*Measurements / location*
2001-	38	1

Sampling strategy:

Randomly on the territory of Osijek and Zagreb. This campaign is part of a national wide monitoring program of soil-gas radon that is currently on-going.

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
Track-etch detector (LR-115)	7 days	50

Statistics of the measurements

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
38	26 300	23 200	10 400	6 300	53 500

Maps: *NA*

CYPRUS

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http://www.ucy.ac.cy/~phyweb/

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Cyprus, indoor measurements

Web address of related project:

- http://www-np.ucy.ac.cy/radio_isotopes/wwwen/radon/map/radon_map.html

Selected References:

- Christofides, S. and Christodoulides, G. (1993). Airborne Rn concentration in Cypriot houses, *Health Physics*, **64**(4): 392-396.
- Anastasiou, T., H. Tsertos, S. Christofides, and G. Christodoulides (2003). Indoor radon (222Rn) concentration measurements in Cyprus using high-sensitivity portable detectors, *Journal of Environmental Radioactivity*, **68**(2): 159-169.
- Sarrou, I. and I. Pashalidis (2003). Radon levels in Cyprus, *Journal of Environmental Radioactivity*, **68**(3):269-277.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
2001-2002	84	1

Sampling strategy:

Random selection of dwellings. The sampling frequency was proportional to the population density.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Passive electronic radon detector (Radim-3, from GT-Analytic)	2 days	September 2001- May 2002	Basements or close living rooms

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Radim 3	2	-	2	2

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
84	19.3	-	14.7	6.2	102.8

Estimated mean annual radon levels in Cypriot dwellings (units in Bq/m^3)		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
19.3	0	0

Maps:

Method:

Local averages were calculated on a regional level. No maps of radon levels are available, regional statistics can be found at:

http://www-np.ucy.ac.cy/radio_isotopes/wwwen/radon/map/radon_map.html

Cyprus, soil-gas measurements

No survey made on a national or large scale level.

CZECH REPUBLIC

Contact point for indoor radon measurements:

National Radiation Protection Institute (SURO)
Srobarova 48
100 00 Prague 10
Czech Republic

http://www.suro.cz/

Reporting contact point

Vera STAROSTOVA

State Office for Nuclear Safety (SUJB)
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110 00 Praha 1
Czech Republic

Tel.: 420 221 624 628
Fax.: 420 224 234 590
e-mail: vera.starostova@sujb.cz

Contact point for soil gas radon measurements:

Czech Geological Survey
Klárov 3
118 21 Praha 1
Czech Republic

http://www.cgu.cz

Reporting contact point:

Vera STAROSTOVA

State Office for Nuclear Safety (SUJB)
Senovazne nam. 9
110 00 Praha 1
Czech Republic

Tel.: 420 221 624 628
Fax.: 420 224 234 590
e-mail: vera.starostova@sujb.cz

Czech Republic, indoor measurements

Web address of related project:

- http://www.suro.cz/en/prirodni/mapy/index.html

Selected References:

- Hůlka, J., Thomas, J. (2004)/ *National Radon Programme : 20 years of experience in Czech Republic*, IRPA congress Madrid 2004.
- http://www.suro.cz/en/index.html

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1984-today	>150 000	2

Sampling strategy:

Random selection of dwellings followed by targeted survey in regions with higher concentrations.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector (LR 115, Kodak)	365	All year	Two detectors/ dwelling. Mainly living rooms

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (LR 115, Kodak)	365	0	365	365

Statistics of the measurements

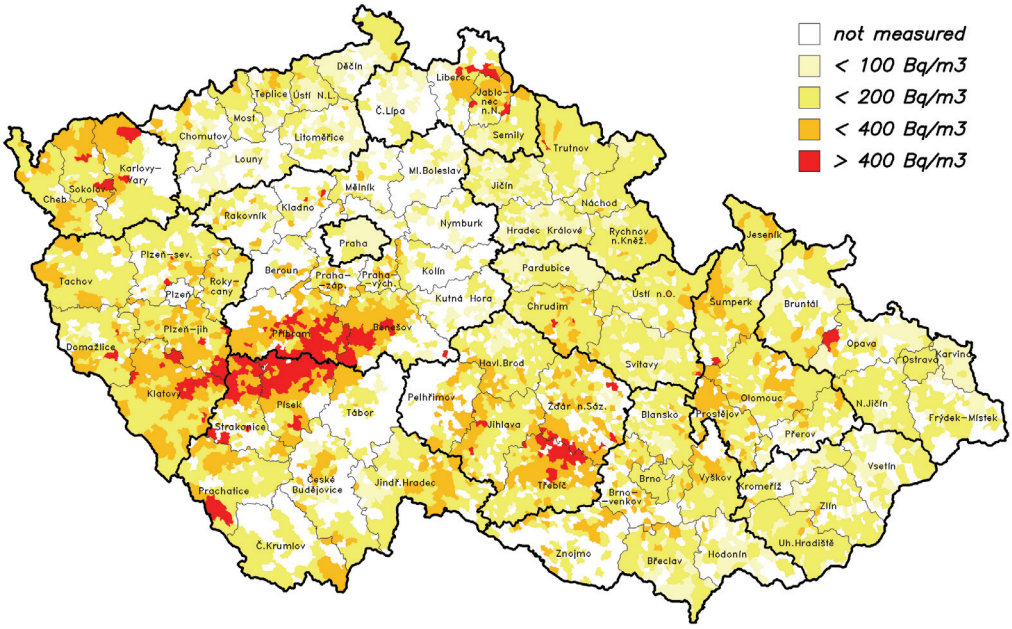
	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
305 000	140	110	2.2	10-20	25 000

Estimated mean annual radon levels in Czech dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
140	10-15	2-3

Maps:

Method:

- Local averages were calculated at the municipal level



Indoor mean radon concentrations levels shown on a municipality level. Map reproduced with the kind courtesy of SURO © (2005). Web address http://www.suro.cz/en/prirodni/mapy/index.html

Czech Republic, soil-gas measurements

Selected References:

- Pacherová, P. (2004). *Radon database – the statistical evaluation*. In: Radon investigations in the Czech Republic X and the 7th International Workshop on the Geological Aspects of Radon Risk Mapping. – 168 p. ČGS Praha. Barnet I., Neznal M., Pacherová P. (Eds).
- Barnet I., Neznal M., Pacherová P. (2004): *Radon investigations in the Czech Republic* In: Radon investigations in the Czech Republic X and the 7th International Workshop on the Geological Aspects of Radon Risk Mapping. – 168 p. ČGS Praha. Barnet I., Neznal M., Pacherová P. (Eds).

Campaign

Survey period	*Number of sample locations*
1995-	9000

Sampling strategy:

Measurements have been made in all geological units.
Soil gas measurements are obligatory in the Czech Republic prior to building a new house or reconstructing the existing building.

Measurement technique

Detector type	*Time*	*Depth (cm)*
Scintillation detectors of various types	A few minutes	80

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
9 000	28 074	18 850	40 421	1000	1 663 900

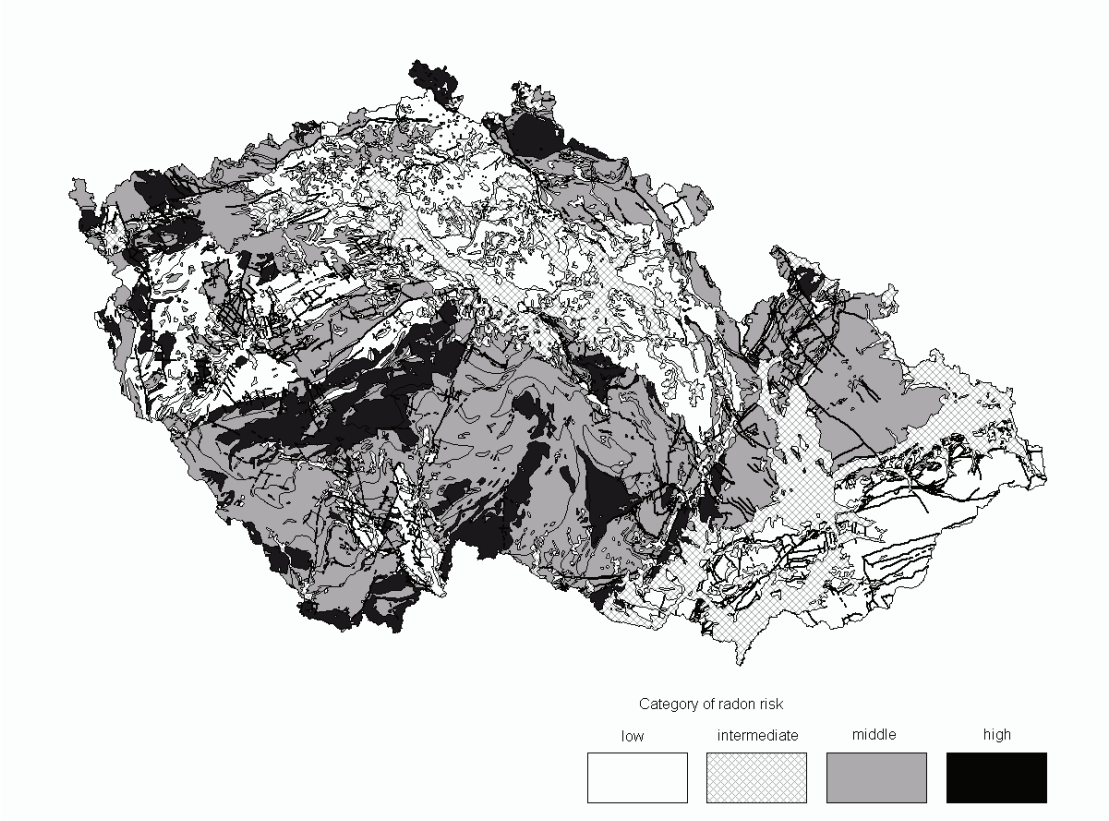
Maps:

Method:

1990 soil gas Rn map 1: 200 000 hand drawn
1998 soil gas Rn map 1: 500 000 vectorised
1999-present: geologically based Rn risk maps are produced at a scale of 1: 50 000, 214 map sheets are expected to be finished by the end of 2005.

The prevailing radon risk index (low, interstage, medium and high categories) for particular geological units is expressed in the vectorised

contours of geological units. The radon risk index of test sites (15 measurements each) is calculated after the uniform method used in the whole country.



Radon risk map. Map reproduced with the kind courtesy of SURO © (2005). Web address http://www.suro.cz/en/prirodni/mapy/geolprogncr.html
Examples of maps in scale 1: 50 000 can be loaded from the Czech Geological Survey (http://www.geology.cz or http://nts2.cgu.cz/)

DENMARK

Contact point for indoor radon measurements:

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Knapholm 7
DK-2730 Herlev
Denmark

http://www.sis.dk

Reporting contact point

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Fax.: +45 44 54 34 50
e-mail: ku@sis.dk

Denmark, indoor measurements

Web addresses of related projects:

- http://www.sst.dk/Borgerinfo/Miljoe_og_sundhed/Radon/Radon_i_boliger/Landsomfattende_radonundersoegelse/Hovedrapport.aspx?lang=da
- http://www.risoe.dk/nuk/radon.htm

Selected References:

- Andersen, C. E., Ulbak, K., Damkjær, A., Kirkegaard, P., and Gravesen, P. (2001). Mapping indoor radon-222 in Denmark: design and test of the statistical model used in the second nationwide survey. *The Science of The Total Environment*, **272**(1-3): 231-241.
- Andersen, C.E., Ulbak, K., Damkjær, A., andGravesen, P. (2001). *Radon i danske boliger. Kortlægning af lands-, amts- og kommuneværdier*. Copenhague; National Institute of Radiation Hygiene, January 2001, 132 pp.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1995-1996	3 120	1

3019 measurements were made in single family houses and 101 in multiple family houses (apartments).

Sampling strategy:

Samples were taken randomly in each of the 275 municipalities for the single family houses and in the 15 counties for the apartments.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector (CR-39)	369	Whole year	Living room

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (CR-39)	369	NA	319	534

Indoor radon levels

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
Single houses: 3 019	89.5	63.6	83.2	2	590
Apartments: 101	19.3	13.2	20.0		

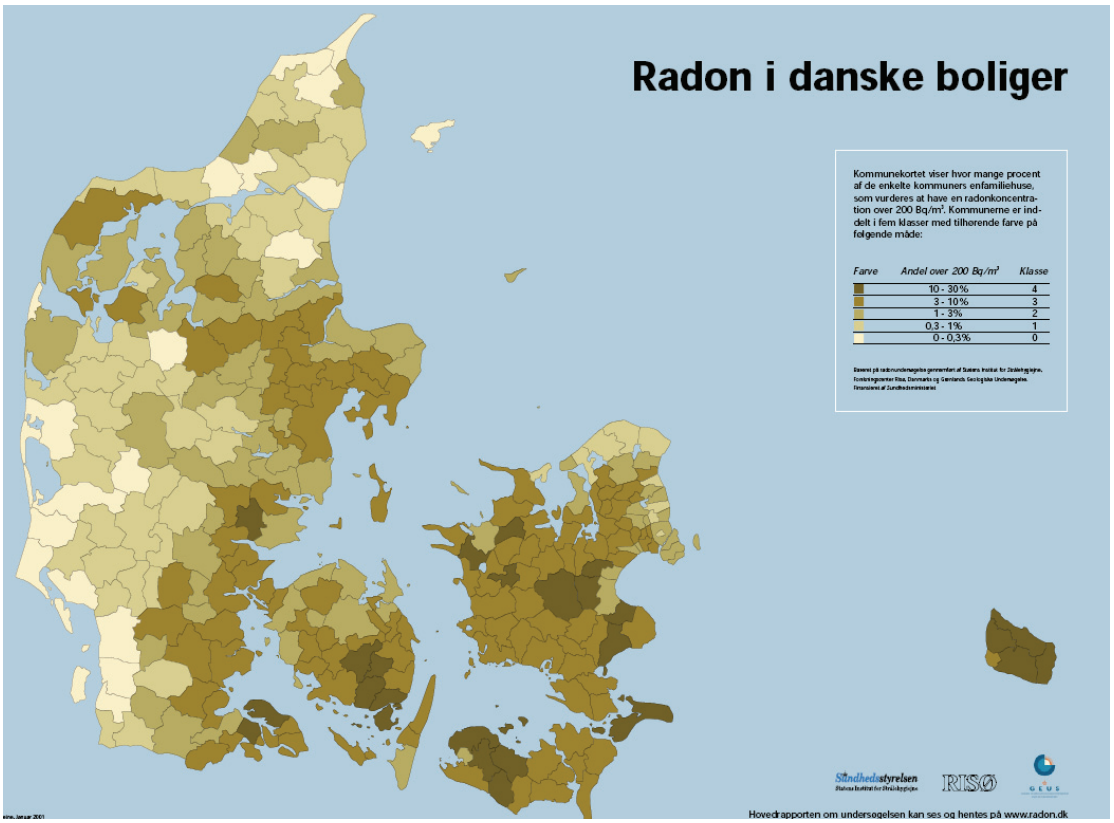
Estimated mean annual radon levels in Danish dwellings*		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
53	2.7	0.2

**Dwelling weighted values (i.e. both single family houses and apartments have been taken into account)*

Maps:

Method:

Local averages were calculated in each of the 275 municipalities and percentage levels above 200 Bq/m^3 were used for mapping.



Map of Danish indoor radon levels showing the percentages of single-family houses with levels above 200 Bq/m^3. Map reproduced with the kind courtesy of the National Institute of Radiation Hygiene. © (2005) Web reference: http://www.sst.dk/faglige_omr/SIS/Radon/2001/Radon_2001_kommunekort.pdf

Denmark, soil-gas measurements

No surveys made on a national or large scale level.

ESTONIA

Contact point for indoor radon measurements:

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76 Kopli str.
10416 Tallinn
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http://www.envir.ee/kiirgus/eng/

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Fax.: (+372) 6 603 352
e-mail: raivo.rajamae@ekk.envir.ee

Contact point for soil gas radon measurements:

Geological Survey of Estonia
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Tallinn 12618
Estonia

http://www.egk.ee/egk/

Reporting contact point

Jaan KIVISILLA

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Estonia

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Fax.: +372 6 720 091
e-mail: j.kivisilla@egk.ee

Estonia, indoor measurements

Web addresses of related projects:

- *NA*

Selected References:

- Pahapill, L., Rulkov A., Rajamäe R., Åkerblom G. (2003). *Radon in Estonian dwellings. Results from a National Radon Survey*. SSI rapport 2003:16, 20 p., ISSN 0282-4434

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1998-2001	515	2

Sampling strategy:

Samples were taken randomly on the whole territory.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector CR-39	60-90	All year	Living room and bedroom.

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (CR-39)	71	11	55	102

Indoor radon levels

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
1 003	98	78	3	15	1044

Radon levels measured in the summer period in single family houses are found to be lower by 15% in comparison with measurements made in the winter. If one considers that heating period lasts 8 months in Estonia, the annual mean in a house is lower by some 10% of the actual measurement data.

Estimated annual mean radon levels in Estonian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
60	2 - 2.5	0.3 – 0.5

Maps:

Method:

- Local averages were calculated at the municipal level

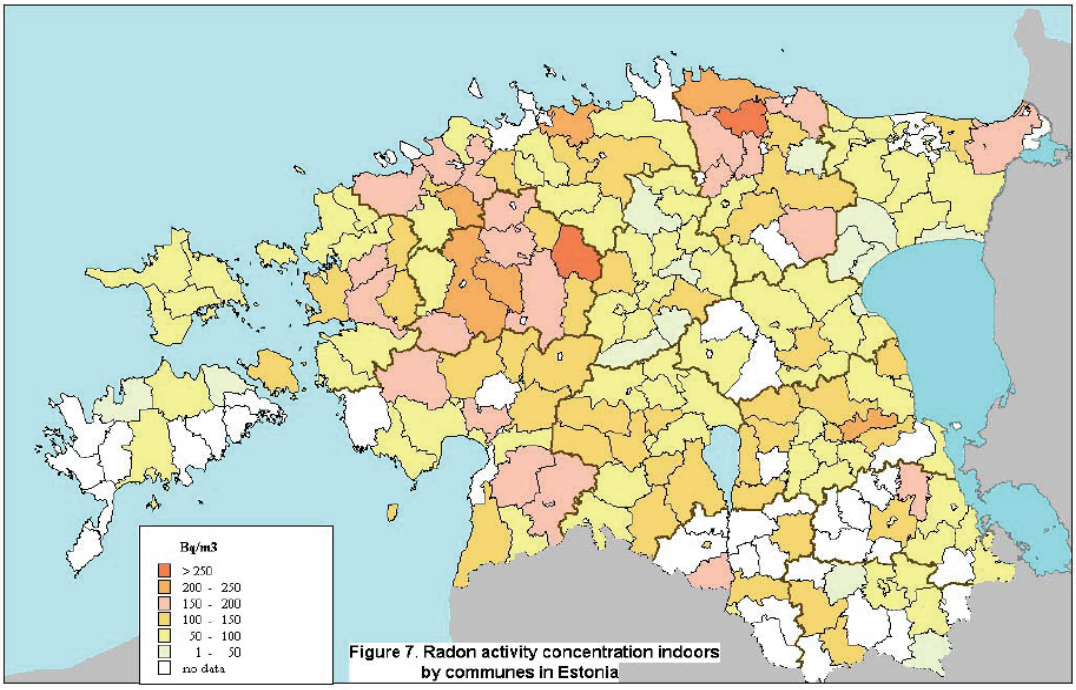


Figure 7. Radon activity concentration indoors by communes in Estonia

Map of annual mean indoor radon concentration values averaged at the level of communes. Map reproduced with the kind courtesy of the Estonian Radiation Protection Centre. © (2005)

Estonia, soil-gas measurements

Selected References:

- Petersell, V., Åkerblom, G., Ek, B.-M., Enel, M., Mõttus, V., Täht, K. (2004). *The radon risk map of Estonia*. EGF, Tallinn-Stockholm.

- Petersell, V., Åkerblom, G., Ek, B.-M., Enel, M., Mõttus, V., Täht, K. (2004). Radon in Estonian soil. In: *Proceedings of the Seventh International Workshop on the Geological Aspects on Radon Risk Mapping.* Prague, September 15th – 18th, 2004.

Campaign

Survey period	*Sample locations*	*Measurements / location*
2001-2004	566	*NA*

Sampling strategy:

Approximately regular grid covering the whole territory. The density of sampling is up to two times bigger in high radon level areas with high population density.

Measurement technique

Detector type	*Measurement time*	*Depth* (*cm*)
Emanometer Markus-10	-	Recalculated to 100
Portable Gama Ray Spectrometer (GRS), Model GPS-21	300 s	80

Statistics of the measurements

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
507 (Markus-10)	49 000	27 000	197	< 1 000	2 112 000
566 (GRS)	62 500	38 000	123	1000	2 224 000

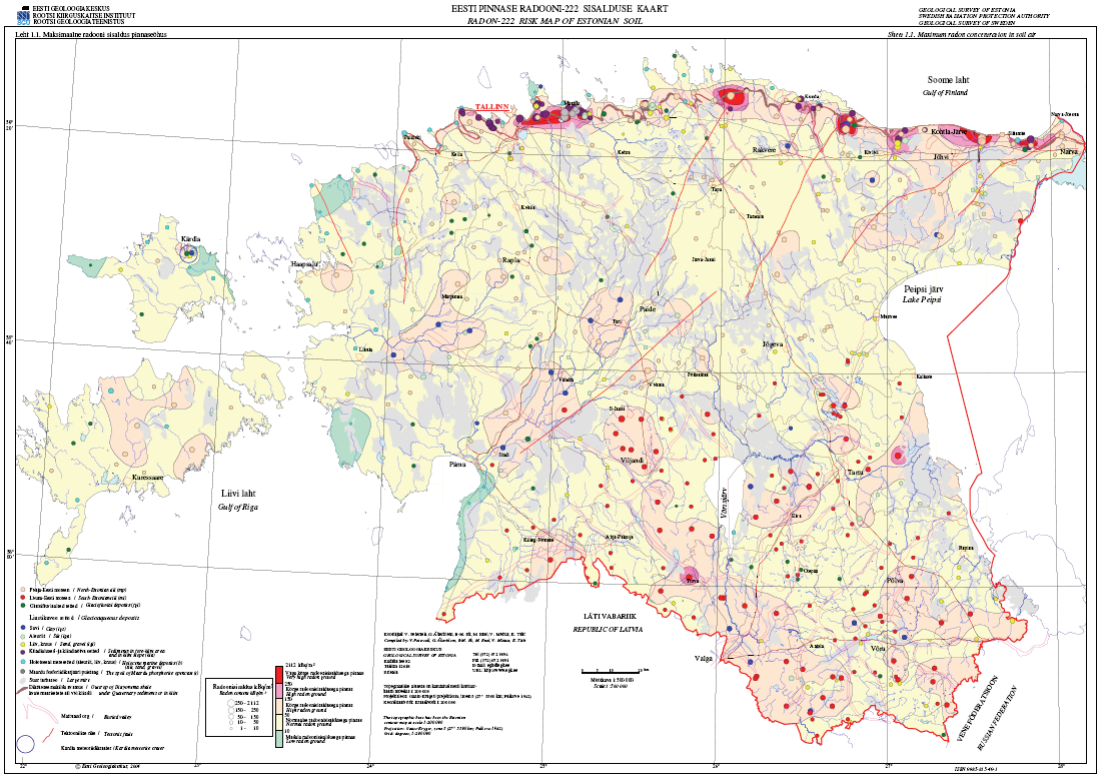
Maps:

Radon risk maps of Estonia in scale 1:500 000 include various sheets:

- Rn concentration in soil (maximum concentration in soil air, kBq/m^3);
- Preliminary Rn risk areas;
- Rn concentration in soil air by direct measurement with Markus 10 (recalculated to depth 1 m);
- Rn concentration in soil air calculated after U (^{226}Ra);

- U (^{226}Ra) concentration in soil;
- Th (^{232}Th) concentration in soil;
- K (^{40}K) concentration in soil;
- Natural radiation of soil;
- Location of observation points (On the map of Quaternary sediments).

