THE ASSESMENT OF THE RADON PROBLEM IN SWITZERLAND AND THE NEW NATIONAL RADON ACTION PLAN 2012-2020.

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Abstract

The potential risk of indoor radon for the public in Switzerland has been comprehensively investigated by the Federal Office of Public Health since 1994. Numerous radon measurements have been carried out to date and they show that several regions in Switzerland are affected by high levels of radon exposure. In a pilot study different methods of indoor radon prevention and remediation have been applied and tested. The results of these investigations and their implications are presented, and it is shown how the findings are used to inform and advise the public concerning protection against radon and how the radon expertise and the continuing education of construction experts are sustained. Furthermore, we present the new national radon action plan (2012-2020) approved by the Swiss Federal council, which incorporates the conclusions drawn from our investigations and describes how we plan to implement our current level of knowledge into practice.

Introduction

Investigations in the 1980s of the different contributions to the average annual exposure to ionizing radiation for the Swiss population showed that indoor radon represents a major fraction of the received dose. In order to better understand the radon problem in Switzerland, determine the potential of radon in different regions, and gain experience with different remediation methods the Radon Program Switzerland (Medici and Rybach, 1992) was established. On the basis of the results obtained in this program the legal requirements for dealing with the radon situation in Switzerland were introduced into the ordinance on radiological protection in 1994 mainly based on WHO recommendations (WHO, 1993). This marks the starting point of an intensification of the efforts to tackle the radon problem in Switzerland.

During the following years the main activities of the newly formed radon group at the Federal Office for Public Health (FOPH) were primarily focused on nationwide measuring campaigns, a pilot study on remediation methods, and the education of radon consultants in all three lingual regions of the country (German, French, Italian). The results of the measuring campaigns were used to assign each community with its potential radon risk and to create the

Swiss radon map. In addition, long-term measurements in selected houses were performed and also the concentration of radon in the atmosphere was determined at specific locations. A pilot study on remediation methods was conducted by building experts at the FOPH and investigated the suitability of techniques used in other countries to the special conditions in Switzerland. The findings from this study led to the publication of recommendations and a technical guide (see www.ch-radon.ch) and were introduced into the training of radon consultants, who more and more took over the planning and execution of remediation work in buildings affected by radon.

In recent years epidemiological studies have provided evidence that indoor radon is causing a significant number of lung cancer cases in the general population (Darby et al., 2006; Krewski et al., 2006). Moreover, the studies indicate that the current reference levels are too high, since an increased risk of lung cancer cannot be excluded even below 200 Bq/m^3. Based on these new findings and the experiences made by our radon group, the FOPH has launched a new National Radon Action Plan 2012 -2020 (FOPH, 2011). The plan lists seven principal measures, which should be implemented in the coming years: revision of the legal regulations; extending our knowledge of radon exposure in dwellings; the promotion of protective measures against radon in new buildings; planning an efficient strategy for remediation; including radon in the training of construction experts; improving public awareness to health problems caused by radon; developing the tools and methods. The Radon Action Plan 2012-2020 has been approved by the Swiss Federal council in May 2011.

Legal requirements in Switzerland

The legal aspects of the radon problem in Switzerland are regulated in the ordinance on radiological protection, which became effective in 1994. The ordinance defines a limiting value of the annual radon concentration in homes and dwelling of 1000 Bq/m^3 and of 3000 Bq/m^3 for work places. For new and renovated buildings a reference value of 400 Bq/m^3 has been defined. Measurements have to be performed by an approved measuring service and have to last at least one month. Approved measurements are saved in a radon database, which is operated by the FOPH. The access to the database is restricted to eligible persons. In

