

INDOOR RADON IN SLOVENIA

by

Janja VAUPOTIČ

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The Slovenian Radon Programme started in 1990. Since then, radon and radon short-lived decay products have been surveyed in 730 kindergartens, 890 schools, 1000 randomly selected homes, 5 major spas, 26 major hospitals, 10 major municipal water supply plants, and 8 major wineries. Alpha scintillation cells, etched track detectors, electret-based detectors and various continuously measuring devices have been used. On the basis of estimated effective doses, decisions were made on appropriate mitigation. In total, 35 buildings have been appropriately modified. The programme is displayed and results reviewed chronologically and discussed.

Key words: indoor radon, workplace, measurement, dose estimates

INTRODUCTION

The first radon measurements in Slovenia were made by the Jožef Stefan Institute in 1969 in the, at that time exploratory, Žirovski vrh uranium mine [1, 2]. Once the mining company had established its own radiation protection service, the Institute turned its attention to underground mines of coal, mercury, and zinc [3], karst caves [4-6], spas [7, 8], and a phosphate mill [9]. Indoor radon surveys started in 1985–86 when, in each of six urban and industrialized areas, 10-30 homes were selected for measuring – once in spring, autumn and winter – instantaneous air radon concentration with alpha scintillation cells [10-12]. The volume of the results was not sufficient to estimate population doses, but adequate to recognise the radon problem in the country and hence to provide a good basis for preparing a nation-wide radon programme. The programme proposal was sent to the Health Inspectorate at the Ministry of Health, the governmental body responsible for radiation protection, for evaluation. After its approval, a systematic indoor radon

survey was started in 1990. Firstly, kindergartens, schools, and homes, and then spas, hospitals, water plants and wineries were surveyed. Effective doses of employees were estimated and used by the Health Inspectorate as a criterion for undertaking mitigation measures. A number of buildings with high radon levels have been appropriately modified. In this review, the results of the Slovene Radon Programme are presented and discussed.

THE PROGRAMME

The programme was carried out in two steps. In the first period, 1990–92, instantaneous indoor air radon concentration was measured in 730 kindergartens [13-23] and 890 schools [19, 22-31] with alpha scintillation cells, and three-month average radon concentration in 1000 randomly selected homes [32, 33] with etched track detectors. At the same time, we were involved in radon monitoring in kindergartens in some neighbouring countries [14, 34-36]. In the second period, 1994–2002, we focused our attention primarily on kindergartens and schools with elevated radon levels. Additional monitoring, using a combination of various measuring techniques, provided data for dose estimates for the personnel as well as for children and/or pupils, on the basis of which the Health Inspectorate decided whether mitigation was needed or not. The Ministry of Education, Science and Sport established the Slovene Radon Centre as the scientific and technical support for undertaking mitigation measures. About 40 buildings have been

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Author's address:
Jožef Stefan Institute
P. O. Box 3000, SI-1001 Ljubljana, Slovenia

Author's e-mail:
janja.vaupotic@ijs.si

modified and radon levels reduced [16] to below 200-400 Bqm⁻³.

In addition, in the second period, the radon survey has been extended to other workplaces potentially exposed to radon. Thus, radon was measured and effective doses estimated for the employees of 26 major hospitals [37], 5 major spas [38], 10 major waterworks [39], and 8 major wineries.

RADON LIMITS

Up to 2002, we followed the ICRP recommendations [40] that radon levels should not exceed 200-600 Bqm⁻³ at home and 500-1500 Bqm⁻³ at workplaces. For the employees of kindergartens, schools, hospitals, spas, waterworks and wineries the first limit was taken into account because they are not declared as radiation workers. In the beginning of 2002, the Slovenian government issued a general law regulating radiation protection [41], also defining radon limits for air. They are: 400 Bqm⁻³ in homes, 1000 Bqm⁻³ at workplaces, and 200 Bqm⁻³ in buildings after mitigation. In addition, the Health Inspectorate uses the annual effective dose of 2.5 mSv per year as the value above which precautionary measures have to be initiated.