On the maps presenting the concentrations of elements in soils total seven genetic lithologic types of the Quaternary deposits are distinguished. They are based on the lithologic differences of the deposits as the main reason for differences in Rn concentration and other geochemical parameters of soils. The genetic-lithologic types are: South-Estonian till (ml), North-Estonian till (mp), glacioaqueous deposits – clay (lgs), silt (lga), sand (lgl) and gravel (fgl), Baltic Sea (Holocene) marine deposits (b) and technogenic (spoils of Maardu phosphorite quarry) (t). Additionally, the fore-klint glacioaqueous and marine deposits are identified which are often mixed with colluvium from the klint (kla). On the maps the colour of the circle marks the genetic-lithotype in the observation point, and the diameter of the circle shows the concentration of element. The dispersion of elements in soil is characterised by the graphs of their occurrence frequency.



Map of maximum radon concentrations found in soil gas. Map reproduced with the kind courtesy of the Estonian Geological Survey © (2005)

FINLAND

Contact point for indoor radon measurements:

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Finland, indoor measurements

Web address of related project:

- http://www.stuk.fi/sateilytietoa/sateily_ymparistossa/radon/

Selected References:

- Castren, O. (1994). Radon reduction potential of Finnish dwellings. *Radiation Protection Dosimetry*, **56**: 375-378.
- Arvela, H. (1995). Seasonal variation in radon concentration of 3000 dwellings with model comparisons. *Radiation Protection Dosimetry*, **59**(1), 33-42.
- Voutilainen, A., Mäkeläinen, I.,Pennanen, M., Reisbacka, H., Castrén, O. (1997). Suomen Radonkartasto – Radon Atlas of Finland. STUK-A148. Helsinki: Oy Edita Ab.
- Arvela, H. (2002). Population distribution of doses from natural radiation in Finland. *International Congress Series*, **1225**: 9-14.
- Weltner A, Mäkeläinen I, Arvela H. (2002). Radon mapping strategy in Finland. *International Congress Series*, **1225**: 63-69.

Campaigns

- National random sample survey by STUK in 1990-1991, 3 074 dwellings
- Data collected in co-operation with local health authorities in 1986-2004, 30 000 dwellings
- Measurements for private citizens in 1986-2004, 30 000 dwellings
- Different surveys (epidemiological, regional, etc.) in 1986-2004, 10 000 dwellings
- "Radon Bee", a campaign in order to activate radon measurements, in co-operation local health authorities in 2003-2005, 4 000 dwellings

Population based random sample survey was used to calculate representative national radon levels. All other data up to 1995 are used in mapping, and published in the Radon Atlas of Finland. It includes national and provincial radon maps with average radon concentration in 5-10 km squares, and radon measurement statistics for municipalities (Voutilainen et al. 1997).

A. Information on the random sample study:

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1990 - 1991	3 074	2 successive

Measurement technique used in random sample study:

Detector type	*Measurement time*	*Season*	*Measurement location*
Track-etch detectors (Makrofol)	2 x 6 months	Winter + Summer	1 in living room or bedroom in the lowest floor

	Measurement time			
Detector type	*Mean*	*Std. Dev.*	*Min*	*Max*
Track-etch detectors (Makrofol)	365	*NA*	*NA*	*NA*

Indoor radon levels according to the random sampling study:

	Measurement statistics				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min*	*Max*
6 148	120	84	*NA*	13	6’629

B. Information regarding other surveys:

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1984 - 2005	70 000	typically 1-2

Measurement technique:

Detector type	*Measurement time*	*Season*	*Measurement location*
Track-etch detectors (Makrofol)	Typically 2 months	October - April*	In living room or bedroom in the lowest floor

**Measurements taken during winter-time are seasonally adjusted (see Arvela 1995).*

C. Overall statistics

Statistics of the measurements

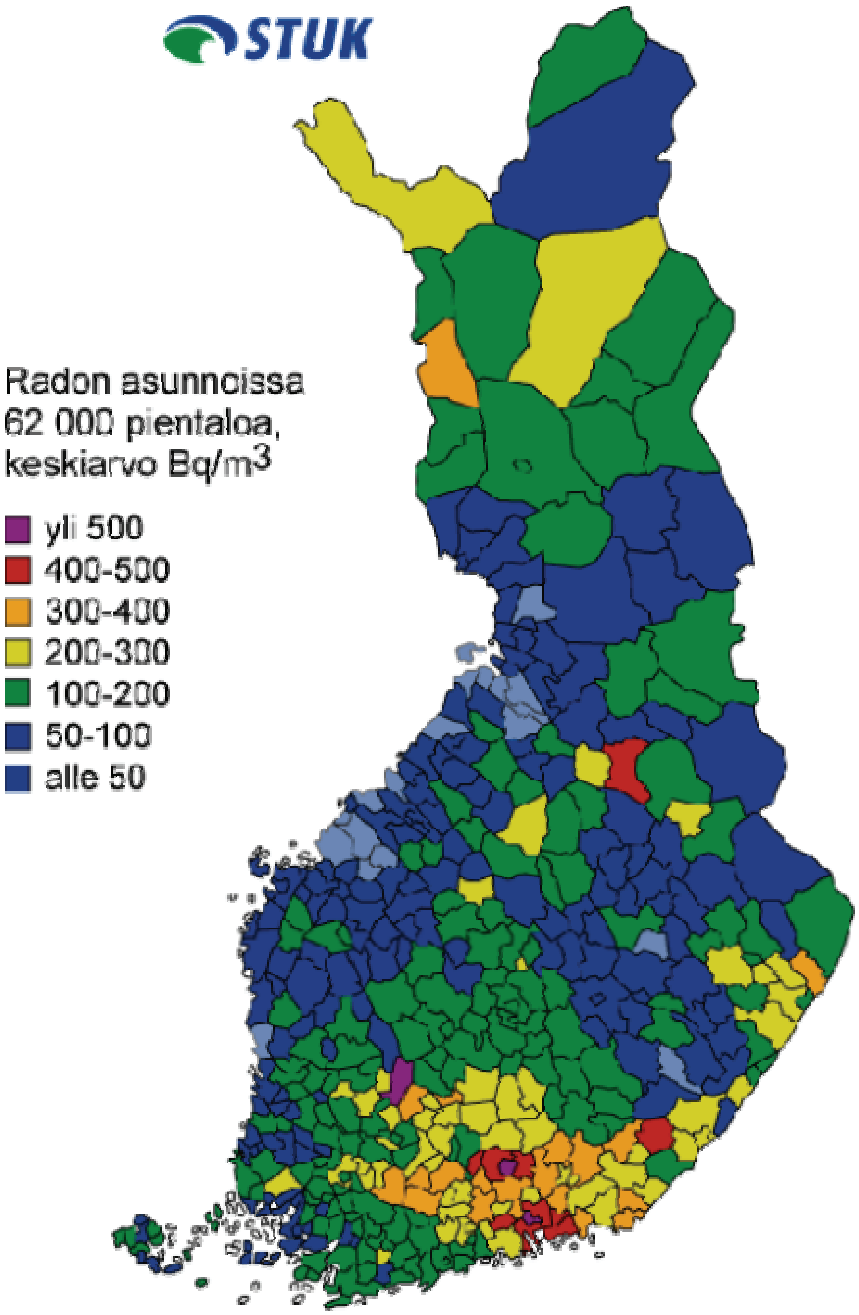
	Measurement statistics				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min*	*Max*
~ 100 000	248	142	*NA*	13	33 000

Estimated mean annual radon levels in Finnish dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
120	8.7	3.6

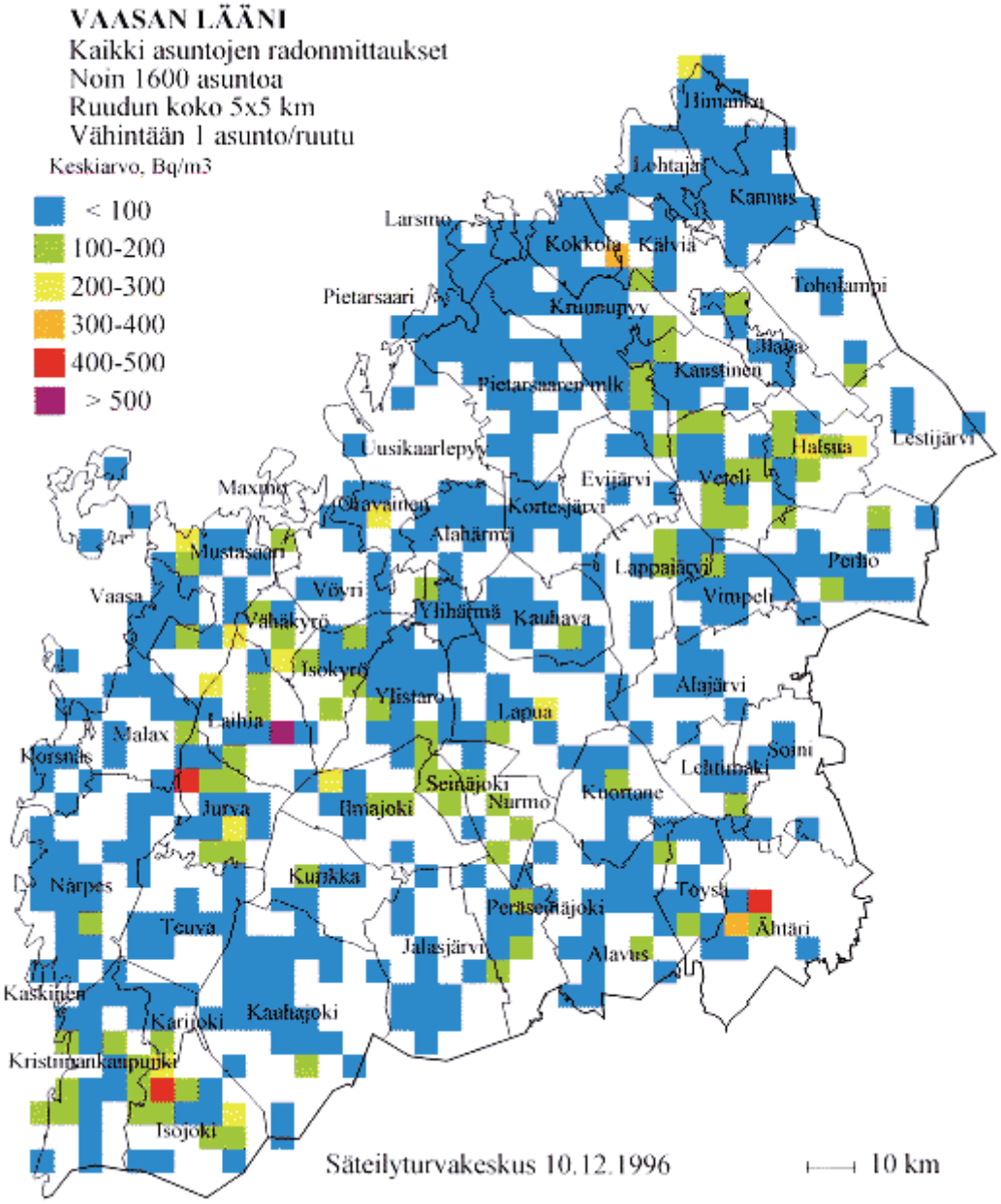
Maps:

The maps have been established on the basis of all the data

Method:
- Local averages were calculated at the municipal level
- A 10 x 10 km grid was used for further in depth exploration.



Map of local annual mean radon concentration values. Map reproduced with the kind courtesy of STUK © (2005). Reference: http://www.stuk.fi/sateilytietoa/sateily_ymparistossa/radon/kartat/fi_FI/



Example of a detailed map of local annual mean radon concentration values. Map reproduced with the kind courtesy of STUK © (2005).
Reference:
http://www.stuk.fi/sateilytietoa/sateily_ymparistossa/radon/kartat/fi_FI/radon_vaasa/

Finland, soil-gas measurements

No surveys made on a national level.

Some information regarding soil gas measurements made in Finland can be found in the following study:

- Markkanen, M., Arvela, H. (1992). Radon Emanation from Soils. *Radiation Protection Dosimetry.* **45**:269-272 [400 measurements made by means of radon-tight cans and Lucas cells]

FRANCE

Contact point for indoor radon measurements:

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77-83, avenue du Général de Gaulle - 92140 Clamart - France
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France, indoor measurements

Web address of related project:

- http://www.irsn.fr/vf/05_inf/05_inf_1dossiers/05_inf_16_radon/05_inf_16_2campagne.shtm

Selected References:

- Gambard, J. P., Mitton, N. and Pirard, P. (2000). Campagne nationale de mesure de l'exposition domestique au radon IPSN-DGS. Bilan et représentation cartographique des mesures au 01 Janvier 2000. *Note technique SEGR/LEADS/00-14*. Institut de Protection et de Sûreté Nucléaire.
- Baysson, H., Billon, S., Laurier, D., Rogel, A., Tirmarche, M. (2003). Seasonsal correction for estimating radon exposure in dwellings in France. *Radiation Protection Dosimetry*, **104**(3): 245-252.
- Billon, S., Morin, A., Caër, S., Baysson, H., Gambard, J. P., Rannou, A., Tirmarche, M. and Laurier, D. (2004). Evaluation de l'exposition de la population française à la radioactivité naturelle. *Radioprotection*, **39**: 213-232.
- Billon, S., Morin, A., Caër, S., Baysson, H., Gambard, J. P., Backe, J. C., Rannou, A., Tirmarche, M. and Laurier, D. (2005). French population exposure to radon, terrestrial gamma and cosmic rays. *Radiation Protection Dosimetry*, **113**(3): 314-320.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1980-2003	12 261	1

Sampling strategy:

Samples were randomly collected; radon prone areas were more sampled than others.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector (Kodalpha LR115)	60	Any	Main room

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (Kodalpha LR115)	70	24	30	334

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
12 261	89.3	53.5	162.0	1	4 964

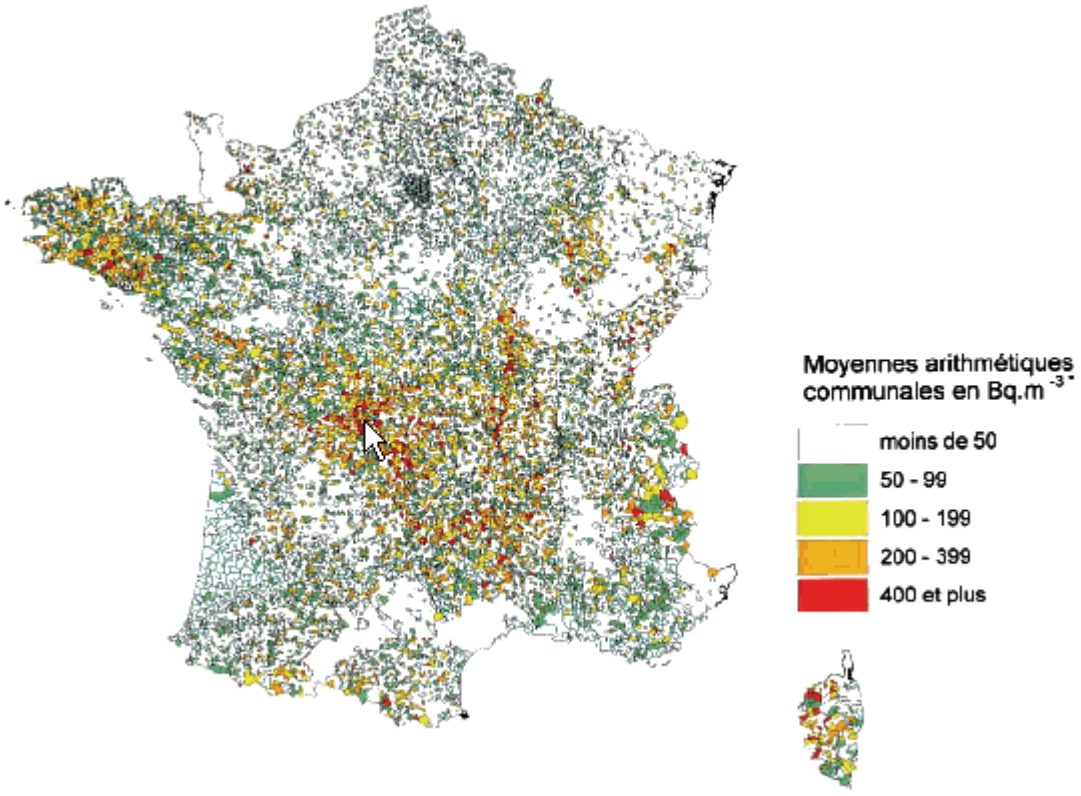
Estimated mean annual radon levels in French dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
63*	6.5	2

** Corrected mean weighted on population density after correction on the season of measurement and on housing characteristics*

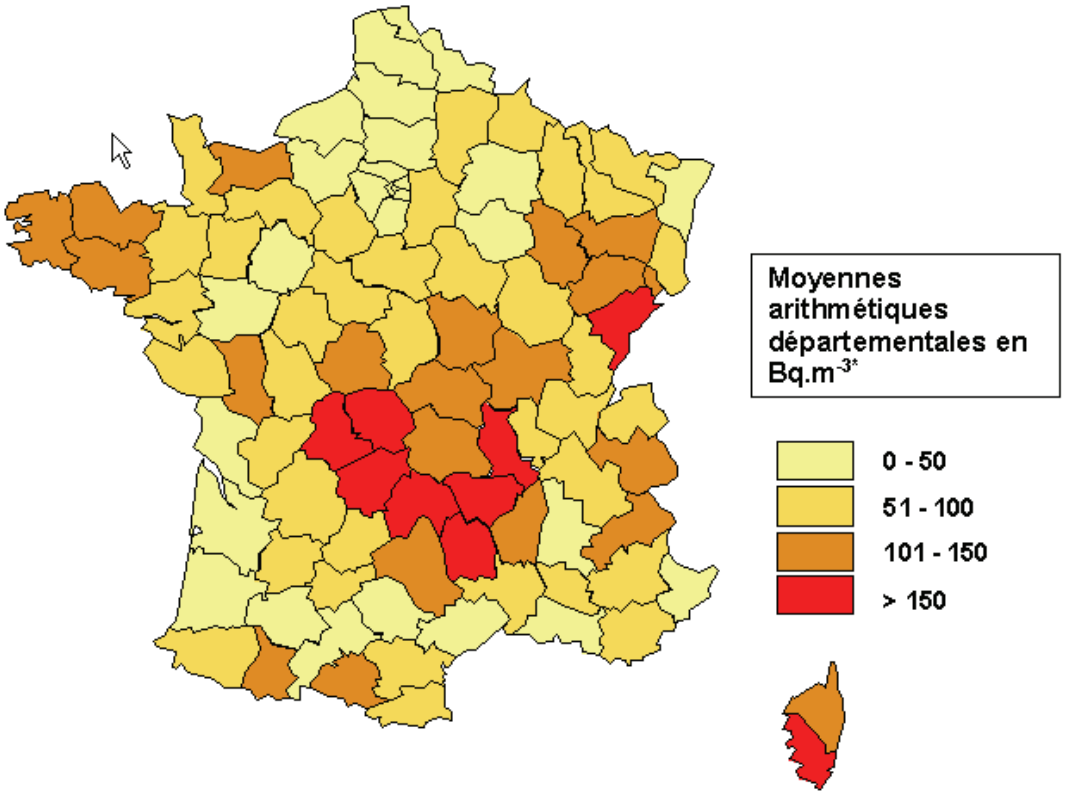
Maps:

Method:

- Local averages were calculated on the basis of a grid or administrative boundaries.



Annual mean indoor radon concentration levels (in Bq/m^3) shown on a municipality level. Map reproduced with the kind courtesy of the IRSN (2005) © Reference: http://www.irsn.fr/vf/05_inf/05_inf_1dossiers/05_inf_16_radon/05_inf_16_2campagne_img1.shtm



Annual mean indoor radon concentrations in Bq/m3 shown on a departemental level.
Map reproduced with the kind courtesy of the IRSN (2005) © Reference: http://www.irsn.fr/vf/05_inf/05_inf_1dossiers/05_inf_16_radon/05_inf_16_2campagne_img2.shtm

France, soil-gas measurements

Selected References:

- Ielsch., G. et Haristoy D. (2001). « Mise au point d'une méthodologie permettant l'élaboration d'un outil cartographique prédictif en vue d'identifier les zones potentiellement exposées à de fortes concentrations de radon » (2 Volumes). Programme Environnement et Santé 1997. Rapport IPSN-BRGM Réf. IPSN/DPRE/SERGD RT 01-05.
- Ielsch G. (2003). Méthodologie de cartographie prédictive du potentiel d'exhalation du radon à la surface des sols : bilan des projets de recherche et validation complémentaire. Rapport IRSN/DEI–SARG 03-02, octobre 2003.

