Assessment of radon exposure in Austria based on geology and settlement

Valeria Gruber*a, Claudia Seidelb, Franz Josef Maringer*a,b

aBOKU – University of Natural Resources and Applied Life Science, Low Level Counting Laboratory Arsenal, Faradaygasse 3, Objekt 214, 1030 Vienna, Austria.
bBEV – Federal Office of Metrology and Surveying, Arltgasse 35, 1160 Vienna, Austria.

Abstract. In Austria a fundamental radon indoor data net (about 40 000 measurements) exists. These radon indoor data are standardized and provide averaged political communities’ values. This data net should be enhanced by soil gas measurements with regard to geological conditions, to avoid averaging and influences by political boundaries. Different geological units (characterized by geology, geochemical conditions, mineralogy, geophysics) will be surveyed regarding radon concentration by soil gas measurements and estimated to their potential radon hazard. To assess the radon exposure of the population geological units are selected which are either existing settlement areas or potential ones. So this survey can also provide a basis for land use planning. In this paper results of first studies for this purpose are shown. 160 soil gas measurements were carried out in different soil and sediment deposits originating from different ice age glacier movements in the Alps. These deposits are popular settlement areas, and indoor radon levels of some 1000 Bq/l were detected. 50 % of the results of soil gas radon measurements were above 60 kBq/m 3, 18 % above 120 kBq/m3, which is likely to exceed the indoor radon standard of 400 Bq/l according to the Austrian standard ÖNORM S 5280-2. Higher radon activity concentrations were found in older ice ages, because of further progressed weathering. The radon soil gas measurements were carried out in different seasons to verify seasonal variations, and other parameters like Ra-226, Ra-228 activity concentration in soils, radon emanation factor, soil permeability and soil moisture were determined and related to the radon activity concentration. According to the example of this study, further soil gas measurements will be carried out in selected geological units.

Additional research on the impact of actual dwelling and inhabitation situation on public exposure due to radon in Austria is being done currently. The soil gas radon measurement data are used as input for geo-statistical modelling. Based on the results an applied assessment and distribution of radon exposure of the population can be carried out and used for radiation protection measures and precautions like regulations, health studies, land use planning and urban development. First exposure assessments and distributions complete this paper.

KEYWORDS: radon exposure; soil gas measurements; geology; ice age deposits; settlement areas; land use planning

1. Introduction

It is well-known that the radioactive noble gas radon (Rn-222) and its progenies increase the risk of lung cancer [1-3]. Hence radon measurements, precaution and reconstructions measures and their implementation to guidelines and legal foundations are major topics of research projects. In Austria radon indoor measurements are well established and a fundamental indoor data net (about 40 000 measurements) exists resulting from the “Austrian National Radon-project (ÖNRAP)” [4]. These indoor data are standardized and represent the medium radon risk (radon potential) in a community or district and are visualized in the Austrian Radon Potential Map [4-5]. The well established indoor data should be enhanced by soil gas measurements with regard to geological conditions, to avoid averaging and influences by political boundaries, but considering influences of geologic zones.

In Austria 40 % of the population radiation exposure is caused by inhalation of radon and radon progenies, which equals a medium effective dose of 2 mSv/a. The contribution varies from 0.8 to 100 mSv/a, depending mainly on geology and building construction [6]. Considerations of geological

* Presenting author, E-mail: valeria.gruber@boku.ac.at
conditions and dwelling and inhabitation situations in Austria in co-operation with radon indoor and
soil gas measurements should afford fundamental assessments of radon exposure of the population,
which can be applied for radiation protection and precaution measures and implemented for land use
planning and urban development.

2. Legal Situation in Austria

Since the 1970s lung cancer risk due to indoor radon aroused increased interest in radiation protection
in Austria. In 1992 the Austrian Radiation Protection Commission published a recommendation [7] on
annual average indoor air radon activity concentrations based on publications of the ICRP and the
European Commission: 400 Bq/m³ as intervention level for existing buildings, and 200 Bq/m² as
design level for new buildings.

