European Commission

JRC TECHNICAL REPORTS

Literature review of Indoor radon surveys in Europe

PANTELIĆ G, ČELIKOVIĆ I, ŽIVANOVIĆ M, VUKANAC I, NIKOLIĆ JK, CINELLI G, GRUBER V

2018

Joint Research Centre

EUR 29613 EN

Contact information
Name: Giorgia Cinelli
Address: Joint Research Centre , TP 441, Via Enrico Fermi 2749, I-21027 Ispra (VA), Italy
Email: giorgia.cinelli@ec.europa.eu
Tel.: +39 0332 786620

EU Science Hub
https://ec.europa.eu/jrc

JRC114370

EUR 29613 EN

PDF ISBN 978-92-79-97643-8 ISSN 1831-9424 doi: 10.2760/977726

Luxembourg: Publications Office of the European Union, 2018

How to cite: PANTELIĆ G, ČELIKOVIĆ I, ŽIVANOVIĆ M, VUKANAC I, NIKOLIĆ JK, CINELLI G, GRUBER V, Literature review of Indoor radon surveys in Europe, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97643-8 (online), doi:10.2760/977726 (online), JRC114370

Joint
Research
Centre

Contents

Acknowledgements

This work is supported by the European Metrology Programme for Innovation and Research (EMPIR), JRP-Contract 16ENV10 MetroRADON (www.euramet.org). The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States.

The support of the Ministry of Education, Science and Technological Development of the Republic of Serbia [P171018, P171007 is acknowledge.

Authors

Gordana Pantelić, Igor Čeliković, Miloš Živanović, Ivana Vukanac, Jelena Krneta Nikolić ("Vinča" Institute of Nuclear Sciences, Belgrade, Serbia)

Giorgia Cinelli (European Commission, Joint Research Centre)

Valeria Gruber (AGES – Austrian Agency for Health and Food Safety)

Abstract

Natural radioactivity is the main source of population exposure to ionising radiation. Radon and its progenies contribute with more than 50% to annual effective dose received from all sources of ionising radiation (UNSCEAR, 2000) and has been identified as a second leading cause of lung cancer after smoking (WHO, 2009).

The aim of this report, under the MetroRadon project, is to provide a literature review of existing indoor Rn surveys in Europe. Different steps of the "survey chain", e.g. from survey design through sampling, measurements to evaluation and interpretation, that yield an output have been explored.

Journal papers and papers in international and national conference proceedings were reviewed, resulting in data collected from 45 countries. The information contained in the report should serve as an input to propose approaches to reduce inconsistencies and improve harmonization of indoor radon data.

1 Introduction

Natural radioactivity is the main source of population exposure to ionising radiation. Radon and its progenies contribute with more than 50% to annual effective dose received from all sources of ionising radiation (UNSCEAR, 2000).

Radon is a radioactive noble gas, with no stable isotopes. Three naturally occurring isotopes ^{222}Rn, ^{220}Rn and ^{219}Rn originate from the decay chain of three primordial decay series ^{238}U, ^{232}Th and ^{235}U, respectively. The relative importance of Rn isotopes with respect to the population exposure, increases with an increase of their half-lives and their relative abundance and thus the most abundant and long-lived one, ^{222}Rn ($T_{1/2}$=3.82 days) is the most important. In the regions with high $^{232}Th/^{232}U$ ratios, ^{220}Rn (also known as thoron) whose half-life is short-lived ($T_{1/2}$=55.6 s) compared to the half-life of ^{222}Rn, cannot be ignored.

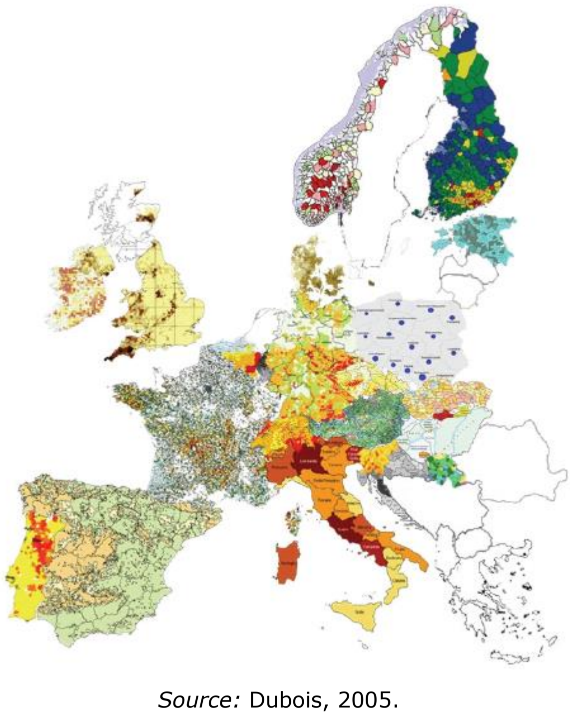
First written documents related to the radon problem dated from XVI century when Paracelsius reported about high mortality of solver miners in Saxony and Bohemia and at the end of XIX century, those deaths were attributed to lung cancer. It took 50 years from the discovery of radon in 1901, to identify radon progenies as major cause of lung cancer.

Based on the epidemiological studies performed in Europe, Asia and America, radon has been identified as a second leading cause of lung cancer after smoking, being responsible between 3-14% of all lung cancers (WHO, 2009).

The exposure of members of the public or of workers to indoor radon is now explicitly taken up in the scope of Council Directive 2013/59/Euratom (Article 2 (2d)) (European Union, 2013). Based on this, the Directive introduces, for the first time, legally binding requirements on protection from exposure to radon.

A first overview of indoor radon surveys in Europe has been performed in 2005 by Dubois (2005). The map shown in Figure 1.1, reported in the document, reflects the strong heterogeneity of indoor radon surveys, mapping strategies, reference levels etc.

Figure 1.1. Overview of indoor radon maps in Europe from 2005

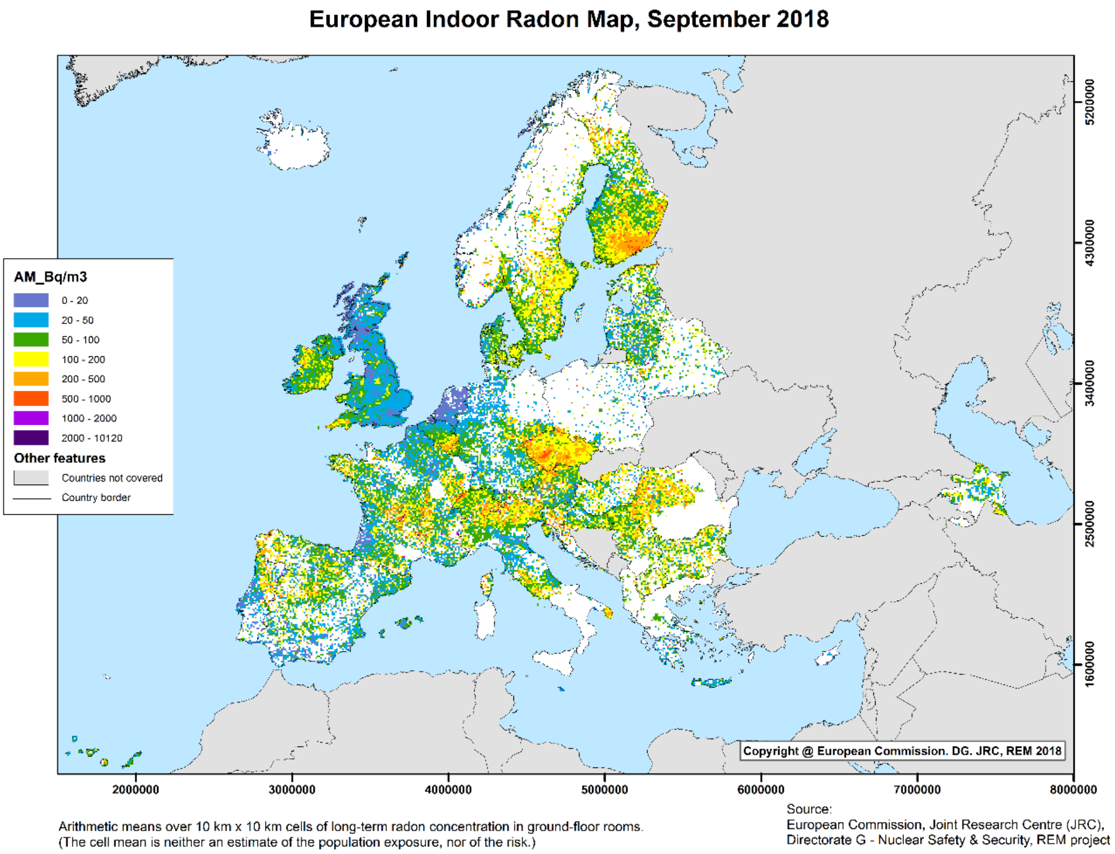


Source: Dubois, 2005.

Already a huge effort has been taken with this respect by the Joint Research Centre of the European Commission, by collecting Rn data from different countries and integrating them in a homogeneous way to produce a European Indoor Radon Map using 10 km x 10 km grid cells (Dubois, 2010). Last update of map has been done in September 2018 (Figure 1.2).

The European indoor radon map is part of the European Atlas of Natural Radiation (EANR), a collection of maps displaying the levels of natural radioactivity from different sources. The digital version of the EANR is available on line at https://remon.jrc.ec.europa.eu/ (Cinelli et al., 2018) and the publication is foreseen in 2019.

Figure 1.2. Arithmetic mean over 10 km × 10 km cells of long-term radon concentration in ground-floor rooms of 35 European countries. Latest update, September 2018



Thirteen years after Dubois (2005) the MetroRADON partners have been working to update information about indoor radon surveys in Europe.

The aim of this report, under the Activity of A 3.1.1 of the MetroRadon project, is to provide a literature review of existing indoor Rn surveys in Europe, regarding different steps of the "survey chain" e.g. from the survey design (corresponding to a given survey policy) through sampling, measurements to evaluation and interpretation that results in an output. Journal papers and papers in international and national conference proceedings were reviewed.

For each country some of the most important details regarding Rn survey were included in the report, such as: Survey goal, Sampling strategy, Sampling procedure, Measurement technique, Evaluation of single measurements, Survey period, Time of year, Single measurement duration, Number and type of locations, Evaluation, Interpretation of results, Quality assurance, Thoron measurements.

Finally, the report contains data available in the literature for 45 countries, and should serve as an input to propose approaches to reduce inconsistencies and improve harmonization of indoor radon data.

References

Cinelli, G. et al., (2018) Digital version of the European Atlas of natural radiation, Journal of Environmental Radioactivity (in press). https://doi.org/10.1016/j.jenvrad.2018.02.008

Dubois, G. (2005), An overview of radon surveys in Europe Report EUR21892, EC, Office for Official Publications of the European Communities, Luxembourg.

Dubois, G., Bossew, P., Tollefsen, T. and de Cort, M. (2010), First steps towards a European atlas of natural radiation: status of the European indoor radon map, Journal of Environmental Radioactivity 101 786-798.

European Union (2013), Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, Official Journal of the European Union OJ L13, 17.1.2014, p. 1 – 73, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2014:013:TOC

UNSCEAR (2000) United Nations Scientific Committee on the Effects of Atomic Radiation Report, Annex B: Exposure due to Natural Radiation Sources. Vol. 1, United Nations, New York.

WHO (2009) WHO Handbook on Indoor Radon. World Health Organisation, WHO, Geneva.

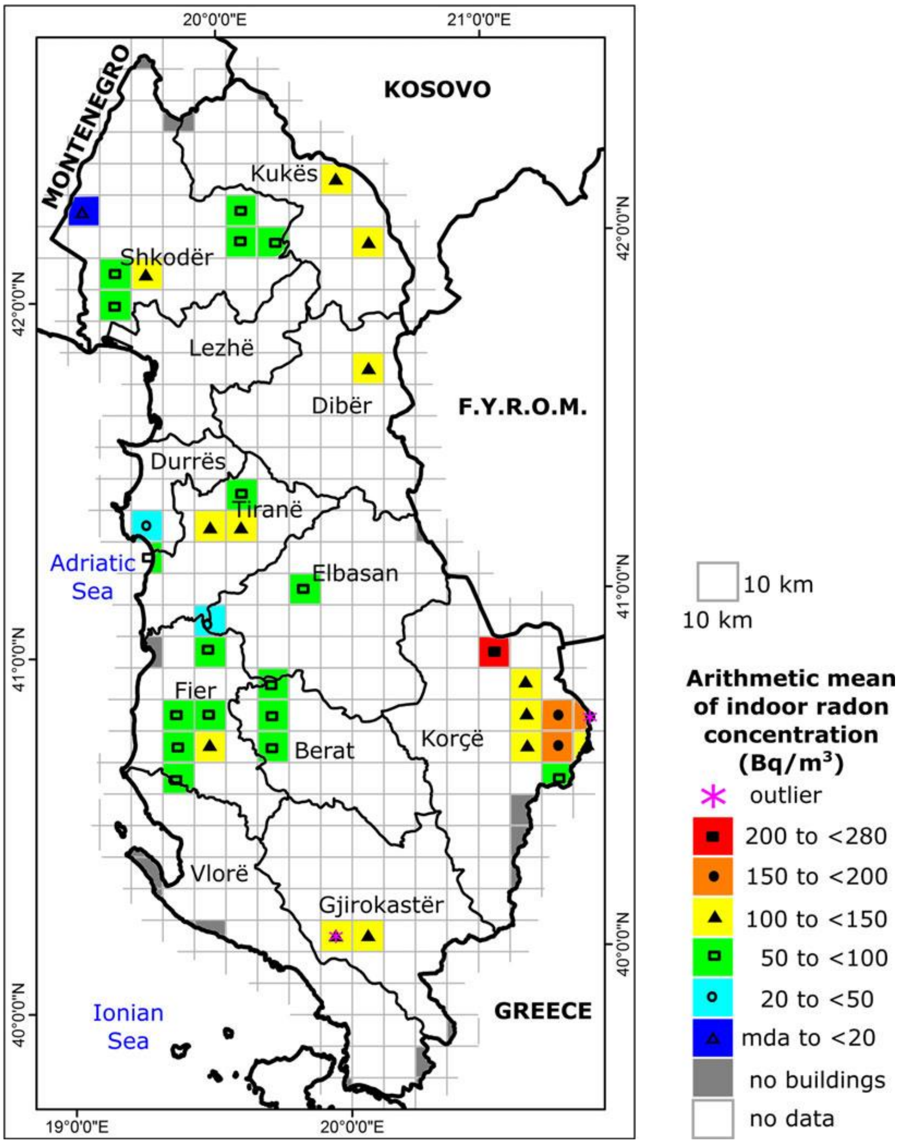
2 Albania

A national survey was conducted between 2009 and 2014. This survey aims to gather operational information by investigating the indoor radon concentrations in the dwellings of the most populated cities located in 10 of the 12 regions of Albania. The first stage of the national indoor radon survey includes the design of a regular grid with 345 cells of 10 x 10 km resolution that covers the whole territory of the Republic of Albania.

The indoor radon concentrations are measured by passive detectors based on SSNTD Radtrak, consisting of track etch detectors made of CR 39 plastic films contained in an antistatic holder (NRPB/SSI type). Detectors are placed in the inhabited rooms of the dwelling at approximately between 1 and 2 m height from the floor and as far as possible from windows and doors in order to avoid air currents. Each detector is exposed for 3 months during summer and winter seasons. For quality control purposes, duplicate detectors were placed in randomly selected dwellings. In order to obtain an estimate of the annual average, the carried out measurements are corrected for seasonal variations. The correction factors are obtained by studying the variations in indoor radon concentration observed in summer and winter seasons with respect to the entire year in randomly selected dwellings located in different geographical regions (Bode Tushe et al., 2016).

The indoor radon survey is conducted from 2009 to 2014, in 10 regions (18 districts) of Albania, where 247 dwellings. The distribution of indoor radon concentrations ranges between 14 and 1238 Bq/m^3, with an arithmetic mean (120±67) Bq/m^3. It was observed that the indoor radon concentrations follow a lognormal distribution. The population-weighted average indoor radon concentration was calculated to be 101 Bq/m^3 (Bode Tushe, 2016).

Figure 2.1. The arithmetic mean of indoor radon concentrations (Bq/m^3) over a 10x10 km cells grid.



Source: data obtained from the survey 2009 to 2014 (Bode Tushe, 2016).

References

Bode Tushe, K. et al., (2016) First Step Towards the Geographical Distribution of Indoor Radon in Dwellings in Albania, Radiation Protection Dosimetry, Volume 172, Issue 4, 1 Pages 488–495.

3 Armenia

Some measurements were performed before 1991. Apart from that measurements, "Radon program" in Armenia is "just starting" as quoted by (Haroyan, 2017).

Within this project, in total 800 alpha track detectors from "GAMADATA" Sweden company were deployed in 2010 and 2011.

In 147 measurements, radon concentration was found to be larger than 200 Bq/m^3.

Figure 3.1. Map of regions of Armenia.

Source: Haroyan, 2017.

Table 3.1. Number of deployed detectors in each region of Armenia.

Region	**I step**	**II step**	**Total**
Yerevan	59	62	121
Armavir	31	19	50
Ararat	25	20	45
Kotayq	37	37	74
Aragacotn	37	32	69
Shirak	25	31	56
Tavush	30	32	62
Gexarqunik	38	44	82
Syuniq	41	34	75
Lori	43	51	94
Vayoc Dzor	27	30	57

Source: Haroyan, 2017.

References

Karen Haroyan, 2017, National Radon Programme and Radon Action Plan, Presentation, RER/9/136-1701370, Yerevan, Armenia, 23 - 27 October, 2017.

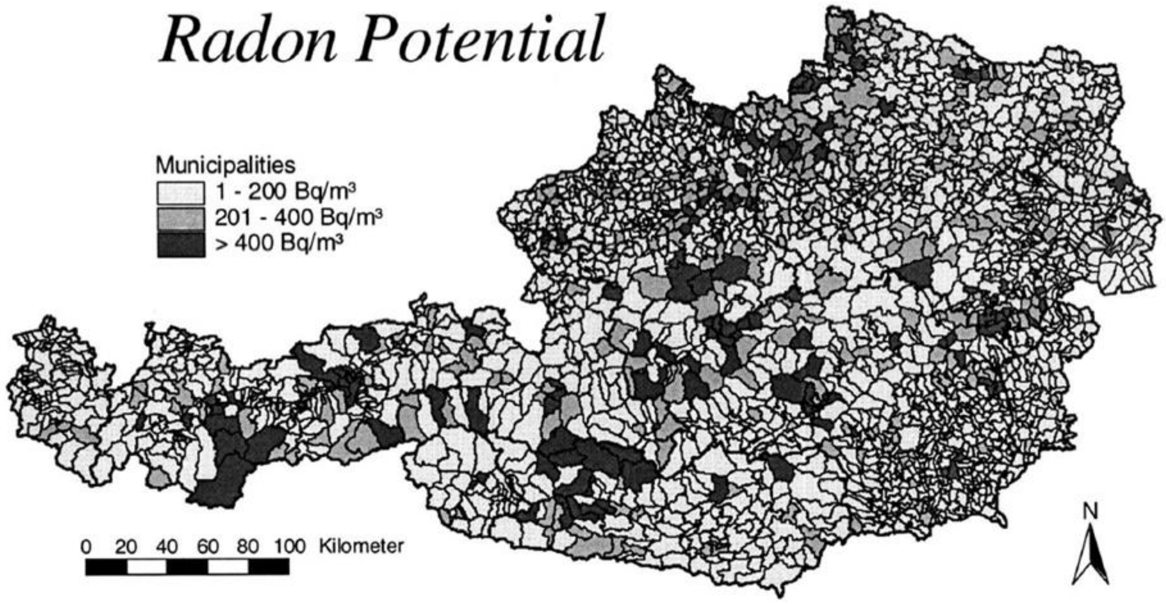
4 Austria

Survey on national scale was performed between 1992 and 2001. Survey goal was to find areas with enhanced indoor radon concentrations and to define areas with elevated risk. Dwellings were selected by random sampling. In total, 40000 measurements were performed in 16000 ground floor rooms. Usual procedure was to place 2 detectors in most frequently used room, 1 to 2 meters from the floor, away from doors and windows. Questionnaires were also distributed with the detectors. Three detector types were used: electret E-Perm detectors, track detectors KFK and charcoal detectors with liquid scintillation counting, Pico-Rad. One single detector type was used in each municipality. Measurements were usually performed in autumn or spring and seasonal correction factors were applied (Friedmann, 2005).

Descriptive statistics and log normality checks were used to evaluate the data. Based on the data, mean radon potential map was constructed (expected radon concentration in standard situation) and mean radon concentration map. Municipalities were divided in three categories – municipalities with mean concentration above 400 Bq/m^3, between 200 Bq/m^3 and 400 Bq/m^3, and below 200 Bq/m^3 (Friedmann, 2005).

The quality of the measurements was checked by intercalibration, intercomparisons, parallel measurements and other QA/QC programs. Thoron measurements were performed in selected locations. Thoron concentration thus measured was negligible (Friedmann, 2005).

Figure 4.1. Radon potential map.



Source: Friedmann, 2005.

References

Friedmann H., (2005), Final Results of the Austrian Radon Project, Health Physics 89, 4, pp. 1-10.

5 Azerbaijan

Indoor radon survey in Azerbaijan was performed in 2010. Since ultimately, data had to be integrated in the European Indoor Radon Map, Institute of Geology and Geophysics got support from the Swiss National Science Foundation of around 2500 radon detectors of the Gammadata–Landauer type.

Radon detectors were placed randomly in 2404 houses in different regions of the country, mainly in residential but in some cases in industrial buildings. Detectors were exposed in the period from November till December 2010 and did not exceed 2 months since cold season in Azerbaijan is short.

Each detector was accompanied with a questionnaire that besides general data (det ID, dates of exposure, etc) contained also information about floor, type and material of the measured building, etc.

Uncertainty of the measurement was considered. The level of uncertainty for each single dosemeter is around 15%, according to the supplier, Gammadata–Landauer and our laboratory, with another 1% error resulting from problems in transport.

The obtained data were processed using purely statistical methods.

Measured radon concentrations varied considerably: from almost radon-free houses to around 1100 Bqm^{-3}. Out of the 2404 measured houses, 169 were above 200 Bqm^{-3} and 418 remained between 100 and 200 Bqm^{-3}.

The frequency distribution of the measured radon concentrations: log-normal character with a median of 58 Bqm^{-3} and a mean of 84 Bqm^{-3}.

Geological aspects as well as distribution of radon concentrations in buildings with respect to the floor level and building materials were analysed. In Figure 5.1, a spatial indoor radon distribution in Azerbaijan is presented.

Figure 5.1. Spatial indoor radon distributions in Azerbaijan.

Source: Hoffmann, 2016.

References

M. Hoffmann et al., 2016 First Map of Residential Indoor Radon Measurements in Azerbaijan. Rad. Prot. Dosim. pp 1-8, doi:10.1093/rpd/ncw284.

6 Belarus

According to the reference (Yaroshevich et al., 2012), the national survey was conducted with main purpose to monitor radon. Radon monitoring was performed in a period 2004 – 2012 in all region of Belarus and in town of Minsk. 3444 locations (exploited dwellings, industrial and public buildings)) in all administrative regions (6) in Belarus were covered by this campaign. A new concept and a research radon program in Belarus for the period up to 2013 are developed. Sampling strategy was based on geological characterization of different regions and population density. Measurements were carried out with solid state track detectors, LR-115 type 2, DOSIRAD (France). Detector were exposed for 1,5 up to 3 months. Evaluation of a single measurement was performed by chemical etching in a NaOH solution (1.22 g/cm^3) at 50 °C for 170 min. Subsequently the tracks on the etched film were counted manually with a microscope (200×).

Evaluation of results contained arithmetic and geometric mean calculation, comparison between different regions and calculation of annual effective dose. Correction for thoron was included. Annual mean indoor EEVA values vary from 31 Bq/m^3 to 76 Bq/m^3, the average annual population doses – over the range of 2.0 – 4.8 mSv/year. The highest percentage of dwellings where Rn concentration exceeded 200 Bq/m^3 was in Grodno region (4.5 %), the lowest one (0.6 %) – in Birest region. (Yaroshevich et al., 2012)

In reference (Vasilyeva, 2015) results of measurements of radon in Republic of Belarus in 2015 are given. For 4078 new buildings, radon concentration was more than 100 Bq/m^3 in one building, and in 424 existing buildings radon concentration was between 100 Bq/m^3 and 200 Bq/m^3 in 8 buildings (in other were less) in Gomel, Grodno and Mogilev region. Descriptive statistic of measurements of radon in Belarus in 2004 – 2013 period (average equilibrium equivalent concentration – EEC, maximum EEC and percentage of measurement results that exceeded 200 Bq/m^3 are given, also.

Table 6.1. Results of measurements of radon indoors in Republic of Belarus in 2004-2013 years (scientific data).

Region	Average equilibrium equivalent concentration (EEC), Bq/m^3	Maximum equilibrium equivalent concentration (EEC), Bq/m^3	Value exceeding equilibrium equivalent concentration (EEC) (%) >200 Bq/m^3
Brest region	31	220	0,6
Vitebsk region	76	515	2,2
Gomel region	35	507	0,7
Grodno region	66	808	4,5
Minsk	74	1052	5,3
Minsk region	84	1052	6,1
Mogilev region	57	313	1,4
All regions	57	1052	2,5

Source: Vasilyeva, 2015.

References

Yaroshevich et al., (2012), Indoor Radon And Radon Component Of Population Radiation Doses In Different Areas Of Belarus, Минск, Белорускаја Наука, 56, No. 6, pp. 92.

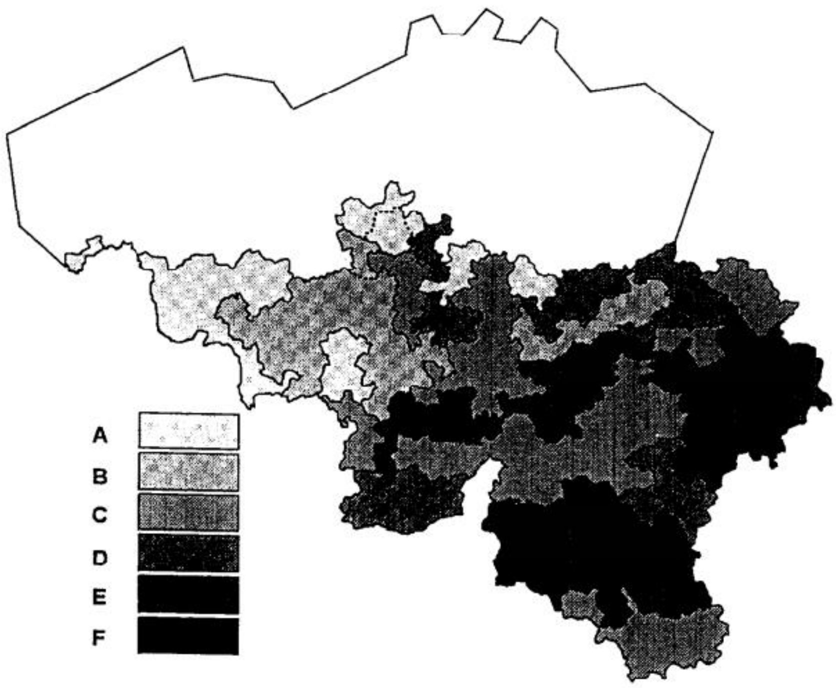
Power Point Presentation, Measurements of radon in workplaces in Republic of Belarus, Marina Vasilyeva, Ministry of Health, 2015.

7 Belgium

Indoor radon measurements in Belgium are described in 5 papers. Surveys described in these papers are regional, covering the region of Waloon (1 papers), Vise (1 paper) and southern Belgium (3 papers).

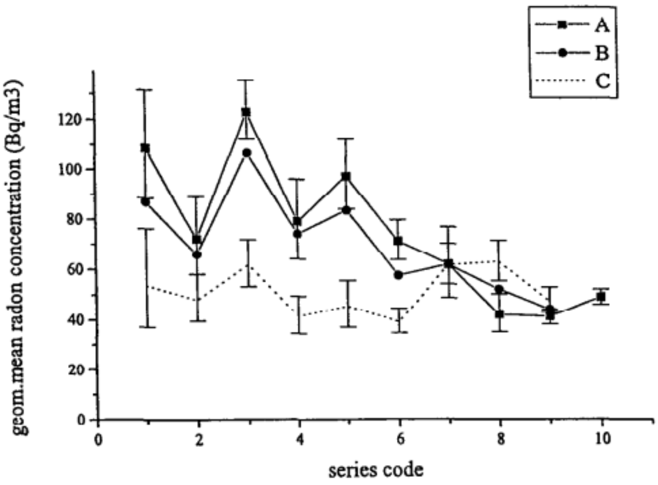
The goal of two papers Tondeur et al., 1996, and Zhu et al., 1998, covering the region of southern Belgium in the period from 1988 to 1995, was the development of indoor radon map of Southern Belgium and study of the correlations between geological features and indoor Rn concentrations. The sampling sites were chosen based on the local structure and composition of the rocks and on the movement of underground waters. Activated charcoal canisters with diffusion barriers were exposed for 3-4 days in semi-confined conditions (closed windows, no permanent opening of the doors) during the whole year. Total of 3404 dwellings were investigated. The results of radon measurements are taken from the database and statistical correlations between indoor Rn concentration and the geological environment of homes are calculated. Map presentation of the results is given in Figure 7.1, taken from Tondeur et al 1996. Also, the geometrical mean indoor concentration was calculated for each geological series. A significant variability associated with geology was observed. Although the most acute radon problems are found in Belgium on the old geological stages, less frequent butstill significant indoor air concentrations are found on Cenozoic formations. Indoor Rn on the ground floors and in the cellars from 83 homes shows a logarithmic linear correlation coefficient of +0.68 which is significant at the 99% confidence level. If ground floors, which are indirectly above a cellar or a basement were distinguished from those directly above a cellar or a basement, then an improved correlation was observed (Table 7.1 taken from Zhu et al, 1998, and Figure 7.2, taken from Tondeur et al., 1996).