Campaign

Survey period	*Sample locations*
1997-2002	230

Sampling strategy:

5 sectors (50 × 70 km wide each) in 5 regions representing the main geological and lithological types observed in France were investigated. Statistics below are thus not representative for the whole territory.

Measurement technique

Detector type	*Time*	*Depth* (*cm*)
Scintillation flasks ("Lucas Cells") and counting chamber	3 minutes for each flasks (×2 countings)	50

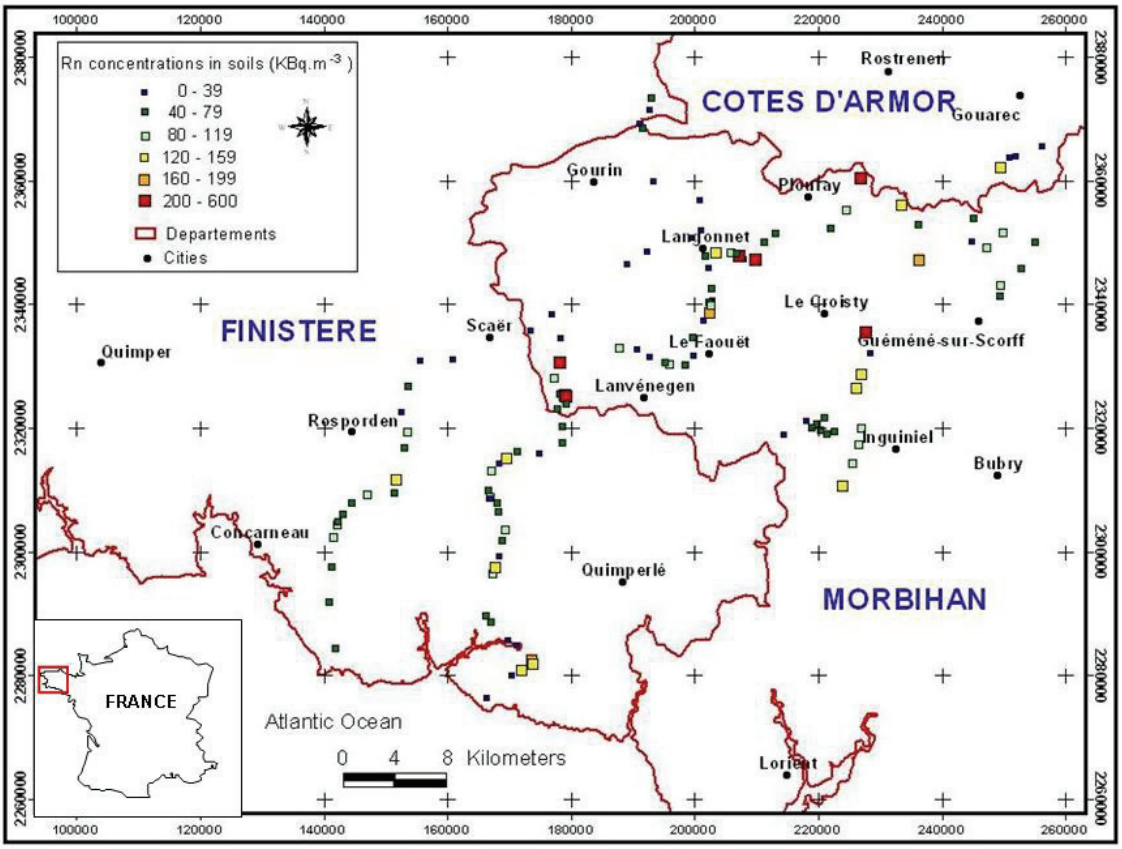
Soil gas levels

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
460	58 000	35 000	42 000	0	598 000

Maps:

Method:

Maps have been produced on a regional scale only, not for the whole French territory. Measurements were shown by means of symbol maps (the colour coding used corresponded to the classification of the radon activity measured: very low, low, medium, high or range of values attributed to each class) on a precise scale map (1/50 000 or 1/80 000). No interpolation or averaging was made.



Radon concentration measured in soils on different sites: results obtained on an area located in Brittany, Western France. Map reproduced with the kind courtesy of the IRSN © (2005)

Former Yugoslav Republic of Macedonia (FYROM)

Contact point for indoor radon measurements:

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Sector of Hygiene and Environmental Protection
Department for Radioecology
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Former Yugoslav Republic of Macedonia

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Reporting contact point

Dušan NEDELKOVSKI

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FYROM, indoor measurements

Web address of radon projects

- *NA*

Selected References:

- RIHP (1998). *Radon in living and working environment*; Report No 40096895, April, 1998.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1998-2005	*NA*	1

Sampling strategy:

Measurements have been made sporadically in a selection of dwellings (collective dwellings), offices and rooms in the basement of the Institute. Several measurements in dwellings located in smaller towns have also been done.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
• Alpha Lucas cells • Radhome	• 1 • 3	*NA*	*NA*

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
• Alpha Lucas cells • Radhome	• 1 • 3	*NA*	*NA*	*NA*

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
NA	96.13	*NA*	*NA*	22	200

Estimated mean annual radon levels in Belgian* dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
NA	*NA*	*NA*

Maps: *NA (not enough data)*

FYROM, soil-gas measurements

No surveys made at the national level or on a large scale.

GERMANY

Contact point for indoor radon measurements:

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Contact point for soil gas radon measurements:

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Germany, indoor measurements

Web address of related project:

- http://www.bfs.de/ion/radon
- http://www.radon-info.de/

Selected References:

- Kemski, J., Klingel, R., Siehl, A., Stegemann, R., Valdivia-Manchego, M. (2002): Transferfunktion für die Radonkonzentration in der Bodenluft und der Wohnraumluft (Abschlussbericht zu den Forschungsvorhaben St. Sch. 4186 und St. Sch. 4187: Ermittlung einer Transferfunktion für die Radonkonzentration in der Bodenluft und der Wohnraumluft incl. Radonmessungen in Häusern zur Validierung des geologisch induzierten Radonpotenzials. Teil A: Bodenuntersuchungen zum geogenen Radonpotenzial. Teil B: Validierung der geologischen Prognose durch Messungen der Radonkonzentration in Gebäuden).- *Schriftenreihe Reaktorsicherheit und Strahlenschutz,* **BMU-2002-598**: 206 pp.
- Lehmann, R., J. Kemski, A. Siehl, R. Stegemann and M. Valdivia-Manchego (2002). The regional distribution of indoor radon concentration in Germany, *International Congress Series*, **1225**: 55-61.
- Kemski, J., Klingel, R., Stegemann, R. (2004): Validierung der regionalen Verteilungen der Radonkonzentration in Häusern mittels Radonmessungen unter Berücksichtigung der Bauweise (Abschlussbericht zum Forschungsvorhaben St. Sch. 4271).- *Schriftenreihe Reaktorsicherheit und Strahlenschutz,* **BMU-2004-641:** 77 pp.

Campaign

Survey period	*Dwellings investigated*	*Measurements / dwelling*
1978-2003	> 50 000	2

Sampling strategy:

Depending on the project, samples were collected either randomly, preferentially in radon prone areas, in mining regions or regions with a characteristic particular underlying geology.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector (Makrofol)	Up to 365	Whole year	Mainly living rooms and bedrooms
Activated charcoal - LSC	1	Any	Living rooms, bed rooms and basements.
Activated charcoal - gamma spectrometry	3	Any	Living rooms and basements.

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (Makrofol)	*NA*	*NA*	60	365

Indoor radon levels

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
~ 50 000	50	40	*NA*	< 10	> 10 000

Estimated annual mean radon levels in German dwellings*		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
50	About 2.5 %	< 1 %

** Defined as houses with 1 or 2 dwellings*

Maps:

Method: See soil-gas section.

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Germany, soil-gas measurements

Web address of related project:

- http://www.bfs.de/ion/radon
- http://www.radon-info.de/

Selected References:

- Kemski, J., Klingel, R., Siehl, A. (1996). Classification and mapping of radon-affected areas in Germany, *Environment International*, **22**, Supplement 1, 789-798.
- Kemski. J., Siehl, A., Stegemann, R., Valdivia-Manchego, M. (1999). Geogene Faktoren der Strahlenexposition unter besonderer Berücksichtigung des Radon-Potentials (Abschlußbericht zum Forschungsvorhaben St. Sch. 4106).- *Schriftenreihe Reaktorsicherheit und Strahlenschutz*, BMU-1999-534, 133 S.
- Lehmann, R., Kemski, J., Siehl, A., Stegemann, R. (2001). Approach to identification of radon areas in Germany, *The Science of The Total Environment*, **272**(1-3): 213-215.
- Kemski. J., Siehl, A., Stegemann, R., Valdivia-Manchego, M. (2001): Mapping the geogenic radon potential in Germany, *The Science of The Total Environment*, **272**(1-3): 217-230.
- Kemski, J., Klingel, R., Siehl, A., Stegemann, R. (2005). Radon transfer from ground to houses and prediction of indoor radon in Germany based on geological information.- in: McLaughlin, J.P.; Simopoulos, S.E.; Steinhäusler, F. (Eds.): *Radioactivity in the Environment,* **7**: The Natural Radiation Environment VII: 820-832.

Campaign

Survey period	*Sample locations*	*Measurements / location*
1992-2003	4 019	3

Sampling strategy:

The sampling strategy is based on the regional variation of geological structure. Areas with homogenous geology were sampled in lower density than regions with complicated hard rock geology.

Measurement technique

Detector type	*Time*	*Depth (cm)*
soil gas sampling by probes with a packer system, radon measurement with Lucas cells and scintillation counter	Grab sampling	100

Soil gas levels

The correlation of soil gas radon and geology can clearly be seen when classified according to geological units:

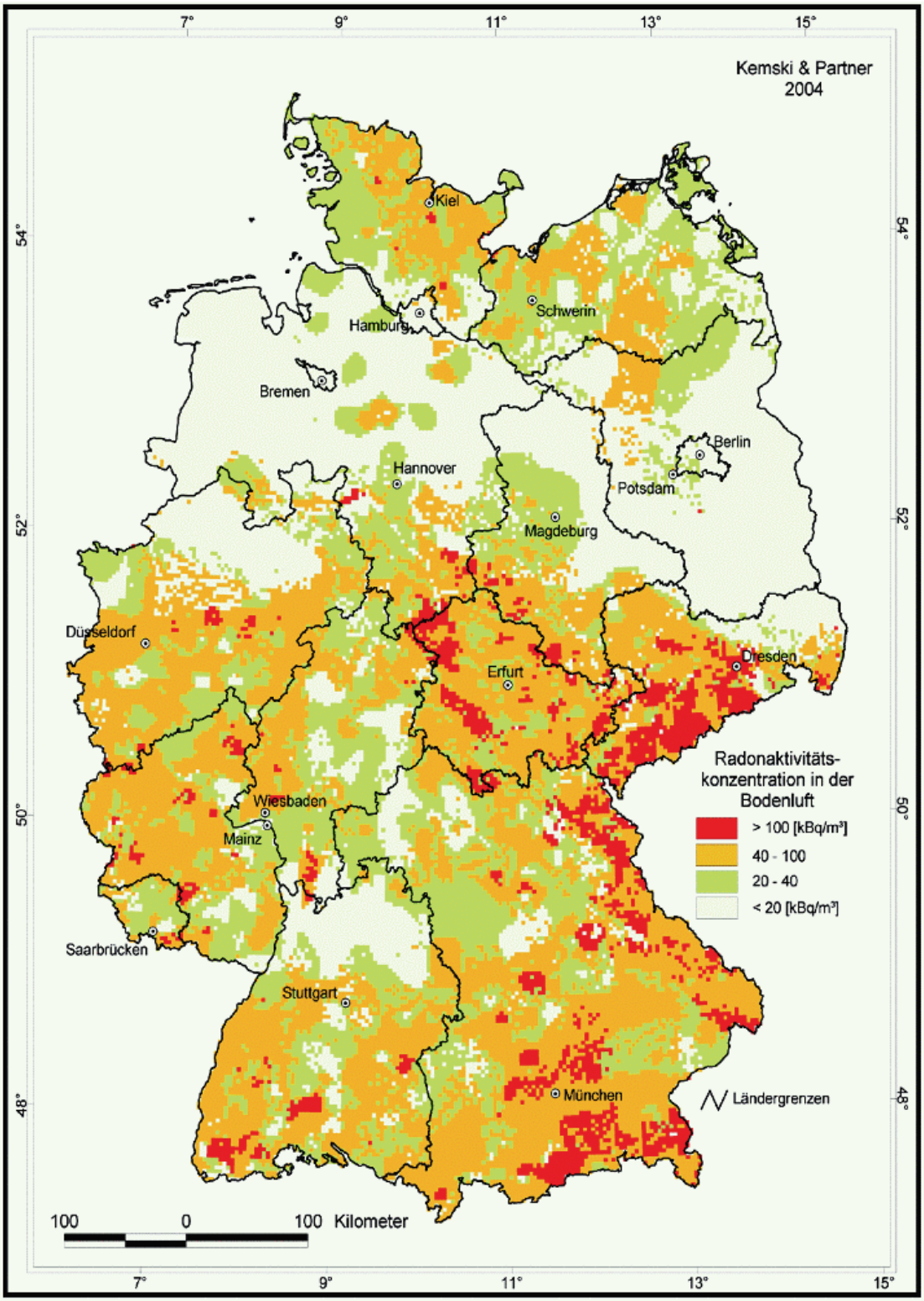
- Cenozoic and Mesozoic sedimentary rocks (CMS)
- Paleozoic sedimentary rocks (PS)
- Paleozoic metamorphic rocks (PM)
- Igneous rocks (IR)

		Measurements statistics (*units in Bq/m^3*)				
Geological units	*Meas.*	*Mean*	*Geom. Mean*	*Std. Dev.*	*Min.*	*Max.*
all	24 000	55 000	33 000	77 000	< 5 000	> 1 000 000
CMS	12 000	37 000	24 000	41 000	< 5 000	841 000
PS	4 500	46 000	40 000	58 000	< 5 000	922 000
PM	3 500	63 000	45 000	67 000	< 5 000	830 000
IR	4 000	110 000	66 000	140 000	< 5 000	> 1 000 000

Maps:

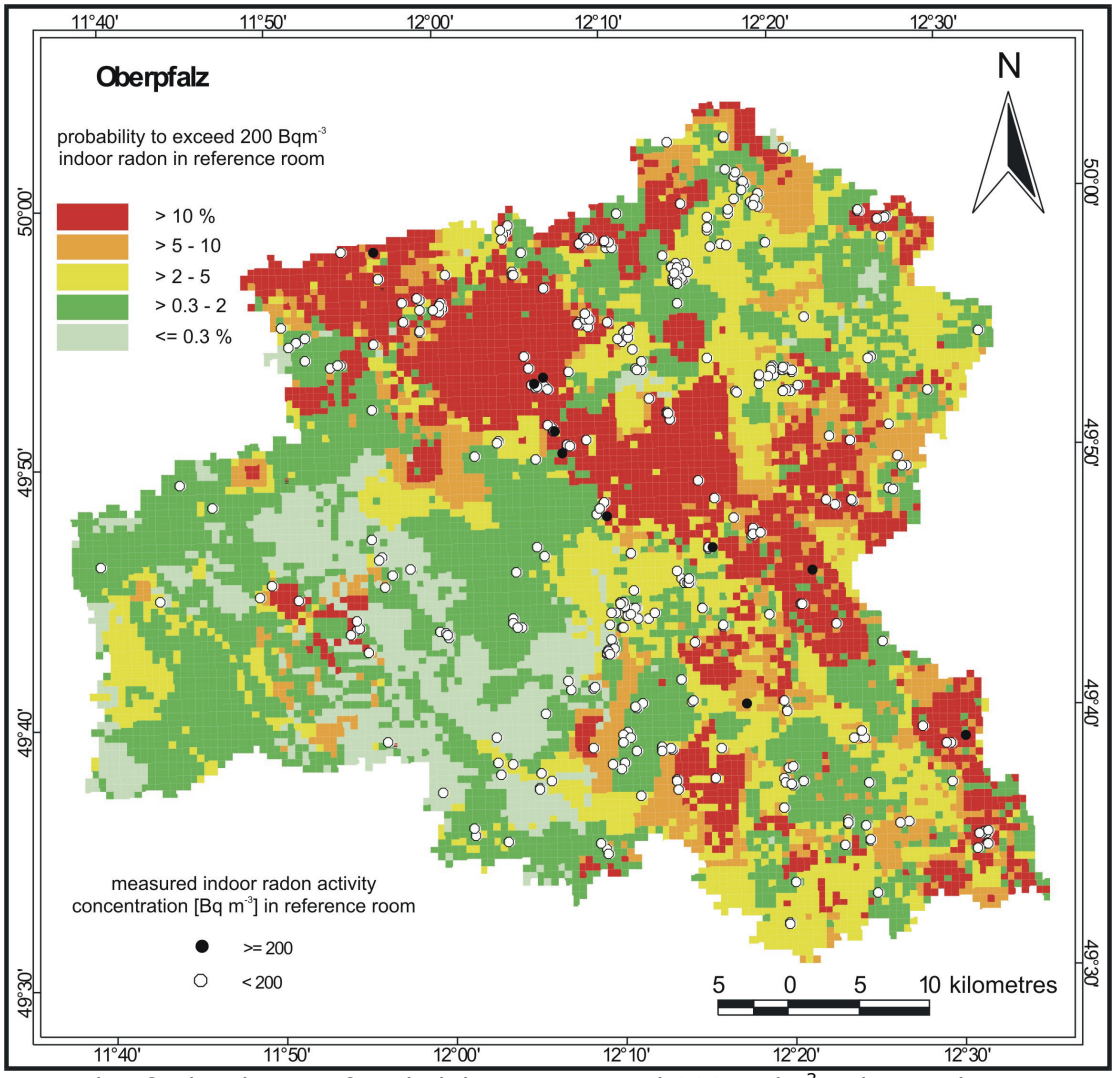
Method:

- Regionalisation of the measured values was realised by a distance-weighted interpolation on a 3 × 3 km grid basis within geological units using GIS.



Map of soil gas radon concentrations in Bq/m^3. Map reproduced with the kind courtesy of the Kemski & Partner © (2005). Reference: http://www.bfs.de/ion/radon/radonatlas.html

- Local maps of probabilities to exceed a specified threshold were derived by applying transfer factors (derived from a regression applied to radon activity concentration in the ground floor related to radon concentration in soil gas).



Example of a local map of probabilities to exceed 200 Bq/m^3 indoor radon concentrations. Map reproduced with the kind courtesy of the Kemski & Partner © (2005).
Reference: http://www.radon-info.de/shtml/karten_rl.shtml

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Greece, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Papastefanou, C., Stoulos, S., Manolopoulou, M., Ioannidou, A., and S. Charalambous (1994). Indoor Radon Concentrations in Greek Apartment Dwellings. *Health Physics*, **66**(3): 270-273.
- Geranios, A., Kakoulidou, M., Mavroidi, Ph., Fisher, S., Burian, I., and J. Holecek (1999). Preliminary Radon Survey in Greece. *Radiation Protection Dosimetry*, **81**(4): 305-309.
- Geranios, A., Kakoulidou, M., Mavroidi, Ph., Moschou, M., Fisher, S., Burian, I., and J. Holecek (2001). Radon Survey in Kalamata (Greece). *Radiation Protection Dosimetry*, **93**(1): 75-79.
- Nikolopoulos, D., Louizi, A., Koukouliou, V., Serefoglou, A., Georgiou, E., Ntalles, K., and C. Proukakis (2002). Radon survey in Greece--risk assessment. *Journal of Environmental Radioactivity*, **63**(2):173-86.
- Clouvas, A., Xanthos, S., and M. Antonopoulos-Domis (2003a). Long term measurements of radon equilibrium factor in Greek dwellings. *Radiation Protection Dosimetry*, **103**(3): 269-271.
- Clouvas, A., Xanthos, S., and M. Antonopoulos-Domis (2003b). A combination study of indoor radon and in situ gamma spectrometry measurements in Greek dwellings. *Radiation Protection Dosimetry*, **103**(4): 363-366.
- Geranios, A., Nikolopoulos D., Louizi A., and A. Karatzi (2004). Multiple radon survey in spa of Loutra Edipsou (Greece). *Radiation Protection Dosimetry*, **112**(2): 251-258.

Campaign

No national indoor radon survey has been organised, the following information is derived to a large scale survey made by the Medical Physics Department, Medical School, Athens University (see Nikolopoulos *et al.*, 2002).

Survey period	*Dwellings investigated*	*Measurements / dwelling*
1994 -1998	1277	1

Sampling strategy:

On a regular grid covering the whole territory (1 on 1000 dwellings selected), 734 locations sampled

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Track-etch detector (CR-39)	365	Whole year	Bedroom (1m above the ground near the wall)

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (CR-39)	365	*NA*	365	365

Indoor radon levels

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
1277	55	44	2.4	3.7	1 700

Estimated mean annual radon levels in Greek dwellings		
Mean (*Bq/m^3*)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
55	2	1.1

Maps:

Various University Laboratories and the Research Laboratory of NRCPS "Demokritos" have worked independently on producing regional radon risk maps that are available in draft versions only. No map of estimated radon levels indoor in the country has been published.

Greece, soil-gas measurements

No national or large scale surveys based on soil-gas measurements.

HUNGARY

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No survey made on a national or large scale level.