SLOVENE RADON CENTRE

The Slovene Radon Centre was established with the aim of designing and executing radon mitigation measures on an interdisciplinary basis. Experts in radon measurement and dosimetry from the Jožef Stefan Institute and the Nova Gorica Polytechnic worked jointly with experts in building engineering from the National Institute of Construction and Building Engineering. Firstly, radon experts carry out thorough measurements of concentrations of radon and radon short-lived decay products, as well as radon equilibrium factors and, in some cases, also the fraction of unattached radon short-lived decay products, by applying combined and complementary techniques. The main radon sources are identified. After the results, together with effective dose estimates, are discussed at the Health Inspectorate, a design for mitigation is prepared by the construction engineers and sent to the owner. Every major step in remodelling the building is supervised both by radon and construction engineering experts. In the end, radon levels are checked in order to prove the success of mitigation [16]. The report is sent to the Health Inspectorate. Following this, yearly radon checking is required.

In 1997 a one week training course entitled "Diagnosis and Mitigating Radon Problems in Buildings" was organised by the Slovene Radon

Centre and the Nova Gorica Polytechnic. The organisers invited eminent experts from Rutgers University, the Eastern Regional Radon Training Center, New Brunswick, USA, to introduce the main radon mitigation techniques to attendees with different profiles, such as health inspectors, radon experts, construction engineers and others involved in radon matters in Slovenia and neighbouring countries.

INSTRUMENTATION OF THE SLOVENE RADON CENTRE

The Radon Centre possesses various measuring devices for different purposes of survey. They are:

- *Alpha counters IGMA and PRM 145* with a set of different size calibrated *alpha scintillation cells* [1, 13] (RACI, AMES, Jožef Stefan Institute, Slovenia),
- *E-PERM System* [42]: *electret-based* short-term and long-term detector chambers (Rad Elec. Inc., USA),
- *Etched-track detectors* provided by Forschungszentrum Karlsruhe and evaluated at Forschungszentrum Karlsruhe, Germany [43],
- *AlphaGuard PQ2000* multiparameter radon monitor (Genitron, Germany),
- *System 30* combined continuous radon gas and radon daughter monitor (Scintrex, Canada),
- *RTM 2010-2* radon and thoron gas monitor (Sarad, Germany),
- *EQF 3020 and EQF 3020-2* [44] radon and radon progeny monitor system with separate measurement of attached and unattached decay products (Sarad, Germany),
- *Barasol* [45] radon monitor system (ALGADE, France),
- *Spectra 5011* alpha spectrometer (Sarad, Germany),
- *Doseman* radon personal dosimeter (Sarad, Germany),
- *Radim 5* radon monitor (Plch – SMM, Czech Republic), and
- *Gamma spectrometry* of samples of building material and soil is performed by the Medium and High Energy Department at the Jožef Stefan Institute.

For fast radon screening and searching for radon sources in a building, alpha scintillation cells are used. To obtain the annual exposure, etched track detectors are exposed all year round. With electret-based detectors, we distinguish the overall radon average concentrations from those measured during working hours only, to which a person is actually exposed. Continuous measurements enable diurnal variations of the concentrations of radon

and radon short-lived decay products to be observed. The values of the equilibrium factor and the fraction of unattached radon short-lived decay products, the two parameters playing a crucial role in radon dosimetry, can also be obtained.

In order to comply with the Quality Assurance/Quality Control requirements, all measuring devices have been regularly checked at the intercomparison experiments organized annually by the Slovenian Nuclear Safety Administration at the Ministry of the Environment, Spatial Planning and Energy [46-48]. We also participated in the international intercomparison experiments held in 1991 in Badgastain (Austria) and 1997 in Příbram (Czech Republic). In addition, alpha scintillation cells are calibrated monthly with $^{226}\text{RaCl}_2$ solution purchased from NIST (National Institute of Standards and Technology US, Standard Reference Material 4953D) [1, 49] and in about 10% of rooms etched track and electret detectors were exposed in duplicate.

RADON LEVELS

Kindergartens and schools

Distributions of the instantaneous indoor air radon concentrations in 730 Slovenian kindergartens and 890 schools [15, 25] are shown as log-normal plots in fig. 1 and as iso-concentration contours in fig. 2. In the karst region in the southern part of the country, radon emanates from deep soil layers through fissures and then enters buildings through cracks and faults in the floor slabs, thus enhancing indoor air radon concentrations. On the other hand, indoor radon concentrations are lower in the north-eastern part of Slovenia because the water saturated clay layers of the sedimentary strata prevent movement of soil gas containing radon.