Figure 7.1. Map of indoor radon in southern Belgium. The different areas are indicated by six grey levels, according to the geometrical mean indoor radon concentration: A (<30 Bq/m^3); B (30-45 Bq/m^3); C (45-70 Bq/m^3); D (70-100 Bq/m^3); E (100-150 Bq/m^3) and F (>150 Bq/m^3).



Source: Tondeur et al., 1996.

Figure 7.2. Geometrical mean indoor radon concentration for the different geological series.



Source: Tondeur et al., 1996.

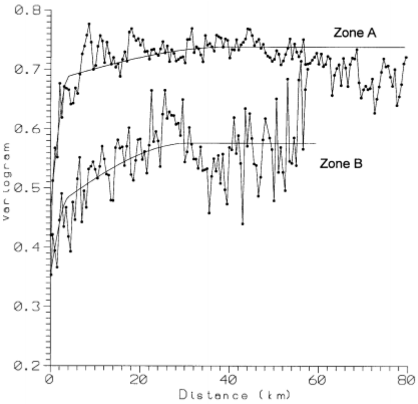
Table 7.1. Statistics on Rn values in homes in Southern Belgium.

	Second floors	First floors	Cellars
Geometric mean (Bq m^{-3})	44	65	215
Geometric standard deviation	3.8	3.2	5.1
Arithmetic mean (Bq m^{-3})	109	149	874
Total nb. of samples	170	1339	236
Range of values (Bq m^{-3})	1–1720	1–6300	1–25 000
Distribution	Lognormal	Lognormal	Lognormal

Source: Zhu et al., 1998.

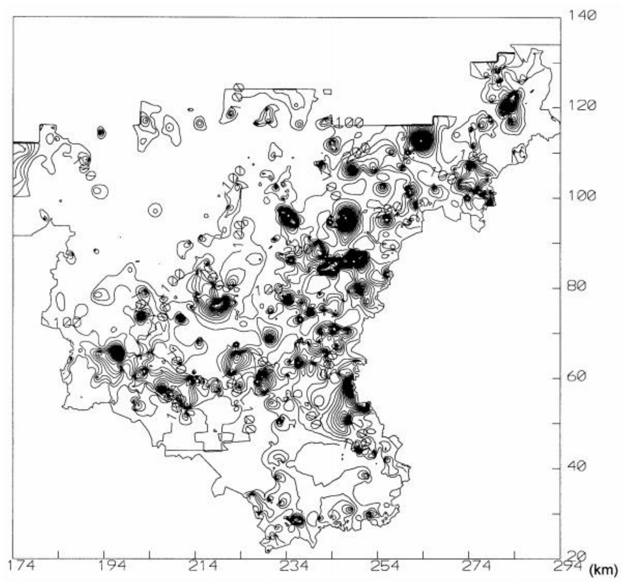
The goal of the third paper covering the southern Belgium region Zhu et al., 2001, was to evaluate the relationships between various spatial datasets, with the goal of producing radon risk maps in digital form. The dataset covering dwellings in southern Belgium were chosen from the national survey from winter of 2001, from 2198 dwellings and the study region was divided into 2 stationary zones (zone A and zone B). The mean logarithmic variograms are shown in Figure 7.3, below. High, medium and low risk areas were determined. All the results were represented in a digitalized map. A radon risk map which integrates a variety of data available, including geological maps, radon map, measured houses and administrative boundaries can simplify any subsequent administrative action and should be useful in design of future surveys. It also allows linking of the radon values to geological environments. This map is represented on Figure 7.4, below.

Figure 7.3. The mean logarithmic variograms for zone A and zone B.



Source: Zhu et al., 2001.

Figure 7.4. Kriged contour map of indoor Rn concentrations. Contour interval is 50 Bq/m^3.



Source: Zhu et al., 2001.

The paper Poffijn *et al.*, 1994, covers the measurements in approximately 8000 dwellings in the region of Vise during several years up to 1994 with the goal to obtain a detailed radon map with clear indication of risk areas and mitigation. Based upon the available information some 160 houses (2% of the building stock) are expected to have real radon problems (>400 Bq/m^3) and 24 of these problem houses have been localized. Three of the most contaminated houses (>3000 Bq/m^3 in the living areas) have been studied in detail for mitigation purposes.

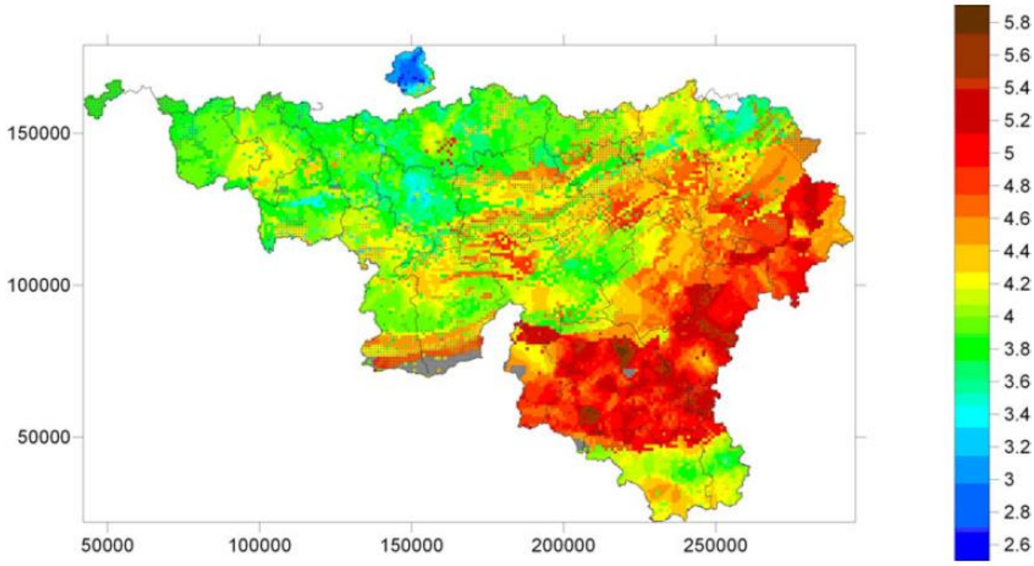
In the paper G. Cinelli *et al* 2011, the goal was producing a radon risk map for Walloon region. The map displays the predicted percentage of dwellings thathave a radon concentration above the action level. The two data sets used have been collected by the federal agency for nuclear control (FANC) and by the Institut Superieur Industriel de Bruxelles (ISIB) covering the survey periods from 1990-2000 and 1995-2004. Charcoal canisters exposed on ground floors of the dwellings for 3-4 days in all seasons except summer and track-etch Makrofol detectors exposed for 3 months. Total of 12500 dwellings were investigated and geometrical mean of the data from two datasets. T-test was performed in order to establish that the datasets are compatible. Variograms have been studied separately for each geological group. In general, the variograms show a low local correlation, and for the most part a constant model is consistent with data. The map has been constructed separately for each geological unit. Map of the logarithmic mean based on the geology and indoor radon measurements, the map of the logarithmic mean in the areas covered by loess and the map of the proportion of the distribution above 400 Bq/m^3 is made. These maps are shown in Figures 7.5, 7.6 and 7.7, below. Also, the data used for creating these maps are presented in the Table 7.2 below.

Table 7.2. Number of data, logarithmic means and standard deviations for each geological group.

	Num FANC	Num ISIB	LM FANC	LM ISIB	LSD FANC	LSD ISIB
Devillian	5	171	3.87	3.94	0.81	0.94
Revinian	78	204	4.65	4.71	1.06	1.36
Salmian	222	72	4.57	4.73	0.79	0.95
Ordivician	18	83	4.12	4.39	0.46	1.15
Silurian	35	49	4.58	3.59	1.01	1.21
Gedinnian	652	69	4.92	4.99	0.90	1.34
Siegenian	2,312	314	4.92	4.88	0.88	1.25
Emsian	143	59	4.69	4.31	0.89	0.98
Couvinian	155	84	4.57	4.37	0.91	1.16
Givetian	77	73	4.36	4.39	0.66	1.01
Frasnian	158	71	4.09	4.17	0.59	0.92
Famennian	275	162	4.17	4.20	0.74	1.11
Tournaisian	83	99	4.18	3.95	0.88	1.13
Visean	116	175	4.39	4.16	0.82	1.29
Namurian	63	76	4.11	4.05	0.79	1.08
Westphalian	111	217	3.92	3.88	0.68	0.87
Permian	24	14	3.79	5.04	0.58	1.19
Trias-Jurassic	373	78	4.14	4.09	0.67	0.65
Cretaceous	148	147	3.78	3.91	0.68	0.94
Eocene	197	730	3.87	3.66	0.61	0.94
Oligocene-Miocene-Pliocene	29	19	4.26	4.26	0.54	0.84
Loess + ale	1,225	809	4.27	3.88	0.76	0.85
Alluvian alm	832	383	4.54	3.68	0.96	0.96

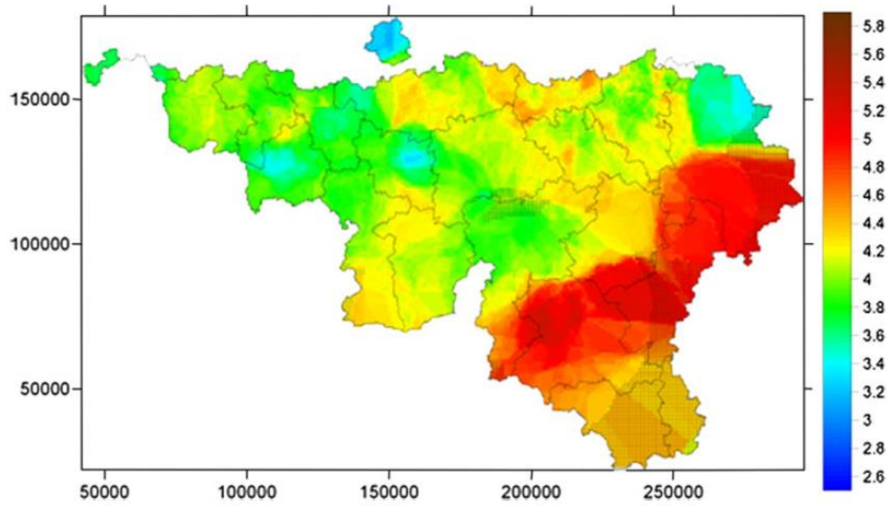
Source: G. Cinelli et al., 2011.

Figure 7.5. Map of the logarithmic mean based on geology and indoor radon measurements.



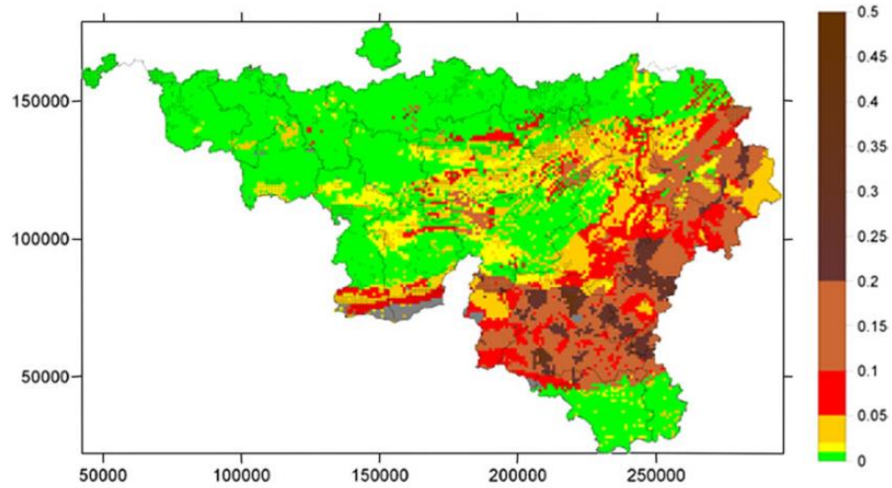
Source: G. Cinelli et al., 2011.

Figure 7.6. Map of the geometrical mean on loess cover.



Source: G. Cinelli et al., 2011.

Figure 7.7. Map of the proportion of the distribution above 400 Bq/m^3 based on geology and indoor radon measurements.



Source: G. Cinelli et al., 2011.

References

Tondeur F., Zhu H.-C., Charlet J.M., Gerardy I. and Perreaux R (1996). Radon from the subsoil to the dwelling in southern Belgium.Environment International, 22(1): S535-S543.

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 insouthern Belgium: an application of geostatistical and GIS techniques, The Science of the Total Environment, 272(1-3): 203-210.

Poffijn, A., Eggermont, G., Hallez, S. and Cohilis, P. (1994). Radon in Belgium: Mapping and Mitigation in the Affected Area of Visé. RadiationProtection Dosimetry, 56(1-4): 77-80 Abstract only.

Cinelli, G. Tondeur, F. and Dehandschutter, B., (2011) Development of an indoor radon risk map of the Walloon region, Environ Earth Sci 62:809–819.

8 Bosnia and Herzegovina

In Bosnia and Herzegovina only local surveys of indoor radon concentrations were conducted.

A radon survey has been carried out in Bihać municipality in 2006 (100 measurements) and Tuzla city in 2010 (48 measurements). Measurements have been made using CR-39, diffusion chamber. The duration of measurement varies from 3 month in Bihać to 4 month in Tuzla. The arithmetic mean of indoor radon concentration was 82.1 Bq/m^3 in Bihać municipality and 27.9 Bq/m^3 in Tuzla city (IAEA-TECDOC-1810, 2017).

From May 2011 to April 2012 the first investigation on indoor radon, thoron and their decay products concentration in 25 primary schools of Banja Luka, capital city of Republic Srpska was performed. The measurements have been carried out using 3 types of commercially available nuclear track detectors, named: long-term radon monitor for radon concentration measurements, radon-thoron discriminative monitor (RADUET) for thoron concentration measurements, while equilibrium equivalent radon concentration and equilibrium equivalent thoron concentrations measured by Direct Radon Progeny Sensors/Direct Thoron Progeny Sensors. In each school the detectors were deployed at 10 cm distance from the wall. The obtained geometric mean concentrations were 99 Bq/m^3 and 51 Bq/m^3 for radon and thoron gases respectively as well as for equilibrium equivalent radon concentration and equilibrium equivalent thoron concentrations were 11.2 Bq/m^3 and 0.4 Bq/m^3, respectively (Ćurguz, 2015).

References

IAEA-TECDOC-1810. Status of Rasdon related Activities in member States Participating in technical Cooperation Projects in Europe, IAEA, Vienna, 2017.

Ćurguz, Z. et al. (2015). Long-Term Measurements of Radon, Thoron and Their Airborne Progeny in 25 Schools in Republic of Srpska, Journal of Environmental Radioactivity,148, 2015, 163-169.

9 Bulgaria

Reference (Ivanova et al., 2013) describes results of a pilot survey in four Bulgarian districts: Sofia city, Sofia, Plovdiv and Varna. Survey goal was to obtain first systematic data and to investigate variability of indoor radon concentration in selected districts. The districts were chosen to meet the diverse topography of a country with a large population.100 detectors were deployed per district. Survey took place from October 2011 to May 2012, and single measurement duration was six months. During the survey, 373 dwellings were investigated. One detector in the most frequently used room was deployed, at least 1 m above the floor and away from windows and doors. The detector consists of a CR-39 chip with active area of 1.4 cm^2 placed in a cylindrical diffusion chamber.

Evaluation of the results included descriptive statistics, and log-normality was checked by Kolmogorov–Smirnov test, Mann–Whitney and Kruskall-Wallis tests for differentiation of regions.

Average radon concentration in rural and urban municipality in 4 districts. The measured values show considerable spatial variability. The indoor radon concentration varied from region to region.

It was found that indoor radon concentration varied between 20 and 3560 Bq/m^3 with median value of 90 Bq/m^3. The fractions of dwellings in four districts: Sofia city, Sofia districts, Plovdiv and Varna above the reference levels of 300 Bq/m^3 were3, 9, 14 and 5%, respectively. Each data set does not follow a log–normal distribution at a significance level of 95%. The results of the analysis of the variance showed statistically significant differences among the indoor radon concentrations for the regions between urban and rural municipalities as well for the building with and without basement. These results may be utilized to set up the methodology for a more systematic survey in Bulgaria.

Table 9.1. Descriptive statistics of indoor radon concentrations in 373 dwellings.

	Indoor radon concentration				
	Plovdiv district	Sofia city	Sofia district	Varna district	All regions
No. of dwellings	91	88	96	98	373
Minimum (Bq m^{-3})	30	20	30	20	20
Median (Bq m^{-3})	100	70	100	70	90
Maximum (Bq m^{-3})	3560	410	800	650	3560
AM (Bq m^{-3})	280	96	151	107	158
SD (Bq m^{-3})	568	72	141	102	304
SE (Bq m^{-3})	60	8	14	10	16
GM (Bq m^{-3})	137	78	111	80	99
GSD	2.62	1.85	2.14	2.09	2.25
Percentage of dwellings above 300 Bq m^{-3}	14.3	3.4	9.4	5.1	8.0

Source: Ivanova et al., 2013.

References

Ivanova, K., Stojanovska, Z., Badulin, V. and Bistra Kunovska (2013). Pilot Survey of Indoor Radon in the Dwellings of Bulgaria. Radiation protection Dosimetry, 157 (4), 594-599.

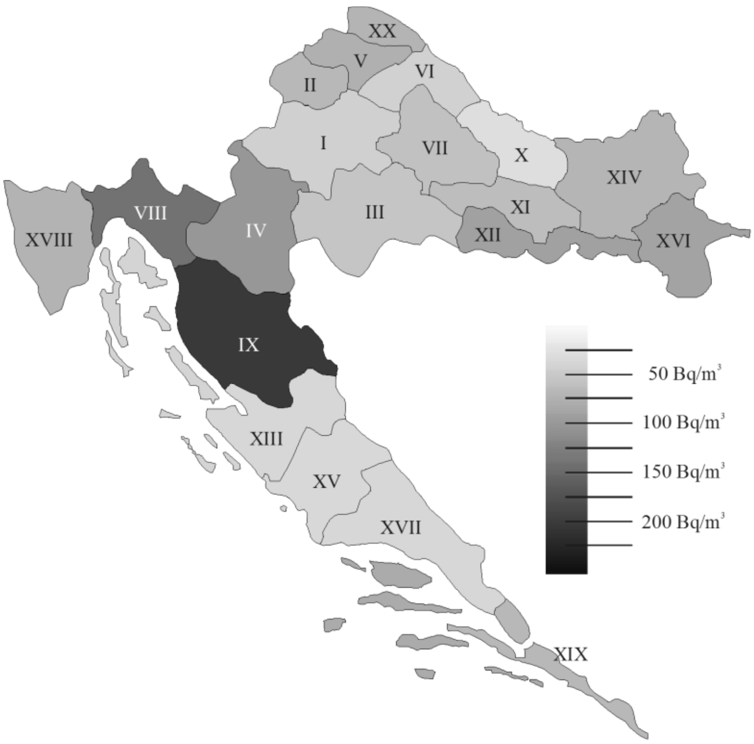
10 Croatia

National survey of indoor radon concentration was performed by a random sampling of 782 dwellings in Croatia from October 2003 to spring 2005.

Continuous measurements of radon and its alpha emitter progeny in the air were performed by means of the passive track etching method with strippable LR-115 SS, film, type II (Kodak-Pathe, France). The cylindrical plastic vessel of detector, with the diameter and length of 11 and 7 cm, respectively, was covered with a paper filter of 0.078 kg/m^2 surface density, inside, on the bottom of the vessel, a LR-115 film of 2×3 cm^2 was fixed that presented the diffusion detector. Outside, on the cylindrical shell of the vessel, another film was fixed, that presented the open detector. The measurement method with two detectors (diffusion and open) enabled determination of the equilibrium factor for radon and its progeny in air (Radolić, 2006).

Random phone numbers was chosen proportionally to the number of inhabitants of the county (in twenty counties) and one detector is sent by mail with short instruction for 12-month exposure. Radon concentrations were measured for one year and arithmetic and geometric means of 68 Bq/m^3 and 50 Bq/m^3 were obtained, respectively. The arithmetic means of radon concentrations on 20 counties were from 33 Bq/m^3 to 198 Bq/m^3. The percentage of dwellings with radon concentrations above 200 Bq/m^3 and 400 Bq/m^3 was 5.4% and 1.8%, respectively. The average annual effective dose of the indoor radon was estimated as 2.2 mSv. The statistical test, applied on the empirical and theoretical frequencies, did not show that the empiricalfrequency distribution for the radon in dwellings of Croatia belonged to the log-normal distribution (Radolić, 2006).

Figure 10.1. Annual indoor radon concentrations of the Croatian counties.



Source: Radolić, 2006.

References

Radolić, V., (2006) National Survey of Indoor Radon Levels in Croatia, J. Radioanal. Nucl. Ch., 269, 87-90.

11 Cyprus

Goal of the survey was to systematically register the indoor ^{222}Rn concentration in Cypriot buildings and dwellings. Part of the work was to compare results with the previous work and another part to investigate a region of Pano Polemidia where a number of cases of leukemia were reported.

Within the paper, it is slightly discussed geology of Cyprus: types of rocks and existence of faults; typical Cypriot houses and climate; and high ventilation rate underlined.

In addition to this project was measurement of the terrestrial gamma radiation.

The measurements were carried out over 9 months (beginning of September 2001 to end of May 2002).

For radon measurements a high–sensitivity modern portable detectors "RADIM3" were used. Besides, an additional sensors to measure ventilation coefficient, the pressure, the temperature and the humidity were used. Measurement was corrected for the humidity.

In total 84 buildings and dwellings were selected in 37 different villages and towns in Cyprus.

Sampling was random by contacting the house owners by telephone. Drought–free areas in the houses were selected such as basement, in order to obtain maximum radon concentrations. The detectors were placed at a height of approximately 1 *meter*. Sampling interval was adjusted from 0.5-24h, but usually it was 4h, over the 48h of operation.

Information on quality assurance was provided. Calibration over the whole dynamical range of the instrument is made by the manufacturer. Accuracy of the calibration was verified in the State Metrological Institute of the Czech Republic. Verification was achieved by comparing the results of measurement of ^{222}Rn concentrations provided by the Radim3 instrument and a reference instrument using a secondary ATMOS standard. Obtained overall uncertainty of the calibration was ±10%.

In the analysis only arithmetic mean, standard deviation and min and max values were reported. Rn concentrations ranged from 6.2 to 102.8 $Bq\ m^{-3}$, with an overall arithmetic mean value of (19.3 ±14.7) $Bq\ m^{-3}$. Overview of obtained radon concentrations in the main regions in Cyprus is given in Table 11.1.

Table 11.1. Radon concentrations in the main regions of Cyprus.

A/A	Region	Samples	^{222}Rn Concentration $[Bq\ m^{-3}]$			
			A.M.	S.D.	Min	Max
1	Ammochostos	4	11.9	3.8	2.0	19.3
2	Larnaka	3	17.3	2.1	9.8	25.1
3	Lemesos	8	29.6	30.3	1.7	183.5
4	Lefkosia	53	19.4	13.1	1.1	111.0
5	Lemesos forest area	3	13.9	5.0	5.3	27.9
6	Pano Polemidia	4	20.2	12.2	0.9	48.2
7	Pafos	2	10.7	3.0	1.1	44.5
8	Larnaka centre	2	8.6	2.0	6.3	12.7
9	Lemesos centre	1	23.5	4.8	6.3	93.0
10	Lefkosia centre	3	19.4	19.6	3.4	55.7
11	Pafos centre	1	15.7	4.0	2.9	66.9

Source: Anastasiou, 2003.

References

Anastasiou T. et al., 2003. Indoor radon (^{222}Rn) concentration measurements in Cyprus using high–sensitivity portable detectors, J Environ Radioact. 68(2):159-69.

12 Czech Republic

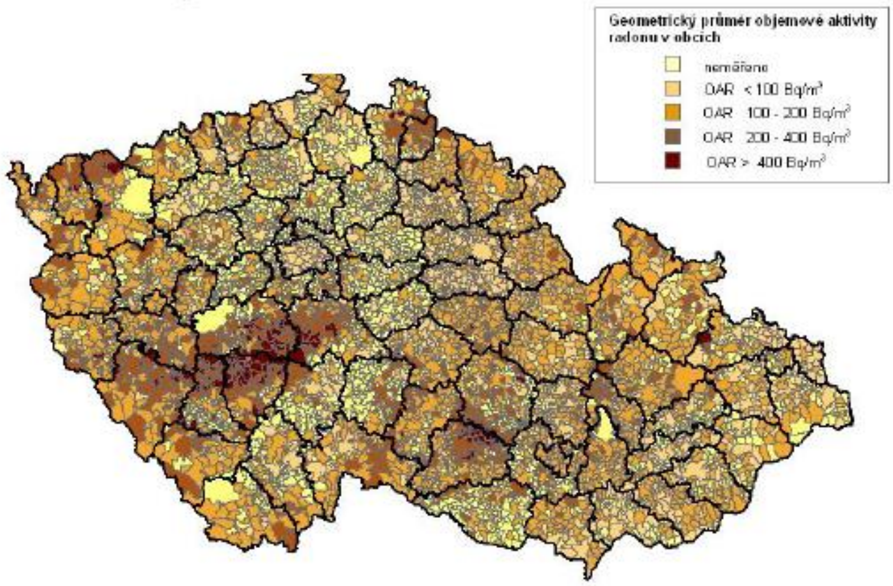
According to the references (Dubois, 2005; Hulka, 2014), the national radon survey has been continuously conducted since 1984.

The general survey goal was/is to create radon database and radon mapping. During that period more than 150000 dwellings were investigated, and two detectors were used per dwelling, mainly in living rooms. Firstly, dwellings were selected randomly, and random selection was followed by targeted survey in regions with higher radon concentrations. Track-etch SSNDs Kodak LR 115 detector placed in diffusion chamber were used for the search with an exposure period of one full year. This approach eliminates the season variations and detectors can be placed continuously during the year. Thus, duration of an single measurement was 365 days (Hulka, 2014).

Based on 305000 measurements in total, arithmetic and geometric mean were calculated. Estimated mean annual radon levels in Czech dwellings was 140 Bq/m^3, while 10-15% of measured radon concentration in dwellings were above 200 and below 400 Bq/m^3 and 2-3 % exceeded 400 Bq/m^3. Local averages were calculated at the municipal level (Dubois, 2005).

Metrology of radon and radon daughters is ensured by national Authorized Metrological Centre. Its calibration is verified and compared internationally. Centre provides certification for used equipment (Thomas et al., 2002).

Figure 12.1. Indoor radon concentrations levels (geometric mean) shown an municipality level (180000 dwelling included).



Source: Hulka, 2014.

References

Dubois, G., An overview of radon surveys in Europe, EC JRC, 2005.

Thomas et al., Review of official measuring methods and official interpretations of measuring results used in the radon program of the Czech Republic, 2002.

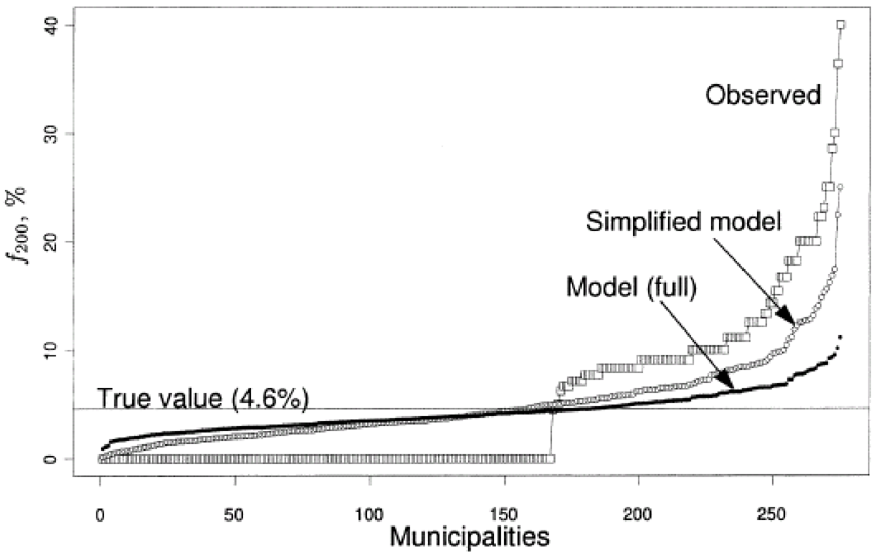
Power Point Presentation, 30 years of experience of Czech radon program, Jirí Hulka, SÚRO - National Radiation Protection Institute, Prague, Czech Republic, Latin American Symposium on Radon and II Symposium on Radon in Brazil, Pocos de Caidas, May 2014.

13 Denmark

Indoor radon measurements in Denmark are described in 2 papers, both describing the results of the national survey, conducted from 1995-1996 and from 1990-2000.

In the first paper, Andersen et al. (2001), the goal was obtaining the statistical model for the prediction of the fraction of houses in each municipality with an annual average radon concentration above 200 Bq/m^3. Alpha track detectors CR-39 were placed in randomly selected single homes (3019 dwellings in all 275 municipalities in the period of 1995-1996). It is assumed that within each municipality,the transformed radon concentration is normallydistributed with a true mean and a true standard deviation. Then estimators were calculated and the final result represents the estimation of number of houses with Rn concentration above 200Bq/m^3. Bayesian statistics, a transformation of the data to normality and on analytical unbiased estimators of the quantities of interest was used for evaluation of the results. Even though model assumptions such as those concerning normality and homogeneous variance may not be perfect, the model does not seem to be strongly biased: on-the-average, the model accounts well for data at the levelof individual counties and for Denmark as a whole. The results of the model prediction and observed values are presented in Figure 13.1, below.