All scientific and practical experience on radon gained in Austria was incorporated recently into three
Austrian Radon Standards:
ÖNORM S 5280-1: Radon, measuring procedures and their applications [8]
ÖNORM S 5280-2: Radon, part 2: Constructive precaution measures for buildings [9]
ÖNORM S 5280-3: Radon, part 3: Mitigation measures for buildings [10]
These standards include comprehensively the state of the art and best technology for radon
measurement, precaution and mitigation for buildings in Austria at present.

In January 2008 the Austrian Ministry for Environment published the Ordinance on Natural Radiation
Sources [11]. In this document the legal radiation protection principles concerning natural radiation at
workplaces (NORM) are regulated. For Rn-222 an exemption level of 400 Bq/m² annual average at
workplaces and two intervention level for workers – 1 mSv/a and 6 mSv/a – have been established.
The maximum additional annual effective dose due to the exposure by Rn-222 inhalation of non-
radiation workers and the public is limited to 1 mSv/a. Workers who are potentially exposed at
workplaces with natural radiation sources between 6 mSv/a and 20 mSv/a are defined as radiation
workers with specific radiation protection requirements.

3. Materials and Methods

As described above the well established soil gas measurements (that methods are not described here -
for further information see [4-5]), should be enhanced by soil gas measurements with regard to
geological dependencies and characteristics. Therefore as a pilot project 160 soil gas measurements
were carried out within a diploma thesis [12] in 2003/2004 at different measurement locations around
Gmunden, Upper Austria. In this area ice-age deposits from different ice ages (Würm (W), Riss (R),
Mindel (M), Günz (G)) exist, and elevated indoor radon levels were found in this region within the
ÖNRAP measurements [4]. The uranium and radium contents of soil in these northern Limestone Alps
are rather low and elevated indoor radon concentrations are not expected primarily. But investigations
in Scandinavia also showed higher radon potential in ice age deposits [13]. The soil gas measurements
were carried out by pore air probes with the ‘principle of lost tip’. Steel probes with different lengths
(1, 1.6, 2.5 m; 12 mm diameter) were pounded into ground by a hammer with a sharpened tip at the
lower end. Afterwards, the tip is pushed a few centimetres lower by a wire inserted into the probe, so a
cavity is formed at the lower end of the probe. After sealing the top of the probe with a rubber, soil gas
is collected out of the cavity with a 150 ml syringe (Fig.1). 100 ml of the collected soil gas sample is
injected directly in one of the 3 used direct indication pulse ionisation chambers ‘Alpha Guard’ by
Genitron. The Alpha Guards were calibrated to this geometry in the laboratory before with a radon
calibration barrel and a radon emanation source. The ionisation chambers were operated with 10
minutes measurement values, the first 10 minute measurement value was rejected, to avoid impact by
thoron concentration in the soil gas. Additionally the permeability of soil was determined at every
measurement point by aspirating soil gas from the probe with a pump and measuring the flow rate and
pressure. So the permeability can be estimated by the formula by Damkjaer and Korsbech [14], but
with the applied measurement setup the estimation is afflicted with high uncertainties and should only
supply dimensional information. Soil samples were taken with a slitted probe at some measuring
points to determine the Ra-226, U-238 and Ra-228 activity concentration of soil by
Gammaspectroscopy and the radon emanation coefficient was estimated out of these measurements. The soil gas measurements were carried out in summer, winter and autumn for different weather conditions and in different zones of the moraines (end moraine (EM), ground moraine (GM), terraces (T)). At every measurement location at least three single measurement points in different depths and with about 10 m distances (measuring profile, Fig.2) were operated to reduce uncertainties caused by stones or leakages.