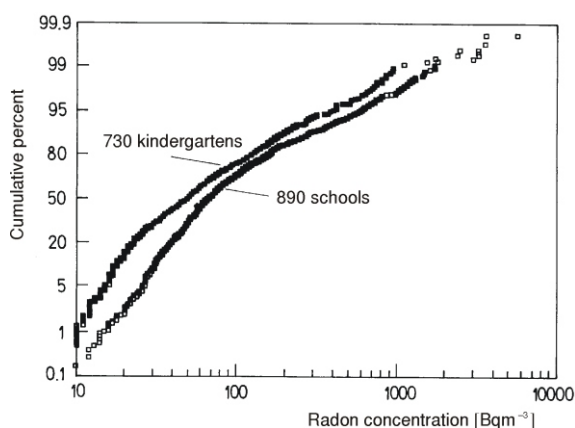


Figure 1. Log-normal distribution of indoor radon concentrations in kindergartens and schools

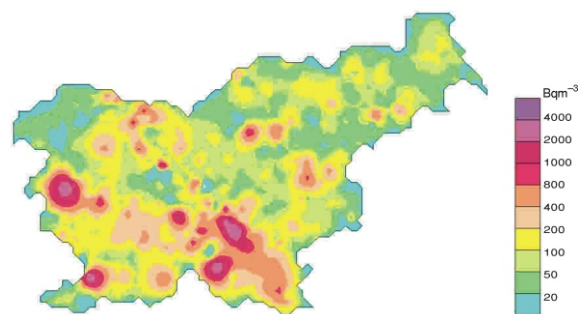


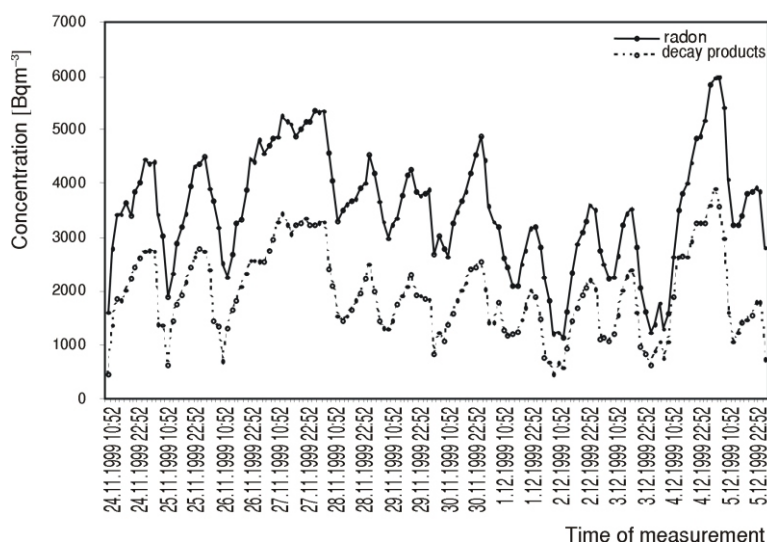
Figure 2. Radon iso-concentration contours in kindergartens and schools (in Bq m^{-3})

Statistics of kindergartens and schools exceeding the Slovenian radon limit of 400 Bq m^{-3} are summarised in tab. 1. Altogether, thorough radon measurements were carried out and annual effective doses of the personnel and children/pupils estimated in 123 buildings (45 kindergartens and 78 schools) with radon levels above this limit. On the basis of the measured radon concentration, equilibrium factor between radon and its progeny and duration of exposure periods effective doses to these personnel and children may be estimated. Here and in other parts of this paper the quoted effective doses received are estimates. In kindergartens, of the 2700 persons (260 workers

Table 1. Statistics of kindergartens and schools exceeding the Slovenian radon limit of 400 Bq m^{-3}

	Kindergarten	School
Total number of buildings	730	890
Rn concentration above 400 Bq m^{-3}	45 (6.2%)	78 (9.0%)
Total number of children/pupils	65,600	280,000
Number of children/pupils in buildings with Rn concentration exceeding 400 Bq m^{-3}	2700 (4.1%)	16,000 (5.7%)
Number of workers in buildings with Rn concentration exceeding 400 Bq m^{-3}	260	270
Maximum Rn concentration	5600 Bq m^{-3}	4680 Bq m^{-3}
Arithmetic mean	133 Bq m^{-3}	168 Bq m^{-3}
Geometric mean	58 Bq m^{-3}	82 Bq m^{-3}
Total number of modified buildings	16 (35.5%)	19 (24.0%)
No action (ignored requirement of health inspectors)	4 (9.0%)	13 (17.0%)
Rn concentration during working hours below 400 Bq m^{-3} – mitigation measures not request	25 (55.5%)	46 (59.0%)