Figure 13.1. Test with synthetic data: Comparison between model estimates ($f_{200,m}$) and observed values for f_{200} in 275 municipalities when true fraction above 200 Bq/m^3 is 4.6%. The curve labeled *simplified model* corresponds to the situation without the Bayesian correction.



Source: Andersen et al., 2001.

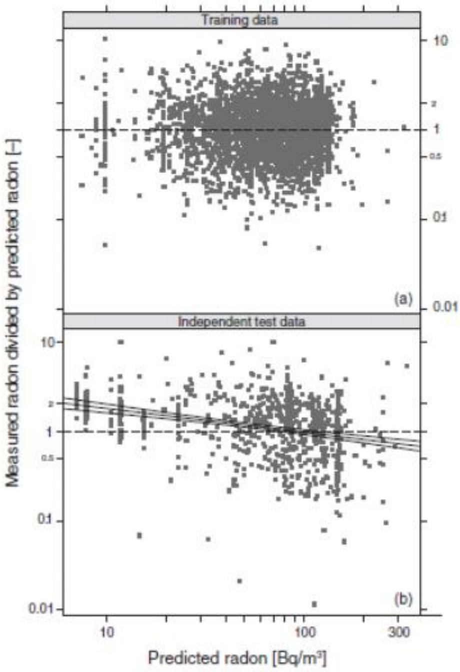
In the second paper, Andersen et al., 2007, a linear regression model has been developed for the prediction of indoor ^{222}Rn in Danish houses, connecting this measurement to the geological data. Track detectors CR-39 were placed in 3120 randomly selected single family houses as a part of previously conducted national survey and regression model with 9 predictors and 59 independent coefficients was obtained. The various tests showed that the model is correct on the average and can predict radon concentrations in the individual houses with an uncertainty of a factor of 2. The model appears to be best at predicting low concentrations. The results used for fitting the model are given in Table 13.1 and the ratio between measured and predicted radon values are depicted in Figure 13.2, below.

Table 13.1. Summary statistics for the radon measurement data (living room concentrations) used to fit and test the model.

	N	AM	ASD	GM	GSD	f_{200}	f_{400}	Min	%-quantiles (Bq m^{-3})					Max
									2.5	25	50	75	97.5	
Training data; 2001 national survey														
Apartments	91	18	19	12	2.4	0	0	0.5	2.5	7.5	12	18	82	100
Single-family houses	3025	94	84	67	2.4	9	1.2	1.8	11	39	71	120	310	790
All	3116	91	83	64	2.5	8.7	1.2	0.5	8.6	37	68	120	310	790
Test data (all)														
Apartments	148	20	12	18	1.5	0	0	8	10	13	18	22	45	118
Single-family houses	610	120	130	88	2.4	15	2.6	1	16	50	97	160	410	1800
All	758	100	120	64	2.8	12	2.1	1	10	29	75	140	350	1800
1. Test data; 1987 national survey														
Apartments	148	20	12	18	1.5	0	0	8	10	13	18	22	45	120
2. Test data; Hvalsø														
Single-family houses	65	120	69	94	2.1	12	0	11	23	56	110	170	250	290
3. Test data; Radon-95														
Single-family houses	270	160	170	110	2.4	20	4.8	0.3	18	75	120	180	430	1800
4. Test data; Risø homeowner measurements														
Single-family houses	275	96	82	68	2.5	10	1.1	1	11	40	75	130	280	620

Source: Andersen et al., 2007.

Figure 13.2. Ratio of measured and predicted radon concentrations for a) the training data (N=3116) and b) the independent test data (N=758). The $\log_e$ - transformed value of this ratio equals to the model residuals. The standard deviation of the residuals is approximately $\log_e(2) \approx 0.7$ for the training data and 0.80 for the independent test data. The mean of the residuals for the independent test data is 0.13 ($\log_e$ - scale) which means that the average measurement – prediction ratio is 1.14 (i.e. on the average, the measurements were 14% higher than predicted by the model). The solid line in b) is a regression line (R^2 = 0.10) which suggests that the measurement errors are not completely independent of the predicted radon concentration. A 95% confidence interval of the regression line is included in the figure.



Source: Andersen et al., 2007.

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. et al., (2007) Prediction of ^{222}Rn in Danish Dwellings Using Geology and House Construction information Radiation Protection Dosimetry 123 (1), 83–94.

14 Georgia

The survey of indoor radon concentration was conducted from 2007 to 2011 in 2000 dwellings in West Georgia (IAEA-TecDoc-1810, 2017).

For radon measurements in the home alpha track detectors were used to provide integrated mean radon concentration normally placed for a period from 6 to 12 months. Criteria to select dwellings were geographically and geologically based. Measurements were conducted in West Georgia. Measured radon concentrations were from 5 Bq/m^3 to 245Bq/m^3 (IAEA-TecDoc-1810, 2017).

Also electrets ion chambers available with different sensitivities for a few days measurements or for measurements over month were used (IAEA TC Project RER/9/127, 2014).

References

IAEA TC Project RER/9/127. Establishing Enhanced Approaches to the Control of Public Exposure to Radon, Presentation, 22.04.2014, Vienna, Austria.

IAEA-TECDOC-1810. Status Of Radon Related Activities in Member States Participating in Technical Cooperation Projects in Europe, Iaea, Vienna, 2017.

15 Greece

Results of national survey of indoor radon concentration in Greece are described in reference (Nikolopoulos D. et al., 2002). Survey was conducted from 1995 to 1998 during whole year, with a main goal to determine the percentage of houses with indoor radon concentration exceed certain reference levels, radon distribution in Greece indoors, and to estimate average risk to the population due to radon exposure. During this survey, 1277 dwellings were investigated. One detector was deployed per 1000 dwellings; trained personnel selected the buildings irrespective of the floor. Detector was placed 1 meter above ground in a bedroom by trained personnel and questionnaire was filled. MPD radon dosimeters consisted of a cylindrical nonconductive plastic cup of 5 cm height and 1.5 cm radius were used. The cover had a 3 mm hole on the center and a filter that prevented radon daughters from entering. Radon was detected by a 2×2 cm CR-39 nuclear track detector placed at the bottom of the cup. The overall uncertainty of radon measurement in the 95% confidence interval was below 10 %. Single measurement duration was 12 months.

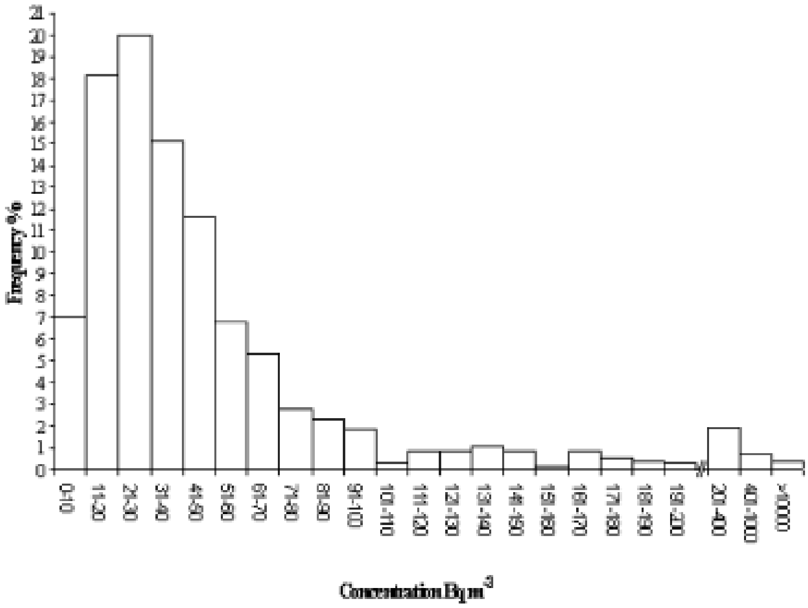
Figure 15.1. Sampling locations, locations where elevated radon concentrations occurred and "radon prone" areas in Greece.

Source: Nikolopoulos D. et al., 2002.

Evaluation of the results included descriptive statistic and tests for lognormality. Descriptive statistic was performed for each prefecture, and percentage of houses with indoor radon concentration over 200 Bq/m^3 was determined. Used detectors were calibrated and tested in the University of Athens.

Residential radon concentration ranged between 200 and 400 Bq/m^3 in 22 dwellings (1.9%), between 400 and 1000 Bq/m^3 in eight (0.7%) dwellings, and above 1000 Bq/m^3 in four (0.4%) dwellings. In the full data set, arithmetic mean was found to be equal to 55 Bq/m^3 and the geometric mean equal to 44.0 Bq/m^3 with a geometric standard deviation of 2.4 Bq/m^3. In only a small percentage (1.1%) of dwellings in Greece did the measured radon concentrations exceed the European Commission (1990) action level (400 Bq/m^3).

Figure 15.2. Frequency distribution histogram of radon concentrations in Greek dwellings (1227 samples).



Source: Nikolopoulos D. et al., 2002.

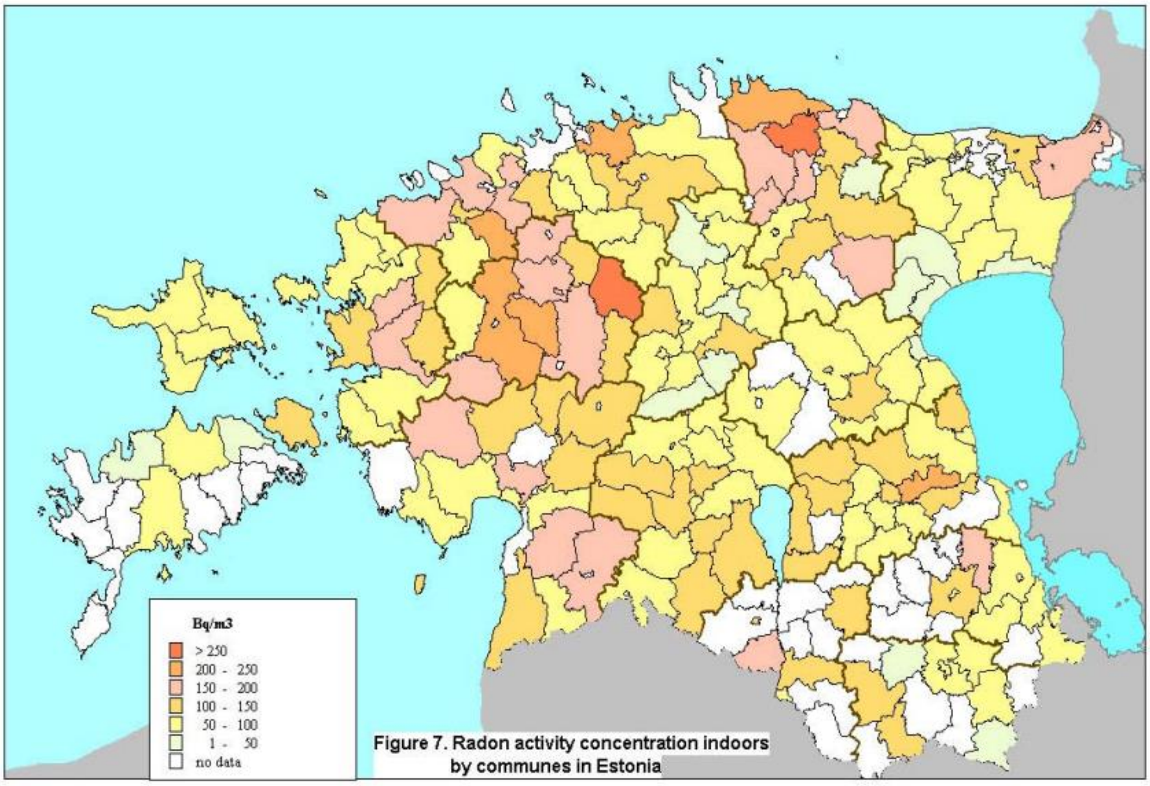
References

Nikolopoulos D. et al., (2002), Radon Survey in Greece - risk assessment, Journal of Environmental Radioactivity 63, 173-186.

16 Estonia

The results of the national survey in Estonia are described in Pahapill et al., 2003. The goal of this survey was to estimate the countrywide radon situation for calculation of the public health risk due to indoor radon and to provide a basis for work on protective measures. The survey was focused on the geographical distribution of indoor radon, measurements in 550 dwellings randomly selected from the 617,400 dwellings. The detectors were exposed during two or three month in the winter heating season. Two detectors were placed in each dwelling, usually, one in a bedroom and one in the living room during the heating season of 1998-1999, 1999-2000 and 2000-2001. Descriptive statistics was used to evaluate the measurement results. The indoor radon concentrations (arithmetic mean and maximum values shown by county, type of dwelling and number of residents living in these dwellings) were calculated. The mean annual effective dose to the whole of the Estonian population was also obtained and the results are presented in the Table 16.1 below. Radon map of Estonia by communes is represented in Figure 16.1 below.

Figure 16.1. Radon activity concentration indoors by communes in Estonia.



Source: Pahapill et al., 2003.

Table 16.1. Indoor radon concentrations in dwellings measured in the national Radon Survey, 1998-2001. Arithmetic mean (Am), maximum values (Max), of indoor radon levels and distribution

of indoor radon activity concentrations (%) are shown. The distributions of data in five activity concentration intervals are shown (%).

COUNTY	No. of dwellings	Indoor radon-222 concentration, Bqm^{-3}		Distribution of indoor radon-222 concentrations (Bqm^{-3}), %				
		Am.	Max.	<100	101-200	201-400	401-800	>800
Harjumaa	41	115	475	57	27	15	1	-
Hiiumaa	10	80	127	87	13	-	-	-
Ida-Virumaa	66	68	317	82	13	5	-	-
Jõgevamaa	31	76	255	74	22	4	-	-
Järvamaa	26	63	137	81	19	-	-	-
Läänemaa	30	86	174	75	25	-	-	-
Lääne-Virumaa	73	130	1,044	64	18	16	-	2
Põlvamaa	22	72	290	89	7	4	-	-
Pärnumaa	35	103	197	56	44	-	-	-
Raplamaa	33	203	558	12	52	25	10	-
Saaremaa	24	66	321	82	10	8	-	-
Tartumaa	39	100	260	61	35	4	-	-
Valgamaa	17	115	272	56	35	9	-	-
Viljandimaa	39	93	220	66	30	4	-	-
Võrumaa	29	66	227	86	11	3	-	-

Source: Pahapill et al., 2003.

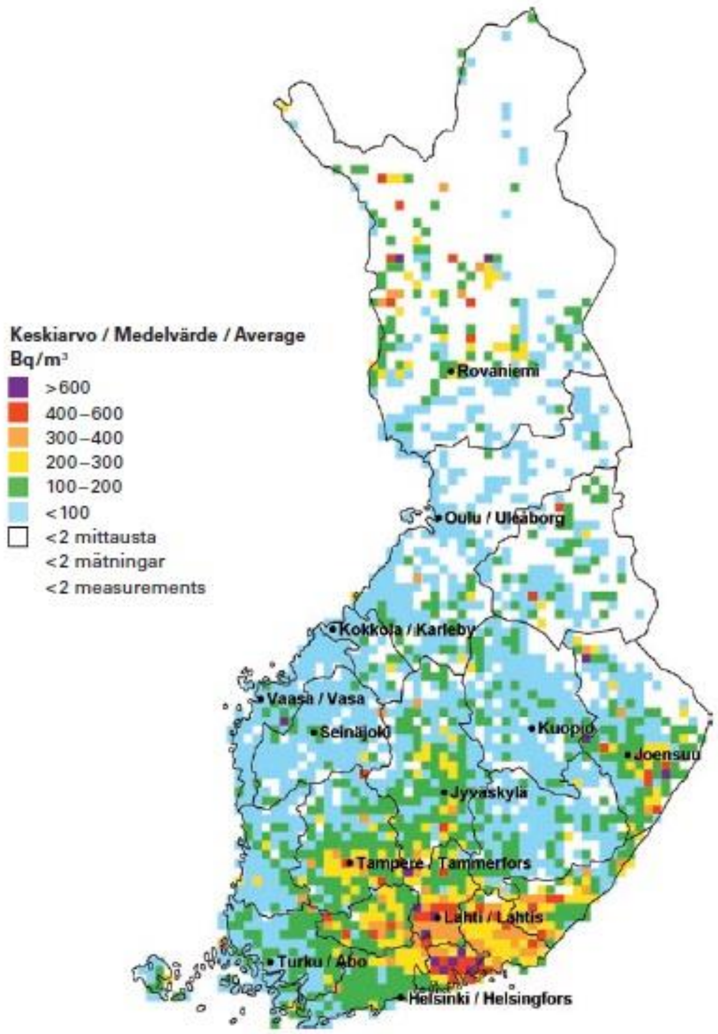
References

Pahapill, L., Rulkov, A., Rajamäe, R., Akerblom, G., (2003) Radon in Estonian Dwellings.

17 Finland

A study on national scale is still ongoing, since 1986. The goal of the study is to identify radon prone areas, defined as areas where concentrations over 400 Bq/m^3 are possible. Measurements were performed in more than 100000 residential objects, with more measurements performed in the identified radon prone areas. Measurements are usually performed in the winter period, between November and April, lasting between 2 months and 1 year. Alpha track detectors were used and the measurements were corrected for the outdoor temperature and wind speed. Based on the results, radon map was created with number of houses over 400, 800 and 1000 Bq/m^3 (Weltner et al., 2002; Valmari et al., 2010).

Figure 17.1. Radon concentration in Finish houses.



Source: Valmari et al, 2010.

References

Weltner A. et al., (2002). Radon Mapping Strategy in Finland, International Congress Series 1225, 63-69.

Valmari T. et al., (2010) Radon Atlas of Finland STUK-A245 / ELOKUU 2010, STUK Radiation and nuclear safety authority, ISBN 978-952-478-538-9.

18 France

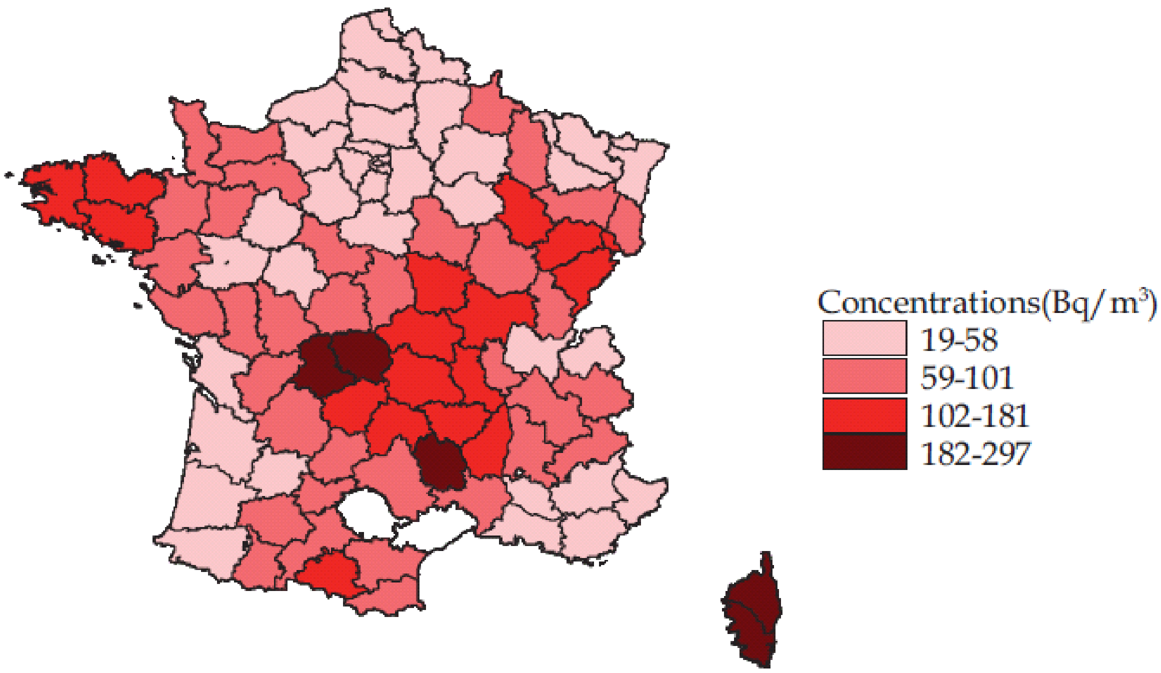
The indoor radon survey was conducted in the period from 1983-2002. The main objectives of the survey were to identify radon priority area, to estimate the percentage of dwelling above the action levels and to investigate factors influencing radon concentration. In total 12261 measurements were performed in 10098 local communities (ref: INSLR).

Bare LR115 detectors were deployed for two months, in one room per dwelling. Correction of seasonal variations was applied (Baysson, 2003). The questionnaire was enclosed with detector with question regarding building characteristics, living habits, etc.

Obtained results followed log-normal distribution, with arithmetic mean of 89 Bq/m^3 (standard deviation 162 Bq/m^3), median value of 55 Bq/m^3 and geometric mean of 53 Bq/m^3 with a GSD = 2 (Billon, 2005).

In the report it was not mentioned if thoron was measured, but since bare LR115 detectors were used they were certainly influenced by the thoron.

Figure 18.1. Distribution of indoor radon concentrations in France (ref: INSLR)



Source: INSERM (2008).

References

Baysson, H., Billon, S., Laurier, D., Rogel, A. And Tirmarche, M. (2003) Seasonal Correction Factors For EstimatingRadon Exposure In Dwellings In France, Radiation Protection Dosimetry 104 (3), 245–252.

Billon S. et al. (2005) French population exposure to radon, terrestrial gamma and cosmic rays. Radiation Protection Dosimetry 113 (3), 314-320.

INSERM (Institut national de la santé et de la recherche médicale Cancer et environnement), 2008. Chapter 55: Données d’exposition aux rayonnements ionisants (report in French)
http://www.ipubli.inserm.fr/bitstream/handle/10608/102/?sequence=72

19 Germany

In the paper by H. Schimer and A. Wicke 1985, a large scale radon survey has been carried out in the Federal Republic of Germany. In approximately 6000 arbitrarily selected dwellings in the Federal Republic of Germany, the mean radon concentration was measured for at least 3 months using the Karlsruhe type nuclear track dosimeter. The main results are presented in the Table 19.1 below.

Table 19.1. Radiation exposure of the lung from Rn and its short-lived daughter products and annual contribution to the effective dose equivalent.

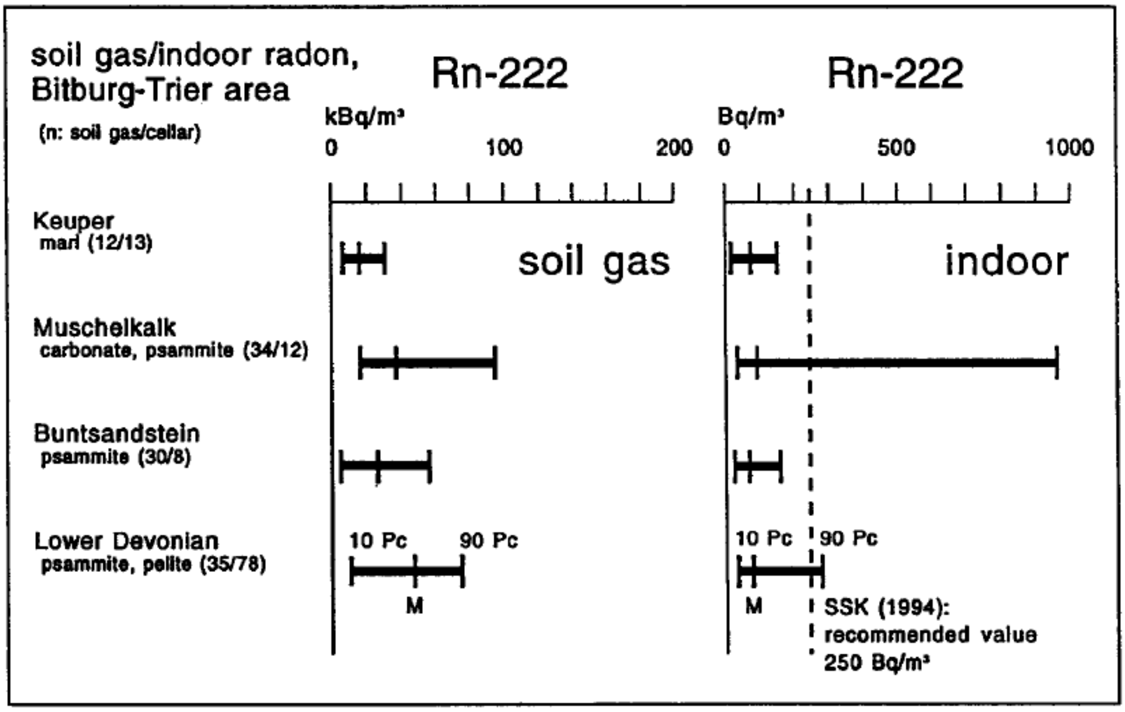
	Radon 222-concentration (Bq/m³)	Annual effective dose of different lung regions (mSv)		Annual contribution to the effective dose equivalent (mSv)
		Trachea & bronchial tree	Pulmonary region	
Median value	40	14	2	0.8
Mean value	49	18	2	1.2
10% exceeding	80	29	3	1.9

Source: Schimer and Wicke, 1985.

In the paper by Kemski et al. 2004, 6000 houses over nine federal states were investigated, with two detectors per building, one in basement one in living room. In the eastern part of the Germany the radon activity concentration in buildings were significantly higher than in the western part due to the differences in the building and construction type of the houses. The paper is in German, so for the present moment, it is not suitable for extracting data.

In paper Kemski et al. 1996, in an on-going research project of the German Federal Ministry for the Environment, Conservation and Reactor Safety, radon-prone areas in Germany have been defined and these results were used in the paper in order to produce a radon prone region map. The aim was to generalize and to extrapolate the results of the test areas to other regions of Germany with comparable geological situations as far as possible. Measurements were conducted from September to December 1994. An indoor radon survey was done in the Bitburg-Trier area in about 130 buildings, where solid-state nuclear track detectors were exposed over a period of 3 months. The first results show in cellars median values generally below 100 Bq/m^3; varying between 65 and 97 Bq/m^3 (Figure 19.1). On the ground floor, the median values of all units are between 41 and 58 Bq/m^3.The data are in agreement with the gross average median values of 52 Bq/m^3 (cellars), respectively, 43 Bq/m^3 (living rooms), for western Germany.

Figure 19.1. Soil gas and indoor radon concentrations in the main stratigraphic units in Bitburg-Trier area; median values and percentiles.



Source: Kemski et al., 1996.

References

Schimer, H. and Wicke, A. (1985). Results from a Survey of Indoor Radon Exposures in the Federal Republic of Germany, The Science of the Total Environment, 45, 307-310.

Kemski, J., Klingel, R., Stegemann, R. (2004): Validierung der regionalen Verteilungen der Radon konzentration in Häusern mittels Radonmessungen unter Berücksichtigung der Bauweise (Abschlussberichtzum orschungsvorhaben St. Sch. 4271).- Schriftenreihe Reaktorsicherheit und Strahlenschutz, BMU-2004-641.

Kemski, J., Klingel, R., and Siehl, A., (1996). Classification and Mapping Of Radon Affected Areas In Germany Environment International, 22 (1), S789-S798.

20 Hungary

A study on national scale was conducted to identify radon prone areas. The study was conducted between 1994 and 2004 in 15277 first floor rooms and 325 upper floor rooms in dwellings. Detectors were distributed by teachers to volunteers. Three measurements were performed in each room in spring, autumn and winter and each measurement lasted 2-3 months. The annual mean was calculated as average for 4 seasons, where the summer concentration was estimated based on the previous studies. CR-39 detectors in plastic cylinders were used. After the exposure, they were etched in 20% NaOH for 4 hours at the temperature 92 °C and counted by image analyzing code (Hamori, 2006).

The data was evaluated by log normality test and Kolmogorov test. The evaluation showed that the whole dataset didn't follow log normal distribution. After defining strata, datasets within each stratum were following log normal distribution. Percentage of dwellings over 4 levels of concentration (150, 200, 400 and 600 Bq/m^3) was determined for each stratum, as well as the mean value (Hamori, 2006).

Table 20.1. Estimated percentage of first-floor dwellings above the given radon levels in Hungarian villages by regions.

Geography	Strata	Number of		Estimated percentage of dwellings above[a]	
		All dwellings	Measured dwellings	150 Bq m^{-3} (%)	600 Bq m^{-3} (%)
Plain	Great Hungarian Plain	670 712	1859	17.8	0.1
Plain	Mezőföld	88 777	313	24.8	0.1
Plain	Little Hungarian Plain	88 442	471	22.9	0.2
Hills	Vas-Zala Hills	81 679	357	7.5	<0.1
Hills	Hilly Region of N. Hun.	35 427	746	24.7	0.2
Hills	The Trans-Danubian H.	137 946	1007	26.1	0.4
Limestone	Vértes-Dunazug M.	76 756	1205	16.2	0.1
Limestone	Bakony Mountain	75 027	393	21.3	0.2
Limestone	Bükk Mountain	15 012	351	36.4	0.6
Granite	Mórágy Hills	1589	779	46.9	1.6
Granite	Velence Hills	6116	665	36.8	2.3
Limestone	Mecsek Mountain	15 405	154	43.1	3.1
Volc.-l.stone	Börzsöny-Cserhát	50 360	1003	51.4	3.4
Volcanic	Mátra Mountain	20 916	1262	50.7	4.6
Warp	Sajó-Hernád-Valley (−*X*)	53 371	903	39.8	1.3
Warp	Village *X*	298	153	78.0	6.9

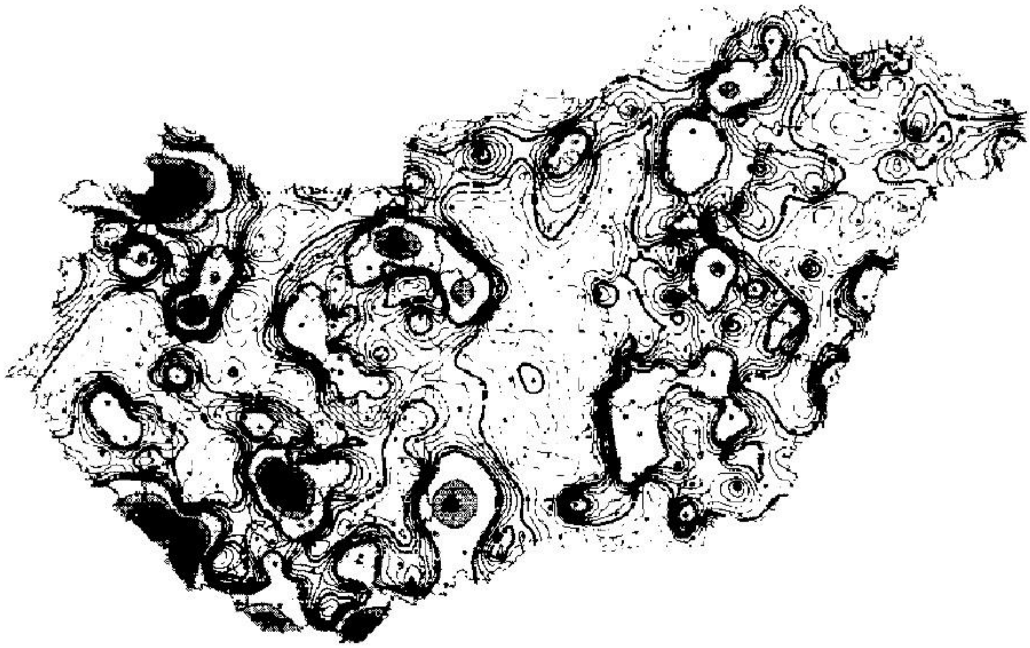
[a] One hundred percent is the total number of first-floor dwellings in the given region.