Figure 1: Soil gas sampling in winter

Figure 2: examples for measurement profiles in different ice age zones in geological map

More soil gas measurements like the above discussed should be carried out in different geological zones in Austria and the results should be combined with the existing indoor radon data for fundamental population dose assessment. Some different studies are in progress for this purpose, e.g. improving the Austrian Radon Potential Map by Bayes statistics with regard to geological radon availability [15]. To enhance the radon dose estimations all these studies should be combined and extended by more soil gas measurements and additionally rounded off by taking into account the actual dwelling, inhabitation and settlement situation. Therefore in this paper the existing soil gas measurements in the area of Gmunden are related to the radon indoor data in this region. Additionally the impact of building construction of dwellings and inhabitation situation to indoor radon concentration is surveyed. For this purpose a population weighted mean indoor radon activity concentration of a geographical unit (1), dependent on the population distribution in Austria, Upper Austria and the region of Gmunden is estimated and defined with data by the Statistik Austria [16] and ÖNRAp [4] and also the population development and migration influences are studied. This research should be done with a combination of radon in soil gas and indoor results in the future, but because of less radon concentration in soil gas data yet, this modelling is only done with indoor data in this paper.

\[
\overline{wR} = \frac{\sum P_i \cdot R_i}{TP}
\]

\(\overline{wR}\) … population weighted mean indoor radon activity concentration of a geographical unit (weighted mean radon concentration) [Bq/m³]

\(P_i\) … population in the district or community \(i\) of the surveyed geographical unit

\(R_i\) … average indoor radon activity concentration in district or community \(i\) (based on the actual indoor radon measurement [Bq/m³])

\(i\) … number of surveyed districts or communities

\(TP\) … total population in the surveyed geographical unit (e.g. province)
4. Results and Discussion

4.1. Soil gas measurement results in ice age deposits

According to the ÖNORM 5280-2 [9] (see chapter 2), the radon activity concentration in soil gas is classified in three classes (1: <60 kBq/m³, 2: 60-120 kBq/m³, 3: >120 kBq/m³). Results of these soil gas measurements are also discussed in [17]. 18 % of the results of soil gas radon measurements in ice age deposits are above 120 kBq/m³, 50 % above 60 kBq/m³. Taking into account the permeability of soil like in other models [18] the radon potential can be high, although the radon activity concentration is relatively low e.g. in high permeable gravel terraces. The soil gas measurements in different zones of the ice age deposits in the northern limestone Alps show the highest radon activity concentrations in older ice ages (Riss, Mindel) because of a further progressed weathering, resulting in a more fine grained soil and therefore a higher radon emanation (Fig.3). In the youngest ice age (Würm) the soil is stony with a very high permeability \(10^{-11} \text{m}^2\) and rather low radon activity concentrations (<30 kBq/m³). The different zones in the moraines (end moraine (EM), ground moraine (GM), terrace (T)) have different conditions (weathering, grain size) and therefore a different permeability which ranges from \(10^{14}\) to \(10^{-11} \text{m}^2\). Highest radon activity concentrations were measured in end moraines, especially in ice age Riss with about 260 kBq/m³ and a medium permeability. It seems that this ground has – caused by weathering – a ratio of fine grain size and yet not too high compactness and density of soil for a high radon emanation factor. The determination of emanation factors out of the token soil samples by gammaspectroscopy range between 0.16 in ice age Würm and up to 0.50 in the Riss end moraines. The soil gas measurements were carried out in summer, autumn and winter for valuation of the impact of seasonal effects on the radon activity concentration in soil (Fig.4). In summer the air temperature was high (about 30°C) and the ground very dry, in autumn the ground was very wet and the air temperature about 5°C, in winter the ground was snow covered, but not frozen. As expected, radon activity concentration in soil was lowest in summer because of the dry soil and highest in autumn, because the emanation factor is highly dependent on soil humidity [19]. Higher soil gas activity concentration was expected in winter, but the ground was not frozen and not as wet as in autumn.