Figure 3. Typical diurnal variation of radon concentration in a school



and 2440 children) 470 received effective doses of more than 2.5 mSv per year. In schools, of 16,000 persons considered (270 workers and 15,730 pupils), 750 received more than 2.5 mSv per year. In one of the high radon level schools, with occupants receiving more than 6 mSv a year, chromosome aberration analyses were performed [27]. Up to the end of 2002, 16 kindergartens and 19 schools have been successfully modified.

Typical diurnal variations of radon concentration in a school, with overnight maxima and minima in the afternoon of the working day, are shown in fig. 3. This type of data on diurnal variations is very important in detailed dose analysis.

Homes

In 1994, 3 month radon concentrations were measured in 1000 randomly selected homes during the winter, using etched-track detectors. Values ranged from 7 to 1890 Bqm⁻³, with a median of 54 Bqm⁻³. In 4.5% of homes the value exceeded 400 Bqm⁻³ [32, 33].

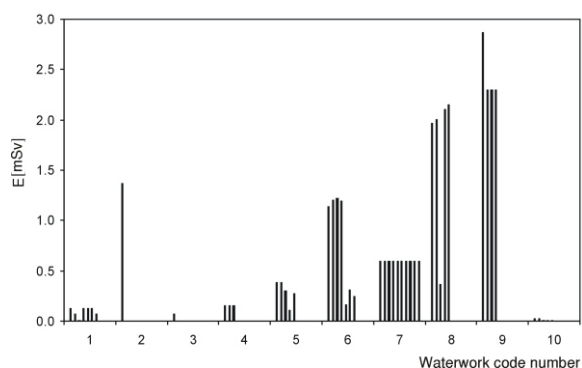


Figure 4. Annual effective doses of each employee in waterworks

All people concerned about radon levels in their home or working place can ask the Slovene Radon Centre to carry out measurement at their expense. In last five years about 250 measurements were performed.

Spas

Fifteen rooms of 5 major spas were surveyed for radon. Radon was analyzed in air and drinking water [38]. Because of very effective ventilation, air radon concentrations everywhere are kept below 250 Bqm⁻³. Therefore, under the present operational conditions and working regime there is no concern about the radon exposure of personnel.

Waterworks

Fifty two workplaces, attended temporarily by about 40 persons, in 10 major drinking water supply plants were surveyed. Radon in air and radium (²²⁶Ra) in water were analyzed [39]. Both instantaneous and 3-month average air radon concentrations were low at the majority of places, although up to 5 kBqm⁻³ was recorded at some. Because of short attendance times, radon exposure at these places is not high, as evidenced from fig. 4, showing annual effective doses of each employee calculated according to the ICRP-65 methodology [40].

Hospitals

Instantaneous and 1-month average air radon concentrations were measured in 186 rooms of 26 major hospitals, with the emphasis on basements [37]. Radon levels were mostly low, fig. 5, but in 7 rooms elevated radon concentrations were observed, in one case up to 15 kBqm⁻³, with a pronounced diurnal variation, fig. 6. Dose estimates were made for 1025 persons. Employees in the above mentioned 7 rooms received from 2.1 to 7.3 mSv annually, while annual effective doses for others are shown in fig. 7.

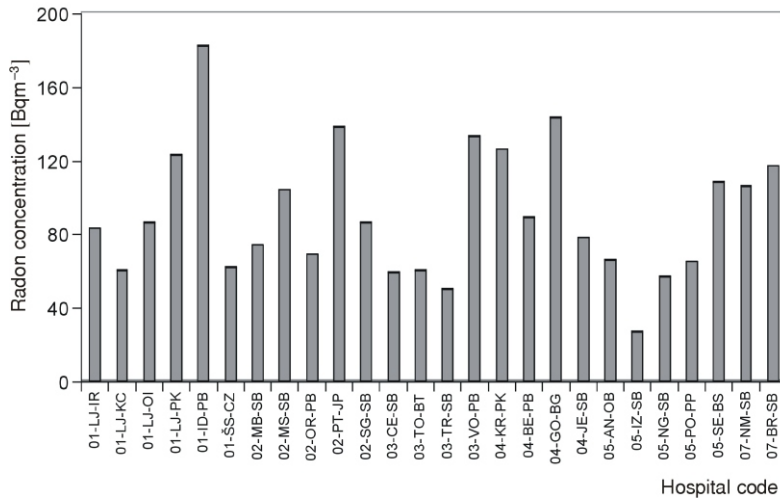


Figure 5. One month average radon concentrations in hospitals obtained by etched-track detectors