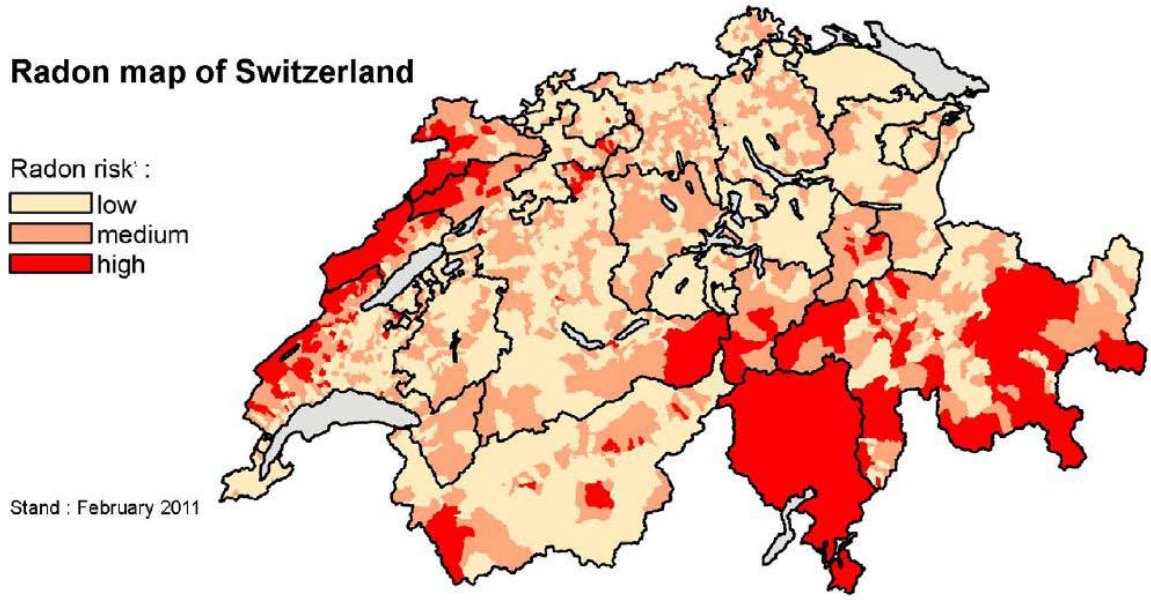

Figure 1: The Radon map of Switzerland. The classification criteria are given in the text. Source: GG25 ©Swisstopo

regions which have been defined as areas of high radon risk, a radon remediation can be enforced by the local authorities, in cases where the limiting value has been exceeded. In order to identify areas of high radon risk, an average radon concentration (Rn_a) in dwellings has been determined for each community based on at least 20 measurements. The communities have then been divided into three groups based on Rn_a:

- $Rn_a < 100$ Bq/m^3: low risk area
- 100 Bq/m^3 $\leq Rn_a < 200$ Bq/m^3: medium risk area
- $Rn_a \geq 200$ Bq/m^3: high risk area

This classification was used to create the Swiss radon map shown in Figure 1.

In particular the limiting and reference values do not correspond to the current level of knowledge anymore. In the ongoing revision of the ordinance it is planned to reduce the legal level in agreement with international standards (WHO, 2009; ICRP, 2010). However, since Switzerland is strongly affected by radon, a reduction of the reference levels would considerably enlarge the areas of high radon risk, encompassing a large fraction of the country.

Radon measurements

Since 1994 large measurement campaigns have been carried out all over Switzerland, in order to obtain enough data to classify all communities according to the criteria mentioned above and to create the radon map (Figure 1). In addition, emphasis was placed on regions, where high levels of radon were suspected to be found. The goal was to find as many buildings as possible with radon concentrations exceeding 1000 Bq/m^3. The campaigns were planned in collaboration with local authorities, which organized the dispatch of the dosimeters and their collection after the measurement. In Figure 2 the number of measurements per year is shown.