Hungary, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Hámori K, Tóth E., Köteles Gy., Pál L.(1994) A magyarországi lakások radonszintje (1994-2004). *Egészségtudomány*, **48**: 283-299. (*In Hungarian*)

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1994 - 2004	15 602 dwellings* = 15 277 on ground floor 325 on higher floors	3

**In the following part of the document, statistics for ground floor dwellings only will be indicated.*

Sampling strategy:

Random selection of dwellings followed by targeted survey in regions with higher concentrations.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (CR-39)	240 days (3 times 80 days measured consecutively)	Autumn, winter, spring, consecutively	Bedrooms

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (CR-39)	80	*NA*	45	160

Statistics of the measurements

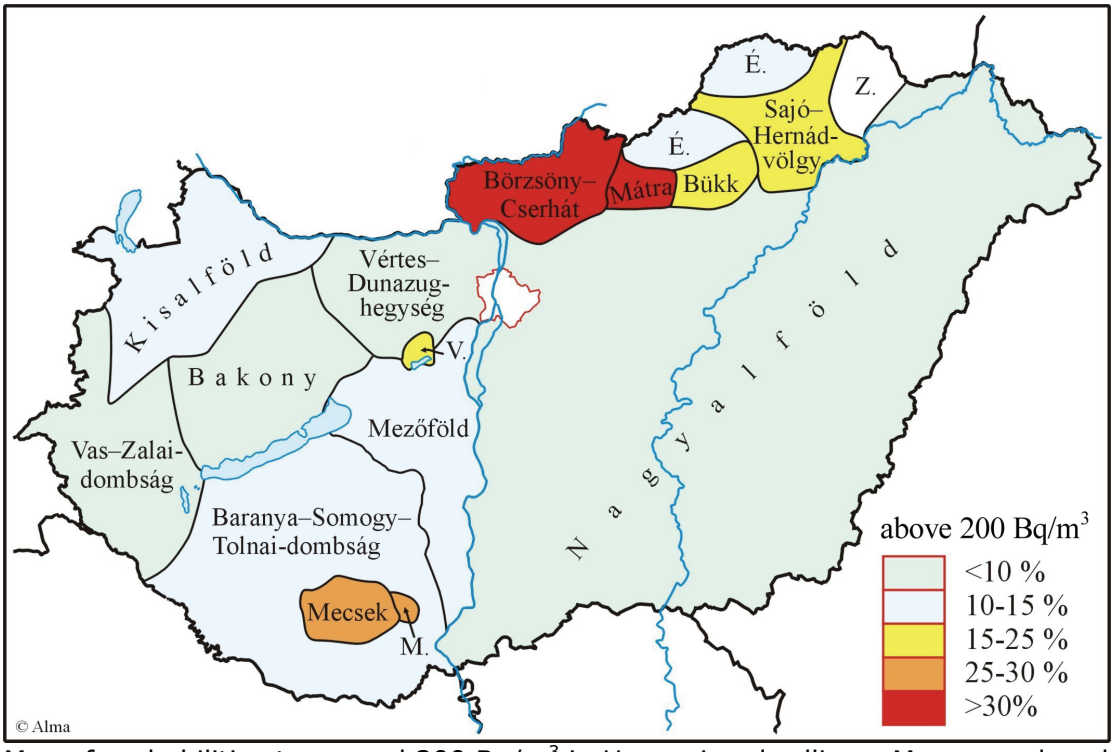
Measurements statistics (units in Bq/m^3)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
~ 60 000	*NA*	*NA*	*NA*	5	> 10 000

Estimated mean annual radon levels in Hungarian dwellings*		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
NA	5.08	0.77

** statistics for 92% of the dwellings (first and higher floors)*

Maps:

- The map shows the percentages of homes in Hungarian villages (< 10 000 inhabitants) in which the annual mean levels measured at the ground floor level were exceeding 200 Bq/m^3.



Map of probabilities to exceed 200 Bq/m^3 in Hungarian dwellings. Map reproduced with the kind courtesy of RAD Labor, © (2005).

Hungary, soil-gas measurements

No survey made on a national or large scale level.

IRELAND

Contact point for indoor radon measurements:

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No national or large scale surveys based on soil-gas measurements.

Ireland, indoor measurements

Web address of related project:

- http://www.rpii.ie/radon/index.html

Selected References:

- Fennell, S.G., G.M. Mackin, J.S. Madden, A.T. McGarry, J.T. Duffy, M. O'Colmáin, P.A. Colgan, D. Pollard (2002). *Radon in Dwellings. The Irish National Radon Survey*. RPII-02/1
- Fennell, S. G., G. M. Mackin, A. T. McGarry and D. Pollard (2002). Radon exposure in Ireland, *International Congress Series*, **1225**: 71-77.

Campaign

Survey period	*Dwellings investigated*	*Measurements / dwelling*
1992-1999	11 319	2

Sampling strategy:

On a regular grid covering the whole territory: dwellings were randomly selected from Irish National Grid 10 km grid squares.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detector (CR-39)	365	Whole year	Living room and bedroom

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (CR-39)	365	0	365	365

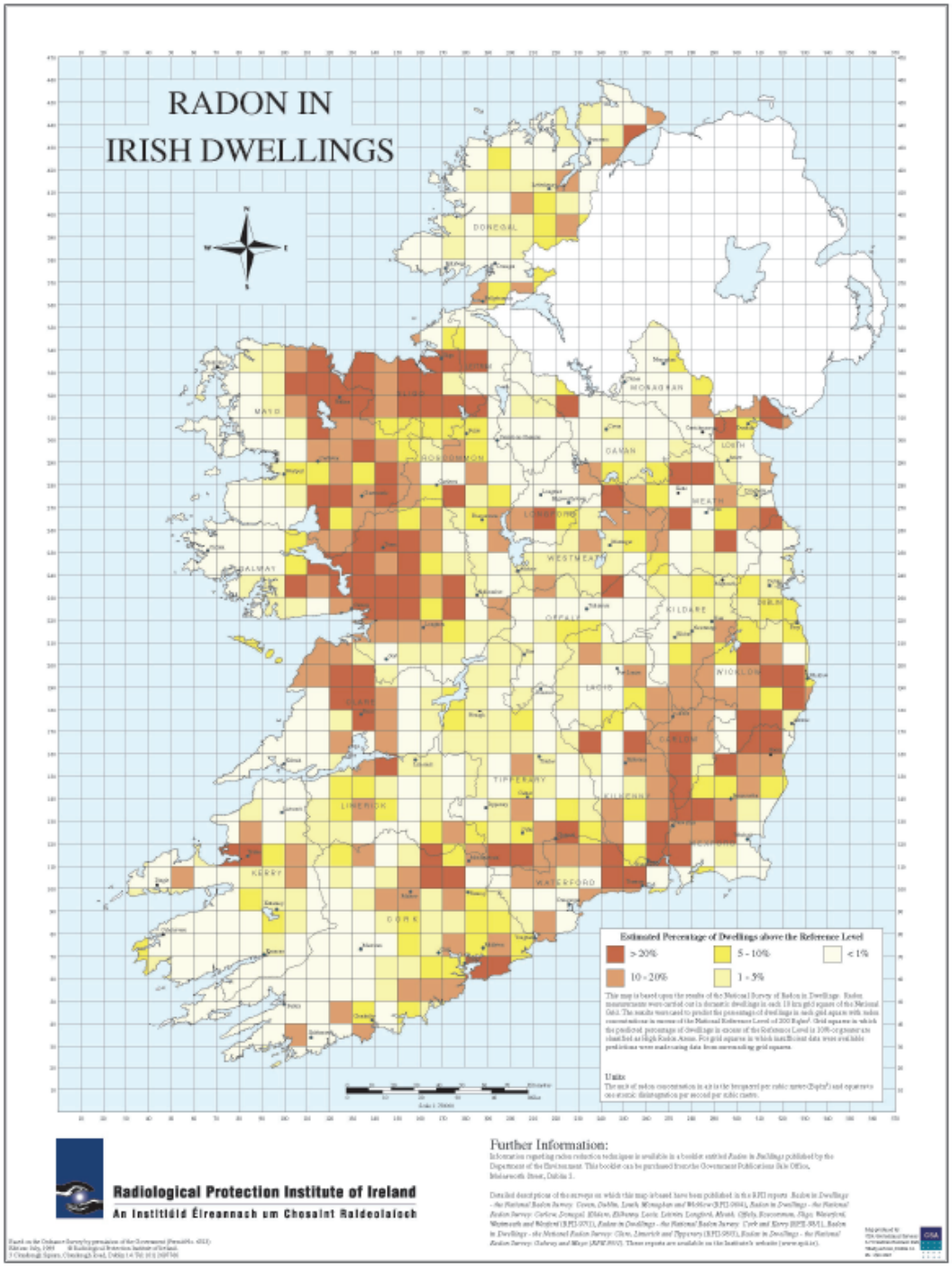
Indoor radon levels

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
22 638	89	57	*NA*	10	1 924

Estimated mean annual radon levels in Irish dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
89	~ 6	~ 1.5

Maps:

A radon prediction map was prepared for the whole country. The percentage of houses in each grid square of 10 ×10 km (837 grid squares in total) with average radon concentrations above the Irish national reference level for dwellings of 200 Bq/m^3 was estimated utilising the log-normal distribution properties of indoor radon concentrations. Five categories of predictions were presented on the map: < 1%, 1-5%, 5-10%, 10-20%, >20% For squares in which there were fewer than five valid measurement results the geometric mean was estimated from data in the surrounding squares.



Map of estimated annual mean radon concentration values in Irish dwellings. Map reproduced with the kind courtesy of RPII © (2005). Web address: http://www.rpii.ie/radon/maps/map.html

Ireland, soil-gas measurements

No national or large scale surveys based on soil-gas measurements.

ITALY

Contact point for indoor radon measurements:

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00144 Rome
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Italy, indoor measurements

Web address of related project:

- http://www.apat.gov.it/site/it-IT/Temi/Radioattivita_e_radiazioni/Radon/
- Web sites of the Italian National Radon Action Plan and of the Italian National Radon Archive will be available in a near future

Selected References:

- Bochicchio F, Campos Venuti G, Nuccetelli C, Piermattei S, Risica S, Tommasino L, Torri G. (1996). Results of the representative Italian national survey on radon indoors. *Health Physics*, **71**(5): 743–750.
- Bochicchio F, Campos Venuti G, Piermattei S, Nuccetelli C, Risica S, Tommasino L, Torri G , Magnoni M, Agnesod G, Sgorbati G, Bonomi M, Minach L, Trotti F, Malisan MR, Maggiolo S, Gaidolfi L, Giannardi C, Rongoni A, Lombardi M, Cherubini G, D'Ostilio S, Cristofaro C, Pugliese M, Martucci V, Crispino A, Cuzzocrea P, Sansone Santamaria A, Cappai M. Annual average and seasonal variations of residential radon concentration for all the Italian Regions*. Radiation Measurements* (2005, in press, already available on-line)
- APAT – Annuario dei dati ambientali – edizione 2004

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1989-1998	5361	Generally 4 (2 consecutive 6-month periods. For each period, 2 detectors were exposed in one room, generally bedroom.)

More detailed regional surveys have been carried out or started in some of the 21 Italian Regions.

Sampling strategy:

All the dwellings were randomly selected using a two-stage stratified sampling scheme. In the first stage, all the 50 towns with > 100 000 inhabitants were selected, whereas 182 smaller towns were randomly sampled. In the second stage, dwellings were randomly sampled within

the selected towns. The sampling proportion was generally 1/4000, and in 5 regions was 1/2000.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (LR 115) by Kodak-Dosirad (France) in a closed-type configuration	Two consecutive six-month periods	Generally, one period covers autumn/winter and the other period covers spring/summer	One room per dwelling (generally bedroom)

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (LR-115)	About 180	NA	NA	NA

Indoor radon levels

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. **Err.***	*Min.*	*Max.*
5 361	70	52	1	~5	1 036

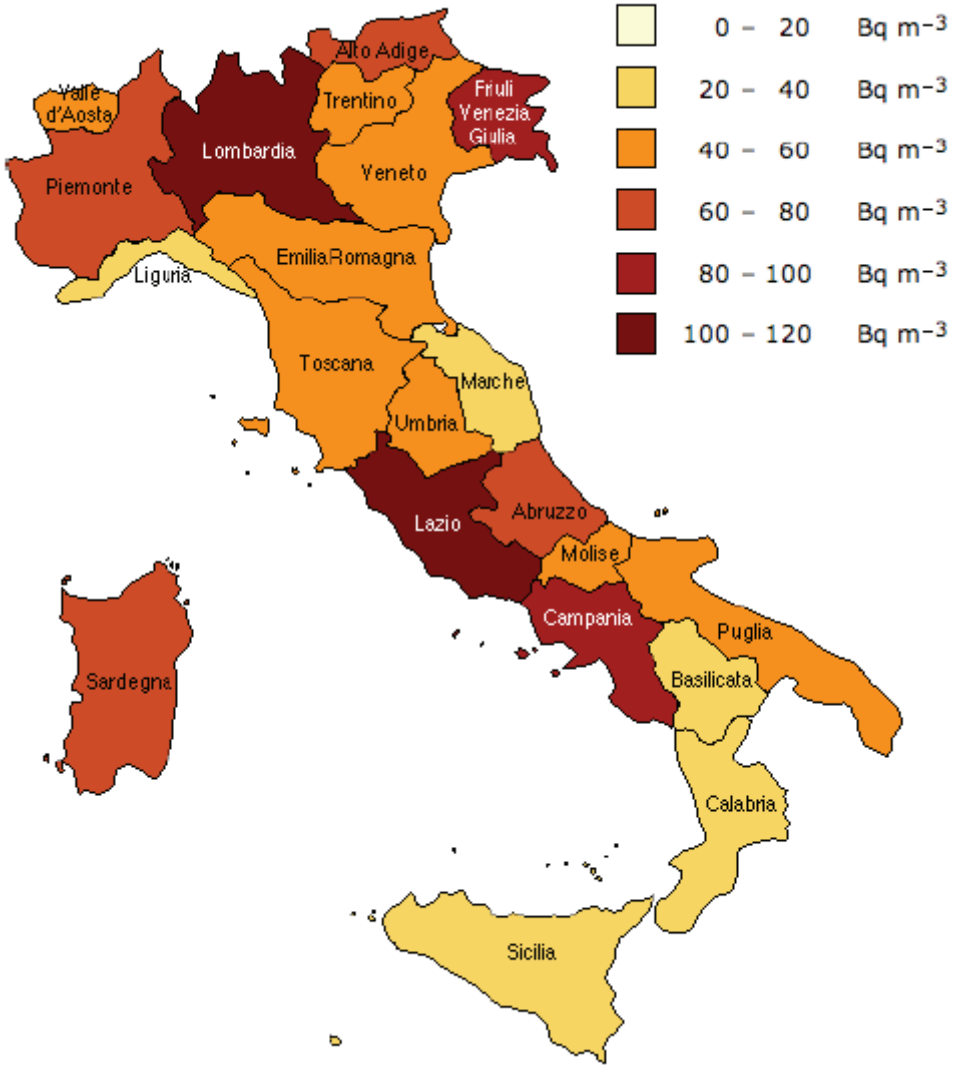
All the measurements refers to annual average. For 619 dwellings only one six-month period measurement was available, and seasonal correction factors were applied.

Estimated mean annual radon levels in Italian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
70	3.2	0.9

Maps:

Method:

- Local averages were calculated on the basis of regional boundaries. Regional statistics can be found in Bochicchio *et al.*, 2005)

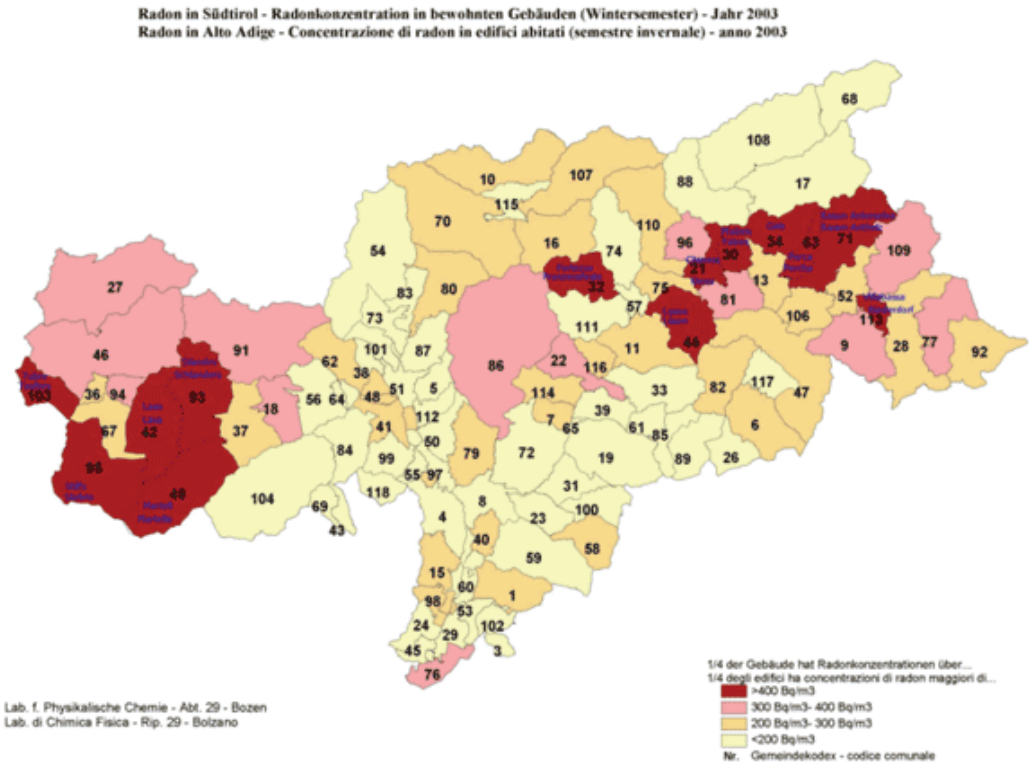


Map of the average annual radon concentration levels in all the 21 Italian Regions as estimated from the Italian National Survey. Map reproduced with the kind courtesy of the ISS and APAT © (2005).
Reference: Bochicchio et al., 2005.

This map will be available in a near future on the website of the Italian National Radon Action Plan and of the Italian National Radon Archive and at:
http://www.apat.gov.it/site/it-IT/Temi/Radioattivita_e_radiazioni/Radon/

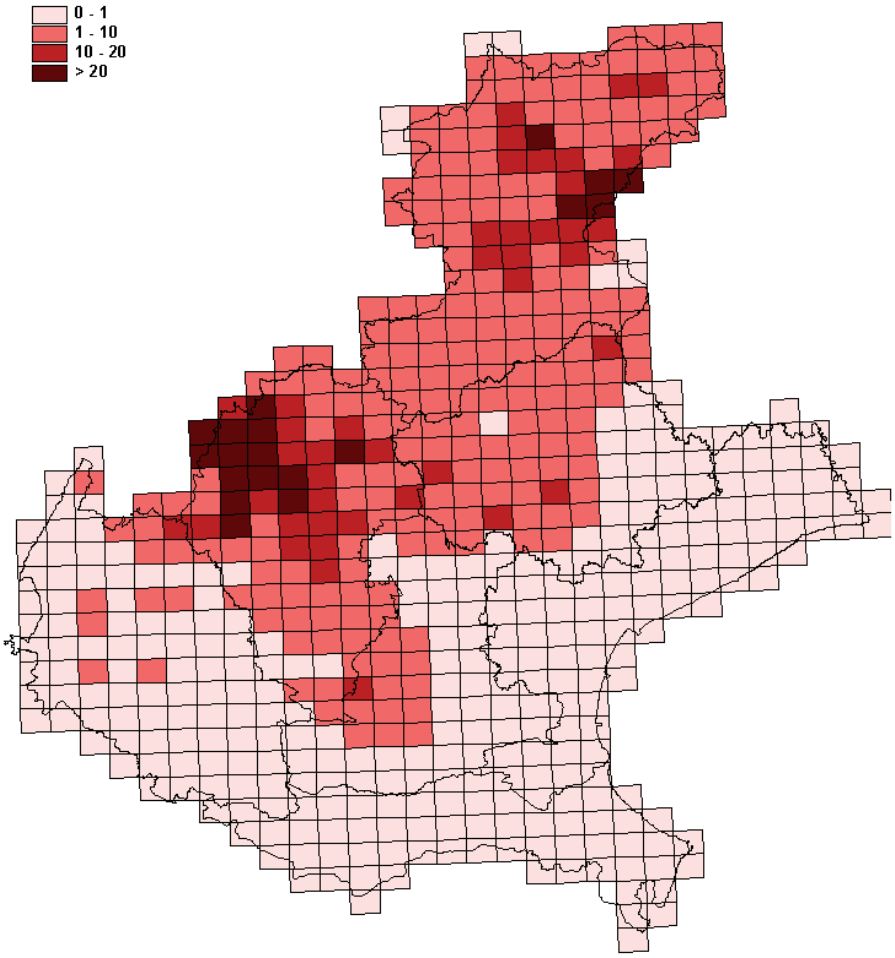
Regional radon maps are expected to appear in 2006 following surveys made in 2005. Below are two examples of regional radon maps.

- Regional map of radon levels in South Tyrol. The map shows local statistics (upper quartile) calculated on the basis of administrative boundaries. Reference: Minach, L. and Verdi, L. (2002) *Radon in South Tyrol.* In: Proceedings of the Fifth International Conference on High Levels of Natural Radiation and Radon Areas, Munich, September (2002) BfS Schrifter, 24/2002, 135–137.



Map reproduced with the kind courtesy of the APPA Bolzano © (2005)
Reference: http://www.provincia.bz.it/agenzia-ambiente/2908/radon/radon_i-04.htm

- Regional map of radon levels of the Veneto region. The map shows local percentages of houses exceeding 200 Bq/m3, obtained from statistics treatment of indoor radon data. The territorial units exceeding the threshold of 10% are considered prone areas by local authority Reference: Report of the Regional Agency for Environmental Prevention and Protection in Veneto. November 2000. http://www.arpa.veneto.it/agenti_fisici/docs/radon/Radon-indagine%20regionale.zip



Map reproduced with the kind courtesy of the A.R.P.A.V (Regional Agency for Environmental Prevention and Protection in Veneto) © (2005). Reference: Report of the Regional Agency for Environmental Prevention and Protection in Veneto. November 2000: http://www.arpa.veneto.it/agenti_fisici/docs/radon/Radon-indagine%20regionale.zip

Italy, soil-gas measurements

No surveys made on a national or a large-scale level.

LATVIA

Contact point for indoor radon measurements:

Radiation Safety Centre
Maskavas 165, Riga
LV1019
Latvia,

http://www.rdc.gov.lv/eng/rdc_eng.htm

Reporting contact point

Antra ZALKALNE

Radiation Safety Centre
Maskavas 165, Riga
LV1019
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Contact point for soil gas radon measurements:

Radiation Safety Centre
Maskavas 165, Riga
LV1019
Latvia

http://www.rdc.gov.lv/eng/rdc_eng.htm

Reporting contact point:

Antra ZALKALNE

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Latvia, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Dambis, M. (1997). *The Indoor Radon Situation in Latvia*, Report of Radon seminar, 4th - 5th September, 1997, Latvia.