Source: Hamori, 2006.

System was calibrated at NPRB, UK. The detector also measured thoron, but it is not possible to estimate the thoron contribution to measured total radon concentration (Hamori, 2006).

Another national survey was organized between December 1993 and December 1994. The measurements were performed with E-Perm electrets for 12 months. The country was divided in 10 km by 10 km squares and one dwelling was selected from each square, giving the total of 998 dwellings. The results were evaluated by performing log normality test and by descriptive statistics. Arithmetic, geometric and weighted means were calculated and annual effective dose was estimated. System was calibrated in Swedish radiation protection institute. Thoron was not measured (Nikl, 1996).

Figure 20.1. Contour map of indoor radon concentrations in ground contact dwellings in Hungary.



Source: Nikl, 1996.

References

Hámori K., Tóth E., Pál L., Köteles G., Minda M., (2006). Evaluation of Indoor Radon Measurements in Hungary, Journal of Environmental Radioactivity 88, 189-198.

Nikl I., (1996) Radon Concentration and Absorbed Dose Rate in Hungarian Dwellings, Radiation Protection Dosimetry, 67, 225−228.

21 Iceland

Previous measurements were performed for the geological/geophysical research, such as prediction of earthquakes. No large surveys performed previously.

The first radon survey was made in 18 basements in 1982, with an average of 11 Bq/m^3 and highest of 26 Bq/m^3 (Ennow K.R. and Magnússon S.M, 1982).

Another survey, performed in 2003 with liquid scintillator, encompassed 51 houses in the area Reykjavík. The results obtained from the 12h measurements show radon level with a mean of 4.7 Bq/m^3 and median 2.8 Bq/m^3 (Jónsson et al., 2003).

National Rn survey performed in 2012-2013, aiming to contribute to European Indoor Radon Map (Jonsson, 2016), with the following characteristics.

Detectors: 500 PADC/CR-39 detector chip from Radosys (Hungary).

Exposure: 12 months, LLD: 7 Bq/m^3; uncertainty under 15% for 12 months exposure at 150 Bq/m^3.

Sampling obtained via volunteers being selected by website and phone.

Detectors were sent to 278 homes (retrieved 250); 31 kindergartens and 40 swimming pools (retrieved 31 and 19, respectively).

Detectors were placed on the lowest floor and in an inhabited room. Survey included 0.2% of homes. Detectors were exposed for 9-13 months. Covered most of the inhabited areas.

The mean obtained radon level was 13 Bq/m^3 and the median 9 Bq/m^3. Only 5% of the results are over 40 Bq/m^3 and the highest measurement was 79 Bq/m^3. In kindergarten the mean radon level is 11 Bq/m^3 and the median 6 Bq/m^3 while for public swimming pools the mean radon level is 6 Bq/m^3 and the median 5 Bq/m^3.

In addition continuous Rn measurement based on liquid scintillation was performed in one indoor and one outdoor location. Radon was monitored for a bit more than 2 months, but no noticeable diurnal, week variations could be observed, while measurement was short in order to observe seasonal variations.

It is concluded that radon is not a health problem in Iceland.

References

Ennow, K.R., Magnússon, S.M. (1982) Natural Radiation in Iceland and the Faroe Islands. Statens Institut for strålehygiejne Denmark.

Jónsson, G., Theódorsson, P. (2003) Radon í andrúmslofti íbúða á Íslandi. Report to the Icelandic, Student Innovation Fund.

Jónsson, G., Halldórsson, Ó., Theodórsson, P., Magnússon, S.M., Karlsson, R.K. (2016) Indoor and outdoor radon levels in Iceland. https://gr.is/wp-content/uploads/2016/09/Indoor-and-outdoor-radon-levels-in-Iceland_NSFS_Final_FINAL_version.pdf. Last access 12/11/2018.

22 Ireland

A national survey was conducted between 1992 and 1999, with the goal to determine geographical radon distribution in Ireland. Random sampling was performed from each 10 km x 10 km square. A total of 12649 measurements were performed out of which 11319 were valid. Detectors were exposed for approximately 12 months, 2 in each dwelling (main living area and main bedroom). Mean value is calculated based on the assumption of equal occupancy. CR-39 detectors were used. After exposure, they were etched with 6.25 M NaOH for 8 hours at 75 °C. Questionnaires were issued with the detectors (Fennell et al, 2002).

Data was evaluated by performing log normality test and by descriptive statistics. Radon map was produced with 10 km squares grid. Percentage of dwellings with over 200 Bq/m^3 was determined for each square. Squares with more than 10% were designated as high radon areas. National average and population weighted national average concentrations were determined. Regular quality checks were performed during the survey (Fennell et al, 2002).

National survey was conducted in 2015 in order to confirm previous findings and to measure average national concentration. Sampling was stratified, based on the previously determined radon risk. Measurements were performed in 649 dwellings. Detectors were exposed for approximately 3 months (September – November), 2 in each dwelling (main living area and main bedroom). Mean value is calculated based on the assumption of equal occupancy. CR-39 detectors were used. After exposure, they were etched with 6.25 M NaOH for 1 hour at 98 °C. Questionnaires were issued with the detectors (Dowdall et al, 2017).

Data was evaluated by identification of outliers, log normality tests, tests for bias due to measurement duration. National average concentration was weighted according to previous findings. Measurements were performed by an accredited laboratory (Dowdall et al, 2017).

Table 22.1. Comparison of 2002 NRS and 2015 national average indoor radon concentration survey key metrics.

	2002	2015
Number of homes measured	11,319	649
No. of homes >200 Bq m^{-3}	9%	8%
Minimum concentration measured (less 6 Bq m^{-3} background subtraction) (Bq m^{-3}) after subtraction of background?	8	5
Maximum concentration measured (Bq m^{-3})	1924	1001
Arithmetic mean (Bq m^{-3})	89	77
Geometric mean (Bq m^{-3})	57	51
Geometric standard deviation (Bq m^{-3})	2.4	2.4

Source: Dowdall et al, 2017.

Table 22.2. Summary of survey results for each county in Ireland.

County	No. of Dwellings Measured	No. >200 Bq/m^3 (% of dwellings measured)	Mean (Bq/m^3)	Max (Bq/m^3)
Carlow	194	30 (15%)	123	1562
Cavan	180	5 (3%)	67	780
Clare	742	66 (9%)	88	1489
Cork	1211	71 (6%)	76	1502
Donegal	487	18 (4%)	69	512
Dublin	155	6 (4%)	73	260
Galway	1213	181 (15%)	112	1881
Kerry	932	52 (6%)	70	1924
Kildare	480	29 (6%)	90	1114
Kilkenny	181	16 (9%)	100	717
Laois	334	17 (5%)	83	565
Leitrim	145	6 (5%)	60	433
Limerick	524	41 (8%)	77	1102
Longford	132	8 (6%)	75	450
Louth	124	14 (11%)	112	751
Mayo	1184	152 (13%)	100	1214
Meath	233	18 (8%)	102	671
Monaghan	120	4 (3%)	68	365
Offaly	286	7 (2%)	68	495
Roscommon	235	17 (7%)	91	1387
Sligo	270	54 (20%)	145	969
Tipperary	852	63 (7%)	79	1318
Waterford	162	20 (12%)	119	1359
Westmeath	289	20 (7%)	91	699
Wexford	469	54 (12%)	99	1124
Wicklow	185	24 (13%)	131	1032

Source: Fennell, 2002.

References

Fennell, S.G. et al, (2002). Radon in Dwellings, the Irish National Radon Survey, RPII-02/1, Radiological Protection Institute of Ireland, Dublin, www.epa.ie/pubs/reports/radiation/radonindwellingstheirishnationalradonsurvey.html

Dowdall, A. et al, (2017). Update of Ireland's national average indoor radon concentration - Application of a new survey protocol, Journal of Environmental Radioactivity 169-170, 1-8.

23 Italy

A national study was performed in order to evaluate novel radon mapping strategy by using Telecom infrastructure. The study was conducted between 2004 and 2007, while the paper reported only the first year results. Underground inspection rooms were used for this purpose, as well as Telecom buildings. The buildings were selected in such way to be similar to normal buildings and also having in mind geographical distribution within each of the 20 Italian regions. A total of 1438 inspection rooms were selected and 1414 Telecom buildings. One CR-39 detector was positioned in each inspection room for 12 months, while 1 detector was positioned in two rooms in each Telecom buildings for the same period. In 10 – 15% of cases, additional detector was positioned for quality control purposes. Concentrations are averaged for each building (Carelli et al, 2009).

The results were evaluated by descriptive statistics and by excluding the results from rooms directly connected to underground pipelines. Average concentrations for each of the 20 regions were calculated. All the equipment used has traceable calibrations and QA/QC procedures are in place (Carelli et al, 2009).

Table 23.1. Detectors summary results of the first year of measurements in Telecom buildings.

Region	Detectors	Radon concentration (Bq/m^3)							
	N	Min	Max	Average	Median	SD	SE	GM	GSD[a]
Abruzzo	133	7	2031	69	19	219	19	49.7	5.9
Basilicata	21	5	2458	200	22	551	120	34.4	5.2
Calabria	210	2	3303	60	16	244	17	20.9	3.0
Campania	281	6	8823	356	96	782	47	105.3	4.7
Emilia-Romagna	483	4	735	33	14	69	3	17.3	2.4
Friuli-Venezia Giulia	75	3	1938	88	18	252	29	24.4	3.9
Lazio	552	8	5941	171	47	483	21	59.6	3.3
Liguria	91	4	214	18	9	29	3	10.9	2.3
Lombardia	669	4	3610	135	40	303	12	51.4	3.4
Marche	77	5	1720	50	11	208	24	16.0	2.7
Molise	30	3	589	40	15	107	20	16.9	2.8
Piemonte	409	2	2204	89	31	192	9	38.7	3.1
Puglia	195	5	1941	120	39	256	18	46.4	3.5
Sardegna	263	5	681	46	21	75	5	26.4	2.5
Sicilia	563	4	1520	65	22	148	6	27.6	3.1
Toscana	269	3	830	58	20	119	7	25.1	3.1
Trentino-Alto Adige	147	7	3207	196	62	401	33	77.3	3.5
Umbria	112	5	807	37	17	91	9	19.2	2.5
Val D'Aosta	17	8	755	139	21	227	55	48.1	4.3
Veneto	140	5	1711	126	43	252	21	50.4	3.4
Italy	4737	2	8823	109	27	327	5	35.5	3.6

SD = standard deviation; SE = standard error; GM = geometrical mean; GSD = geometrical SD.
[a] Dimensionless.

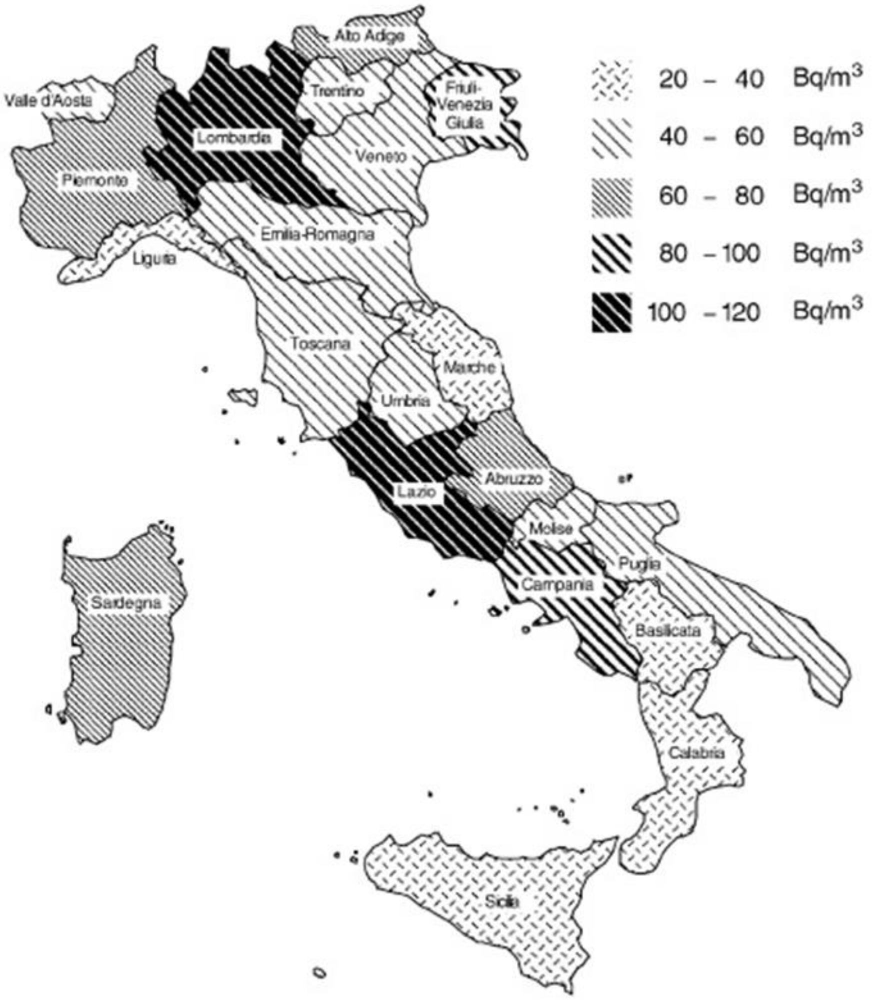
Source: Carelli et al, 2009.

Another national study was conducted between 1989 and 1998 in all 21 Italian regions for the purpose of estimating the national distribution of radon levels in dwellings. Measurements sites were selected by simple random sampling in cities over 100000 inhabitants and cluster sampling in smaller cities. A total of 5631 validated measurements were performed. Median floor for large cities was 2nd floor and for the small cities 1st floor (Bochicchio et al, 2005).

Ad hoc SSNTD detector with KODAK LR115-II was used, made by Dosirad. Spark counting was used for track counting. Thoron was blocked from entering detectors. Detectors were exposed for two consecutive periods of 6 months (spring-summer and autumn-winter). If one period was missing, seasonal correction factors were applied (Bochicchio et al, 2005).

Results were evaluated by descriptive statistics and log-normality tests. Calibration at NPRB UK was performed and several intercomparisons were performed between regional laboratories. Population weighted national average, and percentage of houses over 150, 200, 400 and 600 Bq/m^3 were calculated for national level and for each region. Radon map was also produced (Bochicchio et al, 2005).

Figure 23.1. Map of the average annual radon concentration levels in all the 21 Italian regions.



Source: Bochicchio et al, 2005.

References

Carelli, V. et al, (2009) A National Survey on Radon Concentration in Underground Inspection Rooms and in Buildings of a Telephone Company: Methods and First Results, Radiation Measurements 44, 1058-1063.

Bochicchio, F. et al, (2005). Annual Average and Seasonal Variations of Residential Radon Concentration for all the Italian Regions, Radiation Measurements 40, 686-694.

24 Kazakhstan

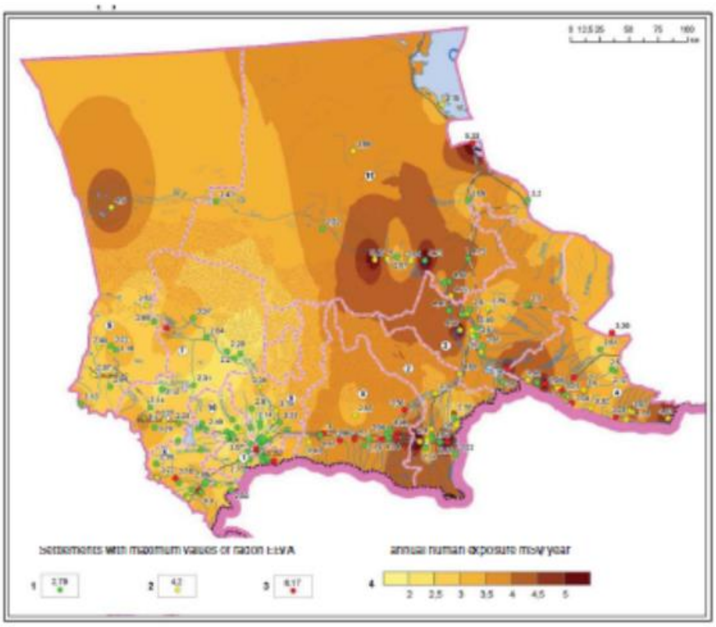
Paper (Fyodorov et al., 2014) describes complex radiation studies that were carried out on territory of Zhambyl oblast in 2011-2013. The territory is situated in the main part of Balkhash uranium ore province, including 12 uranium deposits, more than 20 ore occurrences, which to a greater extent determined the radiation situation in the area. In addition, dozens of areas of radioactive contamination of various origins in the region were identified, also contributing to the formation of high levels of radiation risk.

The main goals of these studies were radiological surveying of the settlements, estimation of radon concentration in soil, water, agricultural products, evaluation of indoor radon concentration and radon concentration in drinking water sources, and estimation of public doses.

Taking into account studies of previous years in Zhambyl oblast, a radiation survey of 316 villages and 4 towns (Taraz, Shu, Karatau and Zhanatas) was made. Analysis of natural and geological features allowed selecting of 4 landscapes-radiogeochemical blocks with various structural tectonic and radiation-geochemical characteristics. Different levels of public exposures were identified 10 areas with high radiation intensity, which occupy about 15% of the territory.

In the result of the radon hazardous assessment it was found that the 26.2% of surveyed villages were exceeding the regulation limit (200 Bq/m^3) of radon concentration.

Figure 24.1. Map of the total radiation dose Zhambyloblast.
Legend: Settlement with maximum values of radon EEVA: 1- to 100 Bq/m^3, 2- from 100 to 200 Bq/m^3, 3- 200 Bq/m^3 and above (upper value of the annual total dose, mSv/year), 4- the annual human exposure mSv/year.



Source: Fyodorov et al., 2014.

References

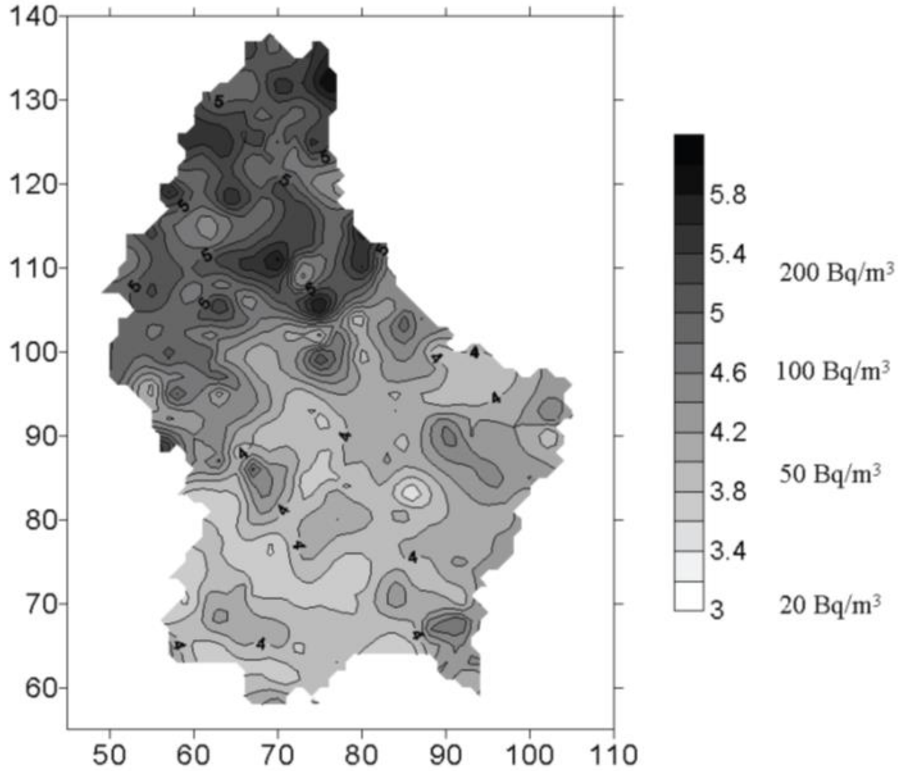
Fyodorov, G.V., Berkinbayev, G.D., Kayukov, P.G. (2014). Radiological atlas of Zhambyl oblast in Kazakhstan, Научные статьитом 7(4), 62-66.

25 Latvia

The survey of indoor radon concentration was conducted from 1993 to 1994 in 300 random selected dwellings in Latvia (Dubois, 2005).

A computer was used to find on the map of Latvia random points at a density proportional to the number of small houses in each region (approximately one point for 780 houses was chosen).They didnot generally know if at the place where the computer put a random point a house is located. Therefore, an additional two random points ineach district were chosen. The radon measurements were made with the E-PERM system, consisting of 60 standard 200 ml ionizing chambers, short term electrets of high sensitivity and 20 long term electrets. The average indoor radon concentration in detached houses is estimated as 68.5 Bq/m^3, but averages in different districts range from 20 Bq/m^3 to 120 Bq/m^3 (Dambis, 1994).

Figure 25.1. Map of annual mean radon concentration values.



Source: Dubois, 2005.

References

Dubois, G. (2005) An Overview of Radon Surveys in Europe, European Communities.

Dambis, M. (1994) Radon in Latvia's Dwellings, Radiation and Society: Comprehending Radiation Risk, Vol.2, IAEA Conference Paris, 24-28 october 1994, IAEA CN-54/31P, 379-382.

26 Lithuania

A national survey of indoor radon levels in Lithuania was performed between 1995 and 1998. The main objective of this survey was to evaluate the average of indoor radon concentrations in Lithuania and to determine whether there were significant variations with different areas (Morkunas and Akerblom, 1999).

Measurements have been carried out in 400 randomly selected detached houses. The duration of one measurement was at least 3 weeks. The levels in two commonly used rooms on the lowest level were measured using passive E-PERMTM electrets. As part of the quality assurance program the measuring system has been tested through intercomparisons. Measurements were carried out during the cold weather season, October 1st - 30 April 30th. Information on house construction and layout, including the age of the house, the building materials and whether there was a basement, the type of water supply, as well as the ambient gamma dose rate, were also recorded.

The results show that the arithmetic mean of indoor radon in the randomly selected detached houses is (55±4) Bq/m^3 (confidence level 95%) and the geometric mean is 22 Bq/m^3 (Morkunas and Akerblom, 1999). A separate set of measurements was performed in Birzai karst region. The arithmetic and geometric mean values in detached houses in this region are (98±16) Bq/m^3 and 50 Bq/m^3, respectively. Five regions (excluding the karst region) where the indoor radon concentrations are two or more times higher than the average concentrations in the rest of Lithuania have been found.

The source of indoor radon in Lithuania is the bedrock and the soils. The type and construction of house have significant influence on the indoor radon concentrations. The radon concentration in ground water is less than 30 Bql^{-1}. Application of the t-test indicates that there are no statistically significant differences between average values in winter and in summer. Statistically significant difference between concentrations in houses in the karst region and in randomly selected houses was found ($p<0.01$). The distribution of indoor radon concentrations in houses obeys the same lognormal shape.

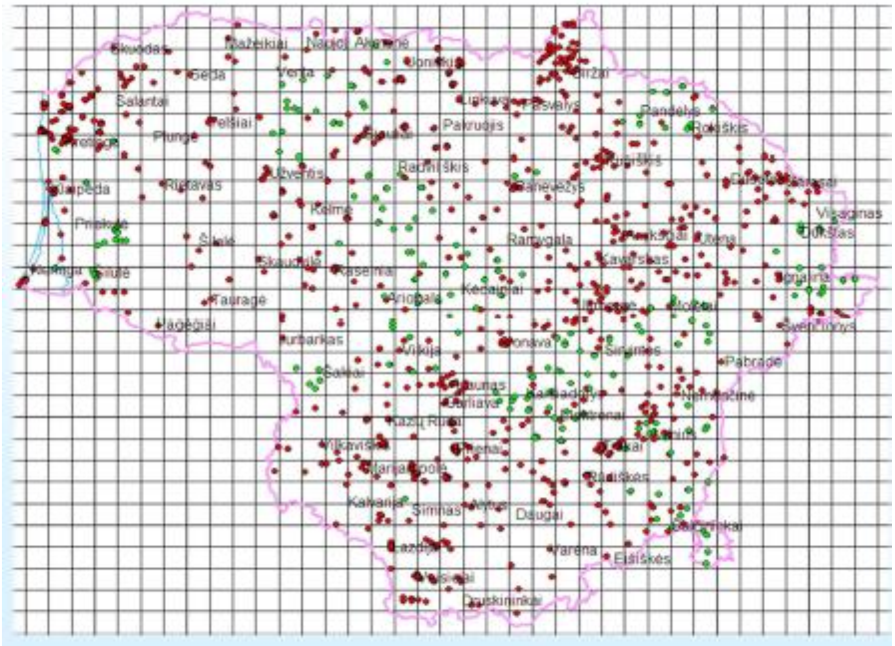
The annual effective doses as a result of indoor radon have been estimated and the average value for detached houses was 0.97 mSv (Morkunas and Akerblom, 1999).

According to reference (Ladygienė, 2015), a different range and purpose indoor radon surveys were performed or are going on starting year 1995, in Lithuania: National survey of indoor radon in 1995-1998; Survey in multi-storey houses and in workplaces in 2001-2004; Survey in region of higher radon risk in Northern part of Lithuania in 2001-2002; Survey in regions with higher conc. of indoor radon in 2002-2007; Children' and teenagers' institutions survey in 2002-2003 and 2014 year; Indoor radon mapping, data transference to EC JRC in 2007 till now; Geogenic radon potential map, starting in 2008.

Average indoor radon concentrations measured in 1995-1998 was 44 Bq/m^3 and exposure was up to 0,55 mSv per year. During year 2011-2015 measurements in the same 11 municipalities show increase of indoor radon up to 44 percent (due to saving energy measures and new dwellings constructed). Average indoor radon concentration (according to data of 2015, (Ladygienė, 2015)) is 79 Bq/m^3, this results in an annual 1.4 mSv for public exposure. In terms of the latest internationally recognized methodology, the average exposure for the population would reach up to 2.0 ± 0.4 mSv per year. This would represent more than 60 percent of public exposure from all sources of ionizing radiation received during the year.

In Figure 26.1 below, the map of indoor radon measurements in dwellings, approx. 3000 measurements, grid 10 x 10 km, is presented (Ladygienė, 2015).

Figure 26.1. Indoor radon measurements in dwellings, approx. 3000 measurements, grid 10 x 10 km, 1 dwelling.



Source: Ladygienė, 2015.

Future plans are to develop a new national radon action plan (to address long-term risks from radon exposures) which will be approved according to requirements of *Council Directive 2013/59/EURATOM of 5 December 2013* laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation and *IAEA GSR Part 3* during 2018 (Ladygienė, 2015).

References

Morkunas, G. and Akerblom, G. (1999). The Results Of The Lithuanian Radon Survey, Radon In The Living Environment, 19-23 April 1999, Athens, Greece.

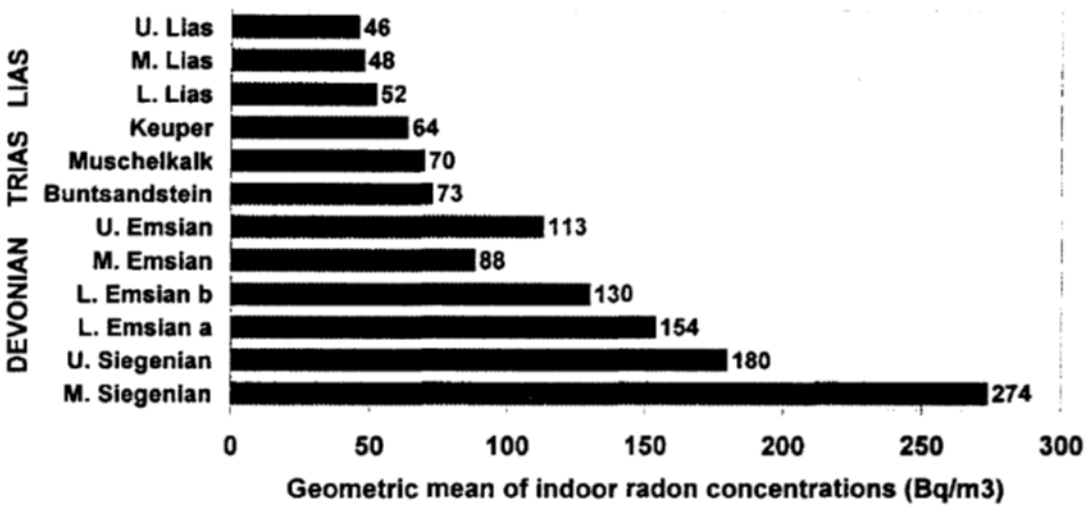
Ladygienė, R., Phd, Power Point Presentation, Current Indoor Radon Situation In Lithuania, Radiation Protection Centre, 2015.

