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RADON IN SWITZERLAND

by : H.Surbeck and H.Völkle
Federal Office of Public Health
c/o Physics Institute, University
Pérolles
CH-1700 Fribourg, Switzerland

and

W.Zeller
Federal Office of Public Health
Bollwerk 27
CH-3001 Bern, Switzerland

ABSTRACT

Based on measurements in nearly 1600 homes, representing 0.15% of the housing stock, we estimate that the Swiss live on the average in rooms with a radon concentration of 80 Bq/m³ and that 5% of them are exposed to concentrations exceeding 200 Bq/m³.

Radon research in Switzerland started nearly a decade ago and shows that building materials and household water use present no serious radon problems, the soil being the main radon source. The highest values are found in homes on highly permeable building grounds (Karst terrains, rockslides).

We discuss the results of the radon surveys and explain how we try to get a representative exposure estimate from biased data. We also present geological aspects of the radon situation in our country and outline the policy for the new decade that will see surveys concentrated on the search for hot spots.

Several mitigation techniques have been tested successfully but few homeowners are interested to take remedial actions. There is no great public concern on radon in Switzerland; radon is natural.

INTRODUCTION

As early as in 1908 Gockel (1) reported on radon ("Radiumemanation") measurements in Switzerland. He already knew that the radon concentration in the soil gas depends on various geological factors, meteorological conditions like wind speed and on the soil moisture content !

Well seven decades later one started to realize that exposure to radon may present a serious health problem and small scale radon surveys were carried out in Switzerland in the early 1980s.

Alarmed by high values (up to 5 kBq/m^3 in living rooms) found in homes in a city in the Western Swiss Jura Mountains (2,3) a task force was set up to study the radon situation in Switzerland. This eventually has led to a nationwide 5-year research program (RAPROS) that started in 1987.

It took some time to correct the then widely accepted but unproven "facts" like : "high radon concentrations are mainly due to building materials", "granitic bedrock shows a high uranium concentration and therefore homes in the Alps have high radon levels", "there can't be high radon concentrations in homes on Jurassic limestone".

Building materials and domestic water use showed to be a negligible radon source in Switzerland (4,5), the main source being the soil. Enhanced ^{226}Ra have been found in various soils not of granitic origin and the highest activity (880 Bq/kg dry weight) has been measured in a soil covering Jurassic limestone.

We show the general radon situation in Switzerland and how we try to gain representative exposure estimates from biased data. Geological aspects of the radon problem are discussed. Mitigation techniques tested in Swiss homes are presented and the policy for the new decade is outlined. This policy is characterized by a concentrated search for radon hot-spots.

GENERAL RADON SITUATION

FREQUENCY DISTRIBUTION AND AVERAGE RADON EXPOSURE

The frequency distribution of the radon concentrations in about 5000 rooms, corresponding to nearly 1600 buildings, representing 0.15% of the

Swiss residential housing stock, is shown in figure 1. The radon levels have been determined by exposing passive (etched-track) detectors for at least two months. In general two detectors are placed per building, one in the basement and one in an inhabited room at or above ground floor. We ask people to use the rooms as usual in order to get radon concentrations under realistic conditions. About 80% of the measurements have been carried out during the winter. Few homes are represented by both summer- and winter-values. These measurements show that summer levels are on the average 1/3 lower than the winter levels.

The raw data in figure 1 are not representative for the radon exposure of the Swiss for the following reasons :

1) Mainly in early surveys single family homes are overrepresented.

2) Certain regions are overrepresented due to particular research programs like the search for radon sources in the Jura Mountains (6) or because of the initiative of local authorities.

3) Most measurements have been carried out during the winter and thus don't give the annual mean.

To correct for bias 1) we sort the room data into building classes like single family homes, blocks of flats, farms and "others". For multistory buildings different stories (up to the forth floor) form separate classes. For every class the number of radon values falling into a concentration interval (subclass) is then multiplied by the percentage of the population living in the respective class (1980 census data). Summing up the weighted subclass contents over all classes leads to the new frequency distribution. This first weighting is carried out for every canton (State of the Swiss Confederation) or in the case of small cantons for a group of cantons.

To correct for bias 2) the numbers in the subclasses of each canton are multiplied by the percentage of the Swiss population living in this canton. This frequency distribution having an arithmetic mean of 80 Bq/m3 is more representative for the radon concentration to which the Swiss are exposed in their homes than the arithmetic mean of 140 Bq/m^3 from the raw data in figure 1.

The mean of 80 Bq/m^3 still lacks the correction for bias 3) and for the fact that few people stay at home 24 hours a day. We estimate that these two factors lower the above 80 Bq/m^3 to an annual mean of about 70 Bq/m^3.