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1993-1994	300	*NA*

Sampling strategy:

Random selection of houses. Sampling frequency was proportional to population density: one house on around 780 was selected randomly in each district.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Electret Ion Chambers (Rad Elec, Inc.); Pulsed Ionization-Chamber (ATMOS-12, Gammadata Matteknik AB)	*NA*	Middle of summer and early autumn	mainly bedrooms and living rooms

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Electrets PIC	*NA*	*NA*	*NA*	*NA*

Statistics of the measurements

Measurements statistics (*units in Bq/m^3*)					
Number	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.**
300	70	*NA*	5	30	143

**A value of 1500 Bq/m^3 was found in a house under other circumstances*

Estimated mean annual radon levels in Latvian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
NA	*NA*	*NA*

Maps: *NA*

Latvia, soil-gas measurements

Selected References:

- Akerblom, G. (2002). *Natural radiation, background concentrations and ranges of variation*, Lecture presented at the NORM Seminar held at the Latvian Radiation Safety Centre, Riga, 7 May 2002.

Campaign

Survey period	*Sample locations*
1997	*NA*

Sampling strategy:

Analysis of different soil types. Random selection of locations.

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
Emanometer Markus-10 (Gammadata Matteknik AB)	*NA*	70-100

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
NA	*NA*	*NA*	*NA*	2 000	52 000

Maps: *NA*

LITHUANIA

Contact point for indoor radon measurements:

Radiation Protection Centre
Kalvariju 153
LT-08221 Vilnius
Lithuania

http://www.rsc.lt/

Reporting contact point

Gendrutis MORKUNAS

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Kalvariju 153
LT-08221 Vilnius
Lithuania

Tel.: (+370) 5 2361934
Fax.: (+370) 5 2763633
e-mail: genmo@takas.lt

Contact point for soil gas radon measurements:

Radiation Protection Centre
Kalvariju 153
LT-08221 Vilnius
Lithuania

http://www.rsc.lt/

Reporting contact point:

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Tel.: (+370) 5 2361934
Fax.: (+370) 5 2763633
e-mail: genmo@takas.lt

Lithuania, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Pahapill L., Dambis M., Morkūnas G., Åkerblom G. (1998) Radon in the Baltic states. In: *Proceedings of the Regional IRPA Congress* "Radiation Protection Issues in the Baltic Region with Emphasis on Co-operative Projects with Estonia, Latvia and Lithuania", June 12-13, 1998, Stockholm, 11-26.
- Morkūnas, G. (2000). *Estimation of effective dose due to indoor radon in the detached houses.* Doctoral thesis. Radiation Protection Centre and Institute of Physics. Vilnius, 94 p.
- Åkerblom G., Morkūnas G. (2001). The outcome of the Lithuanian radon survey. *The Science of the Total Environment*, **272**: 243-244.
- Pilkyte L., Morkūnas G., Åkerblom G. (2005). Indoor radon in the karst region of Lithuania. In: *The Natural Radiation Environmen*t, series "Radioactivity in the Environment", VII-7, 807-812.

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1995-1998	400	2

Sampling strategy:

Random selection of dwellings on the whole territory followed by a preferential sampling of regions with higher levels and/or higher populations.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Electret Ion Chambers (Rad Elec, Inc.);	28	Winter	Main 2 rooms used

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Electret Ion Chambers (Rad Elec, Inc.);	28	5	19	41

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
798	55	36.5	5.6	4	455

Estimated annual mean radon levels in Lithuanian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
55	2.5	0.3

Measurements were made in some places during both seasons - warm and cold. No statistically significant difference between means could be found.

Maps: *NA*

Lithuania, soil-gas measurements

Selected References:

- Morkūnas, G. (2000). *Estimation of effective dose due to indoor radon in the detached houses.* Doctoral thesis. Radiation Protection Centre and Institute of Physics. Vilnius, 94 p.
- Abromaitytė, R., L. Pilkytė, L. Morkūnas (2003). Radon risk investigation in Panevėžys city development area. *Health Sciences*, **13**(3): 32-35.

Campaign

Survey period	*Sample locations*
1995	~70

Sampling strategy:

Regions with expected high levels (karst areas).

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
Emanometer Markus-10 with Ortec Ultra Silicon detector	~10 min	70

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
70	18 500	14 430	13 700	1 000	60 000

Maps: *NA*

LUXEMBOURG

Contact point for indoor radon measurements:

Radioprotection Survey – Health Ministry
Villa Louvigny - Allée Marconi
L- 2120 Luxembourg
Luxembourg

http://www.drp.etat.lu/

Reporting contact point

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L- 2120 Luxembourg

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Contact point for soil gas radon measurements:

Laboratoire Physique des Radiations, University of Luxembourg
162a, avenue de la Faïencerie
L-1511 Luxembourg
Luxembourg

http://www.cu.lu/lpr/

Reporting contact point:

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Luxembourg, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Kies A., Feider M., Biell A. (1994): Indoor Radon Concentrations in the Grand-Duchy of Luxembourg. *Annales Association Belge de Radioprotection*, **19**(1-2): 189-201.
- Kies A., Feider M., Biell A., Rowlinson L. (1994). Radon Mapping in the Grand-Duchy of Luxembourg, In: *2nd Int. workshop on Geological Aspects of Radon Risk Mapping*, Prague, Czech Geol. Surv., pp. 142-152.
- Kies A., Feider M., Biell A., Rowlinson L (1996). Radon Survey in the Grand-Duchy of Luxembourg. Indoor measurements Related to house Features, Soil, Geology and Environment. *Environment International*, **22**(Supp. I): S805-S808.
- Kies A., Feider M., Biell A., Rowlinson L. (1996). Investigation on the Dynamics of Indoor Radon concentrations, *Environment International*, **22**(Supp. I): S899-S904.
- Feider M., Kies A. (1996). The Radon Policy in the Grand-Duchy of Luxembourg, *Annales Association Belge de Radioprotection*, **21**(1): 101-106.
- Kies A., Feider M. (1996). Radon-Messungen im Grossherzogtum Luxemburg - Einfluss der Geologie auf die Radonkonzentration in Häusern, in *Umwelt-radioaktivität*, Agemar Siehl Edit., Ernst&Sohn, Berlin, pp 233-242.
- Miles J., Algar R., Howarth, C., Hubbard L., Risica S., Kies A. Poffijn A. (1996). Results of the 1995 European Commission intercomparison of passive radon detectors. European Commission, *EUR 16949 EN*, pp 1-94.
- Kies A., Robinet A., Feider M., Maquil R. (1996). Study of the radon potential for a traverse of the Grand-Duchy of Luxembourg, In: *3rd Int. workshop on Geological Aspects of Radon Risk Mapping*, Czech, Geol. Surv., pp 46-50.
- Kies, J. Majerus, S. Roth (2001). Test of Geostatistical Software with Simulated and Real Data, *Eurosymposium on Protection against Radon* - Liège (Belgium).
- Kies A., M. Feider (2001). Radon Measurements in Waterworks, Grand Duchy of Luxembourg, *Eurosymposium on Protection against Radon* - Liège (Belgium).
- Kies A., F. Tondeur (2001). In situ Study of Loess Deposits in relation with Indoor Radon Pollution. *Eurosymposium on Protection against Radon* - Liège (Belgium).
- Kies A. (2002). Le radon en Géophysique et en Géologie, In : *Sciences de la Terre,* J. A. Flick et N. Stomp éditeurs, Musée d'Histoire Naturelle et ECGS Walferdange, pp. 106-109.
- Tosheva Z., Stoyanov K., Nicholev L., Kies A. (2004). Comparison of different methods for uranium determination in water, *Journal of Environmental. Radioactivity*, **72**: 57-63.

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1993-2002	2619	1.7

Sampling strategy:

Random selection of dwellings at the beginning of the survey. 300 dwellings were further chosen according to the underlying geology.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (Macrofol)	103	Mainly winter season	Living rooms and bedrooms, mainly living rooms

	Measurement time (units in days)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (Macrofol)	103	26	8	364

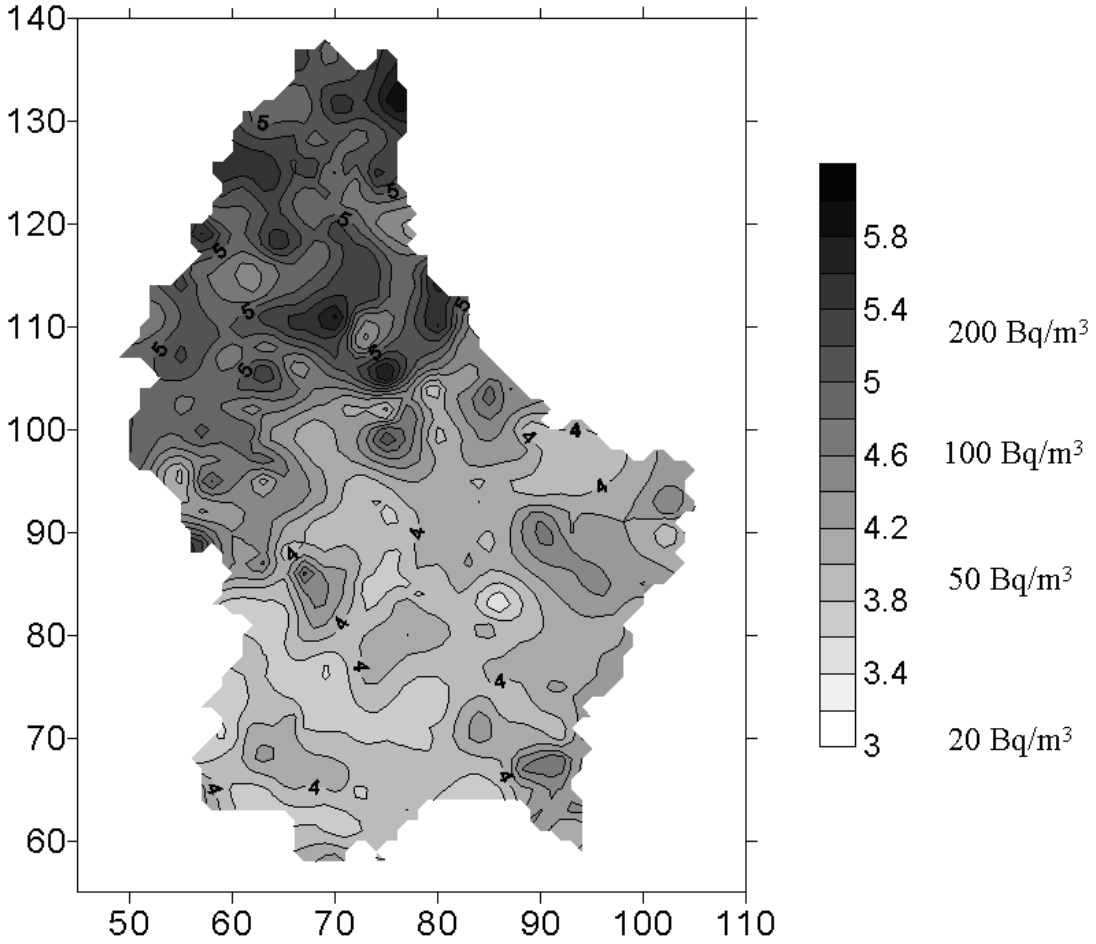
Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
4603	115	*NA*	168	1	2776

Estimated annual mean radon levels in Luxembourgish dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
115	*NA*	3

Maps:

- First published maps were obtained using Surfer^R and the default values of the kriging parameters. The map below shows local annual radon concentration values obtained by interpolating local median values (log-transformed) by means of ordinary kriging.



Map of annual mean radon concentration values. Reproduced with the kind courtesy of A. Kies © (2005)

Luxembourg, soil-gas measurements

Selected References:

- *NA*

Campaign

Survey period	*Number of Sample locations*
1994-2005	*Not known*

Sampling strategy:

Sampling locations were measured in order to cover the variety of geological formations. More intensive samplings occurred in locations where dwellings were showing higher indoor radon concentrations.

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
Scintillation flasks ("Lucas Cells") and counting chamber	100 ml Lucas cells counted for 100 s	100

Statistics of the measurements

Measurements statistics (units in kBq/m^3)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
> 3000	45	37	-	-	120

Maps:

- Maps are published in internal reports and linked to geological studies

MALTA

Contact point for indoor radon measurements:

Radiation Protection Board
OHSA
17 Edgar Ferro Street
Pieta', MSD 07
Malta

http://www.gov.mt/

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Fax.: (+356) 2123 2909
e-mail: paul.brejza@gov.mt

Malta, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Mifsud I., Amato Gauci A., Licari, L. and Sammut M. (1997). Preliminary investigation on Radon levels in local dwellings. *Xjenza* , **2**(1): 34-38.
- Mifsud I and Sammut M. (1999). A survey on radon levels in local dwellings. *Xjenza*, **4**(1): 40 – 41.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1994-1995	68	1
1997-1998	21	1

Sampling strategy:

1st Survey: pilot study. Dwellings from 68 localities were chosen from a list of selected acquaintances through the Dept. of Public Health in 68 localities. The sampling frequency was proportional to the population density.

2nd Survey: Same as above but only 21 dwellings were investigated.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
1st Survey: Apha-Guard detector	1	June-November	Basements, various rooms on different floors
2nd Survey: Track-etch detectors	365	All year	Bedrooms or living rooms

	Measurement time (*units in days)*			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
1st Survey: Apha-Guard detector	1	*NA*	*NA*	*NA*
2nd Survey: Track-etch detectors	2 × 180	*NA*	*NA*	*NA*

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
1st Survey: Alpha-Guard detector: 68	55	40	37	10	199
2nd Survey: Track-etch detectors: 2 × 21	40	32	2	*NA*	*NA*

Estimated mean annual radon levels in Maltese dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
40	0	0

Maps:

Method:

Maps showing local bar charts of the measurements have been published in the cited papers.

Malta, soil-gas measurements

No survey made on a national or large scale level.

The Netherlands

Contact point for indoor radon measurements:

RIVM/LSO (National Institute for Public Health and the Environment/
Laboratory for Radiation Research)
PO Box 1, 3720 BA Bilthoven
The Netherlands

http://www.rivm.nl/

Reporting contact point

Roelf O. BLAAUBOER

RIVM/LSO
PO Box 1, 3720 BA Bilthoven
The Netherlands

Tel.: (+31) 30 274 2645
Fax.: (+31) 30 274 4428
e-mail: Roelf.Blaauboer@rivm.nl

Radium concentrations were considered more relevant. Soil gas surveys were not made.

Contact point for measurements of radium in soils:

RIVM/LSO (National Institute for Public Health and the Environment/
Laboratory for Radiation Research)
PO Box 1, 3720 BA Bilthoven
The Netherlands

http://www.rivm.nl/

Reporting contact point

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The Netherlands, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Put, L. W., Veldhuizen, A. de Meijer, R. J. (1985). Radonconcentraties in Nederland. Report on SAWORA project A2. KVI, Groningen, Report no. 111I, 101 p. (*in Dutch*).
- Hiemstra, Y., Stoop, P., Lembrechts, J. (1997). *The second Dutch national survey on radon in dwellings: set-up of the project.* RIVM Report no. 610058005, 37 p.
- Stoop, P., Glastra. P., Hiemstra. Y., De Vries. L., Lembrechts J. (1998). *Results of the second Dutch national survey on radon in dwellings*. RIVM Report no. 610058006. 45 p.

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1984 (1st survey)	894	Living rooms and bedrooms
1995-1996 (2nd survey)	952*	Living rooms

* *Additional measurements were made in the crawl space in 539 cases*

Sampling strategy:

- 1st survey: houses constructed before 1970
- 2nd survey: houses constructed during the period 1985-1993.
- A 3rd national survey on ventilation and radon concentrations (VERA) in new built dwellings from 1994 onwards is foreseen for 2005-2006.

The 2nd survey was planned to assess the average increase of radon concentration levels due principally to the improvements in insulation since 1970. A minimum of 17 dwellings were selected from 52 (from a total of 636) municipalities. The spatial distribution of the sampling locations is correlated to the population density. For the sample as a whole, the total number of houses per year of construction was kept constant.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors • KVI (1st survey) • FzK(Karlsruhe) (2nd survey)	365	Whole year	Living room and bedroom

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors FzK (Karlsruhe)	366	11	339	431

Statistics of the measurements of the 2nd survey

Measurements statistics (units in Bq/m³)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
Living rooms: 952	30.3	25.2	25.4	5.7	382
Bedrooms: 452	29	24	22	2	265

Estimated mean annual radon levels in Dutch dwellings		
Mean (Bq/m³)	*% of dwellings above 200 Bq/m³ and below 400 Bq/m³*	*% of dwellings above 400 Bq/m³*
23	0.3% of the new houses	0.0001

The average radon concentration in living rooms found in the first survey was of 22 Bq/m^3.

Maps: *NA*

The Netherlands, soil-gas measurements

No soil-gas measurements were made on a national level. However, correlations between indoor and outdoor radon concentrations on the one hand and the radium (^{226}Ra) concentration in the top soil (50 cm) on the other were investigated in a survey of 400 dwellings. It is considered that the measurement of radon in soil is more difficult and the values are not fully representative of the exhalation rate from soil. The water table is here an essential parameter and radon exhalation rates may vary by a factor of three depending on time of the year.

Selected References:

- Stoop, P., Glastra. P., Hiemstra. Y., De Vries. L., Lembrechts J. (1998). *Results of the second Dutch national survey on radon in dwellings*. RIVM Report no. 610058006. 45 p.

Campaign

Survey period	*Number of sample locations*
1995-1996	475

Sampling strategy:

Near about 400 single-family dwellings in 14 municipalities and near the aerosol monitors of the NRM (National Radioactivity Monitoring network) as part of the second radon survey.

Measurement technique

^{226}Ra concentration was derived from the gamma-radiations of ^{214}Pb and ^{214}Bi by means of a high purity Ge-detector. Measurements were made in duplicate on hermetically sealed samples of 300 ml. As the measurements are based on the analysis of the gamma radiations of the radon progeny, the time lag between sealing and analysis was at least three weeks.

Detector type	*Depth (cm)*
high purity Ge-detector	50

Statistics of the measurements

	Measurements statistics (units in Bq/kg)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
475	25	NA	15	6	72

Maps: *NA*

NORWAY

Contact point for indoor radon measurements:

Norwegian Radiation Protection Authority (NRPA)
P.O. Box 55
N-1332 Østerås
Norway

http://www.nrpa.no/

Reporting contact point

Terje STRAND

Norwegian Radiation Protection Authority (NRPA)
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Norway, indoor measurements

Web address of related project:

- http://radon.nrpa.no/

Selected References:

- Strand, T., Green, B.M.R., Lomas P.R. (1992) *Radon in Norwegian Dwellings*, *Radiation Protection Dosimetry*, **45**(1/4): 503-508.
- Strand, T., Ånestad K., Ruden, L., Ramberg, G.B., Jensen, C.L., Wiig, A.H., Thommesen, G. (2001). *Indoor Radon Survey in 114 Municipalities*, Norwegian Radiation Protection Authority, Reportsseries 2001:6 (*in Norwegian – English summary*)
- Strand T., Jensen C.L., Ramberg, G.B, Ruden, L, Ånestad, K. (2003) *Mapping of Radon Concentrations in 44 Norwegian Municipalities,* Norwegian Radiation Protection Authority, Reportseries 2003:9 (*in Norwegian – English summary*)
- Jensen, C.L., Strand, T., Ramberg, G.B., Ruden, L., Ånestad, K. (2004). *The Norwegian Radon Mapping and Remediation Program*. In: *Proceedings of the IRPA 11*, Paper 6a61, 23-28 May 2004.
- Strand T., Jensen C.L., Stranden, E., Sundal A.V., Ånestad, K., (2005) Radon Concentrations in the 2000-2003 Norwegian Housing Stock (in preparation, 2005)

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
• 1987-1989 • 1990-1999 • 2000-2003	• 7 525 • 7 000 • 37 400	• 1 • between 1 and 2 • 1

Sampling strategy:

Three surveys:

- 1st survey (1987-89): The dwellings were randomly selected from the whole country (census data base). One measurement in each dwelling – in the main bedroom.
- 2nd survey (1990 to 1999) and 3rd survey (2000-2003): The dwellings were randomly chosen from each participating municipality. In order to be able to identify radon prone areas the number of measurements were reduced in the densely populated areas and increased in the most rural areas. The sample varies from less than 2% to 20% of the housing stock. The calculated

annual mean radon concentration for the whole country is based on randomly selected samples of dwellings and by comparing the mean concentration for each municipality with the result of the survey 87-89 for the same municipalities.

The distribution of measurements in each municipality in the follow-up surveys are based on the results of initial surveys where different regions have been classified as high, moderate and low risk areas based on the results. In High-risk areas it is recommended that all dwellings are measured, while follow-up surveys are strongly recommended in Moderate risk areas based on additional information (type of dwelling, year of construction, type and construction of the basement, etc.)