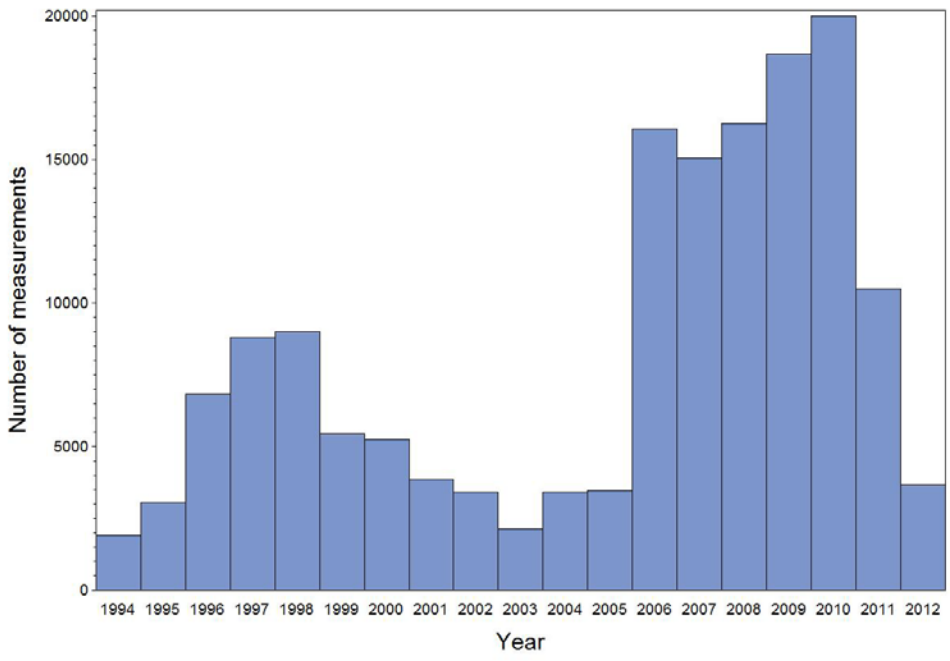

Figure 2: The number of radon measurements per year, only considering measurements in rooms which are used regularly, i.e. excluding cellars etc.

Only measurements in rooms which are occupied regularly are counted. The total number of measurements in the period 1994-2012 is 156761. This number does not correspond to the total number of dwellings, since in some cases more than one measurement has been

performed per house. All measurements have been carried out using passive dosimeters and lasted at least one month, i.e. all are approved and have been included in the radon database.

It is generally recommended to perform the measurements during the winter, when houses are usually heated, which supports the infiltration of radon. On the other hand, houses are evaluated on the basis of the annual average radon concentration. Therefore the measured value, which might have been determined during a period of one to several months, is extrapolated to an annual average. To account for the seasonal differences of the radon concentration a seasonal correction factor is applied. This factor has been determined on the basis of one-year measurements in roughly 300 buildings. In Figure 3 the distribution of the annual average radon concentrations in roughly 140000 buildings is shown. The large majority of buildings (~87%) has a radon concentration < 300 Bq/m^3. However, more than 3000 buildings are above the limiting value of 1000 Bq/m^3. On the other hand, it is very likely