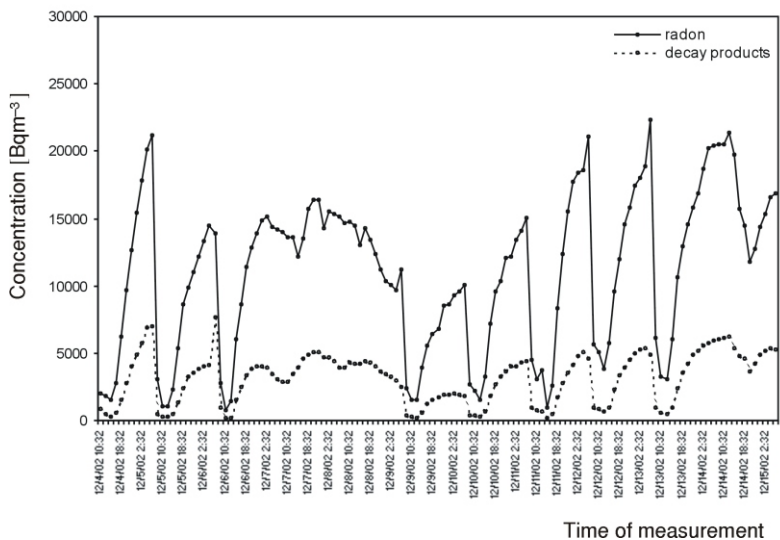


Figure 6. Diurnal variation of radon and decay product concentration in a hospital maintenance shop

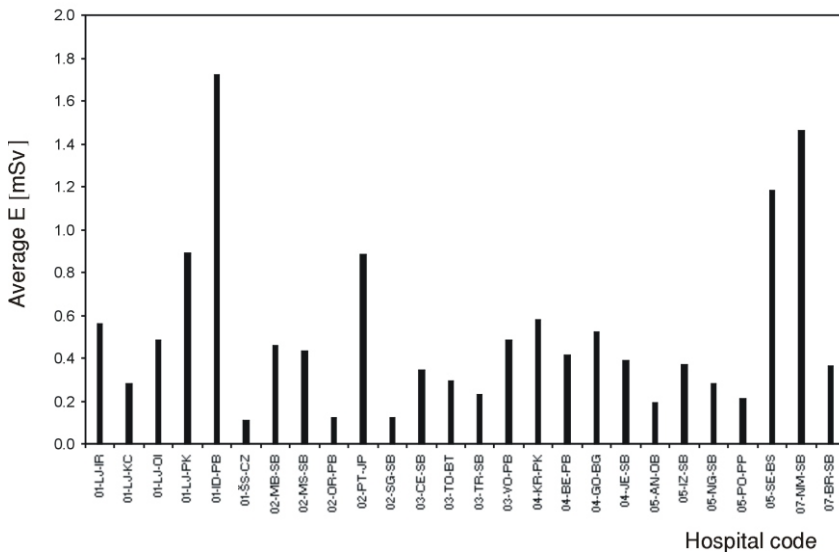


Figure 7. Annual effective doses received by employees averaged for each hospital

Wineries

Instantaneous and long-term average air radon concentrations in 8 major wineries, tab. 2, were below the Slovenian intervention limit of

400 Bqm⁻³. Only in one winery did radon levels exceed this limit, but only during the periods of ventilation shutdown, fig. 8. These periods do not affect the radon exposure of personnel, because nobody is present at that time.