27 Luxembourg

The survey of indoor radon concentration was conducted from 1993 to 2002 in 2619 random selected dwellings in Luxembourg. The average indoor radon concentration in houses is estimated as 115 Bq/m^3 (Dubois, 2005).

Since 1990 more than 5000 Solid State Nuclear Track detectors of the Karlsruhe type measurements in 3000 houses have been taken, 5% of the measurements carried out on request, 95% randomly distributed by the voluntary fire brigades. For the analysis, only single-family houses with at least one exposure period of over three months in the living area and with a complete questionnaire were retained. Descriptive statistics and lognormality checks were used to evaluate the data. Influence of lithology analyses, influence of the existence of a cellar, age and building characteristics were discussed. Higher indoor radon concentrations (geometric mean 150 Bq/m^3) are found in the North and lower ones (geometric mean 60 Bq/m^3) in the South (Kies, 1996).

Figure 27.1. Indoor radon concentrations measured in houses built on different geological stages.



Source: Kies, 1996.

References

Dubois, G. (2005) An Overview of Radon Surveys in Europe, European Communities.

Kies, A., Biell, A., and Eowlinston, L. (1996) Radon Survey in the Grand-Duchy of Luhembourg - Indoor Measurements Related to House Features, Soil, Geology, and Environment, Environment International, 22(l) 1, S805-S808.

28 Macedonia

The results of the national survey in FYR Macedonia are described in Stojanovska et al, 2012. The goal was to estimate the mean radon concentration, annual effective dose and radon distribution by investigating total of 437 dwellings, selected based on the population density. The RSKS and RADUET CR-39 etch track detectors were placed in most used rooms during the whole year from 2008-2009 (4 periods of 3 moths in each dwelling). Descriptive statistics, tests for lognormality and ANOVA tests were used to evaluate the results. The final result of the survey was the annual mean indoor radon concentrations for different statistical regions, presented in the Table 28.1 below. Based on these results, a radon map with descriptive statistic for each region was produced and is presented in Figure 28.1 below.

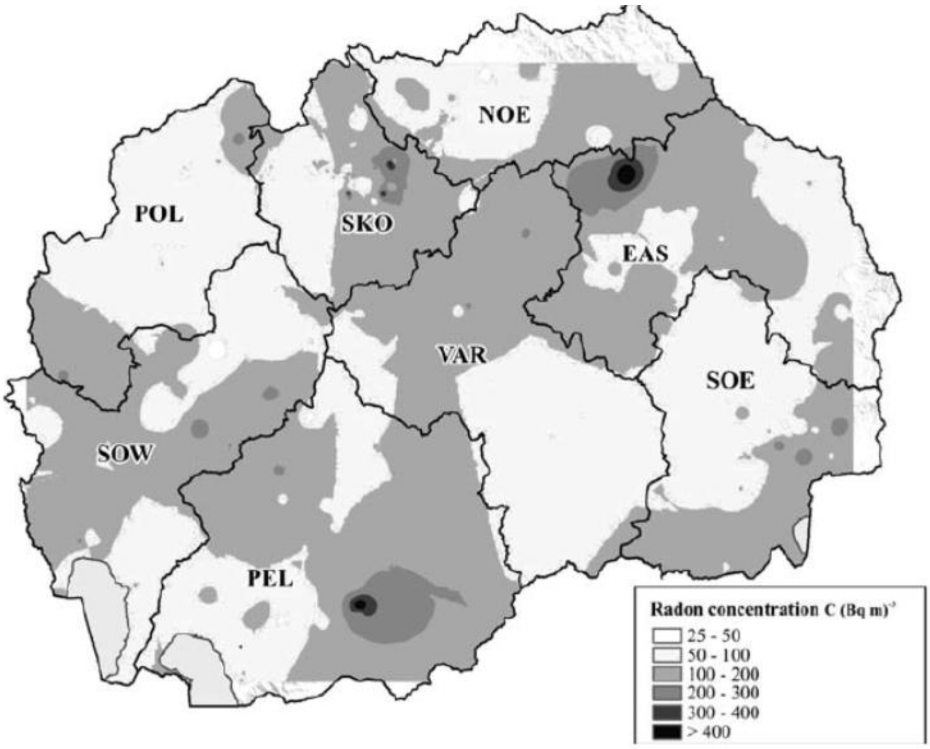
Table 28.1. The annual mean indoor radon concentration.

Statistical region	Code	Geotectonical zone	NM[a]	C (Bq m^{-3})				
				Max[b]	AM	SD[c]	GM	GSD[d]
Northeast	NOE	Serbo-Macedonian massif	43	300	91	58	78	1.7
Easter	EAS	Vardar zone	48	511	127	99	103	1.8
Southwest	SOW		47	245	94	52	81	1.8
Skopje	SKO	Vardar zone	124	502	105	83	83	1.9
Vardar	VAR		20	267	89	55	78	1.6
Polog	POL	Western-Macedonian zone	42	236	77	54	62	1.9
Southeast	SOE		48	307	104	70	88	1.8
Pelagonia	PEL	Western-Macedonian zone Pelagonian massif	65	720	127	120	99	1.9
All regions			437	720	105	84	84	1.9

[a]Number of measurements.
[b]Maximum.
[c]Standard deviation.
[d]Geometric standard deviation.

Source: Stojanovska et al, 2012.

Figure 28.1. Interpolated map of the studied area for the annual mean indoor radon concentration.



Source: Stojanovska et al, 2012.

References

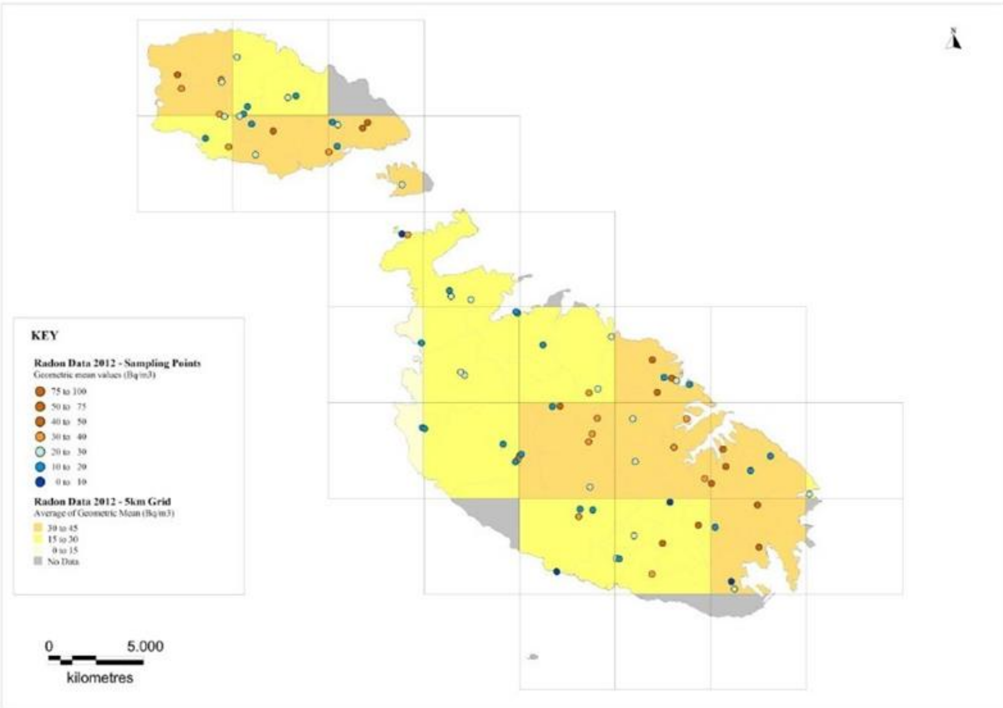
Stojanovska, Z. et al, (2012). Indoor Exposure of Population to Radon in the FYR of Macedonia, Radiation Protection Dosimetry 148 (2), 162–167.

29 Malta

A national survey was conducted between 2010 and 2011 in order to determine distribution of indoor radon gas concentration. The study was performed during the whole year, with two consecutive exposures at each selected building lasting 6 months. Five buildings (1 school, 1 public building and 3 private residences) were sampled from each of the 5 x 5 km grids – a total of 85 buildings. In each building, 2 Kodak LR115 film detectors were positioned in different ground floor rooms by trained personnel, near the head height (Baluci et al, 2013).

Results were evaluated by descriptive statistics and nearest neighbor analysis. All results were lower than 100 Bq/m^3. Method was validated by NPRB, UK (Baluci et al, 2013).

Figure 29.1. Map of indoor radon in Malta.



Source: Baluci et al, 2013.

References

Baluci, C. et al, (2013). National Mapping Survey of Indoor Radon Levels in the Maltese Islands, Malta Medical Journal 25(4), 33-39.

30 Moldova

The aim of the research was focused on the need for a National Radon Strategy and National Action Plan.

Investigation of radon concentration took place between 1991 and 2011.

An active device RTM1688-2 from SARAD company was used. It is not clear whether all measurements were performed by RTM1688-2.

Table 30.1 shows the range of radon concentrations measured in the period 1991-1999.

In 2007, 430 measurements were made in 61 rooms. At 421 measured places, Rn concentrations were below 100 Bq/m^3, 7 between 100 and 200 Bq/m^3 and two above 200 Bq/m^3.

In 2008, 280 indoor measurements were made in 39 areas. Only 2 locations exceeded the level of 200 Bq/m^3.

Table 30.1. Range of radon concentrations measured in the period 1991-1999.

Concentration, Bq/m^3	The years and the number of the measurement							
	1991	1992	1993	1994	1995	1997	1998	1999
15-30	25	71	20	9	14	-	4	4
31-50	15	21	9	5	8	-	2	5
51-70	-	-	4	-	7	3	1	2
71-90	-	-	-	-	5	1	3	1
91-120	-	-	1	-	4	-	1	1
121-141	-	-	4	-	2	-	3	1
201-300	-	-	1	-	2	-	1	-
313-400	-	-	1	-	2	-	1	-
411-500	-	-	-	-	4	-	-	-
516-600	-	-	-	-	1	-	-	-
625-700	-	-	-	-	2	-	-	-
1930	-	-	-	-	-	-	1	-

Source: Ursulean, 2013.

No other details were reported on these measurements.

References

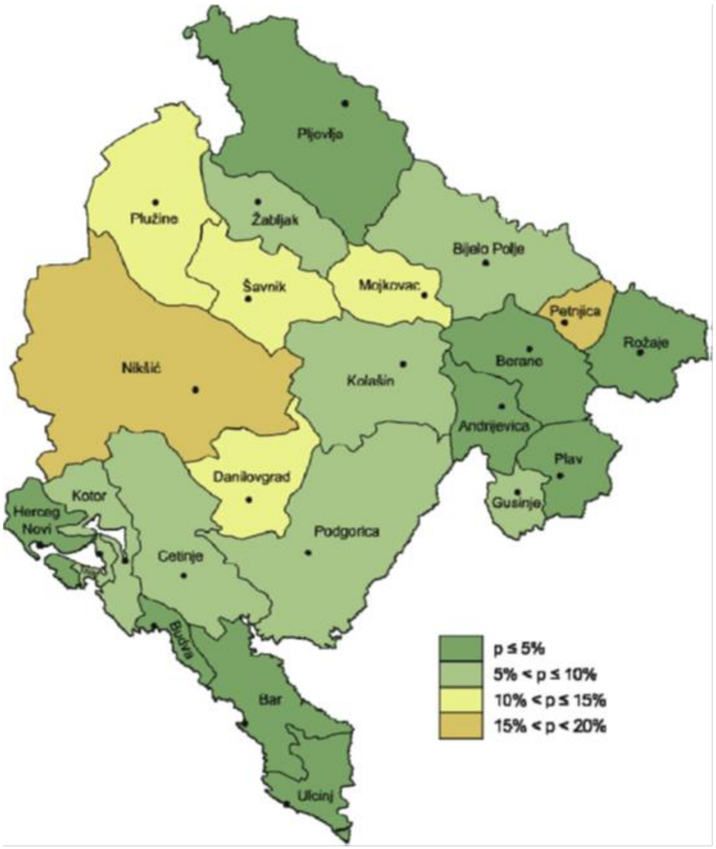
Ursulean, I., Coreţchi, L., Chiruţă, I., and Vîrlan, S. (2013) Estimation of indoor radon concentrations in the air of residential houses and mines in the republic of Moldova. Rom. Journ. Phys., Vol. 58, Supplement, S291–S297, Bucharest.

31 Montenegro

The first systematic indoor radon measurements on the Montenegrin Coast were carried out in the period 2002–2003, when 107 randomly selected homes in urban settlements (in each 500×500 m grid square one house was randomly selected and one dwelling in the house) were surveyed using CR-39 track-etch detectors, twice a year, each time for about 6 months. Dosimeter was regularly located in the living room or a bedroom on the ground floor or the first floor, in a place which is away from windows and doors, and about 1.5 m above the floor and 0.5 m away from the wall. In order to control the consistency and accuracy of dosimeter response, at each 10^{th} measuring location two dosimeters were placed together and, again at each 10^{th} (but the other) location, a passive radon monitoring device of the J. Stefan Institute, Ljubljana, Slovenia utilizing CR-39 detector, was placed beside authors dosimeter. None of the measured radon concentrations exceeded the action level of 400 Bq/m^3. The annual average radon concentrations were found to be lognormally distributed (GM = 25.5 Bq/m^3, GSD = 2.1*)* within the range from 3 to 202 Bq/m^3, with arithmetic mean of 31.8 Bq/m^3, and median of 25.1 Bq/m^3. The average effective dose due to exposure to radon in urban homes on the Montenegrin Coast is estimated to be 0.50 mSv y^{-1} (Antovic, 2007).

The first nationwide indoor radon survey in Montenegro started in 2002 and year-long radon measurements withCR-39 track-etch detectors, within the national grid of 5 km×5 km and local grids in urban areas of 0.5 km×0.5 km, were performed in homes in half of the country's territory. The survey continued in 2014 and measurements in the rest of the country were completed at the end of 2015. The 953 valid results, obtained in the national radon survey, give an average radon activity concentration in Montenegrin homes of 110 Bq/m^3. Assuming a log-normal distribution of the experimental results, geometric mean 58.3 Bq/m^3 is calculated. Normality tests show that the experimental data are not log-normal, and that they become closest to a log-normal distribution after subtracting from them radon concentration in the outdoor air of 7 Bq/m^3, which is theoretically calculated. Based on the results of radon survey, a new national radon reference level of 300 Bq/m^3 and an "urgent action level" of 1000 Bq/m^3 are suggested, with estimated fractions of the national dwelling stock above these levels of 7.4% and 0.8% respectively. Fractions of homes with radon concentrations above the suggested levels are also estimated for each of the 23 municipalities in Montenegro. The six municipalities which have more than 10% of homes with radon concentration above 300 Bq/m^3 are recommended as radon priority areas (Vukotic, 2018).

Figure 31.1. Radon map of Montenegro: percentage (p) of homes, in the municipalities, with radon activity concentrations above 300 Bq/m^3.



Source: Vukotic, 2018.

References

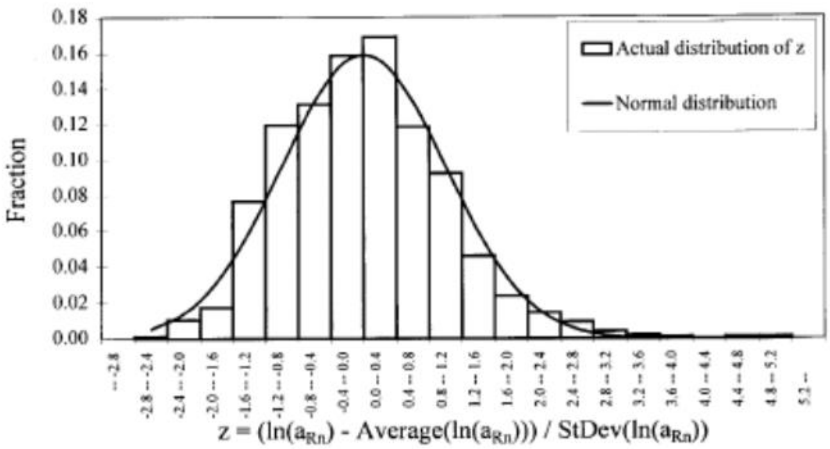
Antovic, N. et al., (2007). Indoor Radon Concentrations in Urban Settlements on the Montenegrin Coast. Radiation Measurements 42, 1573–1579.

Vukotic, P. et al., (2018). Radon Survey In Montenegro – A Base to Set National Radon Reference and "Urgent Action" Level, Journal of Environmental Radioactivity, doi: 10.1016/j.jenvrad.2018.02.009.

32 Netherlands

Two papers describe a national survey in Netherlands: Stoop et al (1998) and Lembrechts et al (1999). The goal of these investigations were to describe the trend in the average radon concentration by supplementing the first survey on dwellings built up to 1984 and to quantify the contributions of the most important sources of radon. The 1500 dwellings, built between 1985 and 1993, were randomly sampled from 52 municipalities. Track etch detectors from the 'Forschungszentrum Karlsruhe' (FzK) were placed in living rooms of 1500 selected houses during the period from 1995-1996. Lognormality tests were performed to evaluate the measurement results and it was concluded that 0.012% of new houses has a radon level above 200 Bq/m^3. The results of lognormality tests are shown in Figure 32.1, below, taken from (Stoop et al, 1998).

Figure 32.1. Test of lognormality of indoor radon concentration.



Source: Stoop, 1998.

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.

Lembrechts, J., Janssen, M., and Stoop, P. (1999). Ventilation and Radon Transport in Dutch Dwellings: Computer Modelling And Field Measurements, Radon in the Living Environment, 19-23 April 1999, Athens, Greece, 525-536.

33 Norway

Norway is among the countries with the highest indoor radon concentrations in the world mainly due to radium rich soil and bedrocks (such as alum shale and uranium rich granites) and highly permeable sediments (such as moraines and eskers).

Several large surveys were performed in Norwegian dwellings. The first one took place from 1984 till 1986. Detectors were deployed in 1600 dwellings in 79 municipalities. Measurements were performed using termoluminiscence detectors in charcoal and measurement lasted between 5 and 7 days. Two measurements per dwelling were deployed.

The second survey took place in the period 1987-89 covering 7500 dwellings. It used CR-39 detectors, one detector per dwelling. Number of dwellings per municipality was proportional to its population. Detectors were deployed for 6 months. Mean annual radon concentration was found to be between 55 and 65 Bq/m^3.

The measurements of the third survey were performed in the period 1991-1998 in 31 municipalities, using 5000 CR-39 detectors with one or two detectors placed in each dwelling for 2-3 months during the heating season. Mean annual radon concentration was found to be between 115 Bq/m^3.

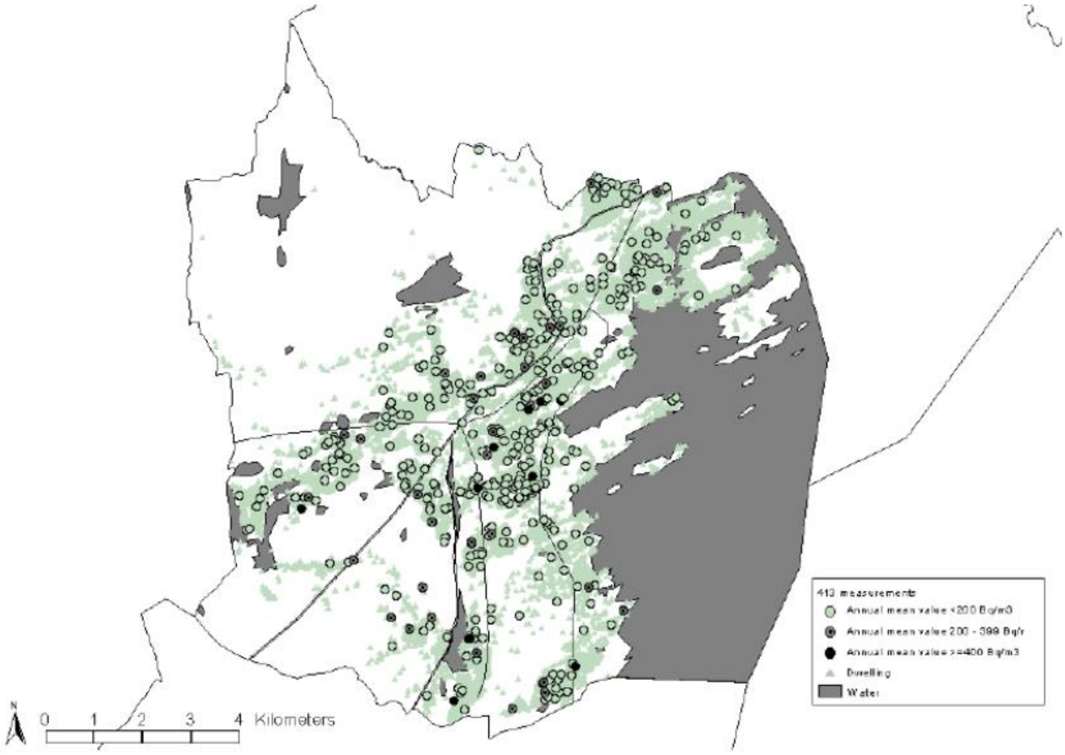
Next survey was conducted in the heating period of 2000/2001, with 29000 CR-39 detectors which were deployed one in each dwelling. Mean annual radon concentration was found to be between 89 Bq/m^3, with 9% and 3% of dwellings with radon concentrations higher than 200 and 400 Bq/m^3, respectively.

And finally, in the fifth survey, conducted in 2002/2003, 8400 dwellings in 44 municipalities were deployed. The detectors were exposed for 2 months in a heating season, with one detector for each dwelling. The primary objective was to identify radon priority areas. The highest value obtained was 18000 Bq/m^3. It was found that 18% and 7% of results exceed 200 Bq/m^3 and 400 Bq/m^3, compared to 9% and 3% for the whole country.

Also, around 20000 Rn measurements were performed by private companies and most of those results are not included in the surveys.

As a conclusion it is estimated that 9% of the dwellings has an annual mean radon concentration exceeding 200 Bq/m^3. However, there are regions where more than 50% of the results exceed the level of 200 Bq/m^3. In regions with only a few percentage points exceeding recommended level, no further surveys are recommended.

Figure 33.1. A point map of municipality in densely populated area.



Source: Jensen et al., 2004.

References

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 6-61, 23-28 May 2004.

34 Poland

A national survey was carried out, starting from 1991. The duration of measurements was between 6 and 12 months. A total of 3305 measurement locations were selected geographically. CR-39 diffusion chamber was used (IAEA, 2017).

A national survey was conducted between 2008 and 2009 in order to perform comprehensive measurements of radon in the whole country. Before the survey, 13 geological regions were identified. In all 13 regions, a total of 129 building were selected. For each building, 12 monthly averages were calculated by placing 3 CR-39 detectors each month, and 4 quarterly averages by placing 3 detectors each quarter. Detectors were placed away from the doors, windows and ventilation and 1-2 m above the floor (Przylibski et al, 2011).

Data was evaluated by descriptive statistics and log-normality test. National mean radon concentration was calculated, as well as means, minimum and maximum value for each geological region. Intercomparison was performed in CLOR's calibration chamber (Przylibski et al, 2011).

Table 34.1. Selected statistical parameters describing the distribution of mean annual values of ^{222}Rn concentration [Bq/m^3] in the air of buildings located in the area of particular major tectonic units of Poland.

Tectonic unit	Number of data	Min.	Max.	Arith. mean	Std. dev.	Median	Geom. mean	Geom. St. dev.	Spread
		[Bq/m^3]							
Sudetes (*M*)	23	54	845	221	194	129	162	2.17	791
Sudetes (*Q*)	23	36	745	220	183	149	158	2.35	709
Fore-Sudetic monocline (*M*)	6	119	201	169	28	176	167	1.18	82
Fore-Sudetic monocline (*Q*)	6	131	212	179	27	184	177	1.16	81
Szczecin–Łódź–Miechów Synclinorium (*M*)	16	56	214	117	56	97	105	1.59	158
Szczecin–Łódź–Miechów Synclinorium (*Q*)	16	55	188	110	50	96	100	1.55	133
Mid-Polish Anticlinorium (*M*)	1	103							
Mid-Polish Anticlinorium (*Q*)	1	115							
Upper-Silesian Foredeep (*M*)	30	42	535	133	102	94	111	1.76	493
Upper-Silesian Foredeep (*Q*)	30	31	500	122	97	86	100	1.82	468
West-European Platform (*M*)	**76**	**42**	**845**	**159**	**133**	**110**	**127**	**1.87**	**803**
West-European Platform (*Q*)	**76**	**31**	**745**	**154**	**127**	**112**	**120**	**1.97**	**714**
Mazury-Podlasie Monocline (*M*)	26	90	556	249	117	226	224	1.59	466
Mazury-Podlasie Monocline (*Q*)	26	104	562	254	116	215	231	1.54	458
Pomeranian–Płock–Puławy Synclinorium (*M*)	7	53	255	117	83	80	98	1.78	202
Pomeranian–Płock–Puławy Synclinorium (*Q*)	7	64	253	120	81	75	101	1.72	189
East-European Craton (*M*)	**33**	**53**	**556**	**221**	**122**	**203**	**188**	**1.81**	**503**
East-European Craton (*Q*)	**33**	**64**	**562**	**225**	**122**	**202**	**194**	**1.76**	**498**
Carpathians (*M*)	5	77	161	114	36	118	110	1.33	84
Carpathians (*Q*)	5	72	117	94	18	88	93	1.19	45
Carpathian Foredeep (*M*)	15	83	257	156	44	151	151	1.31	173
Carpathian Foredeep (*Q*)	15	51	228	113	43	111	106	1.42	177
Carpathians and Carpathian foredeep (*M*)	**20**	**77**	**257**	**146**	**45**	**148**	**139**	**1.36**	**180**
Carpathians and Carpathian foredeep (*M*)	**20**	**51**	**228**	**108**	**39**	**103**	**102**	**1.38**	**179**
Poland (*M*)	**129**	**42**	**845**	**173**	**123**	**147**	**142**	**1.83**	**803**
Poland (*Q*)	**129**	**31**	**745**	**165**	**122**	**133**	**133**	**1.91**	**714**

Mean annual concentrations of ^{222}Rn activity calculated from monthly (*M*) and quarterly (*Q*) measurements.
Values in bold characterizes the main tectonic units of Poland and the country (Poland); values in normal style characterizes the tectonic units being the parts of the main units characterized in bold below them.

Source: Przylibski et al, 2011.

References

IAEA, IAEA-TECDOC-1810, (2017) Status of Radon RelatedActivities in Member StatesParticipating in TechnicalCooperation Projects in Europe, Vienna,ISBN 978–92–0–100617–2.

Przylibski, T.A. et al, Mean Annual ^{222}Rn Concentration in Homes Located in Different Geological Regions of Poland - First Approach to Whole Country Area, Journal of Environmental Radioactivity 102(8) (2011), pp. 735-741.

35 Portugal

The results of the national survey in Portugal, conducted from 1989-1990 are described in Faisca et al, 1992. The goal of the survey was to produce a radon map of the country. LR115 passive track detectors were distributed to the volunteer high school students, so there was no special sampling strategy. Total of 4200 dwellings were investigated by exposing the detectors for 3 months. Descriptive statistics is used to evaluate the measurement results and according to that, the radon map was produced.

References

Faisca, M.C., Teixeira, M.M.G.R., Bettencourt, A.O, Indoor Radon Concentrations in Portugal - A National Survey, Radiation Protection Dosimetry, Volume 45, Issue 1-4, 1 December 1992, pp. 465–467.

36 Romania

First two surveys performed in the periods from 1987-1990 and 1190-1994, covered in total around 460 dwelling. These surveys were performed with Makrofol detectors. Measurement sampling was 10 minutes, performed by filter sucking method. Sampling was performed in bedroom in any time of the season. The equilibrium equivalent concentration of 25 Bq/m^3 was reported from these measurements. (Iacob et al, 2005).

Based on the pilot study performed in Transylvania aiming to investigate relation between radon exposure and lung cancer risk, it was concluded that reported value of 49 Bq/m^3 was underestimated. Therefore, a more systematic research on population exposure to radon in Romania took place from year 2000.

The first map of residential indoor radon was build according to the recommendations of JRC, and it was based on the 10 years of research using CR-39 detectors from Radosys company (type RSK). Measurements have included 883 surveyed buildings in the Băița Ștei radon priority area and 864 in other regions of Romania. Measurements were performed following the HPA-NRPB Measurement Protocol in order to provide quality assurance and control of measurements. Detectors were exposed on the ground floor, at the height of 1-1.5 m from the floor at least 1m from the wall to avoid thoron and away from doors. Measurements lasted for a period of 3-12 months and seasonal correction were applied to obtain annual average mean, using correction factors proposed by Cosma (Cosma et al, 2009).

A large percentage of recovery (90%) was recorded. The influence of exposure outside the measurement point was negligible since storage time was less than 24h. Detailed questionnaire was provided: collect relevant information about factors relating to measurement site as characterisation of house, building materials, living habits etc. Accuracy of the measurement were checked periodically in a reference radon chamber and through international intercomparisons.

The lognormality of the distribution was checked by the D'Agostino–Pearson test.

Data were averaged over 10x10 km^2, except for RPA area of the Ștei - Băițaradon priority area where 1x1 km^2 grid was used. Geometric mean from all measurements was 121.8 Bq/m^3, with GSD=2.8, while it was 84 Bq/m^3 and 2.5 when excluding Ștei - Băița area.