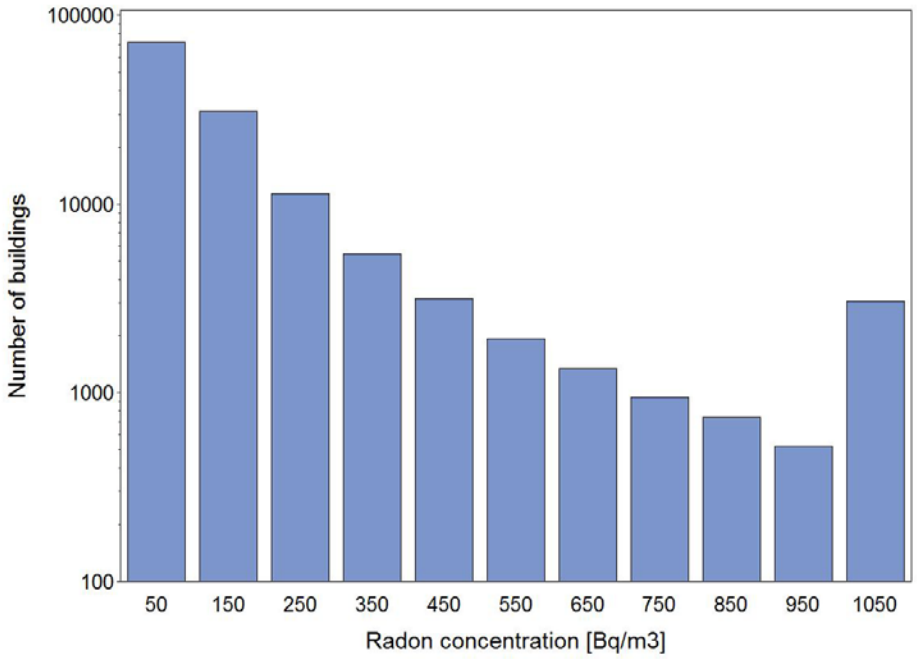

Figure 3: The distribution of the annual average radon concentration for roughly 140000 buildings. The numbers on the horizontal axis indicate the center of the corresponding interval. The last bin includes all buildings with a radon concentration > 1000 Bq/m^3.

that the distribution is somewhat biased towards higher concentrations, since the measuring campaigns have been particularly targeted to areas of high radon risk aiming to reduce the individual risk.

In general, the radon concentration in a house can exhibit large variations in the course of a year, which are not only caused by the heating, but also by specific weather conditions typical in Switzerland. These conditions can prevent the air at ground level to be changed, which leads to an enrichment of radon in the lowest air layers. However, these weather conditions are not equally pronounced every year. In order to test these influences, long-term measurements in some houses have been carried out during several years. They showed that the annual-average radon concentration in a specific house can change by more than a factor of 2 on a yearly basis. The details of the responsible processes are not well understood yet, and they are therefore not considered in the assessment of the radon problem in general.

A pilot study on remediation methods

Already before 1994 the FOPH had tested different remediation methods and tried to gain experience in reducing radon levels in different types of housing and circumstances. An additional goal was to use different materials and techniques and to find the most promising and effective approach depending on the suspected entry points of the radon gas. Three building experts at the FOPH, one for each lingual region, were concerned with finding appropriate buildings and evaluating the situation. It has to be emphasized that the FOPH consultants only made recommendations and were ready to accompany the remediation. The actual work had to be conducted by building professionals and had to be paid by the owner. Therefore, after the recommendations by the consultant only roughly half of the home owners were willing to carry out the remediation.

In order to evaluate the applied remediation methods in terms of their effectiveness, it is crucial to have measured the radon levels before and after the remediation at the same location. In addition, we required that these measurements should conform to the standards for approved measurements for our analysis. Unfortunately, these requirements were not met in many cases. Often the first measurements were carried out by electronic devices and were not confirmed by long-term passive measurements. In other cases the control measurement after the remediation was performed at another location, e.g. in the living room instead of the bedroom as before the remediation. These shortcomings reduce the number of cases suitable for analysis, but might be inevitable in a pilot study.

Finally, 130 cases with approved measurements before and after the remediation could be used for our analysis. They are distributed all over the country; although, most cases are located in the regions with the highest radon risks, e.g. Alps, Jura. The mean radon concentration among the 130 cases before the remediation was 1314 Bq/m^3 and 661 Bq/m^3 after the remediation. These values are rather high due to the fact that cases with particularly