Figure 8. Diurnal variations of radon and radon decay product concentrations in a winery

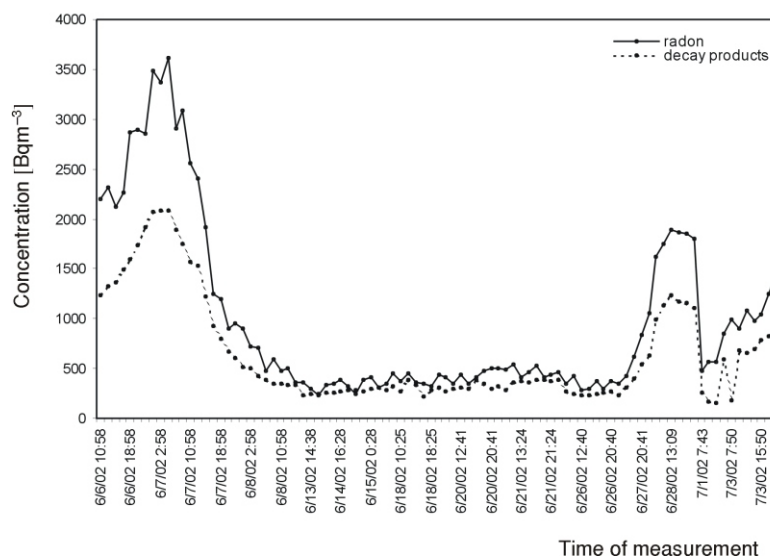


Table 2. Average radon concentrations in wineries

Winery	Time of measurement	Radon concentration Bqm ⁻³	
South-western part of Slovenia			
Winery 1	19.04-23.05.2002	141	16
		47	9
Winery 2	23.04-17.06.2002	91	3
		54	8
		42	7
Winery 3	23.04-18.06.2002	33	6
		88	10
		100	10
		73	9
North-eastern part of Slovenia			
Winery 4	30.05-19.07.2002	109	11
		119	12
Winery 5	06.06-05.07.2002	144	17
		233	21
		216	22
Winery 6	06.06-05.07.2002	456	27
		179	14
Winery 7	20.06-30.08.2002	256	15
Winery 8	20.06-13.11.2002	103	7
		80	6

CONCLUSION

Various living and working environments in which exposure to radon and its short-lived decay products may be expected were included into the indoor radon survey in Slovenia. In 5 major spas based on thermal and mineral water, effective ventilation keeps radon concentrations low, mostly below 250 Bqm⁻³, and no radiation protection concern is needed. The situation is similar in 8 major wineries with underground facilities, in which elevated radon concentrations (the highest value of 3500 Bqm⁻³) were found only during the periods of ventilation shutdown, when workplaces are not occupied. In some of the 15 major waterworks, ele-

vated radon levels (the highest concentration was 2600 Bqm⁻³) have been found, but the attendance time is short and the resulting effective dose is low. Nevertheless, longer maintenance work should be carefully planned. Of 186 rooms surveyed in 26 major hospitals, only in 7 rooms did the radon concentration exceed 400 Bqm⁻³, with the highest value of 2800 Bqm⁻³ in a basement maintenance shop. Concentrations higher than 400 Bqm⁻³ have been found in 45 kindergartens (of total 730), 78 schools (of total 890), and 42 homes and/or flats (of total 1000).

Special attention has been paid to public buildings such as kindergartens and schools with elevated radon levels in which additional thorough monitoring, using sophisticated and complementary measuring devices, was implemented. Based on the results of this monitoring, effective doses were estimated and used by the Health Inspectorate as the criteria for deciding whether mitigation is needed or not. In order to assure an interdisciplinary approach toward mitigation, the Slovene Radon Centre in which experts on radon matters and construction engineering work together was established. In total, 35 buildings have been successfully mitigated. The fundamental and applied research in the Radon Centre is strongly interrelated. Results of the first are immediately transferred into practice, and for problems envisaged in everyday monitoring, scientific solutions are sought. Hence, we use the advantage of performing fundamental research in real buildings, not in model houses, and thus try to simultaneously attain a high scientific level and practical value of our fundamental results.

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Јања ВАУПОТИЧ

РАДОН У ЗАТВОРЕНИМ ПРОСТОРИЈАМА СЛОВЕНИЈЕ

Словеначки радон програм покренут је 1999. године. Од тада се радон и краткоживећи продукти радоновог распада надгледају у 730 дечјих вртића, 890 школа, 1000 домова изабраних насумично, 5 већих бања, 26 главних болница, 10 великих градских фабрика воде, и 8 већих винарија. Коришћене су алфа сцинтилационе ћелије, траг детектори, електрет детектори, и различити уређаји за континуално мерење. На основу оцењених ефективних доза донете су одлуке о одговарајућој заштити. Укупно је на сврсисходан начин направљено 35 зграда. У раду је приказан програм, а резултати су хронолошки изложени и размотрени.