Descriptive statistics of investigated regions is given in Table 36.1.

Table 36.1. Descriptive statistics of investigated regions in counties of Romania.

County	No. of surveyed dwellings	AM/Bq m^{-3}	SD/Bq m^{-3}	GM/Bq m^{-3}	GSD/Bq m^{-3}	Median/Bq m^{-3}	Max/Bq m^{-3}	CV/%	% (number) houses > 400/Bq m^{-3}
Alba	158	111	88	87.2	2.0	87	604	80	2 (3)
Bacău	15	119	62	103.5	1.8	116	237	52	–
Bihor	19	44	48	28.1	2.5	25	172	109	–
	883[a]	292	364	175.3	2.8	185	3653	125	21 (185)
Bistrița-Năsăud	136	125	127	90.2	2.3	99	897	101	4 (5)
Cluj	372	121	138	76.1	2.6	72	1050	114	5 (18)
Galați	12	53	22	48.8	1.5	55	104	42	–
Gorj	28	107	97	69.7	2.7	73	361	90	–
Maramureș	22	231	187	155.6	2.7	157	608	81	27 (6)
Mureș	28	232	154	180.4	2.2	230	696	67	11 (3)
Sibiu	46	95	69	76.0	2.0	74	361	73	–
Suceava	14	269	288	180.3	2.5	169	1140	107	21 (3)
Tulcea	14	205	134	171.2	1.9	158	507	65	7 (1)
Total	1747	210	287	121.8	2.8	123	3653	137	13 (224)
	864[b]	126	132	84.0	2.5	87	1140	105	5 (39)

AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation; CV, coefficient of variation.

[a]Ştei-Băiţa radon-prone area.

[b]Without Ştei-Băiţa radon-prone area.

Source: Cosma et al, 2013.

From 2013, there is an ongoing comprehensive survey of radon in homes, soil and water aiming to complete Romanian indoor radon map with 5000 additional Rn data.

This paper presents the results of radon measurements in homes, soil and water in 5 of 16 counties being analysed since 2013.

The same measurement protocol as described above was used. The average number of measuring location per cell was 4 ± 2, ranging from 4-15 depending on the population density except in the RPA of Ștei - Băița where 428 measurements per cell were made.

Lognormality of the distribution was tested by the Shapiro-Wilk test. The Spearman correlation coefficient was calculated in order to evaluate the relationship between the measured parameters. The comparison between samples was made with non-parametric Kruskal-Wallis test

A total of 1855 indoor radon measurements were carried out in 330 cells (see Table 36.2). The geometric mean of indoor radon measurements was 90 Bq/m^3, with a maximum value of 2592 Bq/m^3.

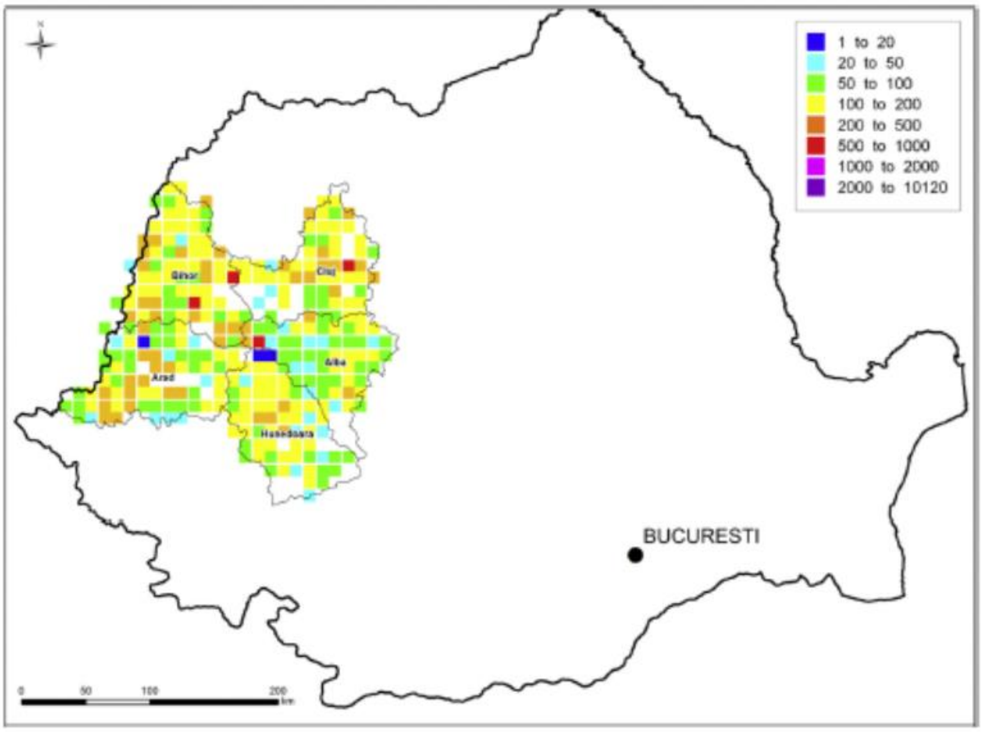
Table 36.2. Descriptive statistics of 5 counties of Romania.

County	No.	Min	Max	AM	SD	G.M	G.S.D.
Cluj	71	4.1	91.3	37.9	21.3	30.9	2.1
Alba	168	0.8	94.7	29.1	18.5	22.5	2.3
Arad	320	2.3	68.6	27.1	9.0	25.7	1.4
Hunedoara	287	8.5	169	36.0	10.1	32.7	1.5
Bihor	235	2.4	126	37.0	19.4	31.8	1.8
Total	**1081**	**0.8**	**169**	**32.6**	**17.2**	**28.4**	**1.8**

Source: Cucos et al, 2017.

In Figure 1, indoor map of average indoor radon concentrations measured at ground floors at 5 different Romanian counties. (Cucos et al, 2017).

Figure 36.1. Indoor map of average indoor radon concentrations measured at ground floors at 5 different Romanian counties.



Source: Cucos et al, 2017.

References

Iacob, O., Grecea, C. and Botezatu, E. (2005). Population Exposure to Inhaled Radon and Thoron Progeny, in The Natural Radiation Environment, NRE – VII, edited by J.P. Mc Laughlin, S.E. Simopoulos and F. Steinhausler, (Elsevier,London, 2005), pp.232–237.

Cosma, C., Szacsvai, K., Dinu, A., Ciorba, D., Dicu, T., Suciu, L., (2009). Preliminary integrated indoor radon measurements in Transylvania (Romania). Isot. Environ. Health Stud. 45 (3), 259-268.

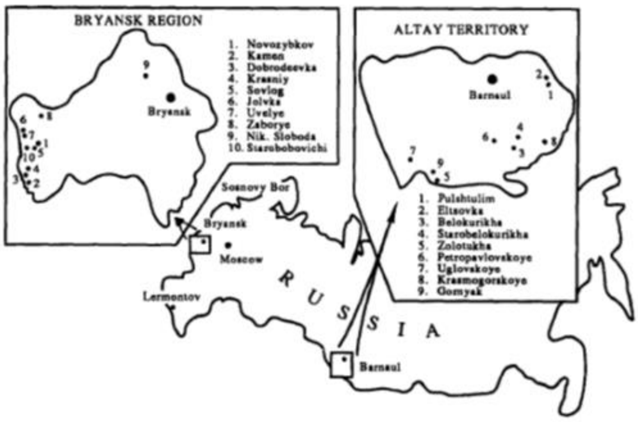
Cosma, C., Cucoş Dinu, A., Dicu, T., (2013). Preliminary results regarding the first map of residential radon in some regions in Romania. Radiat. Prot. Dosim. 155 (3), 343-350.

Cucoş, A. et al. (2017) Residential, soil and water radon surveys in north-western part of Romania, Journal of Environmental Radioactivity 166, 412-416.

37 Russian Federation

Regional surveys that took place in four regions during the period from May to September 1993 are described in reference (Marenny et al, 1996). The main surveys goals were to estimate the collective doses and find the dwellings where the radon concentrations exceed the adopted level in Russian legislative.

Figure 37.1. Map of the Russia with the locations where the indoor and soil radon measurements were carried out.



Source: Marenny et al, 1996.

Sampling strategy was random and when possible, the buildings were selected so as to uniformly distribute the measurement points over the terrain of a given settlement. Measurement locations were predominantly on ground floors and, for comparison, in the cellars and on the upper floors of some buildings. About 1000 measurements of indoor radon concentration in dwellings and social buildings of investigated settlements were performed. Duration of a single measurement was 3 months for the track detectors and 5-8 days for the charcoal detectors.

During these surveys, passive and active methods were used. Indoor measurement chamber was 2.5 cm in diameter and 4.0 cm high with 22 microns thick polyethylene filter (CR-39 or CND). Visual microscopic method (200x) and the spark counting method were used to scan alpha tracks in the CR and CND detectors, respectively. The CR-39 detectors were etched for 3 h in 6N NaOH solution at 70 °C, and the cellulose nitrate detectors for 70 min in 6 N NaOH solution at 50 °C. Charcoal detectors were used also (Marenny et al, 1996).

The mean volume radon activity was calculated by multiplying the calibration factors by the measured track density, while the mean equilibrium equivalent radon concentrations were obtained by multiplying the resultant mean volume radon activities by an equilibrium factor, F = 0.5.

Results of radon indoor surveys in 83 regions in Russian federation are given in reference (Yarmoshenko et al, 2015). Survey period was from 2008 to 2013. Main survey goal was to estimate the arithmetic average indoor radon concentration. Sampling strategy was based on official annual reports - radiation measurements in 83 regions, those included more than 400000 indoor radon measurements, in all regions and for tree types of houses.

Table 37.1. The indoor mean EEC and mean annual EDE values.

	EEC, Bq m^{-3}			EDE, mSv y^{-1}		
Location	Range	Mean	Median	Range	Mean	Median
Altay Territory						
Pushtulim	23–218	93	96	1.4–13.3	5.7	5.7
Eltsovka	22–265	90	79	1.3–16.2	5.5	4.8
Belokurikha	22–577	80	52	1.3–31.5	4.8	3.2
Starobelokurikha	90–338	158	123	5.5–20.6	9.6	7.5
Zolotukha	44–170	93	76	2.7–10.4	5.7	4.6
Petropavlovskoye*	53–237	145	147	3.2–14.5	8.8	8.9
Uglovskoye	11–63	41	43	0.7–3.8	2.5	2.6
Krasnogorskoye	8–143	53	49	0.5–8.7	3.2	3.0
Gornyak	10–288	63	47	0.6–17.6	3.8	2.9
Bryansk region						
Novozybkov	29–111	67	67	1.8–6.8	4.1	4.1
Kamen	14–29	21	21	0.9–1.8	1.3	1.3
Dobrodeevka	10–92	28	20	0.6–5.6	1.7	1.2
Krasniy	12–69	22	16	0.7–4.2	1.3	1.0
Sovlog	16–26	21	21	1.0–1.6	1.3	1.3
Jalovka	14–48	27	28	0.9–3.0	1.6	1.7
Uvelye	30–82	57	58	1.8–5.0	3.5	3.5
Zaborye	23–56	35	32	1.4–3.4	2.1	2.0
Nik.Sloboda	8–85	38	40	0.5–5.2	2.3	2.4
Starobobovitchi	22–105	58	57	1.3–6.4	3.5	3.5
St Petersburg region						
Sosnovy Bor†	12–101	48	41	0.7–6.2	2.9	2.5
Lermontov (North Caucasus)	85–1554	549	369	5.2–95.0	33.5	22.5

*Charcoal measurements.
†The measurements were carried out during summer season of 1991.

Source: Marenny et al, 1996.

During performed surveys mostly short term radon measurements devices (grab sampling) were used. Only few laboratories were equipped with long term nuclear track detectors. Equilibrium factor 0.5 is used in Russia. Evaluation of the results were done using descriptive statistics, and test for lognormality.

Table 37.2. Parameters of the distributions of generated values of EEC of radon isotopes.

Type of building	Arithmetic mean, Bq/m^3	Geometric mean, Bq/m^3	GSD	Percentage above 300 Bq/m^3
Wooden houses	75	37	3.1	3.5%
One-storey brick and stone houses	59	32	3.0	2.1%
Multi-storey brick and stone houses[a]	46	24	3.0	1.1%
All types	48	25	3.1	1.3%

[a] Average over all floors.

Source: Yarmoshenko et al, 2015.

It is important to mention that legal restriction on indoor annual equivalent equilibrium concentration of radon isotopes in Russian legislation is calculated as ^{222}Rn EEC + 4.6 ^{220}Rn EEC, i.e. activity of thoron is not neglected.

References

Marenny, A.M. et al, (1996) Results of radon concentration measurements in some regions of Russia, Radiation Measurements, 26 (3), 43-48.

Yarmoshenko I. et al, (2015). Reconstruction of national distribution of indoor radon concentrations in Russia using results of regional indoor radon measurement programs, Journal of Environmental Radioactivity 150, 99-103.

38 Serbia

In Serbia there were several local and regional surveys of indoor radon concentrations. Some of those researches were conducted by individual efforts to identify regions with high indoor radon. Perennial survey in several regions of Serbia (former Yugoslavia, former Serbia and Montenegro) starting 1997 had a specific goal to estimated population exposure to natural radioactivity based on geochemical and integrative pattern research approach. This was the first identification and assessment of high areas of natural radiation in Serbia which provides insight into its regional characteristics, the interpretation of the results in terms of geological aspects, building types and human habits, the first introduction and field applicability of both (surface and volume trap) retro techniques in Serbia and assessment of doses and risks to the population in investigated high natural radiation rural communities. Several differently designed chambers for the CR-39 and polycarbonate detectors were used such as: SSI/NRPB detectors, the CR-39 detectors enclosed in small cylindrical (5 cm height, 3 cm diameter) diffusion chamber, passive discriminative Cr-39 Radopot and Raduet detectors, passive discriminative polycarbonate UFO detectors. Exposure periods were generally of about 3 months covering one season. Annual averages were obtained using either results of all the seasonal measurements, if available, or results of some periods corrected with seasonal factors. Annual averages were obtained using either results of all the seasonal measurements, if available, or results of some periods corrected with seasonal factors. In these surveys, indoor radon concentration of rural communities of Serbia and some part of Balkans were investigated. Obtained data followed lognormal distribution, strongly depending on the type of underlying rock and average radon levels range between 45 Bq/m^3 for limestone in Montenegro and 1560 Bq/m^3 for travertine in Niška Banja (Žunić, 2009). A radon priority area of Niška Banja was investigated in details by Žunić and collaborators. In one of those surveys the region of Gornja Stubla an area with high radon and thoron was identified (Žunić, 2010). Besides indoor radon concentrations in dwellings, radon concentrations in schools in rural parts of Serbia were investigated as well (Žunić, 2017).

In Vojvodina, the northern province of Serbia, radon was monitored from 1992 till 2003 by using charcoal canisters. In total 220 measurements were performed in Novi Sad, with maximal radon concentration of 503 Bq/m^3, minimal of 1,2 Bq/m^3 and geometric mean of 28.5 Bq/m^3 (Forkapić, 2007).

The first large survey in Serbia, was conducted in Vojvodina in the winter period from December 2002- March 2003. In total 968 measurements with CR-39 detectors were performed with 1 measurement per dwelling. Radon was measured in dwellings that were considered typical and thus the most representative in rural regions of 45 municipalities. A lognormal distribution was obtained with descriptive statistics given in Table 38.1.

Table 38.1. Descriptive statistics of the indoor radon measurements in Vojvodina covering the period December 2002 - March 2003.

Number of measurements	Measurements statistics (in Bq m^{-3} units)					
	Mean	Standard deviation	Geo. Mean	Standard deviation of Geo. Mean	Min.	Max.
968	144	120	104.2	2.3	2 measured at Ada	893 measured at Zrenjanin

Source: Forkapic, 2007.

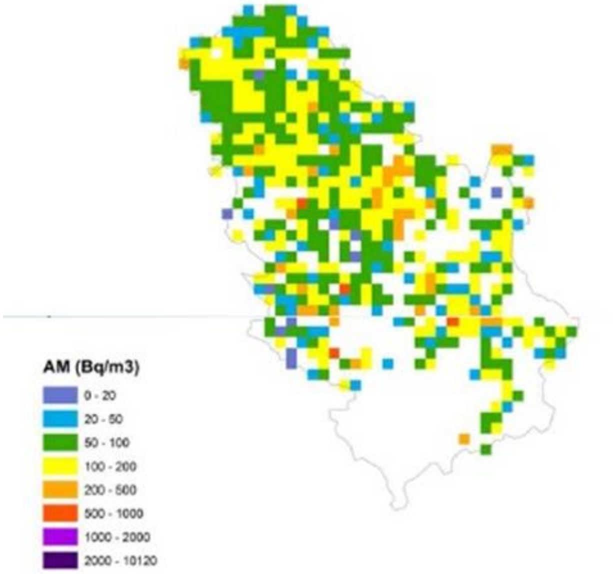
A radon map of Vojvodina, from the same survey, is presented in Figure 38.1.

Figure 38.1. Radon map of Vojvodina. Numbers given along the names of municipalities indicate geometric mean radon concentration in Bq/m^3.

Source: Forkapić, 2007.

Serbia started work on Radon action plan in 2014, with the first step of preparing, and performed the national indoor radon survey in Serbia, planned and conducted to be done in 2015 (Udovičić, 2016). Indoor radon survey was conducted in 2015 and 2016 using CR-39 detectors. The project was supported by IAEA through the national project: SRB/9/003 - Enhancing the Regulatory Infrastructure and Legislative System. During the realization of the national programme for indoor radon measurements several institutes involved in the project together with the Serbian Radiation Protection and Nuclear Safety Agency performed good communication strategy (first basic information leaflet on radon to accompany the measurement explaining the purpose of the measurement, internet site, public relation, public education, etc) which led to high survey efficiency (about 88 %), together with very hard field work. In total 6000 detectors have been distributed during October 2015 and exposed in houses and apartments for six months (till April 2016). Afterwards, 5300 detectors were collected and sent to an authorized laboratory (Landauer Nordic AB) to be processed. Measured indoor radon concentrations varied in a wide range: from 3 Bq/m^{3}to 4335 Bq/m^3. In 87 % measurement radon concentration was below 200 Bq/m^3, 10% between 200 and 400 Bq/m^3, 3% higher than 400 Bq/m^3 and 0.3 % higher than 1000 Bq/m^3. Average radon concentration was 105 Bq/m^3 (*IAEA SRB/9/006, 2018*). In selected dwellings additional detector was exposed for 1 year, and thus seasonal correction was obtained. Data were averaged over the 10 km x 10 km, and from March 2017 they are incorporated in the European Indoor Radon Map. Indoor radon map of Republic of Serbia is shown in Figure 38.2.

Figure 38.2. Indoor radon map of Republic of Serbia, January 2017.



*Source:*IAEA SRB/9/006 , 2018.

References

Žunić, Z.S. et al.,(2009) Identification and assessment of elevated exposure to natural radiation in Balkan region (Serbia), Radioprotection 44(5): 919–925 (and reference therein).

Žunić, Z.S. et al., (2010) Collaborative investigations on thoron and radon in some rural communities of Balkans, Radiation Protection Dosimetry 141(4): 346–350 (and reference therein).

Žunić, Z.S. et al., (2010) The indoor radon survey in Serbian schools: can it reflect also the general population exposure, Nukleonika 55, 419-427.

Forkapić, S. et al., (2007) Indoor Radon In Rural Dwellings Of The South-Pannonian Region, Radiat. Prot. Dosim., 123, 378−383.

Udovičić V. et al., (2016) First steps towards national radon action plan in Serbia, Nukleonika, 61(3): 361-365.

IAEA SRB/9/006 (2018) Upgrading National Capabilities and Infrastructure for the Systematic Approach to the Control of Public Exposure to Radon, presentation on meeting in Belgrade, Serbian Radiation Protection and Nuclear Safety Agency, 22 February 2018.

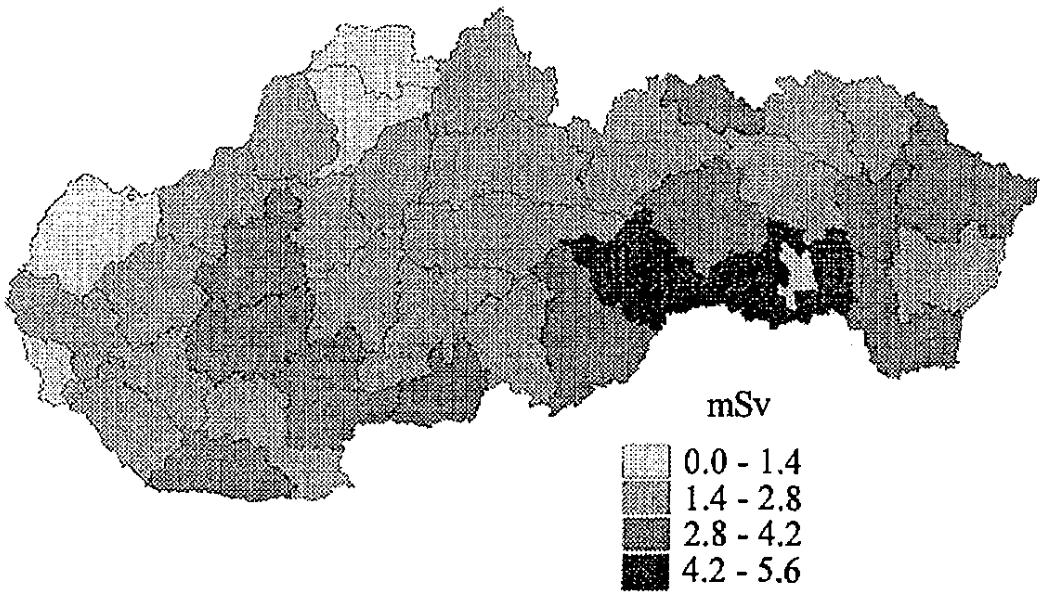
39 Slovakia

Three regional surveys were conducted in Slovakia in 2014, which effectively covered the whole country and thus qualifying it as a national survey. Three papers that present the results of these surveys are Vicanova et al. 1998, Vladár et al. 1996 and M. Mullerova et al. 2014. Descriptive statistics, population weighted, was used to evaluate the results in all three surveys. The annual average effective dose from indoor radon exposure is 2.1 mSv per inhabitant. The soil is marked as probably the main source of radon in Slovak dwellings.

Slovak National Radon Program started in order to investigate Radon concentrations and radiation load in dwellings (family and multifamily), schools, public buildings, spa buildings, caves and mines.6000 selected dwellings (minimum two detectors for every residence), 1,000 selected buildings of the kindergartens and elementary schools and 12 selected spa buildings were investigated and the results were published in Vicanova et al. 1998. The geometric mean (GM) was about 41±2.22 Bq/m^3 and 11% of dwellings (N=409) had a greater EEC of radon than the action level. The sample of family houses (N=2,363) has AM 125±135 Bq/m^3, GM 73±1.8 Bq/m^3 and the sample of multifamily houses (N= 1,294) has AM 22±24 Bq/m^3, GM 15± 1.46 Bq/m^3. The population-weighted AM of EEC for every district by different type of house was calculated, and then estimated this value for the whole of Slovakia obtaining a figure of 48 Bq/m^3.

The paper Vladár et al. 1996 was based on measurement of EEC in 1832 dwellings. Passive solid state nuclear track detectors (SSNTD type CR-39) were used to measure indoor radon concentrations. Detectors were placed in about 6,000 selected dwellings (minimum two detectors for every residence). The results were used to produce a map of annual average effective doses from indoor radon exposure, presented in the Figure 39.1 below. The distribution of indoor radon concentrations in Slovakia is presented in the Table 39.1 below.

Figure 39.1. Annual average effective doses from indoor radon exposure in districts of Slovakia.



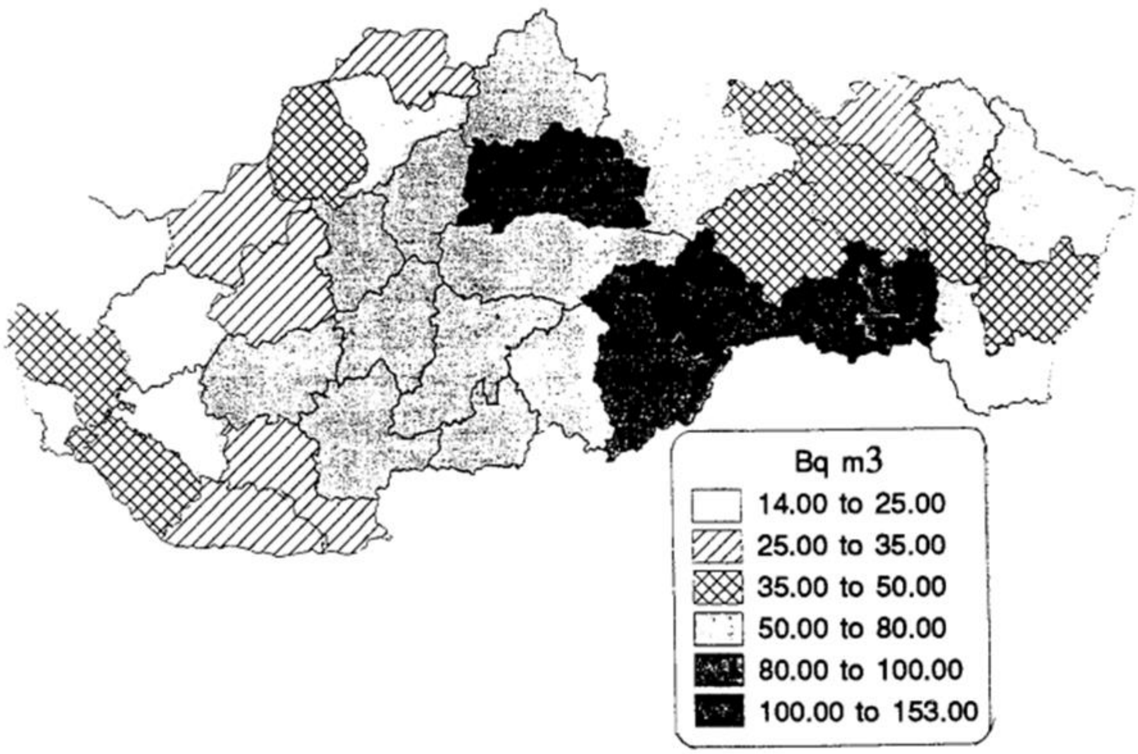
Source: Vicanova et al., 1998.

Table 39.1. Distribution of indoor radon concentrations in Slovakia.

EEC [Bq.m^{-3}]	Number of dwellings [%]	Remedial Actions
< 200	88.6	-
200 – 599	10.6	to 10 years
> 600	0.8	to 3 years

Source: Vicanova et al., 1998.

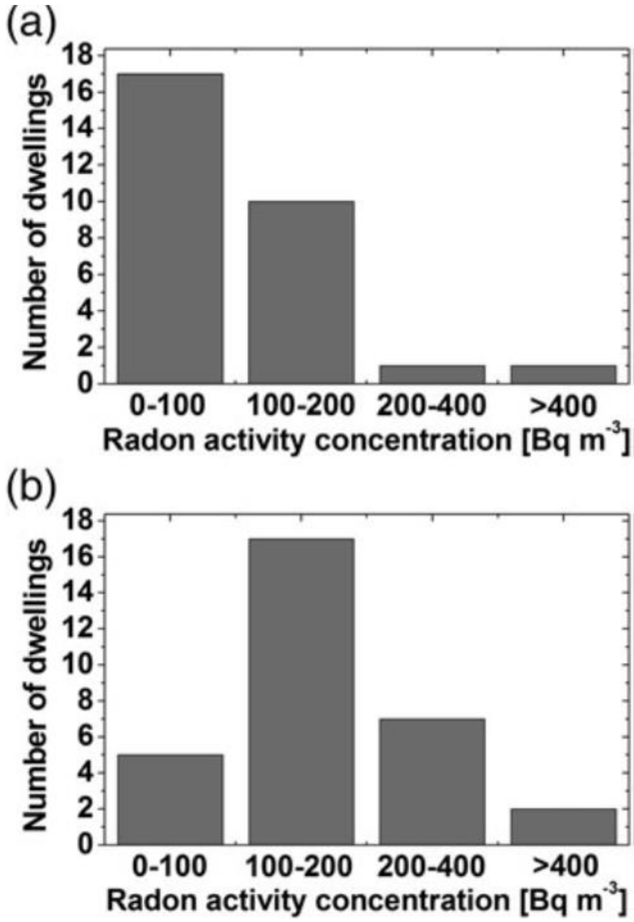
Figure 39.2. Equivalent radon concentration in Slovakia.



Source: Vladár et al., 1996.

The goal of the survey, published in Mullerova et al. 2014, which covered the region spanning through selected regions with possible higher than average concentrations, was harmonization of determination of the radiation dose due to indoor radon, improving radon and thoron map. Miners and tourist guides had personal dosimeters and the third publication was made on bases of measurements in 3,657 residences.

Figure 39.3. The frequency distribution of the radon activity concentration in two localities in Slovakia: Bratislava (a) and Mochovice (b).



Source: Mullerova et al., 2014.

References

Vicanova, M., Durcik, M., Nikodemova, D., (1998). Radiation load from radon exposure in Slovakia, Radiation Hygiene Days Conference Proceedings of the 21-st Radiation Hygiene Days.

Vladár, M. et al., (1996) Monitoring of Natural Radioactivity in Slovakia, Journal of Radioanalytical and Nuclear Chemistry, Articles Vol. 209, No. 2 (1996) 325-330.

Mullerova, M. et al. (2014). Preliminary Results of Indoor Radon Survey in V4 Countries, Radiation Protection Dosimetry, 160(1-3):210-213.