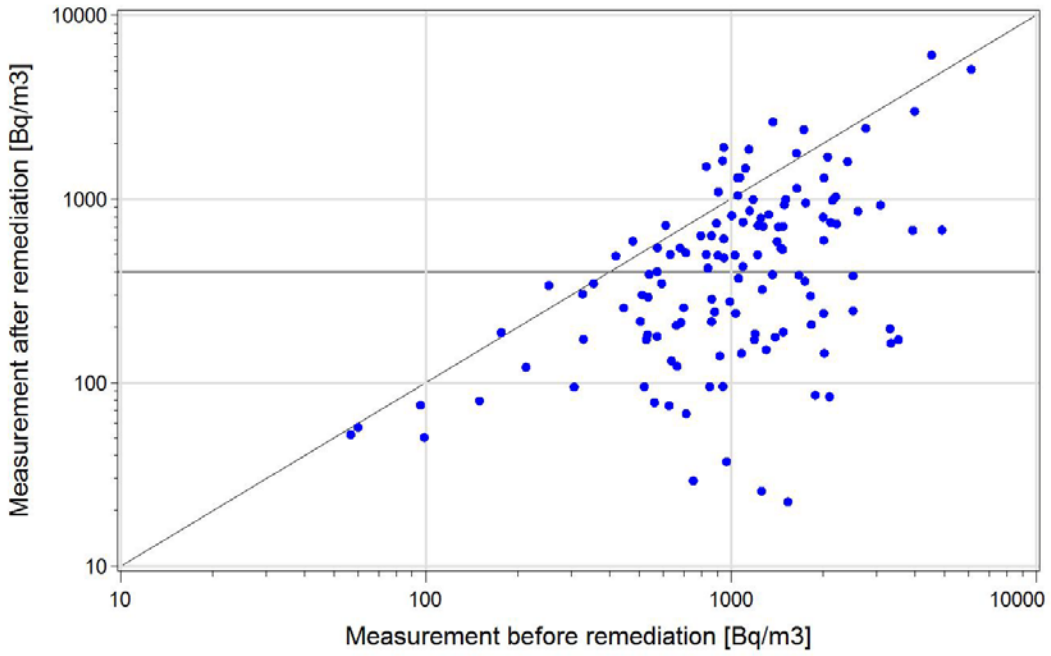

Figure 4: The radon concentrations in the 130 considered cases before (x-axis) and after (y-axis) the remediation. The horizontal line indicates the reference level of 400 Bq/m^3, which should be achieved by a radon remediation as per the ordinance on radiological protection. The uncertainties are of the order of 20% for these measurements.

high radon levels were considered for the pilot study. The two values also show that on average a reduction of roughly 50% of the radon level was achieved. In Figure 4 a comparison of the values before and after the remediation is shown.

It is obviously quite difficult to reach the reference level of 400 Bq/m^3 (indicated by the horizontal line in Figure 4) by a remediation. However, it has to be pointed out again that the initial values were rather high and that in many cases a substantial remediation was prevented by financial issues or the fact that the buildings were old and therefore difficult to modify.

Different methods have been used to reduce the radon concentration. They can be divided into four general types: improvement of the leak tightness; ventilation; radon drainage system or radon well; ventilation of a hollow space beneath the foundation. Since all our cases are concerned with existing buildings, methods requiring modifications beneath the foundation are not so numerous. The effectiveness in terms of the achieved reduction of the radon concentration of the four types described are summarized in Table 1. Note that in some cases two methods have been applied, which is why the total number of cases in the table is larger than 130. If two methods have been used, 50% of the reduction has been assigned to each method.

Remediation method	**Ventilation**	**Leak tightness**	**Drainage/ Radon well**	**Hollow space**
Number of cases	67	50	21	9
Average reduction all cases	38%	26%	48%	49%
Average reduction Initial radon concentration <1000 Bq/m^3	24%	31%	44%	52%
Average reduction Initial radon concentration >1000 Bq/m^3	48%	22%	56%	48%

Table 1: Reductions of the radon concentrations achieved by the four general types of remediation methods. The total number of cases is larger than 130, since in some cases two methods have been applied. In these cases 50% of the reduction has been assigned to each method.

The more incisive methods (drainage/radon well, ventilation of hollow space) are more effective than simpler approaches. On the other hand ventilation and the improvement of the leak tightness perform quite differently depending on the initial value of the radon concentration. If the initial radon concentration is high (>1000 Bq/m^3, corresponding to the limiting value in Switzerland) a ventilation performs better than the improvement of the tightness; if the initial radon concentration is rather low the situation is vice versa. Such findings can offer some help in evaluating a specific situation and in working out the most promising approach to solve the radon problem in a building. In terms of costs, methods using ventilation, either in the building or in a hollow space, are in general much cheaper than other methods. However, since in some cases we do not have any information about the costs and for the others only rough estimates, we cannot analyze the cost-effectiveness in detail.