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (CR 39)	60-180	Heating season and whole year	Living room and/or bedroom

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (CR 39)				
1. Survey 1987-89	185	*NA*	180	200
2. Surveys after 1990	70	*NA*	45	100

Indoor radon levels

Measurements statistics (units in Bq/m^3)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
~53 500	89	*NA*	*NA*	< 10	50 000

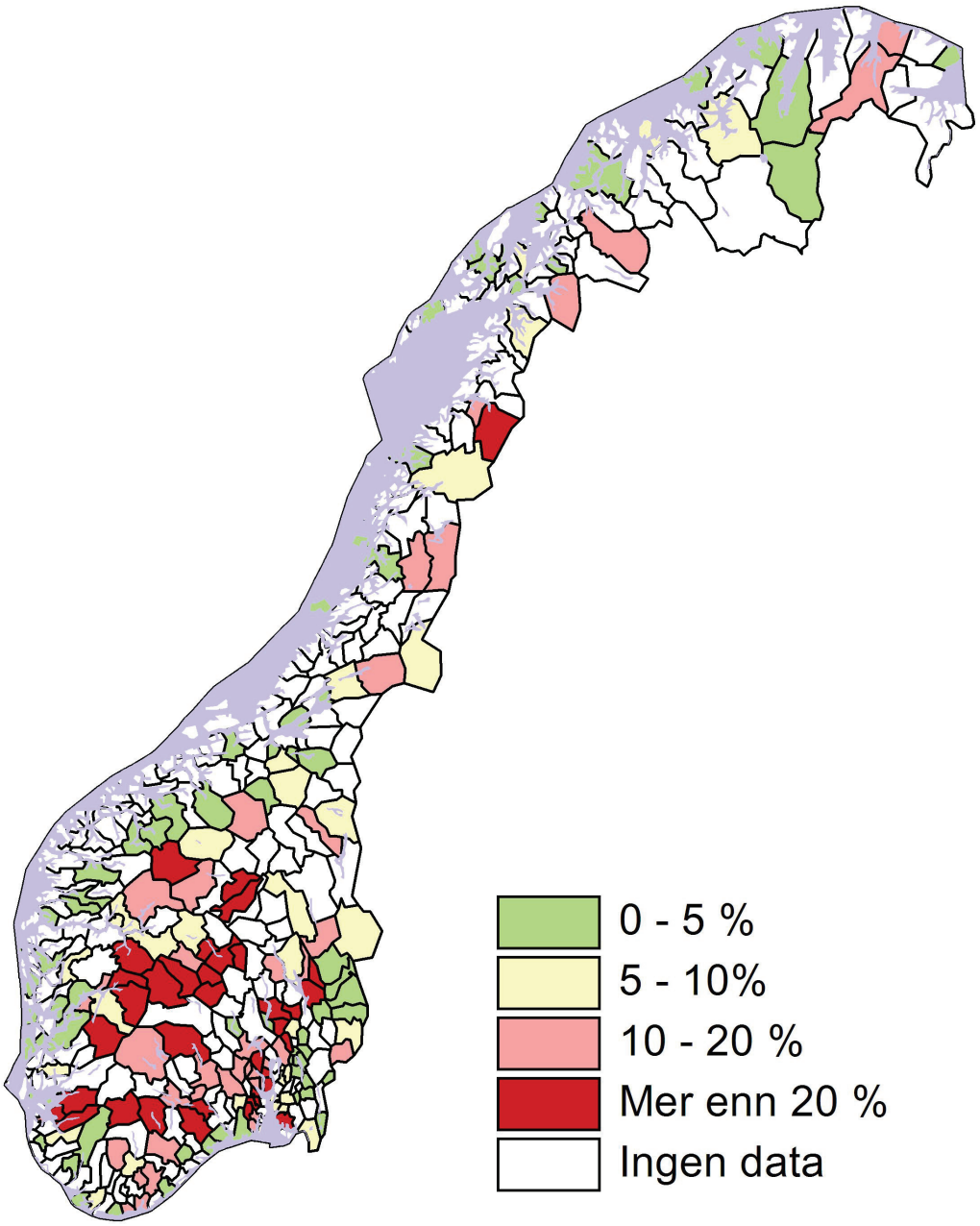
Estimated mean annual radon levels in Norwegian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
89	6	3

The arithmetic annual mean radon concentration during the heating season is 118 Bq/m^3. Results of measurements in the heating season are corrected to an annual mean value by multiplying by a factor of 0.75.

Maps:

Method:

- Radon data are aggregated at the municipal level. See http://radon.nrpa.no



Map showing for 189 municipalities the percentage of the housing stock estimated to be above the action level (200 Bq/m^3) Categories are less than 5%, 5-10%, 10-20% and more than 20% above 200 Bq/ m^3. Map reproduced with the kind courtesy of NRPA © (2005). Reference (Strand et al., 2005):

Norway, soil-gas measurements

No national or large scale surveys based on soil-gas measurements.

POLAND

Contact point for indoor radon measurements:

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Contact points for soil gas radon measurements:

Central Mining Institute (CMI) Plac Gwarków 1 40-166 Katowice Poland http://www.gig.katowice.pl/	The Henryk Niewodniczański Institute of Nuclear Physics PAS (IFJ PAN) ul. Radzikowskiego 152 31-342 Cracow Poland http://www.ifj.edu.pl/Dept6/Lpn

Reporting contact points:

Małgorzata WYSOCKA CMI Plac Gwarków 1 40-166 Katowice Poland Tel.: (+48) 32 259 2814 Fax.: (+48) 32 258 5979 e-mail: m.wysocka@gig.katowice.pl	Krzysztof KOZAK HNINP PAS ul. Radzikowskiego 152 31-342 Cracow Poland Tel.: (+48) 12 66 28 332 Fax.: (+48) 12 66 28 458 e-mail: Krzysztof.Kozak@ifj.edu.pl

Poland, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Mamont-Ciesla, K., Rosiński, S.W.., Sosińska, A., Bysiek, M., Henschke, J., Jagielak, J. (1994). Study of radon concentrations indoors and estimation of hazard to inhabitants in Poland. *CLOR Bi-Annual report 1992-1993*, Warsaw 1994.
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- Zalewski, M., Mnich, Z., Kapała, J., Karpińska, M. (1997). Radioecological analysis of the north-eastern region of Poland. *Polish Journal of Environmental Studies*, **6**(6): 51-55.
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- Karpińska, M., Zalewski, M., Mnich, Z., Kapała, J., Kleszczewska, E. (1999). Radiological hazard to the population from radon in the air in various types of dwellings in the north-eastern region of Poland. *Polish Journal of Environmental Studies*, **8**: 304-307.
- Karpińska, M., Zalewski, M., Mnich, Z., Kapała, J. (1999). Radon concentrations in dwellings in the Suwałki region. *Polish Journal of Medical Physics and Engineering*, **5**(2): 57-62.
- Zalewski, M., Mnich, Z., Karpińska, M., Kapała, J., Zalewski, P. (2001). Indoor radon concentrations in Poland as determined in short-term (two-day) measurements. *Radiation Protection Dosimetry*, **95**(2): 157-163.
- Karpińska, M., Wołkowicz, S., Mnich, Z., Zalewski, M., Mamont-Cieśla, K., Kapała, J. (2002). Comparative studies of health hazard from radon (Rn-222) in two selected lithologic formations in the Suwałki region (in Poland). *Journal of Environmental Radioactivity*, **61**(2): 149-158.
- Karpińska, M., Wołkowicz, S., Mamont-Cieśla, K., Mnich, Z., Kapała, J. (2003). Comparison of radon hazard to inhabitants of the Augustów Plane sandr and inhabitants of the Suwałki region of fluvioglacial sands and gravels. *Nukleonika*, **48**(4): 197-200.

- Wysocka M., Chałupnik S., (2003). Correlation of radon concentration level with mining and geological conditions in Upper Silesia Region. *Journal of Mining Science*, **39**(2), 191-198.

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1992-1994	2886	2
1995-2003	1212	2

Sampling strategy:

1st survey: random selection of dwellings.

2nd survey: preferential sampling in regions with expected higher values or where the underlying geology would generate higher radon concentrations.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
CR-39 (1st survey)	90	Autumn - spring	Living room and Bedroom
CR-39, Charcoal detectors, LR115 (2nd survey)	90	Autumn - spring	Living room and Bedroom

	Measurement time (*units in days*)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
CR-39 (1st survey)	270	NA	180	360
CR-39, Charcoal detectors, LR115 (2nd survey)	NA	NA	3	180

Statistics of the measurements

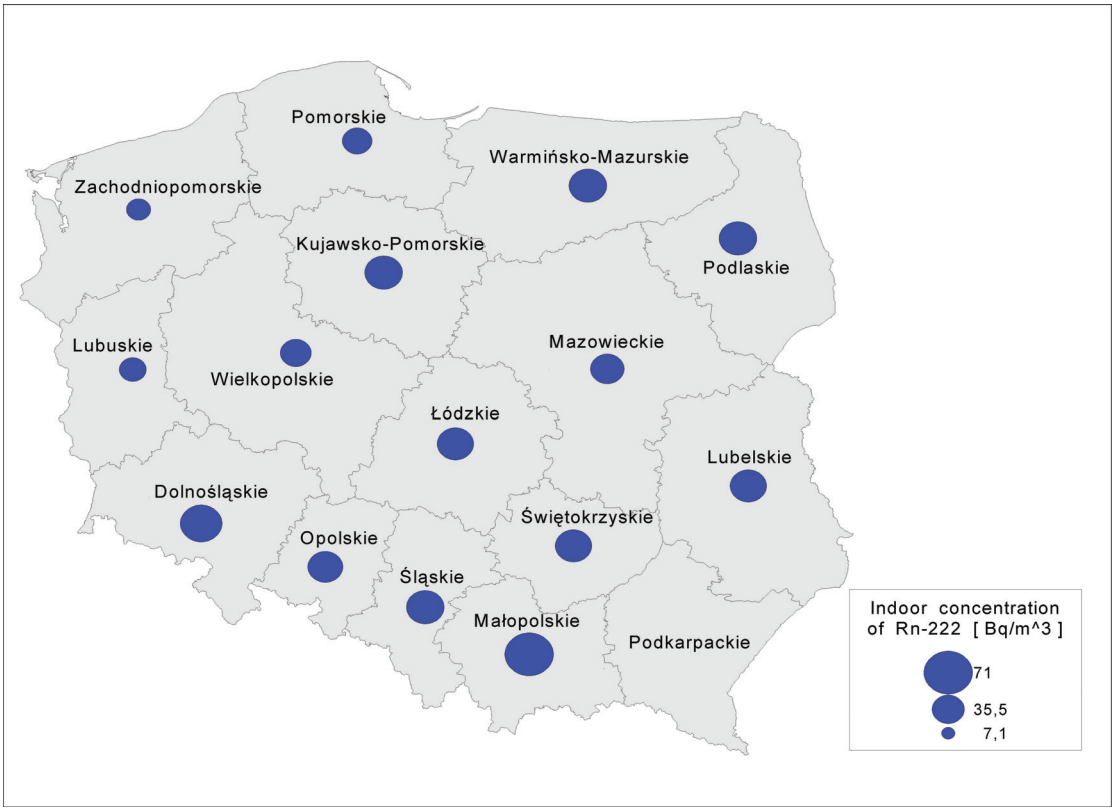
Measurements statistics (*units in Bq/m^3*)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
5 772 (1st survey)	44.5	32.0	39	4	756
2 324 (2nd survey)	118	*NA*	*NA*	7	3 261

Estimated mean annual radon levels in Polish dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
49	1.6	0.4

Maps

Method:

- Local averages were calculated on the basis of administrative boundaries. Radon concentration levels obtained from the first survey have been presented by means of map prepared using local averages on the basis of administrative boundaries. Radon levels obtained from the second survey have been presented in tables for particular areas with statistics.



Map of local annual mean radon concentration values. Map reproduced with the kind courtesy of Central Laboratory for Radiological Protection © (2005). References: Jagielak, J., Biernacka, M., Henschke, J., Sosińska, A. (1998). *Radiation Atlas of Poland*, 1997. Environmental Monitoring Books, ISBN 83-85787-22-4, 45 p.

Poland, soil-gas measurements

Selected References:

- Wysocka M., Skowronek, J., Skubacz., K. (1995). Changes of radon concentration in soil gas over some main fault in Upper Silesia Coal Basin. In: *Proceedings of the 5th International Conference on Rare Gas Geochemistry*, 30 August-3 September, Debrecen, Hungary
- Chałupnik, S., Wysocka, M. (2003). Measurements of radon exhalation from soil – development of the method and preliminary results. *Journal of Mining Science* **39**(2): 199-206.
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Campaign

Survey period	*Number of sample locations*
CMI: 1996-2004	120
HNINP PAS: 2000-2003	90

Sampling strategy:

Both CMI and HNINP PAS have made surveys in regions with expected high levels.

CMI: regions with faults, in areas of surface disposal of mining and industrial waste materials

HNINP PAS: local disjunctive tectonic zones

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
CMI: Lucas cells	Instantaneous	100
HNINP PAS: Alpha GUARD	30 minutes	100

Statistics of the measurements

	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
CMI: 126	16 000	12 562	9 267	120	66 700
HNINP PAS: 180	38 730	33 291	19 880	3 172	89 020

Maps: *NA*

PORTUGAL

Contact point for indoor radon measurements:

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Tel.: (+351) 21 994 6319
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e-mail: mcapucho@itn.mcies.pt

Portugal, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Faísca, M.C., M.M.G.R. Teixeira and A.O. Bettencourt (1992), Indoor radon concentrations in Portugal – a national survey. *Radiation Protection Dosimetry*, **45**: 465-467.
- Faísca, M.C. (1995), O risco de exposição ao radão, *Protecção Civil*, **5**, Ano VII, 2ª Série, pp. 25-30, (i*n Portuguese*).
- Faísca M.C., M.M.R. Teixeira (1998), Medidas da Concentração de Radão nos Diferentes Concelhos de Portugal Continental, DGA-DPSR, ISBN-972-8419-12-0. (*in Portuguese*).

Campaign

Survey period	*Dwellings investigated*	*Measurements / dwelling*
1988-1991	3 317	1

Sampling strategy:

Dosimeters were distributed randomly to 1 on 2000 inhabitants with regions with known higher radon levels receiving a higher proportion.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Track-etch detector (LR-115, type II, Kodak®)	80	Mainly winter season	Living rooms and Bedrooms

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (LR-115, type II, Kodak®)	*80*	*48*	20	512

Indoor radon levels

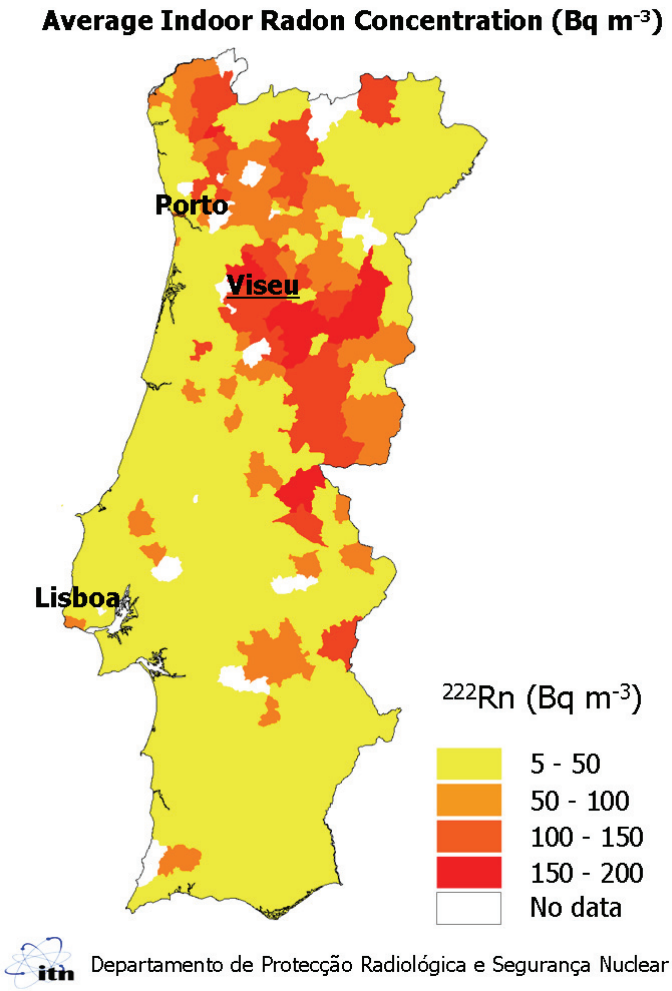
	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
3747	86	39	160	6	3 588

Estimated mean annual radon levels in Portuguese dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
NA	*NA*	*NA*

Maps:

Method:

Maps were prepared by averaging values on the basis of administrative boundaries.



Map of local mean radon concentration values in dwellings. Map reproduced with the kind courtesy of ITN. © (2005). References: Faísca, M.C. (1995), O risco de exposição ao radão, *Protecção Civil*, **5**, Ano VII, 2ª Série, pp. 25-30, (*in Portuguese*).

Portugal, soil-gas measurements

No national or large scale surveys based on soil-gas measurements.

ROMANIA

Contact point for indoor radon measurements:

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Romania, indoor measurements

Web addresses of related projects:

- *NA*

Selected References:

- Cuculeanu, V., Sonoc, S. and M. Georgescu (1992). Radioactivity of Radon and Thoron daughters in Romania. *Radiation Protection Dosimetry*, **45**: 483-485.
- Milu, C, R. Gheorghe, S. Sonoc, D. Gheorghe, G. Modoran, D. Velea, *et al* (1992). *Indoor air exposure to radon and thoron daughters in Romanian houses*. In: Proceedings of International Conference on "Indoor Air Quality in Central and Eastern Europe", Bratislava, pp. 253-259.
- Milu, C, R. Gheorghe, S. Sonoc, D. Gheorghe, G. Modoran, D. Velea, *et al* (1993). Indoor air exposure to radon and thoron daughters in Romanian houses. *Romanian Journal of Biophysics*, **3**(3):157-162.
- Iacob, O., C. Grecea and L. Clain (1996). *Radiation exposure of the Moldavian population from radon and thoron progeny*, International Congress on Radiation Protection (IRPA-9), Vienna, V.2-35.
- Iacob, O. (1996). Exposure from natural radiation sources in Romania, *Journal of Preventive Medicine,* **4**(2): 73-82.
- Dumitrescu, A., C. Milu, J. Vautopic, R. Gheorghe and P. Stegner (2001). *Preliminary indoor radon and gamma measurements in kindergartens and schools in Bucharest.* In: Proceedings of the International Conference on Nuclear Energy in Central Europe, Portoroz, Slovenia.

Campaign

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
• 1987-1990 • 1990-1994 • 2000	• 119 [Milu *et al*., 1992] • 348 [Iacob *et al.*, 1996] • 100 [Dumitrescu *et al.*, 2001]	• 1 • 1 • *NA*

Sampling strategy:

Samples were taken in regions with high population density

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Air sampling on membrane filters [Milu *et al.*]	10 minutes	Any	Bedrooms
Air sampling on membrane filters [Iacob *et al.*]	10 minutes	Any	Bedrooms
Track Etch detectors [Dumitrescu *et al.*]	31	December	Class rooms and ground floors

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector	*NA*	*NA*	*NA*	*NA*

Indoor radon levels

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	***Geo.** Std. Dev.*	*Min.*	*Max.*
[Milu *et al.*] 119*	*NA*	17.20	4.66	3	127
[Iacob *et al.*] 348*	20.2	*NA*	*NA*	3.8	534
[Dumitrescu *et al.*] 100	146	128.18	1.65	43	477

** The indoor levels for Milu et al. and Iacob et al. are Equilibrium Equivalent Concentrations.*

Estimated mean annual radon levels in Romanian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
45 [Iacob, 1996]	*NA*	*NA*

Maps:

NA

Romania, soil-gas measurements

No national or large scale surveys based on soil-gas measurements.

SERBIA-MONTENEGRO

Contact point for indoor radon measurements:

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Serbia-Montenegro, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Curcic, S., I. Bikit, Lj. Conkic, M. Veskovic, J. Slivka, E. Varga, N. Todorovic, D. Mrdja (2004). The first radon map of Vojvodina. In: *Proceedings of the 11th International Congress of the International Radiation Protection Association*, 23-28 May 2004, Madrid, Spain (paper 6a11 published on CD).
- Curcic S.M., I. Bikit, J. Slivka, M.J. Veskovic, Lj. U. Conkic, E. Varga (2003). Radioecological problems in home building in the city of Novi Sad. In: *Proceedings of the 6th International Symposium &Exhibition on Environmental Contamination in Central and Eastern Europe and the Commonwealth of Independent States*, 1-4 September 2003, Prague, Czech Republic (Book of Abstracts p.138, published on CD).
- Curcic, S., I. Bikit, J. Slivka, Lj. Conkic, M. Veskovic, E. Varga, N. Zikic-Todorovic, D. Mrdja (2003). The first radon map of Vojvodina. In: *Proceedings of the XXII Symposium of Yugoslav Radiation Protection Association*, Petrovac, Serbia and Montenegro, pp. 195-198.

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
2002 - 2003	968	1

Sampling strategy:

For geological reasons, the Northern part of the country was expected to have the highest radon levels: the province of Vojvodina was thus first investigated. Indoor radon activity concentration in air has been measured in rural regions of 45 municipalities in dwellings considered as the most representative of the province.

The preparation of a Radon Map of Montenegro is currently under progress. It is managed by the Ministry of Environment of Montenegro and the Jozef Stefan Institute from Slovenia. See http://www.ceti.cg.yu/projects.html

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (CR-39)	90	Winter	Living rooms

	Measurement time (*units in days*)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors	90	*NA*	*NA*	*NA*

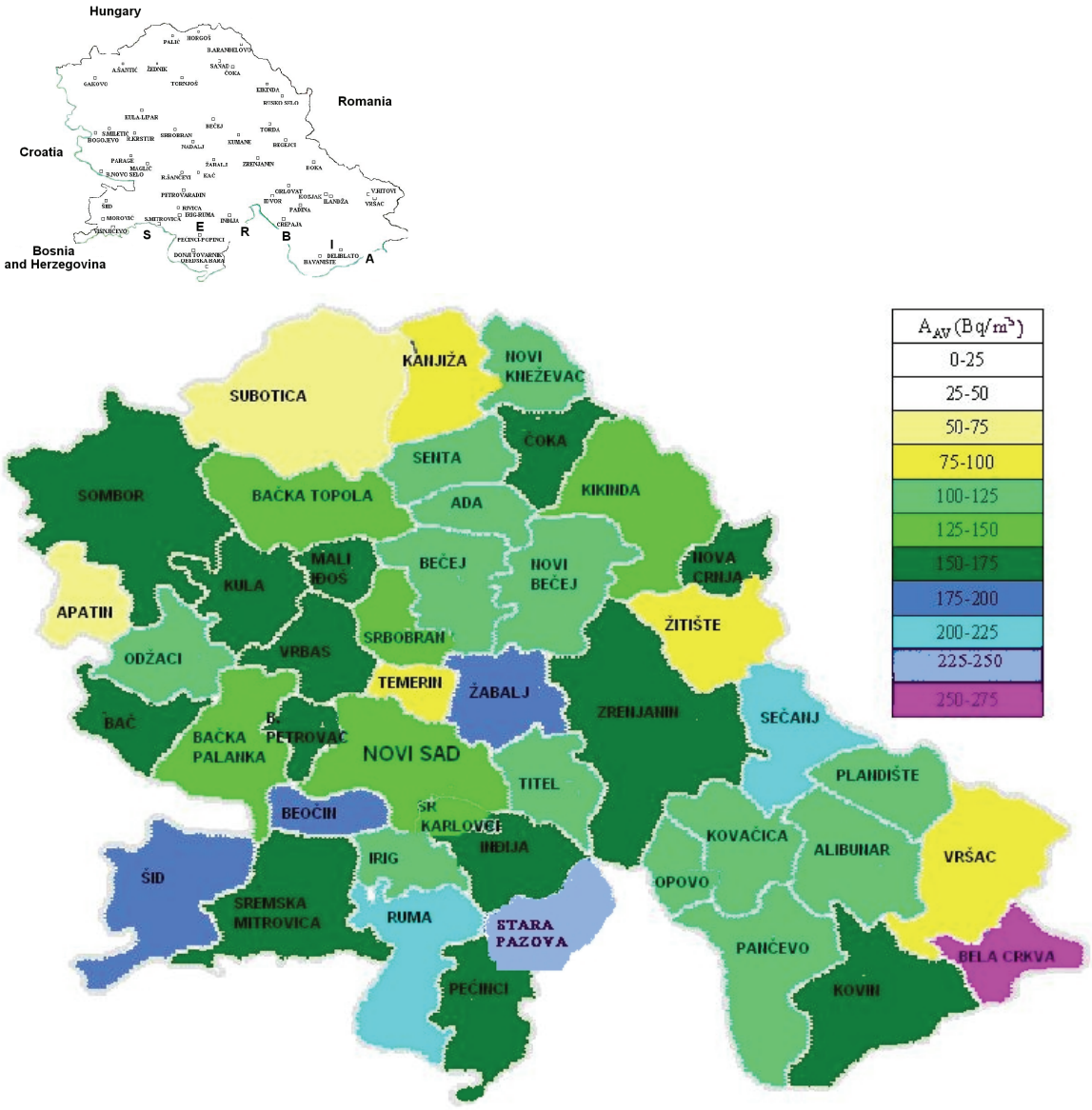
Statistics of the measurements

Measurements statistics (*units in Bq/m^3*)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
968	144	104.6	120	2	893

Estimated mean annual radon levels in dwellings of the Province of Vojvodina		
Mean (*Bq/m^3*)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
144	18	4

Maps:

- The current map of indoor radon levels shows mean values on an administrative level.