40 Slovenia

The results of the national survey in Slovenia were published in Humar, M., et al. 1995. The survey was conducted during 1990-1992 in kindergartens, 1992-1994 in schools and 1993-1995 in dwellings. The goal was the construction of map of estimated annual mean radon concentration values in dwellings for EUR_RADON. Track-etch detectors were distributed to total of 730 kindergartens, 890 schools and 892 dwellings and exposed for 96 days. The annual mean values were derived using the relation Cmean = 0.7 Cwinter. Descriptive statistics was used to evaluate the results. 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.

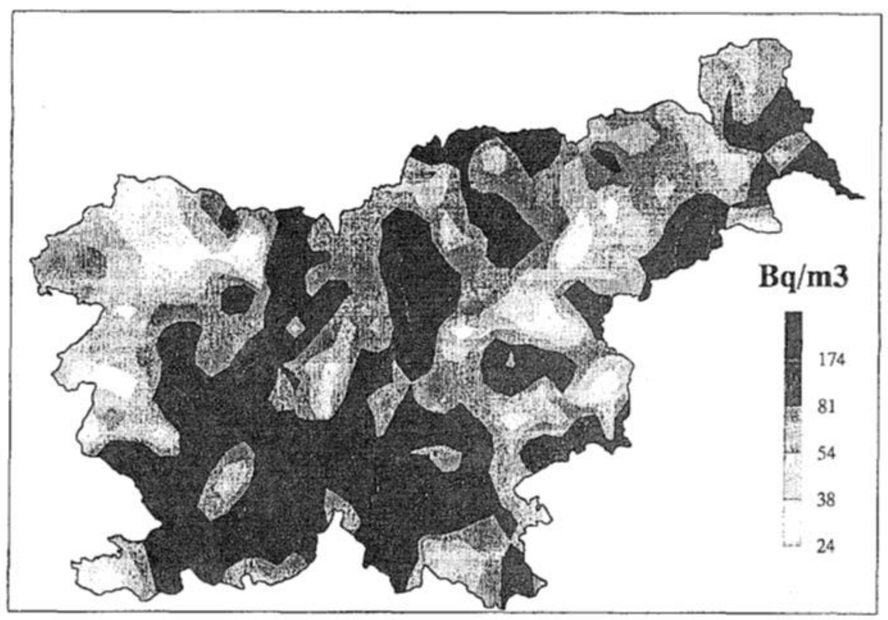
Also, the results of the national survey in Slovenia, conducted in 1993-1994, were published in Križman M. et al, 1995. The goal was to produce a radon map and identify radon prone areas. CR-39 etch track detectors were randomly distributed in 892 dwellings during the winter period. Results were corrected by multiplying with seasonal correction factor and descriptive statistic and tests for lognormality were performed. The results are summarized in Table 40.1 below. The map of the indoor radon measurement results is given in Figure 40.1 below.

Table 40.1. Summary statistics for radon-222 in dwellings in Slovenia.

No. of meas.dwell.	AM (Bq/m^3)	1 SD (Bq/m^3)	GM (Bq/m^3)	1 GSD (Bq/m^3)	Median (Bq/m^3)
892	**86.9**	110	**59.6**	2.23	**54.0**

Source: Križman M. et al, 1995.

Figure 40.1. Map of indoor radon in Slovenia (percentile values in Bq/m^3).



Source: Križman M. et al, 1995.

References

Humar, M. et al, (1995). Radon Concentrations in Living Environment of Slovenia (final report-in Slovene), Jožef Stefan Institute, Ljubljana, IJS-DP-7164, January 1995.

Križman, M. et al, (1996). A survey of Indoor Radon Concentrations in Dwellings in Slovenia, In: Proceedings of the IRPA Regional Congress, Portorose, September 4-8th, 1995 (Glavič-Cindro, D., ed.) J. Stefan Institute, Ljubljana, January 1996, pp. 66-70.

41 Spain

Extensive investigation of indoor radon in Spain was performed in several different surveys. There were numerous references, yet in this report, only the last one was used which summarize data from previous surveys.

The aim was to produce a radon map of the Spanish territory that shows the probability of finding areas with levels of radon indoors, and is related to the European legislation that has to be implemented in the member states before the end of 2018.

In total 9211 indoor radon measurements were performed since 1989 in a few sampling campaigns and all data ware included in the Spanish indoor radon map. In summary: 2117 data were performed in the period from 1989-2010, in the first campaign organised from 2010-2012 in total 5556 indoor Rn data were gathered, with additional 344 measurements in period from 2012-2012. An finally, in the second campaign organised from 2013 till 2014, data of 1194 measurements were performed.

Sampling strategy was based on several criteria: 1.surface criterion: at least one measurement per 10x10km grid; 2. population criterion: additional measurements for towns with population >50000 and similar, 3. MARNA criterion: considering geological factors i.e. considering 226Ra content in soil, and 4. Litostratigrafic criterion.

Random selection of location within the cell was chosen. Detectors were placed in ground-level buildings in the main room, height 1-2 m, on wardrobe separated from the walls, away from air flow and heat source.

With each detector, detailed questionnaire was enclosed regarding the building design, materials, living habits, etc.

Quality control and quality assurance was validated annually by the validation scheme designed by Public Health England. In addition, national and international comparisons were performed on a regular basis.

Data averaged in the grid consisting of 10x10 km^2 cells. Data confirmed lognormal distribution. Descriptive statistics are given in Table 41.1.

Table 41.1. Descriptive statistics of data used to produce the Spanish indoor radon map up-to-date.

Number of measurements	Arithmetic mean	Arithmetic standard deviation	Geometric mean	Geometric standard deviation	Median	Range
9211	95.0	270	56.6	2.6	54	10–15,400

Source: Fernandez, 2017.

The classification of data was carried out into four categories: <50, 50-100, 100-300 and > 300 Bq/m^3, in compliance with recommendations of the World Health Organization. Distribution of radon data according to the classification of data is given in Table 41.2.

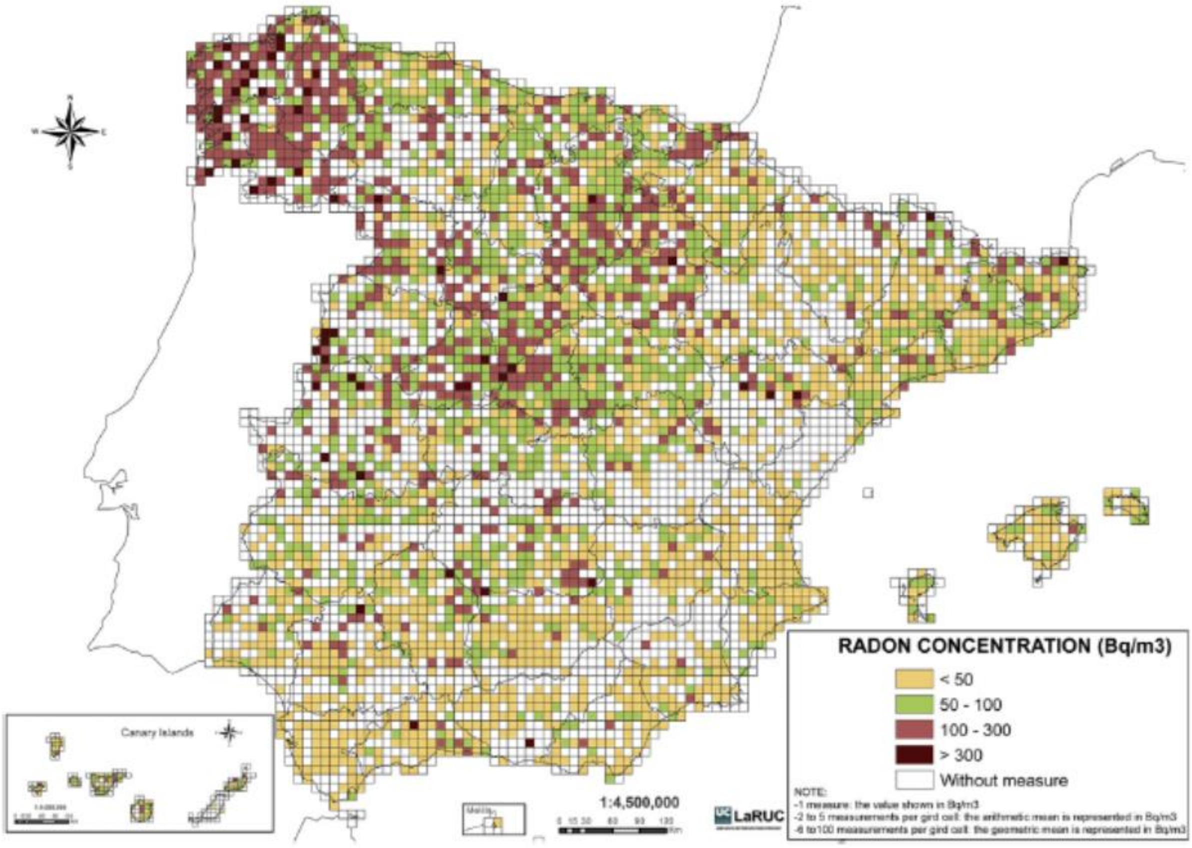
Table 41.2. Number of cells and data classified by 4 categories of radon concentration.

Range (Bq/m^3)	Number of cells	Number of data
<50	1606 (29%)	4294 (46%)
50–100	967 (18%)	2922 (32%)
100–300	602 (11%)	1902 (21%)
>300	42 (1%)	93 (1%)

Source: Fernandez, 2017.

In Figure 41.1 is presented an up-to-date Spanish indoor radon map based on 9211 measurements.

Figure 41.1. Map of indoor radon in Spain based on 9211 measurements.



Source: Fernandez, 2017.

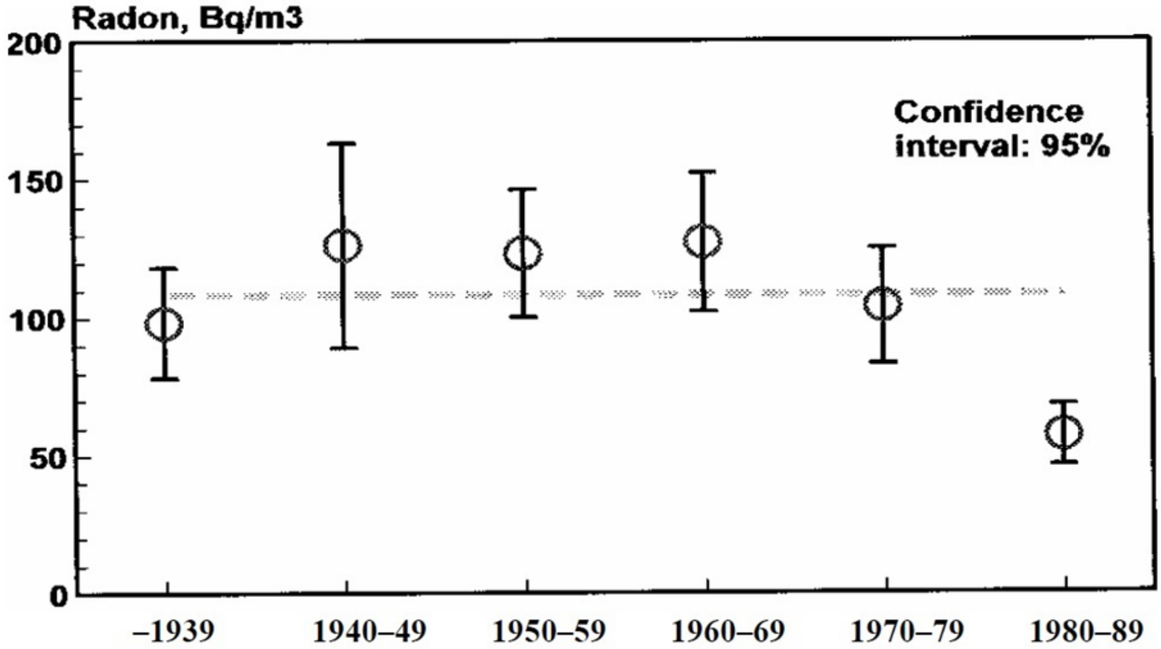
References

Fernández, C.S. et al., (2017) Spanish experience on the design of radon surveys based on the use of geogenic information, Journal of Environmental Radioactivity 166, 390-397 (and reference therein).

42 Sweden

A national energy and climate study was conducted in 1991 and 1992. A total of 1300 dwelling were randomly selected. Alpha track detectors were placed for 3 months in each dwelling during the heating season. Percentage of houses over the action level of 400 Bq/m^3 was determined for single family houses and multifamily houses, as well as the average radon concentration for buildings built during each decade since 1930s (Swedjermark et al, 1993, Swedjermark, 2002).

Figure 42.1. The arithmetical averages of radon concentrations in Swedish swellings as a function of the building year as measured in the investigation of the 1988 building stock.



Source: Swedjermark, 2002.

References

Swedjemark, G.A. et al, (1993). Radon levels in the1988 Swedish housing stock. Indoor Air '93: 6. international conference on indoor air quality and climate, Helsinki (Finland), 1993, pp 491– 496 (only abstract available online).

Swedjemark, G.A., Residential radon Case 4 in the Swedish ICRP-project, SWIP, 2002.

43 Switzerland

Nationwide large-scale radon surveys have been conducted since the early 1980s to establish the distribution of indoor radon concentrations in Switzerland. The aim of this work was to study the factors influencing indoor radon concentrations in Switzerland using univariate analyses that take into account biases caused by spatial irregularities of sampling.

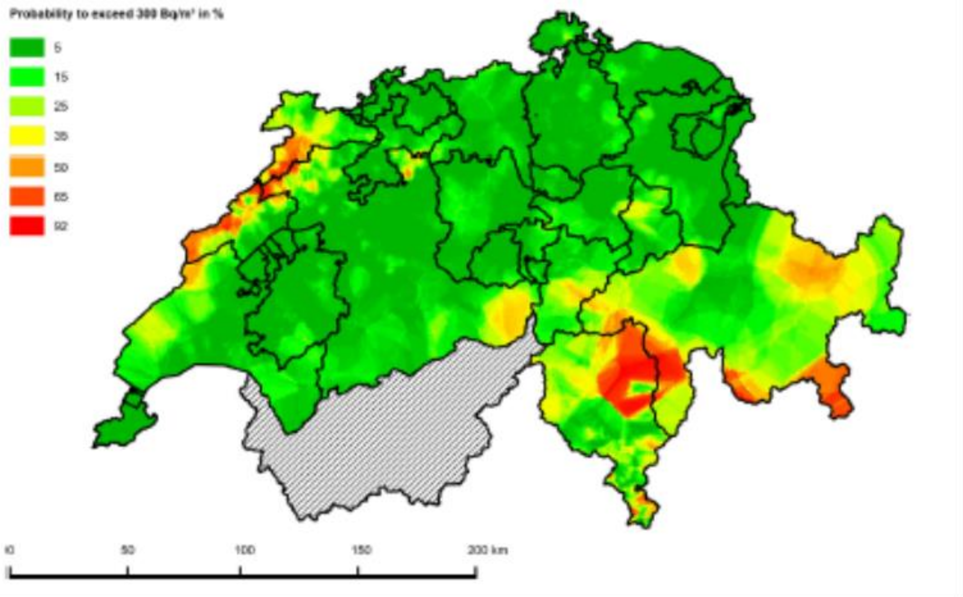
About 212,000 indoor radon concentrations measurements carried out in more than 136,000 dwellings were available for this study. A probability map to assess risk of exceeding an indoor radon concentration of 300 Bq/m^3 was produced using basic geostatistical techniques. Univariate analyses of indoor radon concentrations for different variables, namely the type of radon detector, various building characteristics such as foundation type, year of construction and building type, as well as the altitude, the average outdoor temperature during measurement and the lithology, were performed comparing 95% confidence intervals among classes of each variable. Furthermore, a map showing the spatial aggregation of the number of measurements was generated for each class of variable in order to assess biases due to spatially irregular sampling. Indoor radon concentrations measurements carried out with electret detectors were 35% higher than measurements performed with track detectors.

Regarding building characteristics, the indoor radon concentrations of apartments are significantly lower than individual houses. Furthermore, buildings with concrete foundations have the lowest indoor radon concentrations. A significant decrease in indoor radon concentrations was found in buildings constructed after 1900 and again after 1970.Moreover, indoor radon concentrations decreases at higher outdoor temperatures. There is also a tendency to have higher indoor radon concentrations with altitude.

Regarding lithology, carbonate rock in the Jura Mountains produces significantly higher indoor radon concentrations, almost by a factor of 2, than carbonate rock in the Alps. Sedimentary rock and sediment produce the lowest indoor radon concentrations while carbonate rock from the Jura Mountains and igneous rock produce the highest indoor radon concentrations. Potential biases due to spatially unbalanced sampling of measurements were identified for several influencing factors.

Significant associations were found between indoor radon concentrations and all variables under study. Spatial distribution of samples strongly affected the relevance of those associations (Kropat, 2014).

Figure 43.1. Map of Switzerland indicating the local probability to exceed 300 Bq/m^3.



Source: Kropat, 2014.

References

Kropat, G. et al., (2014) Major Influencing Factors Of Indoor Radon Concentrations In Switzerland, Journal of Environmental Radioactivity 129, 7-22.

44 Turkey

Reference (Can et al., 2012) describes surveys in selected regions (Kilis, Osmaniye and Antakya) in Turkey, with main goal to determine average indoor radon concentration in those selected areas. Surveys took place in spring seasons till 2011. Surveys covered 204 houses, and detectors were placed in living rooms. The detectors were exposed for 2 months. Effective dose was measured, too.

A Radosys radon measurement system was used for analysis. CR-39 track detectors were used. Detectors were chemically etched in a 4 M NaOH solution bath unit at 60 °C for 4 hours. After etching detectors were put into a 'radometer 2000' evaluation unit to count the number tracks on them. The track densities on detectors were determined automatically by a system with 500x microscope. Minimum, maximum and average indoor radon concentrations were reported. Average indoor radon concentrations were compared with global average. Indoor radon concentration levels for Kilis, Osmaniye and Antakya are 5–171, 6–209 and 4–135 Bq/m^3, respectively. Average radon concentration for Kilis, Osmaniye and Antakya were calculated as 50, 51 and 40 Bq/m^3, respectively. The radon concentrations in Kilis and Osmaniye are above global average radon concentration (40.3 Bq/m^3) while that for Antakya is slightly below the global average. Average annual effective doses are compared with the global average. No significant difference was found in comparison with the data acquired from other provinces of Turkey.

Table 44.1. Indoor ^{222}Rn activity concentrations and comparison with different part of Turkey.

District	Number of houses	Min.	Max.	^{222}Rn activity concentrations (Bq/m^3)	Effective dose (mSv/y)	References
Kilis	62	5	171	50	1.26	Present study
Osmaniye	70	6	209	51	1.29	Present study
Antakya	72	4	135	40	1.01	Present study
Manisa				97 (47–146)	4.83 (2.35–7.3)	[16]
Kastamonu				98.4 (29–177)	2.48 (0.73–4.46)	[17]
Giresun				130 (52–360)	3	[18]
Tekirdağ				87	2.01	[19]
Batman				84 (23–145)		[20]
Karabük				131.6	3.32	[21]
İstanbul				10–260	0.5–13	[22]

The ranges corresponding to data are given in parentheses

Source: Can et al., 2012.

Reference (Köksal et al., 2004) describes survey that was a part of a national program designed to determine public exposure to natural radiation. Indoor radon concentrations have been measured in 27 cities/towns and 1414 randomly chosen houses. Detectors were placed in living rooms and bedrooms. Monitoring was implemented in two 3-month periods during the winter and summer seasons. So, single measurement duration was 3 months.

Passive solid state nuclear track detectors (SSNTD type CR-39) in the diffusion chamber were used. CR-39 detectors were etched in a 30% NaOH at 70 °C for 17 hours. Subsequently the tracks on the etched film were counted manually with a microscope (200×).

The arithmetic mean value of radon concentration level in two different rooms was used as a measure of the indoor air concentration in the building. The mean value of summer and winter measurements is considered as the arithmetic mean value of the dwellings. Regions with higher natural background radiation were observed. The measured distribution of radon levels varied between 10 and 380 Bq/m^3. The arithmetic mean value of the radon concentration was found to be 35 Bq/m^3 with a standard deviation 12 Bq/m^3.

Figure 44.1. Arithmetic mean of indoor radon concentration in Turkey.

Source: Köksal et al., 2004.

Table 44.2. Indoor radon concentrations of Turkish dwellings.

Towns and cities under study	Number of surveyed houses	Number of houses of different radon concentrations				
		1–50 Bq·m⁻³	51–100 Bq·m⁻³	101–200 Bq·m⁻³	201–300 Bq·m⁻³	301–400 Bq·m⁻³
Istanbul	524	267	234	23	–	–
Bursa	50	34	15	1	–	–
Eskişehir	50	12	37	1	–	–
Adana	25	3	22	–	–	–
Mersin	97	87	10	–	–	–
Kahramanmaraş	45	45	–	–	–	–
Adıyaman	43	42	1	–	–	–
Şanlıurfa	24	2	19	3	–	–
Elazığ	19	5	12	2	–	–
Erzurum	23	8	11	4	–	–
Kocaeli	81	78	–	3	–	–
Köprübaşı	15	8	7	–	–	–
Tosya	26	14	10	2	–	–
Afyon	25	4	19	2	–	–
Balıkesir	30	24	6	–	–	–
Sındırgı	19	10	8	1	–	–
Gaziantep	27	18	8	1	–	–
Kestanbolu Çanakkale	47	–	7	30	7	3
Zeytinburnu İstanbul	77	53	22	2	–	–
Yatağan Thermic Central	13	–	9	4	–	–
Antalya	23	19	4	–	–	–
Sakarya	27	13	9	2	1	2
Gölcük	27	16	5	5	–	1
Bolu	18	9	4	2	2	1
Düzce	18	12	–	5	1	–
Kırklareli	14	–	2	12	–	–
Malatya	27	18	9	–	–	–

Source: Köksal et al., 2004.

Regarding quality assurance, calibration of SSNTDs at standard radon atmosphere was repeated for each CR-39 foil using a 222 litre closed oil barrel containing a ^{226}Ra source. The calibration chamber was calibrated by sampling with Lucas flasks. Participations in the NRPB intercomparison took place in 1989, 1991, 1995 and 2000.

References

Can, B. et al., (2012). Measurements of Indoor Radon Concentration Levels in Kilis, Osmaniye and Antakya, Turkey During Spring Season, J. Radioanal. Nucl. Ch., 292 1059−1063.

Köksal, E.M. et al, (2004) A Survey of Rn-222 Concentration in Dwellings of Turkey, J. Radioanal. Nucl. Ch. 259 213−216.

45 Ukraine

First indoor radon survey in Ukraine is described in the reference (Pavlenko et al., 1997). It was conducted during 1989-93, and a main survey goal was to estimate a value and structure of the total exposure dose to the Ukrainian population, and to reveal the most "radon-dangerous" territories. More than 9500 measurements of indoor radon concentration were performed in dwellings (bedroom) of different types taking into account number of floors, type of building materials and scheme of the apartments all over Ukraine.

Table 45.1. The weighted average by types of buildings and structure of housing facilities effective population exposure doses for Ukraine.

Region	The average ^{222}Rn ECC, Bq·m^{-3}			Weighted average values of the ^{222}Rn ECC, Bq·m^{-3}	Weighted average values of the effective dose, mSv·year^{-1}
	I type	II type	III type		
Vinnitsa	79	38	28	65	4.32
Volyn	19	13	10	16	1.34
Donetsk	102	89	34	65	4.34
Zhitomir	70	45	26	55	3.76
Zaporozh'e	94	43	24	56	4.54
Ivano-Frankovsk	55	38	20	45	3.14
Kyiv	54	29	23	34	2.42
Odessa	115	78	34	77	5.05
Poltava	44	32	23	36	2.57
Rivne	65	32	20	51	3.49
Sumy	36	18	13	27	2.00
Ternopil	132	48	33	104	6.74
Cherkassy	89	34	25	68	4.54
Chernigiv	38	24	20	32	2.34
Cherson	156	106	34	111	7.14
Chernovtsy	55	38	20	45	3.10
Chmelnitsk	75	49	30	61	4.07
Ukraine					***3.8***

Source: Pavlenko et al., 1997.

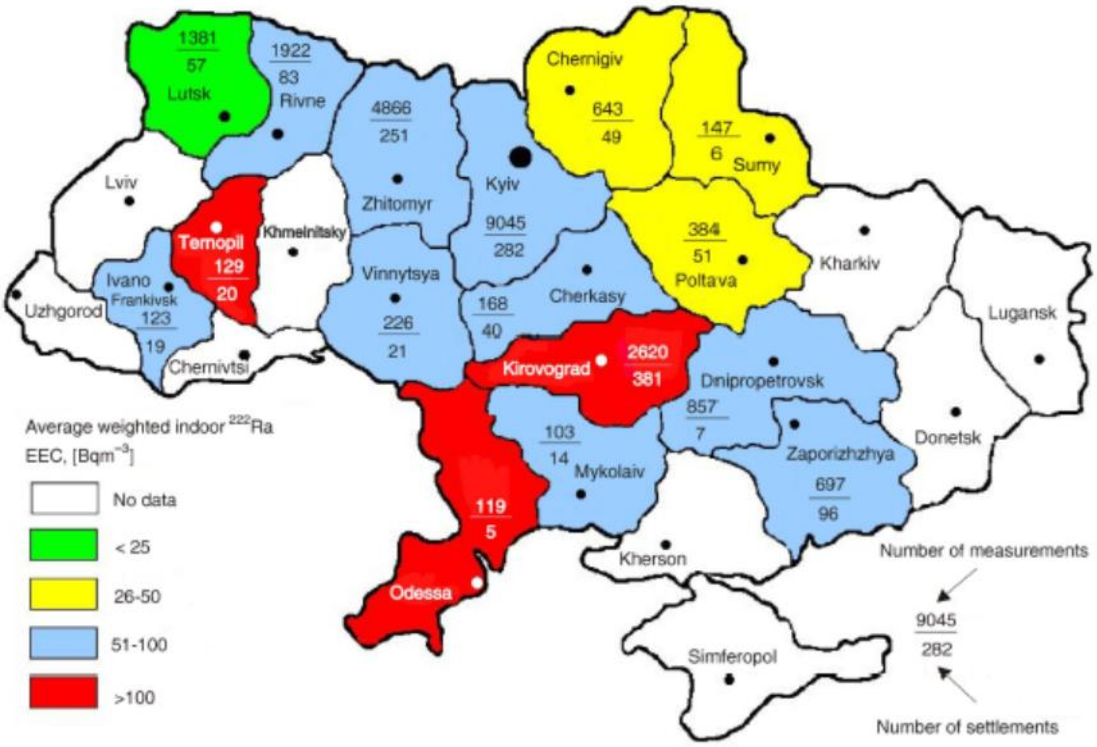
Simultaneously with radon detection system development, radon atmosphere was established in RCRM, Kiev, Ukraine. A national bureau for standardisation certified the atmospheres a primary source of measurements. Procedures of radiation services certification and intercomparison were elaborated. Thus a system of a quality assurance for Rn in air measurements was developed.

Measurements were performed by passive track dosimetry. Nitro-cellulose film, LRII5 II type (Kodak, France) or similar one of CND type produced by State Research Institute of Photochemical Industry (Pereslavl Branch, Russia) were used as a detector. Exposed detectors were processed at the spark counter "TRACK 2010Z" after a standard procedure of treating in NaOH solution. Exposure time was 1-2 months, and they took place during the Spring-Summer and Autum-Winter period. Results – data were processed by means of special computer databases. Equilibrium factor of 0.4 was used. An average value of the radon equilibrium concentration was calculated and weighted by type of buildings. Annual effective dose was calculated. It is found that hydrogeological peculiarities of a territory determine the number of buildings with an elevated radon concentration (Pavlenko et al., 1997).

Experimental data allowed optimizing the system of control of radon-222 taking account of possibilities of decreasing total exposure doses for population on the territories contaminated from Chernobyl. Basic directions for establishing the system of countermeasures against exposure to radon-222 were determined (Pavlenko et al., 1997).

Regional survey under the pilot project aiming reduction the radon risk in |Kirovograd region during 2010-13 are described in reference (Pavlenko et al., 2014). Under this project 1043 public buildings including 870 schools and nurseries were examined. Detectors used were passive track detector (LR-115 film). Chemical etching of the film was applied and track counting was performed with the spark counter. The sensitivity of the method: 8-10 Bq/m^3.The detectors were exposed for two months during the heating season (November-March).

Figure 45.1. Average radon EEC in Ukraine dwellings.



Source: Pavlenko et al., 2014

Analysis of the results included descriptive statistics and test for lognormality. The season correction factors were applied. Effective dose was calculated. The radon risk factors for the region were analyzed. Lognormal frequency distribution was established for Rn concentrations in school and nurseries. In 53% the limit of 50 Bq/m^3 was exceeded. Mean value was determined for schools and nurseries, building with the wooden and forced concrete floors. Radon activity is 1.2-2 times higher in the dwellings with slag filling (Pavlenko et al., 2014).

Efficiency calibration of the track detectors were done in the radon atmosphere at the IHME (secondary calibration source accredited by the National Standardization and Accreditation Authority of Ukraine). Additionally, each film production was tested and adjusted for the optimal etching parameter (Pavlenko et al., 2014).