In order to improve our knowledge of radon remediation in Switzerland, we have started an initiative to collect data from all radon experts carrying out such work asking them to complete a specific form and share their information. This will allow us to carry out a more

detailed analysis of the suitability, effectiveness, and costs of the diverse methods of radon remediation applied in Switzerland.

Education of radon consultants

Gaining knowledge and experience on radon remediation, the FOPH, in collaboration with several universities of applied sciences, started to work out training courses for interested building and construction experts. The goal was to commit radon consultation and prevention to the private sector. The radon courses had to be developed and organized in all three lingual regions in Switzerland, i.e. the course documentations had to be available in German, French, and Italian. The successful participants of the radon courses are added to the list of approved radon consultants published by the FOPH.

In order to keep contact, guarantee continuing education, and monitor the activities of the approved consultants, the FOPH has appointed three radon delegates, one for each lingual region, who work at an architecture or building construction division of a university of applied sciences. The delegates contribute to the elaboration of advanced radon courses, follow the developments of new remediation techniques and materials, and support the consultants in complicated remediation cases. Moreover, they organize yearly meetings of the consultants, where the FOPH discusses the developments on the national level and the consultants can present their work. As mentioned in the previous section, the FOPH encourages the consultants to report their radon remediation works in order to enlarge our data base started with the pilot study.

At present there are 146 approved consultants (43 German, 46 French, and 57 Italian speaking). Since it is very likely that the Swiss legal level for the radon concentration in buildings will be reduced in the current revision of the ordinance on radiological protection, the FOPH anticipates a growing demand among building experts to become an approved radon consultant.

The National Radon Action Plan 2012-2020

Since the radon program started in 1994, the knowledge about the radon situation in Switzerland has been significantly extended. However, there are still many aspects of the radon problem, where improvements are necessary and new challenges have arisen. It has become clear that the focus of the main activities of the FOPH has to be adjusted. Therefore, a new national radon action plan has been developed, which defines seven major work areas, where improvements should be achieved in the coming years.

1. Revision of the legal regulations

New findings of epidemiological studies (Darby et al., 2006; Krewski et al., 2006) indicate that the assessment of the risk of indoor radon has to be reevaluated. This is also supported by new recommendations issued by several international organizations (WHO, 2009; ICRP 2010; and others). It will therefore be necessary to introduce new limit and guideline values into the legislation on radiological protection. To prepare the upcoming revision of the ordinance on radiological protection the FOPH has to frame propositions for the amendment of the articles dealing with radon. In the process it will be crucial to involve all concerned parties, in particular the executive authorities in the cantons and the construction and real estate sectors.

2. Extending our knowledge of radon exposure in dwellings

The new risk estimation does also affect the classification of the radon risk areas. Assuming a doubling of the radon risk factor, the Swiss radon map shown in Figure 1 would turn much redder. As a consequence the denser populated regions in the Swiss plateau will turn into areas of medium to high radon risk, which will increase the expected number of lung cancer diseases due to radon exposure compared to the more affected, but less populated regions in the Alps and the Jura. A study into the attributive risks due to radon conducted with data concerning Switzerland from 2005 confirms this assumption (Menzler & Kreienbrock, 2005). Future measuring campaigns will therefore not be exclusively targeted to high risk areas, but should be directed to evaluate the radon risk depending on the type of construction. Special emphasis will be given to measurements in schools and kindergartens, since children have a much greater sensitivity to the effects of ionizing radiation (in fact, there is poor knowledge concerning the radon exposure in childhood), and to other administrative buildings that are conceived for extended stays (hospitals, prisons, communal accommodations, etc.). In fact, in cantons where measuring campaigns in schools have been carried out, the fraction of school buildings with high radon levels has turned out to be higher than of single family houses.