In Fig.5 the minimum, maximum and mean value of the measured radon activity concentration in soil gas at measurement locations in the district of Gmunden (area 1432.4 km²) are compared with the medium indoor radon activity concentration in the 20 communities by ÖNRAP. The radon activity concentrations in soil gas given in the figure are minimum, maximum and mean values of all soil gas measurements at one measurement point (different seasons, different depths). At each measurement location the zone and age of the ice age deposit is listed and the mean values are classified according to the above mentioned ÖNORM 5280-2 [9] (red, orange, yellow). The indoor radon value is the mean radon activity concentration of all measurements in this community by ÖNRAP, also classified according to the ÖNORM S 8280-2 [9] (light blue, blue, dark blue). The radon in soil gas results show that the measured activity concentrations at one measurement location in different depths and seasons...
in the most cases vary within a wide range. The highest mean radon activity concentration in soil gas was detected in end moraines and in the older ice ages as discussed above. Deposits of older ice ages are found in the north of district Gmunden, whereas in the central part of the district only ice age deposits of the youngest ice age Würm are available. The figure points out, that the radon activity concentration in soil gas and the medium indoor radon activity concentration in a community do not correspond very well. The highest radon activity concentrations in soil gas were detected in communities with a medium indoor activity concentration of below 200 Bq/m³. So this points out that averaged political communities’ radon values often not consider high radon risk caused by geology in some regions. Therefore it is fundamental for radon risk assessments to combine indoor data with soil gas measurements regarding to geological aspects. Additionally further studies have to be done to determine the impacts on radon activity concentration in soil gas (meterological, physical – e.g. Baumgartner, 2006 [20, 17]) on the one hand, and transfer from radon in soil gas to indoor air, taking into account the building constructions and environmental effects on the other.

4.2. Radon exposure assessments in Austria

For the above discussed intention of a fundamental assessment of radon exposure of the population in Austria as a first step a Austrian population weighted mean indoor radon activity concentration according to formula (1) is estimated out of the mean annual indoor radon concentration of the Austrian districts measured within the ÖNRAP [4] and the population distribution [16]. In Fig.6 the classified mean annual district indoor radon concentration is shown, together with the population number in each district. The classification in this case is not the one given in the ÖNORM S 8280-2 [9], because the mean district indoor radon concentrations are rather low, and so a finer classification was chosen. Only few districts show a mean annual indoor radon concentration of above 200 Bq/m³, and with this rough averaging with political district boundaries, no clear correlations with geology can be found. According to formula (1) a weighted mean radon concentration for the Austrian population (2001) of 102.2 Bq/m³ was estimated, which equates a population weighted effective dose of 1.70
mSv/a with regard to ICRP65 [21] and Friedmann, 2007 [4]. The measurements within the ÖNRP were done from 1992 to 2003, therefore the data are primarily related to the population of 2001 (the last population census in Austria), but it is also interesting to combine the mean annual indoor concentrations data from ÖNRP with former population to see the impact of population variation and migration to weighted mean radon concentration. The weighted mean radon concentration for the Austrian population in 1991 is nearly the same with 101.7 Bq/m³ (weighted effective dose 1.69 mSv/a). Considered with the data from only one federal state of Austria more variation is detected. The weighted mean radon concentration in Upper Austria is clearly higher with 165.7 Bq/m³ (weighted effective dose 2.76 mSv/a), because of geology (granite and gneiss, ice age deposits).

Figure 6: Mean annual indoor radon concentration in Austrian districts with population distribution 2001 (data source [5, 16])

In Fig.7 population change in the districts of Upper Austria (one of Austria's 9 provinces) is illustrated from 1869 to 2001, showing the relative population (percentage of the total Upper Austrian population in the district) and the total Upper Austrian population. In Fig.8 the population weighted mean effective dose by radon in Upper Austria is shown, which decreases from 2.81 mSv/a in 1869 to a minimum of 2.62 mSv/a in 1951 and than rises constant to 2.76 mSv/a in 2001. This distribution can be explained with the stagnation of the population growth in Linz, the capital of Upper Austria since the 1960s and increase of population in the surrounding districts (e.g. Linz Land, Urfahr Umgebung), which have higher medium radon activity concentrations (Fig.9) because of geology, building construction and living situation. In this survey, only population variations were considered, impacts of different building construction in former times are not taken into account.