Map of local annual mean radon concentration values of the province of Vojvodina and relative position of the province. Maps reproduced with the kind courtesy of the I. Bikit and M. Veskovic © (2005).

Serbia-Montenegro, soil-gas measurements

No surveys made on a national or large scale level.

SLOVAK REPUBLIC

Contact point for indoor radon measurements:

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Slovak Republic, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Vičanová, M., Ďurčík, M., Nikodemová, D. (1999). Radon exposure in Slovak dwellings and workplaces. In: *IRPA regional congress on Radiation protection in Central Europe*. Budapest 1999
- Ministry of the Environment of Slovak Republic (2003). *State of the Environment.* Report of the Slovak Republic 2003, pp168-169. (*in Slovak*).
- Vičanová, M. (2003). Utilisation of solid state nuclear track detectors at the solution radon problems. Ph.D. Thesis, Faculty of Mathematics, Physics and Informatics, Comenius University of Bratislava, 82 p. (*in Slovak*).
- Vičanová, M., Nikodemová, D., Pinter, I. (2003). Indoor Radon Risk Assessment of Slovak Population. In: *Proceedings of the V. Banskoštiavnické dni*, Banská Štiavnica, 2003, pp.124-131. ISBN 80-88682-59-2. (*in Slovak*).

Campaign

Survey period	*Dwellings investigated*	*Measurements / dwelling*
1992-2003	4 019	2

Sampling strategy:

The dwellings investigated have been chosen randomly on the whole territory. Family dwellings were preferred to flats.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Track-etch detectors (CR-39)	183	½ heating and ½ non-heating season	Two different rooms

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector (CR-39)	177	36	90	240

Indoor radon levels

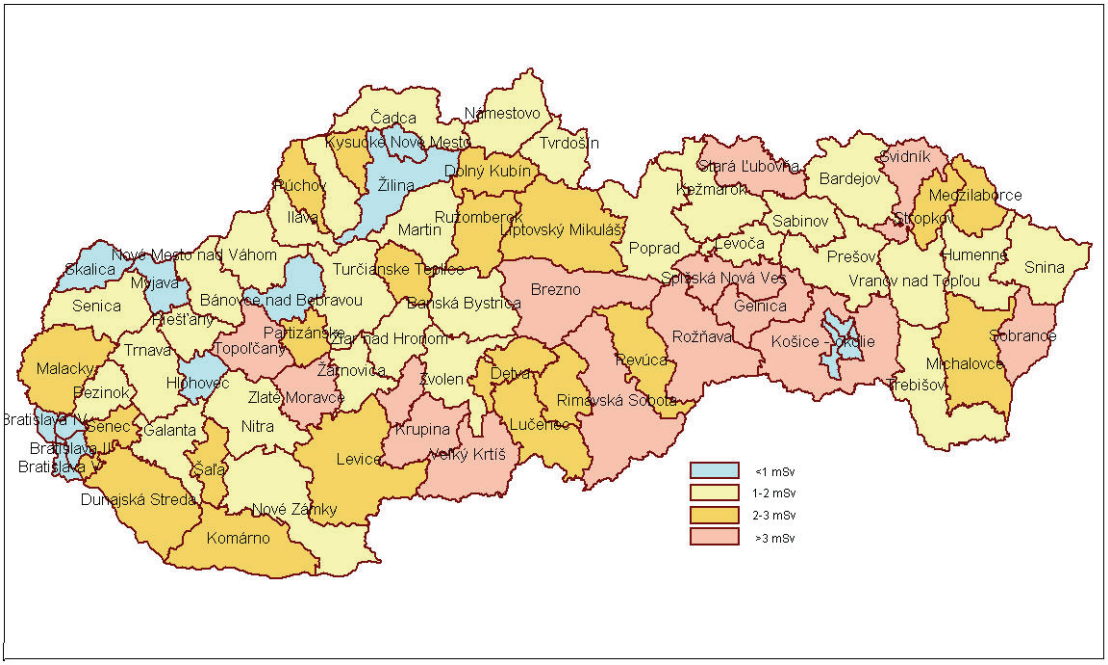
	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
8 270	172	83	119	10	3 750

Estimated mean annual radon levels in Slovakian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
108	14	11

Maps:

Method:

Annual average effective doses from indoor radon exposure were calculated for each districts of Slovakia. The population-weighted arithmetic mean of indoor radon concentration was calculated for every district considering different types of houses.



Map of estimated annual average effective doses from indoor radon exposure in districts of Slovakia.
Map reproduced with the kind courtesy of the Slovak Medical University in Bratislava © (2005). Reference: Ministry of the Environment of Slovak Republic: State of the Environment Report of the Slovak Republic 2003. pp 168-169. Web reference:
http://www.sazp.sk/slovak/periodika/sprava/sprava2003/kapitoly/svk2003s_fyzi.pdf

Slovak Republic, soil-gas measurements

Selected References:

NA

Campaign

Survey period	Number of Sample locations
1992-2005	*NA*

Sampling strategy:

Regions with expected high levels were more densely sampled than others.

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
(1990-1994) *NA*	*NA*	*NA*
(1994-2005) Scintillation flasks ("Lucas Cells") and counting chamber	400 s	60

Statistics of the measurements

Measurements statistics (*units in Bq/m^3*)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
NA	21 600	*NA*	*NA*	500	712 400

Maps:

Maps of soil gas radon concentrations were produced by means of spatial interpolation. No other information is available

SLOVENIA

Contact point for indoor radon measurements:

Ministry of Health
Slovenian Radiation Protection Administration
Tržaška cesta 21,
SI-1000 Ljubljana
Slovenia

http://www2.gov.si/mz/mz-splet.nsf

Reporting contact point

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Tržaška cesta 21,
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Tel.: (+ 386) 1 478 87 08
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Slovenia, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Vaupotič, J., Križman, M., Planinić, J., Adamič, K., Stegnar, P., Kobal, I., Pezdič, J. (1994). Systematic indoor radon and gamma measurements in kindergartens and play schools in Slovenia. *Health Physics*, **66**: 550-556.
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Campaign

Survey period	*Dwellings investigated*	*Measurements / dwelling*
Kindergartens: 1990-1992	730	1
Schools: 1992-1994	890	1
Dwellings: 1993-1995	892	1
Kindergartens and schools with radon levels > 400 Bq/m^3: 1996-2005	45 kindergartens 78 schools	6/building

The information presented hereafter will focus only on radon levels in dwellings.

Sampling strategy:

The initial survey targeting kindergartens (95 %) and primary schools (80 %) was almost exhaustive. Additional measurements were made in kindergartens and schools from the first survey with Rn concentration levels larger than 400 Bq/m^3.

Dwellings investigated have been chosen randomly on the whole territory.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Track-etch detectors (Jožef Stefan Institute)	96	Winter	Living rooms (45%) bedrooms (45%) other (10%)

	Measurement time (*units in days*)			
Type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detector	96.3	11.7	31	148

Indoor radon levels

	Measurements statistics (*units in Bq/m^3*)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
892	121	81	157	7	1 890

Estimated annual mean radon levels in Slovenian dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
87	5.7	2

The annual mean values were derived (see Humar *et al*., 1995) from the following equation, considering that the average annual mean radon concentration (C_{mean}) can be defined by

C_{mean} = ¼ C_{winter} + ¼ C_{spring} + ¼ C_{summer} + ¼ C_{autumn}

with the assumption that $C_{spring} = C_{autumn} = C_{mean}$ and $C_{summer} = 0.4\ C_{winter}$

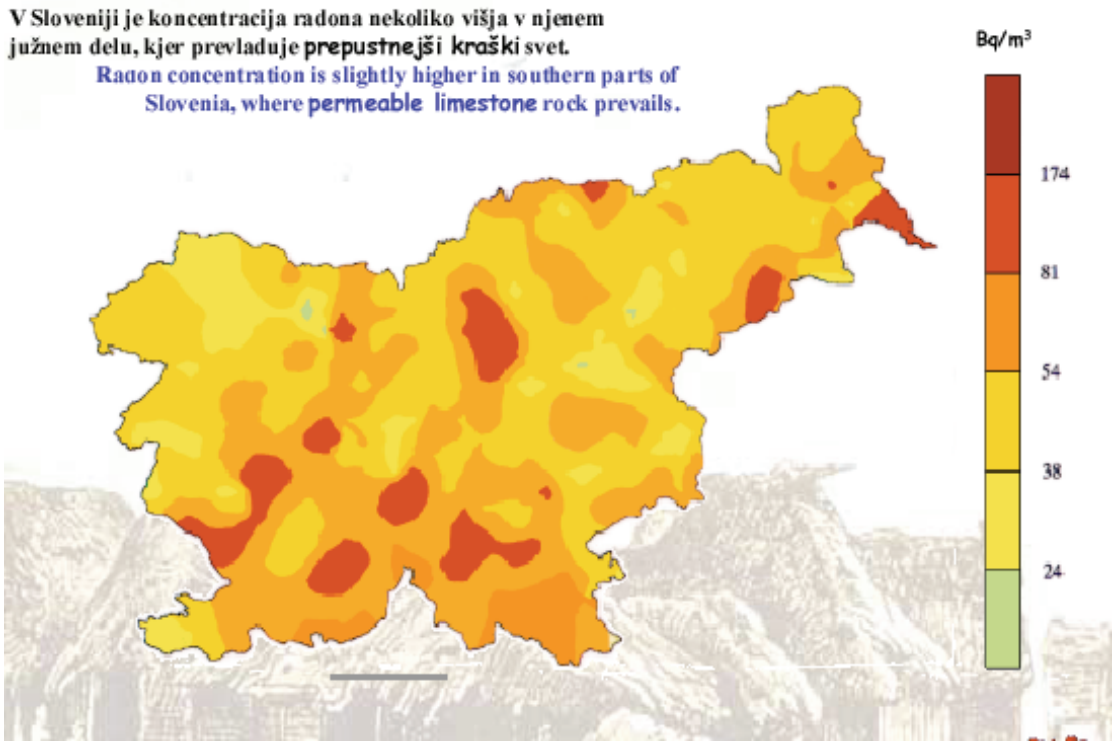
one gets $C_{mean} = 0.7\ C_{winter}$

The uncertainty of the factor 0.7 is estimated to be of +/- 7% (see J.C.H. Miles *et al.*, NRPB Report on Radon Affected Areas, 1990; M. Križman, MSc Thesis, 1990, L. Mljač, MSc Thesis, 1993).

Maps:

Method:

The map shown hereafter was generated by interpolating the values on a grid with a resolution of 2 km × 2 km. The interpolation method is universal kriging with linear drift. The model chosen for the spatial correlation (variogram) was linear. All values were selected for estimating the value in each cell.



Map of estimated annual mean radon concentration values in dwellings. Map reproduced with the kind courtesy of M. Križman. © (2005). Web address: http://www.icjt.org/tech/atlas/Atlas16.pdf

Slovenia, soil-gas measurements

No national or large scale surveys based on soil-gas measurements.

SPAIN

Contact point for indoor radon measurements:

Consejo de Seguridad Nuclear
Pedro Justo Dorado Dellmans, 11
28040 Madrid
Spain

http://www.csn.es

Reporting contact point

Jose Luis MARTÍN MATARRANZ

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Pedro Justo Dorado Dellmans, 11
28040 Madrid
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Tel.: (+34) 91 3460422
Fax.: (+34) 91 3460497
e-mail: jlmm@csn.es

Spain, indoor measurements

Web address of related project:

- *NA*

Selected References:

- Quindós, L.S. , P.L. Fernandez, J. Soto. (1991). National survey on indoor radon in Spain. *Environment International*, **17**: 449-453.
- Quindós, L.S., P.L. Fernandez, J. Soto. (1991). Short-VS Long-term indoor radon measurements. *Health Physics*, **61**(4): 539-542.
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- Martín Matarranz, J.L., B. Frutos Vazquez, J.P. García Cadierno, M. Olaya Adán, J.I. Serrano Renedo, E. Suarez Mahou, J.A. Fernandez Amigot, F. Rodrigo Vilaseca (2004). Radon Protection in the Spanish Technical Building Code. In: *Proceedings of the 11th International Congress of the International Radiation Protection Association.* 23-28 May 2004 Madrid. Spain.
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Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1990 - 2005	~ 5 600	1

Sampling strategy:

The surveys have focused mainly on rural areas and zones with high levels.

Surveys of indoor radon levels in Spain have, so far, been mainly based on different programs set up by CSN and performed by research groups of Spanish universities and the CIEMAT (*Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas / Research Centre for Energy, Environment and Technology*).

The main surveys were:

- One nationwide survey in rural areas dwellings (Cantabria University).
- Four regional surveys in the Canary Islands and the Autonomous Communities of Valencia, Extremadura and Asturias. (Universities of La Laguna, Valencia, Cáceres and Oviedo).
- One survey in the cities of Madrid and Barcelona (CIEMAT and Autonomous University of Barcelona).
- Studies of two specific regions with high values of radon: Arribes del Duero (Salamanca) and Guadarrama Mountains (Madrid) (Cantabria University).
- Surveys in the surroundings of nuclear power plants, old uranium mines and other nuclear fuel cycle facilities (Cantabria University).

Measurement techniques

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track–etch detectors, Terradex (Cantabria Univ.) KfK detectors, (Ciemat-Autonomous Univ. Barcelona and La Laguna Univ.)	90	Any	Living rooms and bedrooms
Charcoal detectors and Lucas cells were also used in some cases	*NA*	Any	Living rooms and bedrooms

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track–etch detectors	90	*NA*	*NA*	365

Statistics of the measurements

Measurements statistics (units in Bq/m^3)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
9800	90.4	45	349.6	10	15 400

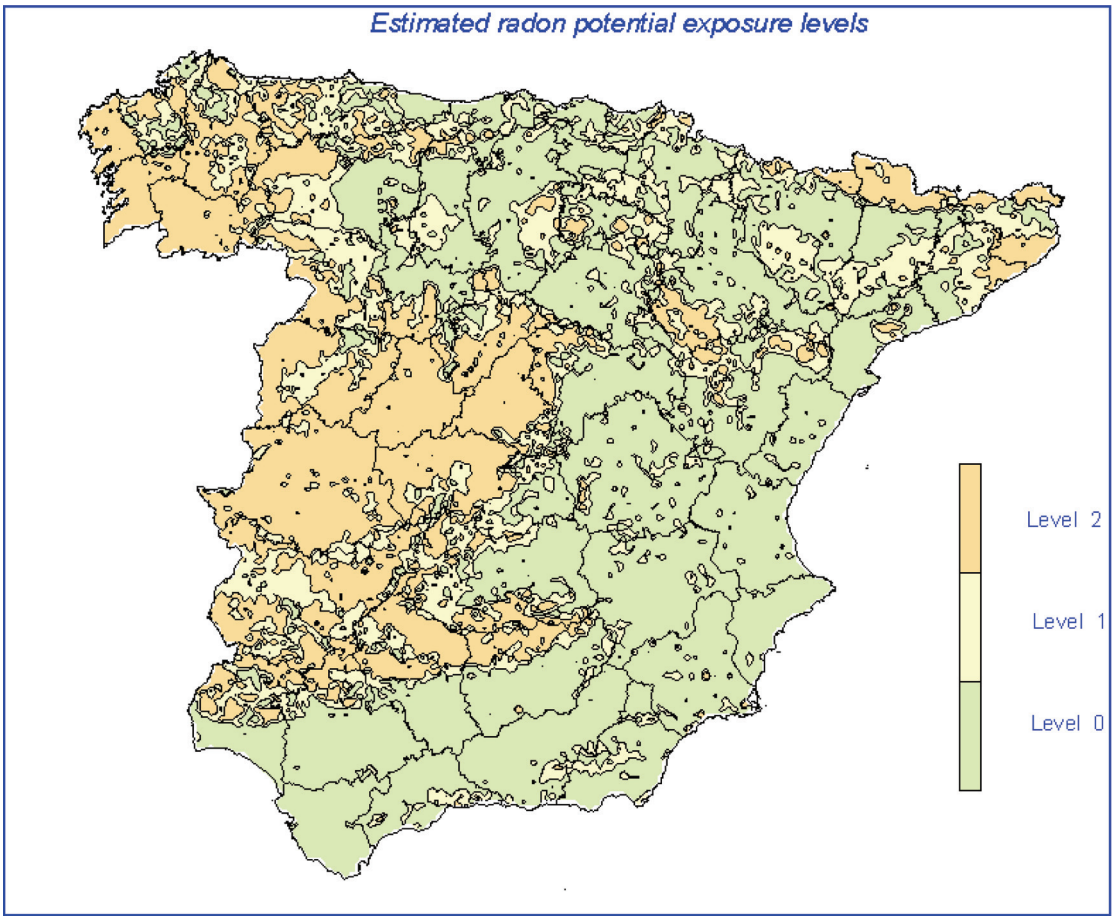
Estimated annual mean radon levels in Spanish dwellings		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwelling above 400 Bq/m^3*
90	4	2

Maps

Method:

Estimated soil exhalation rates and annual average of indoor-radon concentrations in a standard dwelling were derived from models. These models were using geological data, 1.500.000 terrestrial gamma radiation values, and measurements of ^{40}K, ^{232}Th and ^{226}Ra concentrations in soils that are representative of the country. Estimated results of radon indoor were then compared to 5.000 radon concentration values measured in dwellings pertaining to 400 cities and villages throughout the country.

Category	Potential exposure to ^{222}Rn
0	Low (< 200 Bq/m^3)
1	Medium (200 - 400 Bq/m^3)
2	High (> 400 Bq/m^3)



Map of estimated annual mean radon concentration values in Spanish dwellings. Map reproduced with the kind courtesy of CSN © (2005). References: Martin Matarranz *et al*., 2004; Frutos *et al*., 2003.

Spain, soil-gas measurements

No surveys made on a national or a large-scale level.

SWEDEN

Contact point for indoor radon measurements:

Swedish Radiation Protection Authority (SSI)
171 16 Stockholm,
Sweden

http://www.ssi.se/

Reporting contact point

Ann-Louis SÖDERMAN

Swedish Radiation Protection Authority (SSI)
171 16 Stockholm,
Sweden

Tel.: (+46) 8 729 71 00, (+ 46) 8 729 72 01
Fax.: (+ 46) 8 729 71 08
e-mail: Ann-louis.soderman@ssi.se

Contact point for soil gas radon measurements:

Soil gas measurements are used to establish radon risk maps in each municipality. The measurements and maps are made by private companies.

Reporting contact point:

Ann-Louis SÖDERMAN

Swedish Radiation Protection Authority (SSI)
171 16 Stockholm,
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Tel.: (+46) 8 729 71 00, (+ 46) 8 729 72 01
Fax.: (+ 46) 8 729 71 08
e-mail: Ann-louis.soderman@ssi.se

Sweden, indoor measurements

Web address of related project:

- *NA*

Selected References:

- *Bostadsbeståndets inneklimat.* Urban Norlén, Kjell Andersson, ELIB-rapport nr 7, TN: 30, Statens institut för byggnadsforskning, 1993.

Campaign

Two national radon surveys have been organised in the past, a new one started in 2004:

- 1980-1982 by the Swedish Radiation Protection Authority (SSI);
- 1991-1992, in cooperation with the Swedish Research council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), the SSI and the Örebro University Hospital;
- 2004-2006: a new survey was launched by the Institute of Environmental Medicine at Region Västra Götala with financial support from SSI, the Board of Health and Welfare and the Board of Housing, Building and Planning. The results will be presented in 2006.

The results presented hereafter are from the ELIB-study of 1991-1992 only as both national surveys have shown very similar results.

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1991-1992	1360	~2.5

Campaigns are organized by each local environmental health office in Sweden. Although there is nothing such as a national database, the number of dwellings in which radon levels have been measured is about 500 000 (around 10 % of all dwellings).

Sampling strategy:

Municipalities all over the country were chosen for the survey. In the second stage houses and flats were randomly selected in each municipality.