3. The promotion of protective measures against radon in buildings

If it would be guaranteed that new buildings are constructed radon safe, the radon problem would disappear in the long run. To this end radon prevention has to be considered already at the design stage of a new building. This approach is also much cheaper than being forced to remediate afterwards. In view of roughly 30000 building permits per year in Switzerland, many opportunities are missed if radon is not accounted for before the construction of the building. The situation could even aggravate, since more and more low-energy houses are built, which can favor high radon levels. That this effect might have set in already is indicated in Figure 5.

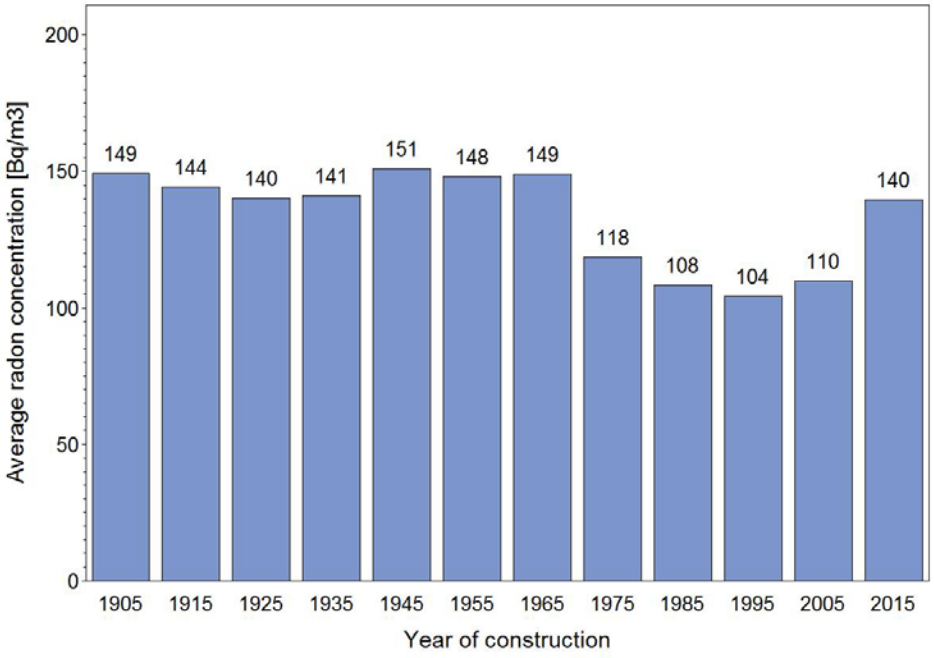

Figure 5: The average radon concentration as a function of year of construction. The dates indicate the middle of the corresponding decade.

The average radon concentration remained rather constant from the beginning of the century until the 1960s. The general shift in building construction from strip foundations to continuous ground slabs in the 1970s helped to reduce the average radon levels. However, in the current decade the average radon concentration increased again, which is likely due to a better isolation of the building shells to save energy. In order to reverse this trend stricter building regulations are required, which have to be worked out in collaboration with the local executive authorities.

4. Planning an efficient strategy for remediation

Another consequence of the new risk evaluation is the necessity to remediate more buildings to protect the population. For Switzerland it is estimated that the number of radon remediations will increase by a factor of ten. The current resources are inadequate to meet this challenge. We have already started an initiative to monitor radon remediations and to collect as much information as possible about applied methods and techniques. Moreover, the remediation results have to be documented and recorded. This will allow us to identify the most effective remediation methods for specific cases from a cost/performance point of view. On the international level the FOPH hosts an internet platform to exchange remediation methods and experiences (www.worldradonsolutions.info). Finally, a quality control of the remediation must be carried out based on an accredited measurement, which should be repeated some years later to ensure the long-term effectiveness of the remediation measure.