As a model different possible future population migration scenarios in Upper Austria were simulated and surveyed for their impact on the population weighted mean radon concentration and effective dose of the Upper Austrian population. As an example 15 % of the population of the rural districts migrates to the central region of Upper Austria (districts Linz, Steyr, Wels, Wels Land, Linz Land, Grieskirchen, Eferding). This migration reduces the weighted mean radon concentration to 162.8 Bq/m³ (weighted effective dose 2.71 mSv/a), although the district Linz Land has a rather high mean radon activity concentration (248 Bq/m³), but clearly the highest mean radon activity concentration exists in the district Freistadt (Fig.9).
A second assumption is a migration from the city (Linz) to the surrounding districts (Urfahr Umgebung, Perg, Eferding, Linz Land). If the population grows by 10% in the surrounding districts and stagnate in the city with a constant total population in Upper Austria, the population weighted mean indoor radon concentration increases to 168.5 Bq/m³ (weighted effective dose 2.81 mSv/a), because of higher mean indoor radon activity concentration in the surrounding areas, although the relative population is rather low in these districts, except Linz Land (Fig.9).

**Figure 7: Population distribution in Upper Austria from 1869-2001**

**Figure 8: Population weighted mean effective dose in Upper Austria from 1869-2001**
Within the above discussed impact to the population weighted mean radon concentration of migration models and population distribution, building construction and living situation were not taken into account. In the Austrian radon project (ÖNARP) the measured indoor radon activity concentrations are converted with a standard living and building situation to a radon potential value for each community or district. The standard situation is defined as a mean annual measurement result, measured in a room in the ground floor in a building without or only with a partial basement, with a conventional utilization, no stone building, no simple windows, two adults and less than two children. The converting factors for the standard situation vary for each province.

In the framework of the study of radon exposure assessments, impact of the variation of the circumstances, which mainly influences the indoor radon activity concentration, on the population weighted mean radon concentration was surveyed. As an example the district Gmunden (Fig.5) was surveyed. The weighted mean radon concentration in Gmunden is clearly above the weighted mean radon concentration in Austria and Upper Austria with 192.3 Bq/m³, which may be a geological effect because of ice age deposits and the dwelling situation (one-family dwellings). The assumption that no building in the district Gmunden has a basement increases the weighted mean radon concentration clearly to 262.3 Bq/m³ (weighted effective dose 4.37 mSv/a). On the other hand, if every building in district Gmunden has a basement the weighted mean radon concentration reduces to 138.8 Bq/m³ (weighted effective dose 2.31 mSv/a). Hence a basement has a clear impact on the weighted mean radon concentration and is an important factor for radon precaution and population exposure. A similar situation results from surveying the impact of the living floor on the weighted mean radon concentration. If all people in district Gmunden lived in the ground floor the weighted mean radon concentration would enhance to 241.2 Bq/m³ (weighted effective dose 4.02 mSv/a), but if all dwellings in Gmunden were in a higher level than ground floor the weighted mean radon concentration would reduce to 154.6 Bq/m³ (weighted effective dose 2.58 mSv/a).
5. Outlook

The discussed studies and results in this paper are first steps and a good basis for further assessments of radon exposure in Austria taking into account geology and settlement. For this purpose more soil gas measurements should be carried out in different geological regions (origin, bedrock, soil,…) in Austria to define the geogenic radon potential like in other countries (e.g. Germany, Czech republic [22-23]). With this information and the already existing indoor radon data net a fundamental population dose assessment should be possible (e.g. [15]). These studies should be rounded off by considering the actual dwelling, inhabitation and settlement situation and by modelling radon soil gas-indoor transfer factors (e.g. like [23-24]).

For the radon population dose assessments (present and future) more modelling should be done in further studies like taking into account the population distribution and migration not within political boundaries but within geological zones and with regard to present and future building constructions, building material and living situations. This modelling will give fundamental information of radon population dose assessments and will provide a basis for radon precaution measures and settlement planning for population radiation protection.

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