References

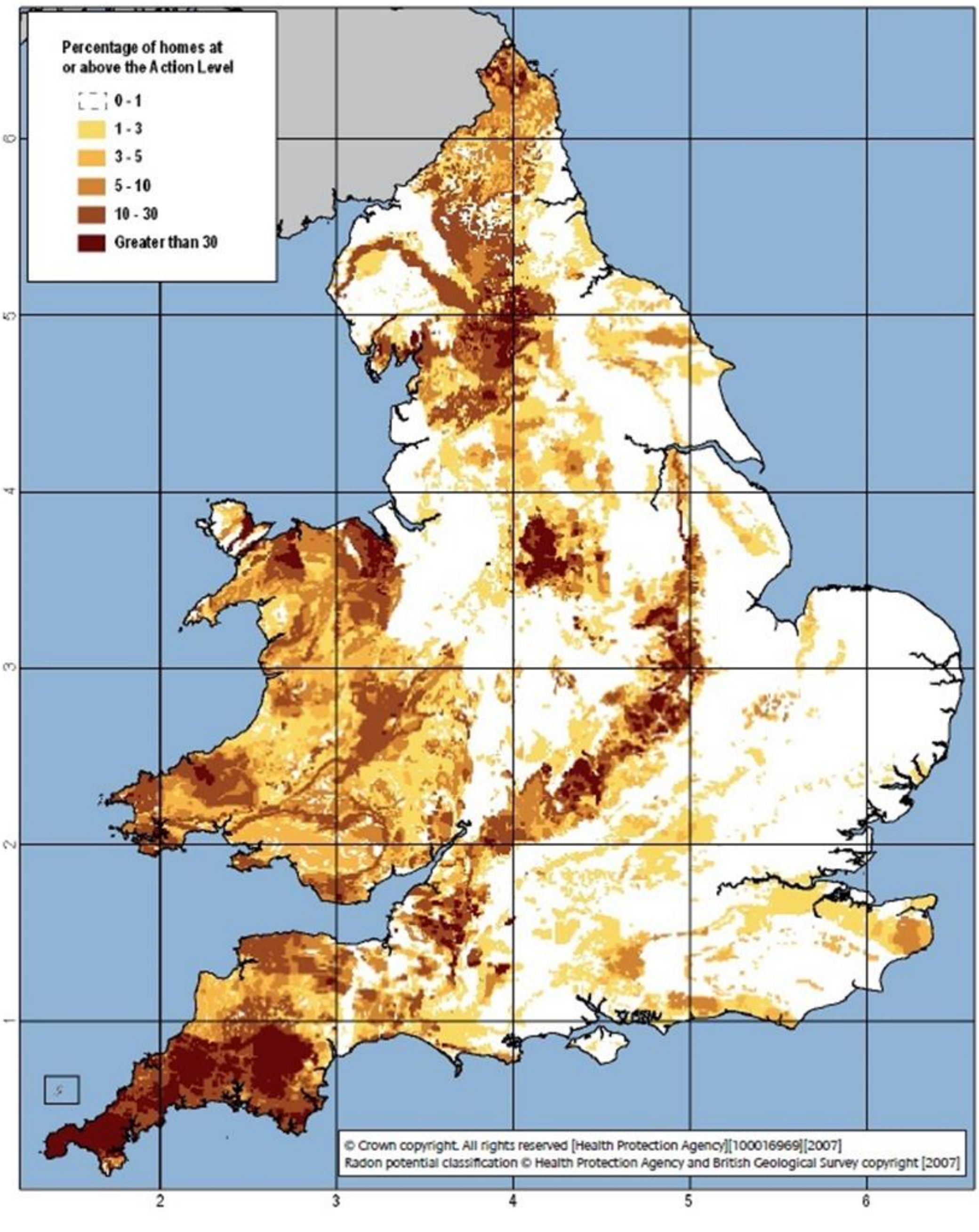
Pavlenko, T.A., Los, I.P., Aksenov, N.V., (1997) Exposure Doses due to Indoor Rn-222 in Ukraine and Basic Directions for Their Decrease, Radiat. Meas., 28, 733−738.

T. Pavlenko et al., (2014) The Ukrainian Pilot Project "Stop Radon", Nuclear Technology & Radiation Protection 29(2), 1-7.

46 United Kingdom

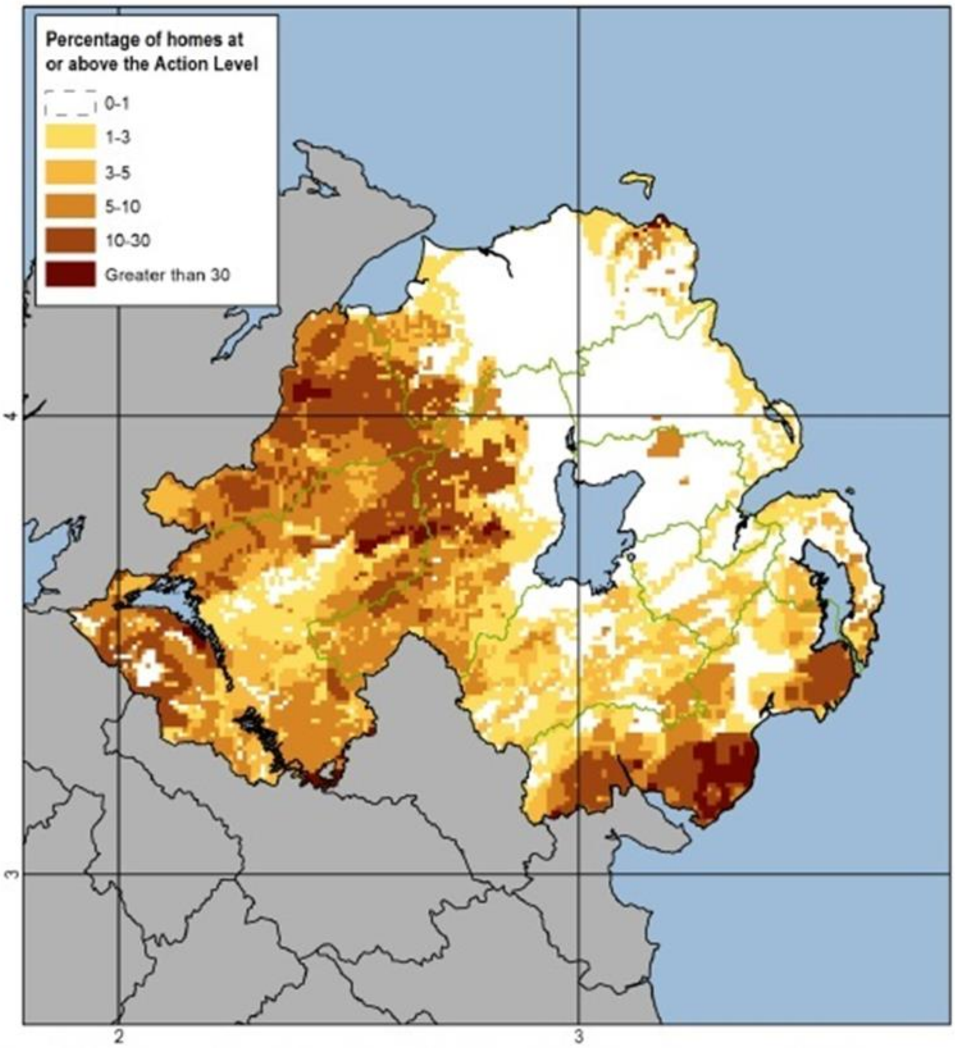
Multiple studies that covered the whole United Kingdom were aggregated to produce three Atlases, one for England and Wales, one for Northern Ireland and one for Scotland. The goal was to produce map of radon potential based on the number of homes with concentration over 200 Bq/m^3. Two passive integrating detectors were used in each dwelling, one in main living room and one in main bedroom. Individual exposures were 3 months long and seasonal correction factors were applied, as well as temperature corrections for different years. In total, 460000 houses were examined in England and Wales, 23000 in Northern Ireland and 19000 in Scotland. Results were evaluated by descriptive statistics. Radon map with 1 km^2 grid was produced (Miles et al, 2007; Daraktchieva et al, 2015; Miles et al, 2011).

Figure 46.1. Overall map of radon affected areas in England and Wales.



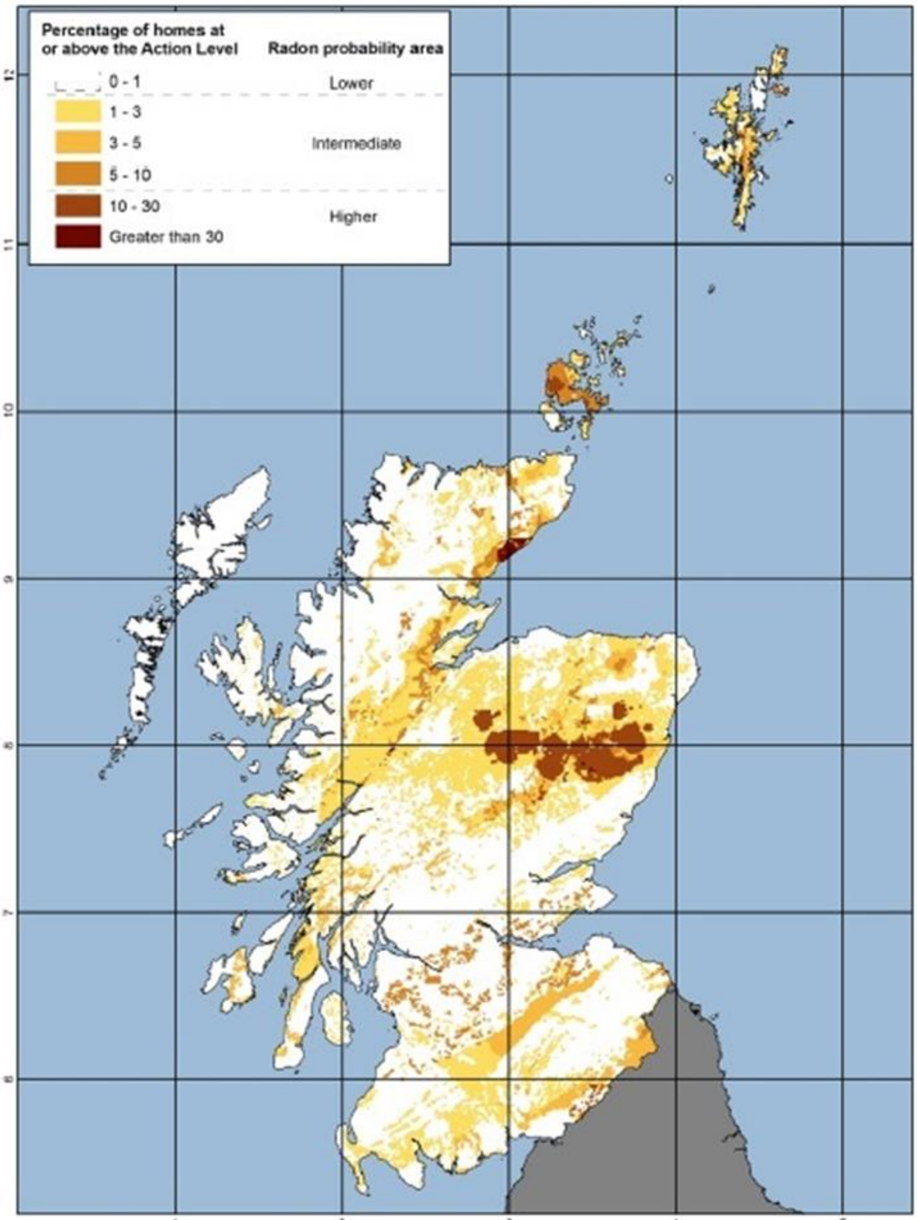
Source: Miles et al, 2007.

Figure 46.2. Overall map of radon affected areas in Northern Ireland.



Source: Daraktchieva et al, 2015.

Figure 46.3. Overall map of radon potential in Scotland.



Source: Miles et al, 2011.

References

Miles, J.C.H. et al, (2007) Indicative Atlas of Radon in England and Wales, HPA-RPD-033, Health Protection Agency, United Kingdom, ISBN 978-0-85951-608-2.

Daraktchieva, Z. et al, (2015) Radon in Northern Ireland: Indicative Atlas, PHE-CRCE-017, Public Health England, United Kingdom, ISBN 978-0-85951-764-5.

Miles, J.C.H. et al, (2011) Indicative Atlas of Radon in Scotland, HPA-CRCE-023, Health Protection Agency, United Kingdom, ISBN 978-0-85951-701-0.

47 Conclusions

TO BE COMPLETED.

References

INTRODUCTION:

Cinelli, G. et al., (2018) Digital version of the European Atlas of natural radiation, Journal of Environmental Radioactivity (in press).

De Cort, M. et al., (2011), Towards a european atlas of natural radiation: Goal, status and future perspectives, Radioprotection 46, 6, S737-S743.

Dubois, G. (2005), An overview of radon surveys in Europe Report EUR21892, EC, Office for Official Publications of the European Communities, Luxembourg.

Dubois, G., Bossew, P., Tollefsen, T. and de Cort, M. (2010), First steps towards a European atlas of natural radiation: status of the European indoor radon map, Journal of Environmental Radioactivity 101 786-798.

EC (2013) Council Directive 2013/59/Euratom of 5 December 2013 Laying down Basic Safety Standards for Protection against the Dangers Arising from Exposure to Ionising Radiation, Official Journal L13 of 17/01/2014. European Commission, Bruxelles.

UNSCEAR (2000) United Nations Scientific Committee on the Effects of Atomic Radiation Report, Annex B: Exposure due to Natural Radiation Sources. Vol. 1, United Nations, New York.

WHO (2009) WHO Handbook on Indoor Radon. World Health Organisation, WHO, Geneva.

ALBANIA:

Bode Tushe, K. et al., (2016) First Step Towards the Geographical Distribution of Indoor Radon in Dwellings in Albania, Radiation Protection Dosimetry, Volume 172, Issue 4, 1 Pages 488–495.

ARMENIA:

Karen Haroyan, 2017, National Radon Programme and Radon Action Plan, Presentation, RER/9/136-1701370, Yerevan, Armenia, 23 - 27 October, 2017.

AUSTRIA:

Friedmann H., (2005), Final Results of the Austrian Radon Project, Health Physics 89, 4, pp. 1-10.

AZERBAIJAN:

M. Hoffmann et al., 2016 First Map of Residential Indoor Radon Measurements in Azerbaijan. Rad. Prot. Dosim. pp 1-8, doi:10.1093/rpd/ncw284.

BELARUS:

Yaroshevich et al., (2012), Indoor Radon And Radon Component Of Population Radiation Doses In Different Areas Of Belarus, Минск, Белорускаја Наука, 56, No. 6, pp. 92.

Power Point Presentation, Measurements of radon in workplaces in Republic of Belarus, Marina Vasilyeva, Ministry of Health, 2015.

BELGIUM:

Tondeur F., Zhu H.-C., Charlet J.M., Gerardy I. and Perreaux R (1996). Radon from the subsoil to the dwelling in southern Belgium.Environment International, 22(1): S535-S543.

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 insouthern Belgium: an application of geostatistical and GIS techniques, The Science of the Total Environment, 272(1-3): 203-210.

Poffijn, A., Eggermont, G., Hallez, S. and Cohilis, P. (1994). Radon in Belgium: Mapping and Mitigation in the Affected Area of Visé. RadiationProtection Dosimetry, 56(1-4): 77-80 Abstract only.

Cinelli, G. Tondeur, F. and Dehandschutter, B., (2011) Development of an indoor radon risk map of the Walloon region, Environ Earth Sci 62:809–819.

BOSNIA AND HERZEGOVINA:

IAEA-TECDOC-1810. Status of Rasdon related Activities in member States Participating in technical Cooperation Projects in Europe, IAEA, Vienna, 2017.

Ćurguz, Z. et al. (2015). Long-Term Measurements of Radon, Thoron and Their Airborne Progeny in 25 Schools in Republic of Srpska, Journal of Environmental Radioactivity,148, 2015, 163-169.

BULGARIA:

Ivanova, K., Stojanovska, Z., Badulin, V. and Bistra Kunovska (2013). Pilot Survey of Indoor Radon in the Dwellings of Bulgaria. Radiation protection Dosimetry, 157 (4), 594-599.

CROATIA:

Radolić, V., (2006) National Survey of Indoor Radon Levels in Croatia, J. Radioanal. Nucl. Ch., 269, 87-90.

CYPRUS:

Anastasiou T. et al., 2003. Indoor radon (222Rn) concentration measurements in Cyprus using high–sensitivity portable detectors, J Environ Radioact. 68(2):159-69.

CZECH REPUBLIC:

Dubois, G., An overview of radon surveys in Europe, EC JRC, 2005.

Thomas et al., Review of official measuring methods and official interpretations of measuring results used in the radon program of the Czech Republic, 2002.

Power Point Presentation, 30 years of experience of Czech radon program, Jirí Hulka, SÚRO - National Radiation Protection Institute, Prague, Czech Republic, Latin American Symposium on Radon and II Symposium on Radon in Brazil, Pocos de Caidas, May 2014.

DENMARK:

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. et al., (2007) Prediction of ^{222}Rn in Danish Dwellings Using Geology and House Construction information Radiation Protection Dosimetry 123 (1), 83–94.

GEORGIA:

IAEA TC Project RER/9/127. Establishing Enhanced Approaches to the Control of Public Exposure to Radon, Presentation, 22.04.2014, Vienna, Austria.

IAEA-TECDOC-1810. Status Of Radon Related Activities in Member States Participating in Technical Cooperation Projects in Europe, Iaea, Vienna, 2017.

GREECE:

Nikolopoulos D. et al., (2002), Radon Survey in Greece - risk assessment, Journal of Environmental Radioactivity 63, 173-186.

ESTONIA:

Pahapill, L., Rulkov, A., Rajamäe, R., Akerblom, G., (2003) Radon in Estonian Dwellings.

FINLAND:

Weltner A. et al., (2002). Radon Mapping Strategy in Finland, International Congress Series 1225, 63-69.

Valmari T. et al., (2010) Radon Atlas of Finland STUK-A245 / ELOKUU 2010, STUK Radiation and nuclear safety authority, ISBN 978-952-478-538-9.

FRANCE:

Baysson, H., Billon, S., Laurier, D., Rogel, A. And Tirmarche, M. (2003) Seasonal Correction Factors For EstimatingRadon Exposure In Dwellings In France, Radiation Protection Dosimetry 104 (3), 245–252.

Billon S. et al. (2005) French population exposure to radon, terrestrial gamma and cosmic rays. Radiation Protection Dosimetry 113 (3), 314-320.

INSERM (Institut national de la santé et de la recherche médicale Cancer et environnement), 2008. Chapter 55: Données d'exposition aux rayonnements ionisants (report in French) http://www.ipubli.inserm.fr/bitstream/handle/10608/102/?sequence=72

GERMANY:

Schimer, H. and Wicke, A. (1985). Results from a Survey of Indoor Radon Exposures in the Federal Republic of Germany, The Science of the Total Environment, 45, 307-310.

Kemski, J., Klingel, R., Stegemann, R. (2004): Validierung der regionalen Verteilungen der Radon konzentration in Häusern mittels Radonmessungen unter Berücksichtigung der Bauweise (Abschlussberichtzum orschungsvorhaben St. Sch. 4271).- Schriftenreihe Reaktorsicherheit und Strahlenschutz, BMU-2004-641.

Kemski, J., Klingel, R., and Siehl, A., (1996). Classification and Mapping Of Radon Affected Areas In Germany Environment International, 22 (1), S789-S798.

HUNGARY:

Hámori K., Tóth E., Pál L., Köteles G., Minda M., (2006). Evaluation of Indoor Radon Measurements in Hungary, Journal of Environmental Radioactivity 88, 189-198.

Nikl I., (1996) Radon Concentration and Absorbed Dose Rate in Hungarian Dwellings, Radiation Protection Dosimetry, 67, 225−228.

ICELAND:

Ennow, K.R., Magnússon, S.M. (1982) Natural Radiation in Iceland and the Faroe Islands. Statens Institut for strålehygiejne Denmark.

Jónsson, G., Theódorsson, P. (2003) Radon í andrúmslofti íbúða á Íslandi. Report to the Icelandic, Student Innovation Fund.

Jónsson, G., Halldórsson, Ó., Theodórsson, P., Magnússon, S.M., Karlsson, R.K. (2016) Indoor and outdoor radon levels in Iceland. https://gr.is/wp-content/uploads/2016/09/Indoor-and-outdoor-radon-levels-in-Iceland_NSFS_Final_FINAL_version.pdf. Last access 12/11/2018.

IRELAND:

Fennell, S.G. et al, (2002). Radon in Dwellings, the Irish National Radon Survey, RPII-02/1, Radiological Protection Institute of Ireland, Dublin, www.epa.ie/pubs/reports/radiation/radonindwellingstheirishnationalradonsurvey.html

Dowdall, A. et al, (2017). Update of Ireland's national average indoor radon concentration - Application of a new survey protocol, Journal of Environmental Radioactivity 169-170, 1-8.

ITALY:

Carelli, V. et al, (2009) A National Survey on Radon Concentration in Underground Inspection Rooms and in Buildings of a Telephone Company: Methods and First Results, Radiation Measurements 44, 1058-1063.

Bochicchio, F. et al, (2005). Annual Average and Seasonal Variations of Residential Radon Concentration for all the Italian Regions, Radiation Measurements 40, 686-694.

KAZAKHSTAN:

Fyodorov, G.V., Berkinbayev, G.D., Kayukov, P.G. (2014). Radiological atlas of Zhambyl oblast in Kazakhstan, Научные статьитом 7(4), 62-66.

LATVIA:

Dubois, G. (2005) An Overview of Radon Surveys in Europe, European Communities.

Dambis, M. (1994) Radon in Latvia's Dwellings, Radiation and Society: Comprehending Radiation Risk, Vol.2, IAEA Conference Paris, 24-28 october 1994, IAEA CN-54/31P, 379-382.

LITHUANIA:

Morkunas, G. and Akerblom, G. (1999). The Results Of The Lithuanian Radon Survey, Radon In The Living Environment, 19-23 April 1999, Athens, Greece.

Ladygienė, R., Phd, Power Point Presentation, Current Indoor Radon Situation In Lithuania, Radiation Protection Centre, 2015.

LUXEMBOURG:

Dubois, G. (2005) An Overview of Radon Surveys in Europe, European Communities.

Kies, A., Biell, A., and Eowlinston, L. (1996) Radon Survey in the Grand-Duchy of Luhembourg - Indoor Measurements Related to House Features, Soil, Geology, and Environment, Environment International, 22(l) 1, S805-S808.

MACEDONIA:

Stojanovska, Z. et al, (2012). Indoor Exposure of Population to Radon in the FYR of Macedonia, Radiation Protection Dosimetry 148 (2), 162–167.

MALTA:

Baluci, C. et al, (2013). National Mapping Survey of Indoor Radon Levels in the Maltese Islands, Malta Medical Journal 25(4), 33-39.

MOLDOVA:

Ursulean, I., Coreţchi, L., Chiruţă, I., and Vîrlan, S. (2013) Estimation of indoor radon concentrations in the air of residential houses and mines in the republic of Moldova. Rom. Journ. Phys., Vol. 58, Supplement, S291–S297, Bucharest.

MONTENEGRO:

Antovic, N. et al., (2007). Indoor Radon Concentrations in Urban Settlements on the Montenegrin Coast. Radiation Measurements 42, 1573–1579.

Vukotic, P. et al., (2018). Radon Survey In Montenegro – A Base to Set National Radon Reference and "Urgent Action" Level, Journal of Environmental Radioactivity, doi: 10.1016/j.jenvrad.2018.02.009.

NETHERLANDS:

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.

Lembrechts, J., Janssen, M., and Stoop, P. (1999). Ventilation and Radon Transport in Dutch Dwellings: Computer Modelling And Field Measurements, Radon in the Living Environment, 19-23 April 1999, Athens, Greece, 525-536.

NORWAY:

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 6-61, 23-28 May 2004.

POLAND:

IAEA, IAEA-TECDOC-1810, (2017) Status of Radon RelatedActivities in Member StatesParticipating in TechnicalCooperation Projects in Europe, Vienna,ISBN 978–92–0–100617–2.

Przylibski, T.A. et al, Mean Annual ^{222}Rn Concentration in Homes Located in Different Geological Regions of Poland - First Approach to Whole Country Area, Journal of Environmental Radioactivity 102(8) (2011), pp. 735-741.

PORTUGAL:

Faisca, M.C., Teixeira, M.M.G.R., Bettencourt, A.O, Indoor Radon Concentrations in Portugal - A National Survey, Radiation Protection Dosimetry, Volume 45, Issue 1-4, 1 December 1992, pp. 465–467.

ROMANIA:

Iacob, O., Grecea, C. and Botezatu, E. (2005). Population Exposure to Inhaled Radon and Thoron Progeny, in The Natural Radiation Environment, NRE – VII, edited by J.P. Mc Laughlin, S.E. Simopoulos and F. Steinhausler, (Elsevier,London, 2005), pp.232–237.

Cosma, C., Szacsvai, K., Dinu, A., Ciorba, D., Dicu, T., Suciu, L., (2009). Preliminary integrated indoor radon measurements in Transylvania (Romania). Isot. Environ. Health Stud. 45 (3), 259-268.

Cosma, C., Cucoş Dinu, A., Dicu, T., (2013). Preliminary results regarding the first map of residential radon in some regions in Romania. Radiat. Prot. Dosim. 155 (3), 343-350.

Cucoş, A. et al. (2017) Residential, soil and water radon surveys in north-western part of Romania, Journal of Environmental Radioactivity 166, 412-416.

RUSSIAN FEDERATION:

Marenny, A.M. et al, (1996) Results of radon concentration measurements in some regions of Russia, Radiation Measurements, 26 (3), 43-48.

Yarmoshenko I. et al, (2015). Reconstruction of national distribution of indoor radon concentrations in Russia using results of regional indoor radon measurement programs, Journal of Environmental Radioactivity 150, 99-103.

SERBIA:

Žunić, Z.S. et al.,(2009) Identification and assessment of elevated exposure to natural radiation in Balkan region (Serbia), Radioprotection 44(5): 919–925 (and reference therein).

Žunić, Z.S. et al., (2010) Collaborative investigations on thoron and radon in some rural communities of Balkans, Radiation Protection Dosimetry 141(4): 346–350 (and reference therein).

Žunić, Z.S. et al., (2010) The indoor radon survey in Serbian schools: can it reflect also the general population exposure, Nukleonika 55, 419-427.

Forkapić, S. et al., (2007) Indoor Radon In Rural Dwellings Of The South-Pannonian Region, Radiat. Prot. Dosim., 123, 378−383.

Udovičić V. et al., (2016) First steps towards national radon action plan in Serbia, Nukleonika, 61(3): 361-365.

IAEA SRB/9/006 (2018) Upgrading National Capabilities and Infrastructure for the Systematic Approach to the Control of Public Exposure to Radon, presentation on meeting in Belgrade, Serbian Radiation Protection and Nuclear Safety Agency, 22 February 2018.

SLOVAKIA:

Vicanova, M., Durcik, M., Nikodemova, D., (1998). Radiation load from radon exposure in Slovakia, Radiation Hygiene Days Conference Proceedings of the 21-st Radiation Hygiene Days.

Vladár, M. et al., (1996) Monitoring of Natural Radioactivity in Slovakia, Journal of Radioanalytical and Nuclear Chemistry, Articles Vol. 209, No. 2 (1996) 325-330.

Mullerova, M. et al. (2014). Preliminary Results of Indoor Radon Survey in V4 Countries, Radiation Protection Dosimetry, 160(1-3):210-213.

SLOVENIA:

Humar, M. et al, (1995). Radon Concentrations in Living Environment of Slovenia (final report-in Slovene), Jožef Stefan Institute, Ljubljana, IJS-DP-7164, January 1995.

Križman, M. et al, (1996). A survey of Indoor Radon Concentrations in Dwellings in Slovenia, In: Proceedings of the IRPA Regional Congress, Portorose, September 4-8th, 1995 (Glavič-Cindro, D., ed.) J. Stefan Institute, Ljubljana, January 1996, pp. 66-70.

SPAIN:

Fernández, C.S. et al., (2017) Spanish experience on the design of radon surveys based on the use of geogenic information, Journal of Environmental Radioactivity 166, 390-397 (and reference therein).

SWEDEN:

Swedjemark, G.A. et al, (1993). Radon levels in the1988 Swedish housing stock. Indoor Air '93: 6. international conference on indoor air quality and climate, Helsinki (Finland), 1993, pp 491– 496 (only abstract available online).

Swedjemark, G.A., Residential radon Case 4 in the Swedish ICRP-project, SWIP, 2002.

SWITZERLAND:

Kropat, G. et al., (2014) Major Influencing Factors Of Indoor Radon Concentrations In Switzerland, Journal of Environmental Radioactivity 129, 7-22.

TURKEY:

Can, B. et al., (2012). Measurements of Indoor Radon Concentration Levels in Kilis, Osmaniye and Antakya, Turkey During Spring Season, J. Radioanal. Nucl. Ch., 292 1059−1063.

Köksal, E.M. et al, (2004) A Survey of Rn-222 Concentration in Dwellings of Turkey, J. Radioanal. Nucl. Ch. 259 213−216.

UNITED KINGDOM:

Miles, J.C.H. et al, (2007) Indicative Atlas of Radon in England and Wales, HPA-RPD-033, Health Protection Agency, United Kingdom, ISBN 978-0-85951-608-2.

Daraktchieva, Z. et al, (2015) Radon in Northern Ireland: Indicative Atlas, PHE-CRCE-017, Public Health England, United Kingdom, ISBN 978-0-85951-764-5.

Miles, J.C.H. et al, (2011) Indicative Atlas of Radon in Scotland, HPA-CRCE-023, Health Protection Agency, United Kingdom, ISBN 978-0-85951-701-0.

UKRAINE:

Pavlenko, T.A., Los, I.P., Aksenov, N.V., (1997) Exposure Doses due to Indoor Rn-222 in Ukraine and Basic Directions for Their Decrease, Radiat. Meas., 28, 733−738.

T. Pavlenko et al., (2014) The Ukrainian Pilot Project "Stop Radon", Nuclear Technology & Radiation Protection 29(2), 1-7.

List of abbreviations and definitions

EANR	European Atlas of Natural Radiation
EC	European Commission
IAEA	International Atomic Energy Agency
JRC	The Joint Research Centre of the European Commission
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organisation

List of figures

List of tables

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

- at the following standard number: +32 22999696, or

- by electronic mail via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

KJ-NA-29613-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2760/977726 (online)
ISBN 978-92-79-97643-8 (online)