Measurement technique

Detector type	*Measurements time* (*days*)	*Season*	*Measurement location*
Track-etch detectors (CR-39)	90	1st of October - 30th of April	2 rooms or 1 for each floor

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (CR-39)	90	NA	NA	NA

Indoor radon levels

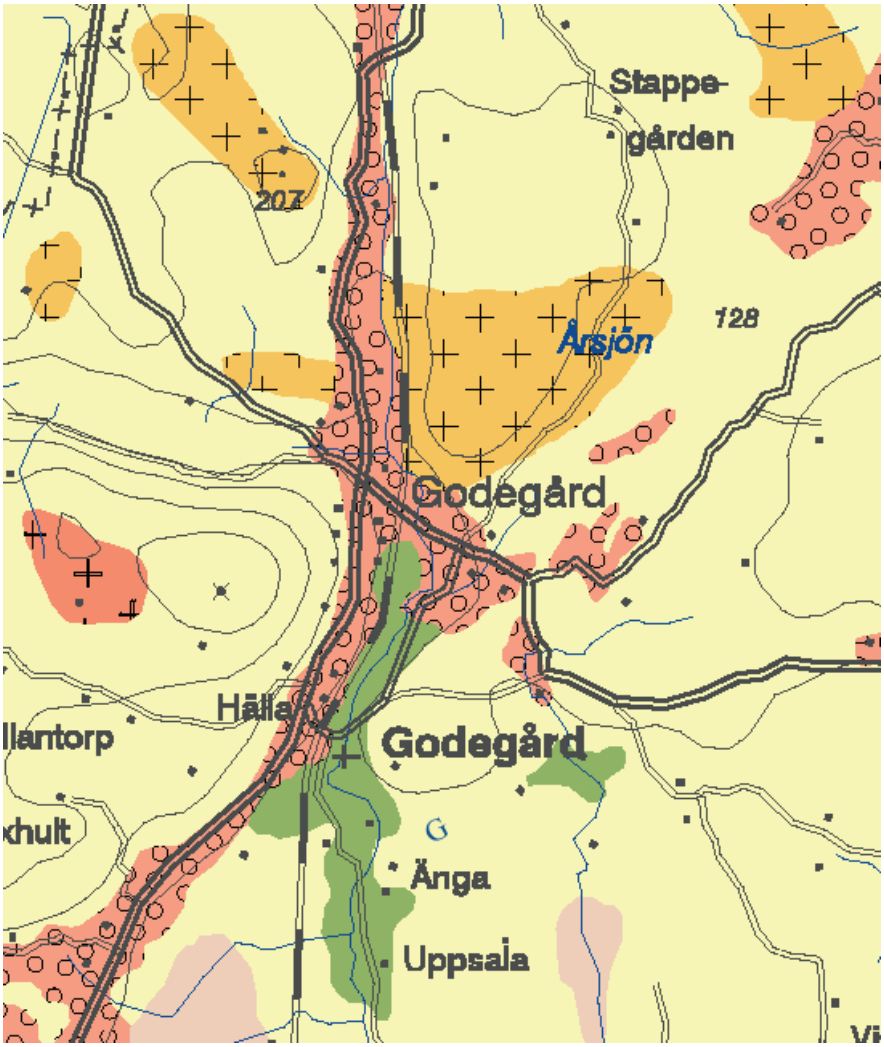
	Measurements statistics (units in Bq/m^3)				
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
~3400	108	56	179	NA	3 904

Estimated mean annual radon levels in Swedish dwellings*		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
108	6-7 Detached houses: 9-14 %, Multifamily houses 1-4 %	3-4 Detached houses: 4-7 %, Multifamily houses: 0.8-4 %

**There are approximately 4.25 million dwellings in Sweden out of which 1.95 million are single family houses and 2.3 are in multifamily houses*

Maps:

Radon Risk maps are produced in Sweden since 1979 and are derived from various types of information: geological and geotechnical information, airborne radiometric surveys (these surveys cover almost all of Sweden on a grid of resolution 40 × 200 m), measurements of indoor radon in houses and workplaces and soil-gas measurements. Radon risk maps are available only at the municipal level and there is no map of radon levels or radon risks for the whole country.



Example of a radon risk map of a municipality in Sweden. © Map reproduced with the kind courtesy of the SSI. High risk area (red), Probable high risk area (dark yellow), Normal risk area (light yellow), Low risk area (green). The risk levels are defined in the table below.

Classification of risk areas	Percentage of the Swedish surface	Types of ground	Technical building requirements
High risk	10 %	Uranium-rich granites, pegmatites and alum shale. Highly permeable soils, for example gravel and coarse sand. Radon concentration in soil gas >50 000 Bq/m^3	Radon safe construction, such as thicker, reinforced concrete foundation or ventilation below the foundation
Normal risk	70 %	Rocks and soil with low or normal U content and average permeability. Rn concentration in soil gas 10 000 - 50 000 Bq/m^3	Radon protective construction. No apparent fissures or leaks in the foundation
Low risk	20 %	Rocks with very low U content, for example limestone, sandstone and basic igneous and volcanic rocks. Soils with very low permeability, for example clay and silt or soils where the Rn gas concentration in the soil gas is < 10 000 Bq/m^3	Traditional

Summary of recommendations regarding classification of the ground in Sweden according to the risk for indoor radon and the types of protective measures.

Sweden, soil-gas measurements

Selected References:

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- Åkerblom G. and Wilson C. (1981): *Radon –geological aspects of an environmental problem*. Papers presented at the International Meeting on Radon – Radon Progeny Measurements. Montgomery Alabama, August 27-28 1981. Geological Survey of Sweden. Reports and communications no. 30, Uppsala 1982, 47 p. ISBN 91-7158-271-1.
- Åkerblom G. (1986): *Investigation and mapping of radon risk areas.* Paper presented at the International Symposium on Geological Mapping in the Service of Environmental Planning: Commission for the Geological Map of the World, Trondheim, Norway. 6 - 9 May, 1986. In: Geology for Environmental planning. Edited by Wolff F C. Geological of Survey of Norway. Special Papers 2. 15 p.
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- Åkerblom G. (1995): *The use of airborne radiometric and exploration survey data and techniques in radon risk mapping in Sweden*. In: Application of uranium exploration data and techniques in environmental studies. Proceedings of a Technical Committee meeting held in Vienna, 9-12 November 1993. IAEA-TECDOC-827. pp.159-158.
- Åkerblom G. and Lindgren J. (1997): *Mapping of Ground Water Radon Potential*. In: Uranium exploration data and techniques applied to the preparation of radioelement maps. Proceedings of a Technical Committee meeting held in Vienna, 13-17 May 1996. IAEA-TECDOC-980.

Campaign

Soil-gas measurements are used to produce radon risk maps that are made in Sweden since 1979. Measurements are still done today and maps are updated regularly.

Survey period	*Number of Sample locations*
1979 -	Several thousands

Sampling strategy:

Sample locations are selected on geological grounds.

Measurement technique

Detector type	*Measurement time*	*Depth (cm)*
Activated Charcoal	7 days	80-100
Emanometers (Markus 10, Gammadata)	Instantaneous	80-100

Statistics of the measurements

Normal radon-222 activity concentration in Swedish soils measured at 1 m depth are given here for different soil types:

Soil type	^{222}Rn (Bq/m^3)
Till, normal	5 000 - 50 000
Till, with granitic material	20 000 - 60 000
Till with uranium-rich granitic material	40 000 - 200 000
Gravel and coarse sand in glaciofluvial deposits	10 000 - 150 000
Sand and coarse silt	4 000 - 20 000
Silt	20 000 - 60 000
Clay	10 000 - 120 000
Soils containing alum shale	50 000 - > 1 million

Maps:

Radon risk maps have been produced in almost every municipality and are constantly updated. No national map has been produced. See an example in the previous section

SWITZERLAND

Contact point for indoor radon measurements:

Swiss Federal Office of Public Health (SFOPH)
Consumer Protection Directorate
Division of Radiological Protection
Radon Unit
3003 Bern
Switzerland

http://www.bag.ch/

Reporting contact point

Martha GRUSON

Swiss Federal Office of Public Health
Consumer Protection Directorate
Division of Radiological Protection
Radon Unit
3003 Bern
Switzerland

Tel.: (+ 41) (0)31 324 61 83
Fax.: (+ 41) (0)31 322 83 83
e-mail: martha.gruson@bag.admin.ch

Switzerland, indoor measurements

Web address of related project:

- http://www.ch-radon.ch

Selected References:

- Chaouch, A., M. Kanevski, M. Maignan, J. Rodriguez and G. Piller (2003). Indoor radon data mining with geostatistical tools: case study with a highly clustered and variable dataset. In: *Proceedings of IAMG 2003, International Association for Mathematical Geology,* IAMG 2003 Portsmouth, UK, September 7-12, 2003
- Kanevski, M., M. Maignan, G. Piller (2004). Advanced analysis and modelling tools for spatial environmental data. Case study: indoor radon data in Switzerland In: *Proceedings of EnviroInfo 2004, the 18th International Conference on Informatics for Environmental Protection, Geneva, Switzerland, October 21-23, 2004.*
- *2004 Annual report of the Division of Radiological Protection*. Report BAG VS 6.05 3000 d-f-kombi 40 EXT05004 (*in German and French*).

Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1980 - 2005	~55 000	~1.5

Sampling strategy:

Dwellings are initially randomly selected. Old buildings and schools had nevertheless the priority over more recent constructions. Municipalities presenting an average value of measurements exceeding 200 Bq/m^3 have currently all of their building systematically screened.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (60%) and electrets (40%)	100	November-March	Living room (35%) Basements (36%) Bedrooms (8%)

	Measurement time (units in days)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors and electrets	100	24	2	578

Statistics of the measurements

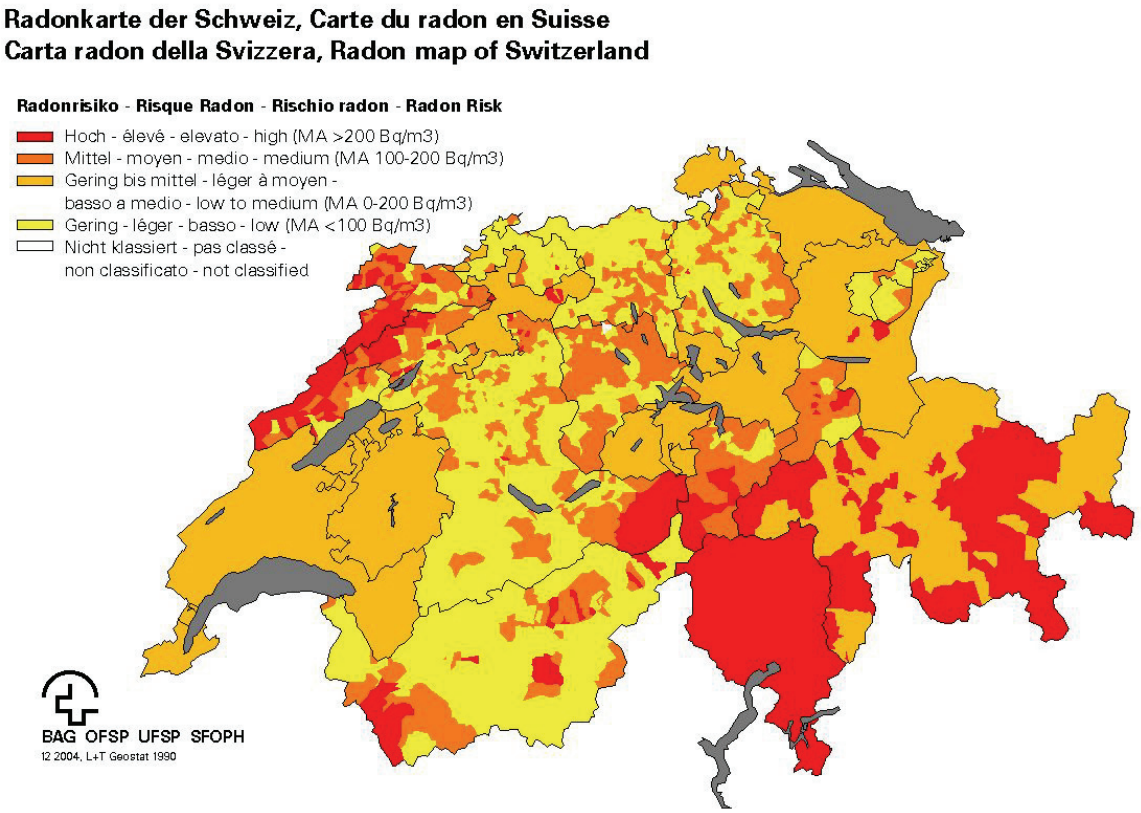
Measurements statistics (units in Bq/m^3)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
96 000	230	112	560	20	29 705

Estimated mean annual radon levels in Swiss dwellings*		
Mean (Bq/m^3)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
77	10	7

**estimation made strictly for inhabited rooms only*

Maps:

- The current Swiss map of indoor radon levels in inhabited rooms shows the mean values at the municipal level. A radon atlas derived from geostatistical techniques (see Chaouch *et al.*, 2003; Kanevski *et al.*, 2004) is in preparation.



Map of municipal annual mean radon concentration values. Map reproduced with the kind courtesy of SFOPH © (2005). Web address: http://www.bag.admin.ch/strahlen/ionisant/radon/generalites/images/carte-radon-2004.pdf

Switzerland, soil-gas measurements

No survey made on a national or large scale level.

UNITED KINGDOM

Contact point for indoor radon measurements:

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United Kingdom, indoor measurements

Web address of related project:

- http://www.hpa.org.uk/radiation/radon/

Selected References:

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Campaigns

Survey period	*Dwellings investigated*	*Integrated measurements / dwelling*
1980-2005	450 000	2.1

Sampling strategy:

The dwellings investigated have been chosen in different ways at different times: randomly on the whole territory, on a regular grid covering the whole territory and preferentially in regions with expected higher levels. The great majority were made for the purpose of identifying houses above the radon action level (400 Bq/m^3 at working place, 200 Bq/m^3 at home), so were made in the highest radon areas.

Measurement technique

Detector type	*Measurements time (days)*	*Season*	*Measurement location*
Track-etch detectors (NRPB/HPA, NET, Gammadata)	90-365	all	living room and bedroom

	Measurement time (*units in days*)			
Detector type	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Track-etch detectors (NRPB/HPA, NET, Gammadata)	107	35	30	550

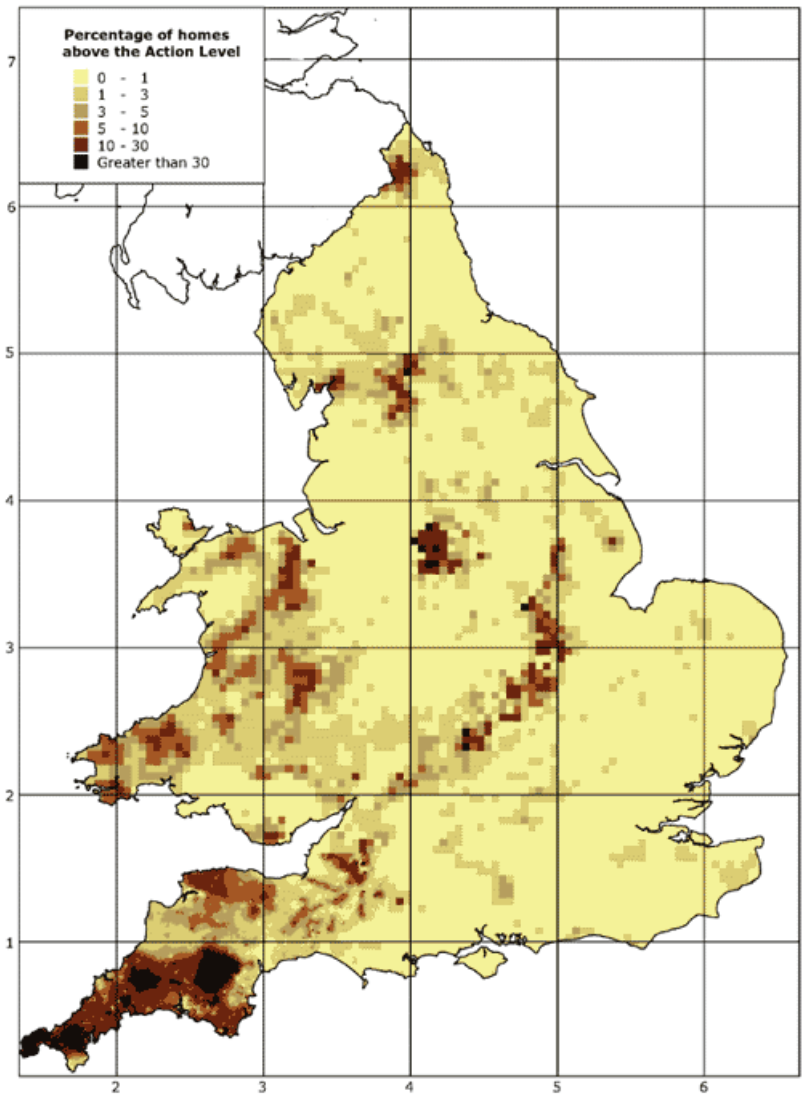
Statistics of the measurements

Measurements statistics (*units in Bq/m^3*)					
Measurements	*Mean*	*Geo. Mean*	*Std. Dev.*	*Min.*	*Max.*
945 000	87	46	148	0	17 000

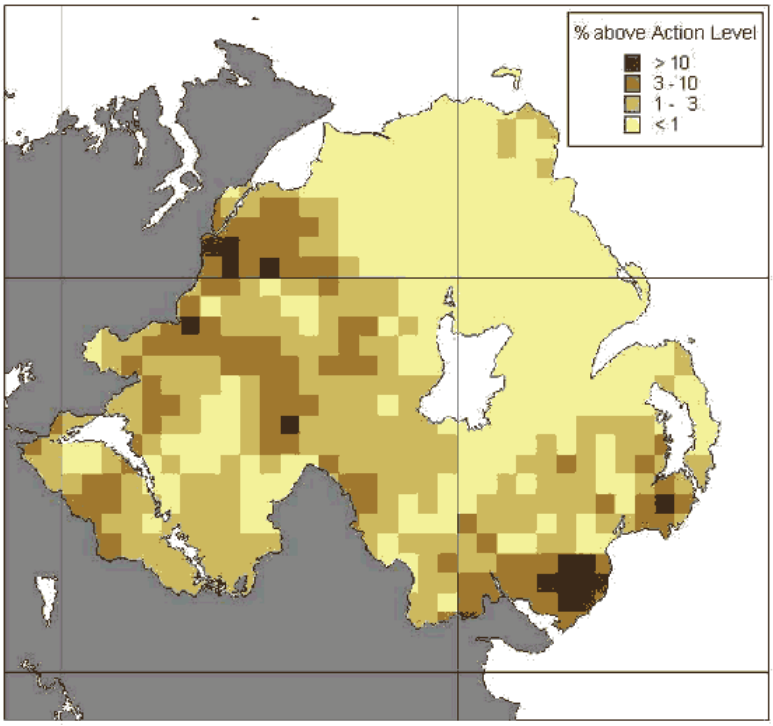
Estimated mean annual radon levels in British dwellings		
Mean (*Bq/m^3*)	*% of dwellings above 200 Bq/m^3 and below 400 Bq/m^3*	*% of dwellings above 400 Bq/m^3*
20	0.4	0.1

Maps:

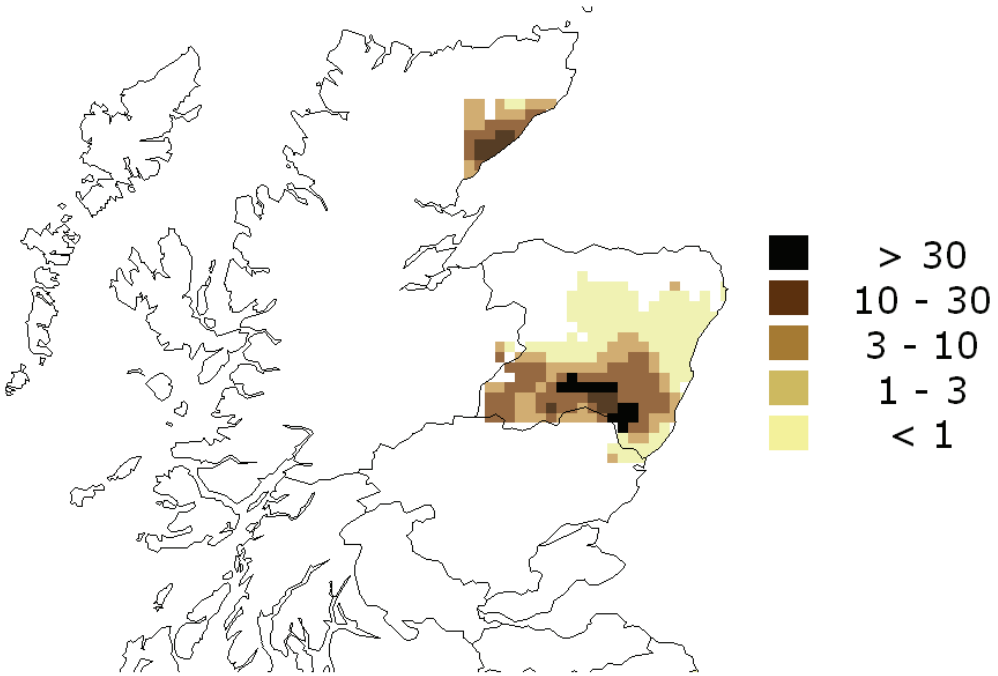
Maps were generated using local averages on a predefined grid. The cell size of the grid is 5 km by 5 km but areas with higher measurement density are mapped with a resolution of 1 km. Minimum number of measurements/cells: 5 for 5 km grid square mapping, 30 measurements within 5 km for 1 km mapping.



Map of radon affected areas in England and Wales. Map reproduced with the kind courtesy of J. Miles © (2005). Web address: http://www.hpa.org.uk/radiation/radon/radon_maps/uk_map.htm



Map of radon affected areas in Northern Ireland. Map reproduced with the kind courtesy of J. Miles © (2005). Web address: http://www.hpa.org.uk/radiation/publications/archive/reports/1999/nrpb_r308.htm



Map of radon affected areas in parts of Scotland. Map reproduced with the kind courtesy of J. Miles © (2005)

United Kingdom, soil-gas measurements

No survey made on a national or large scale level.

European Commission

EUR 21892 EN - An overview of radon surveys in Europe
Author: G. Dubois
Luxembourg: Office for Official Publications of the European Communities
2005 – 168 pp. – 21.0 x 29.7 cm
Scientific and Technical Research Series
ISBN 92-79-01066-2

Summary

With the aim of preparing a European atlas of natural radiation, the Institute for Environment and Sustainability (IES) of the Directorate General Joint Research Centre (JRC) of the European Commission (EC) has conducted a European survey to assess the means and methods used by national authorities to describe radon levels in their countries.

Radon is a naturally radioactive gas that is, by far, the main contributor to the exposure received by the population from natural background radiation. It is also considered to be the main leading cause of lung cancer second to smoking, and most European countries have therefore adopted a number of regulations and made large efforts to identify radon-prone areas. Because indoor radon levels can fluctuate largely over short scale, establishing radon risk maps can become very difficult. It is the purpose of this report to present the variety of the means and methods used in the European countries to measure and report radon levels.

LB-NA-21892-EN-C

The mission of the Joint Research Centre is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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