A special challenge arises from the increasing number of energy-conserving remediations, which are government-funded. On the one hand, an energy-conserving remediation offers a convenient opportunity to go about a radon problem, if present. On the other hand energy saving measures can create a radon problem, where none has existed before. This is indicated by a recent study, which compares the radon concentration in dwellings before and after an energy-conserving remediation (Pampuri et al., 2012). The average radon concentration increased by roughly 26% in the 163 analyzed buildings. It is therefore imperative to coordinate the activities between energy conservation and radon prevention. This implies the guarantee of a low radon level in the strategy of energy-conserving remediation. Thus, the involvement of the local authorities responsible for energy and radon is required.

5. Including radon in the training of construction experts

There are still many architects and construction experts who are not aware of the radon problem, particularly those working in the areas of middle and low risk. Including radon in the training of building professionals is therefore one of the priority actions to be carried out if remediation techniques and protective measures against radon are to be put into practice on a permanent basis. One of the first measures taken by the FOPH in that regard is the appointment of three radon delegates anchored at three universities of applied sciences educating building professionals. The delegates try to establish the task of radon prevention in the basic courses at their schools. It is anticipated that other universities will follow in their track, in particular since lower limiting values require an increased recruitment of competent specialists in this field.

6. Improving public awareness to health problems caused by radon

As already discussed, the reevaluation of the radon risk turns most of the country into a medium or even high risk area. This means that the radon problem should be a concern for the entire population. However, currently most of the people in Switzerland do not know about radon; 60% have never heard about the radon problem, 30% in high-risk areas (Gruson et al.,

2010). The FOPH tries to increase the awareness of radon, in particular among homeowners. One possible measure could be to introduce an obligation to indicate the radon value of a house in all property transactions and even to include this indication in rental contracts. Since the corresponding regulations are in the responsibility of local authorities, the implementation of such a measure is complicated. Another possibility is to publish information material for homeowners or builders. In this regard, the FOPH, in collaboration with authorities in the other Alpine countries Germany, Austria, and Italy, has published brochures covering the topics: mitigation measures in existing houses; precautions for new buildings; the effect of retrofitting thermal insulation; measurement and evaluation. These brochures are distributed as part of the documents handed out together with building permits.

7. Developing the tools and methods

There are many aspects of the radon problem, which could be better understood and many problem solving methods, which could be improved. The action plan focuses on two areas. Since the limiting values are likely to be lowered, the measurement accuracy has to improve at lower radon levels, where the uncertainties are typically higher. This requires an adaption of the measurement protocols and a stricter quality control of the measuring devices. In addition, short-term measurements will become more important if the radon level of a house has to be communicated during a real estate transaction. This requires a measuring technique, which allows the assessment of the radon level of a building in a rather short period of time (e.g., one week), taking into account daily and seasonal variations. These techniques have to be thoroughly tested and analyzed, so that the measuring results can be legally relevant. Secondly, a more detailed statistical evaluation of the available data should be considered for the immediate future. The influence of thoron and the building material has to be studied, as well as how radon spreads in buildings and the fact that upper floors of dwellings exhibit considerably lower levels of radon. Finally, the way in which geological factors influence the presence of radon has to be better understood. An improved knowledge of these aspects would allow a more efficient search for high radon levels, based on a predictive mapping of risk as a function of geographical and architectural criteria. Projects have been started in these fields.

Conclusions

The challenge posed by the radon problem in Switzerland has been accepted by the FOPH more than 20 years ago. Since then many aspects of radon in living and working spaces have been investigated and many improvements in terms of prevention and mitigation have been achieved. Thousands of houses and workplaces have been measured and many of the most affected buildings have been remediated. The FOPH shares its knowledge and experience with public authorities, schools, and involved organizations in other countries and in turn profits from their expertise and know-how. In order to make further progress and to be prepared for the latest developments in terms of new risk evaluations and building techniques a new national radon action plan has been worked out. The plan serves as a guideline in the coming years and will bring us a step closer to radon-safe living and working environments. In fact, protecting the population from radon represents a significant contribution to the reduction of air pollutants and therefore to the general improvement of the indoor air quality.

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