The Swiss map in figure 2 shows the geographical terms used.

REGIONAL DISTRIBUTION

In figure 3 we show the regional distribution of the 1540 buildings that have at least one inhabited room at or above ground floor measured.

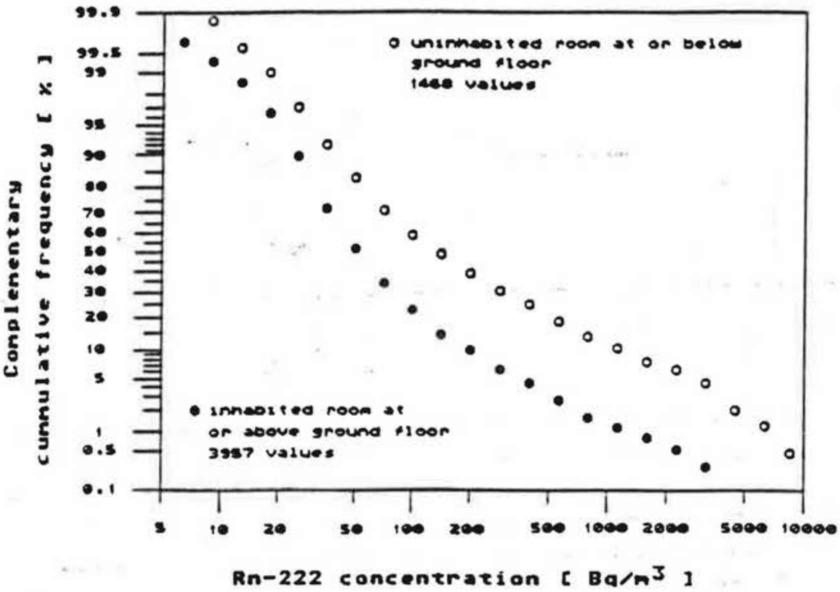

Figure 1. Frequency distribution of radon measurement results

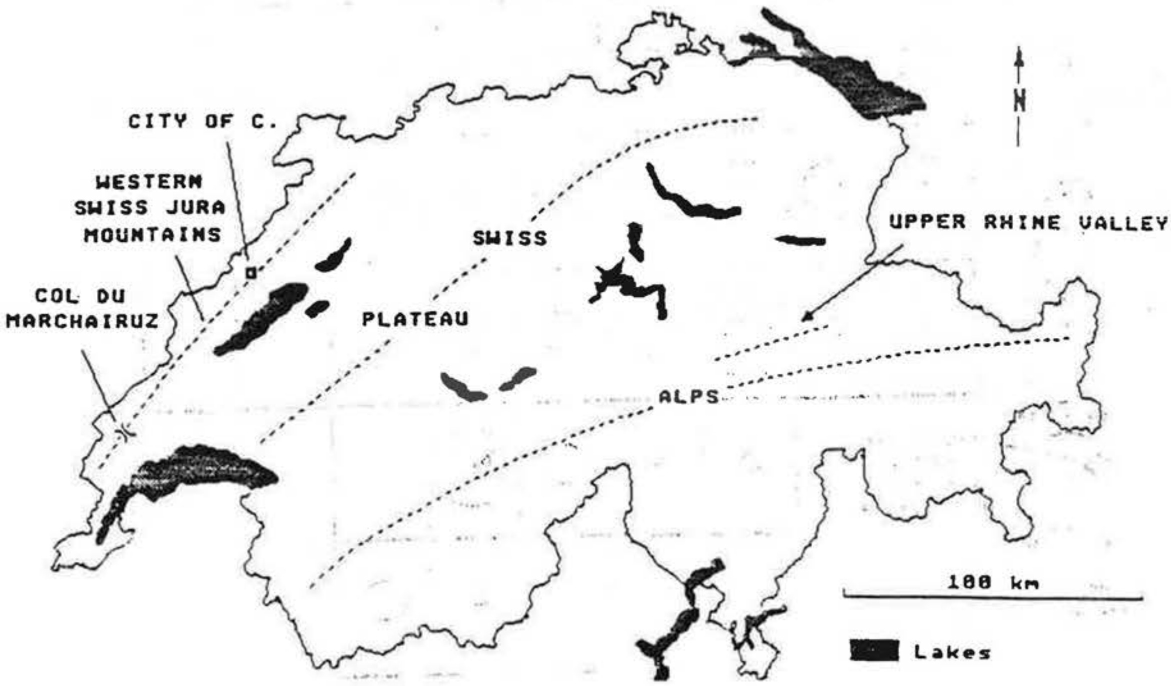

Figure 2. Swiss map. The dashed lines roughly represent the axis of the respective geographic unit.

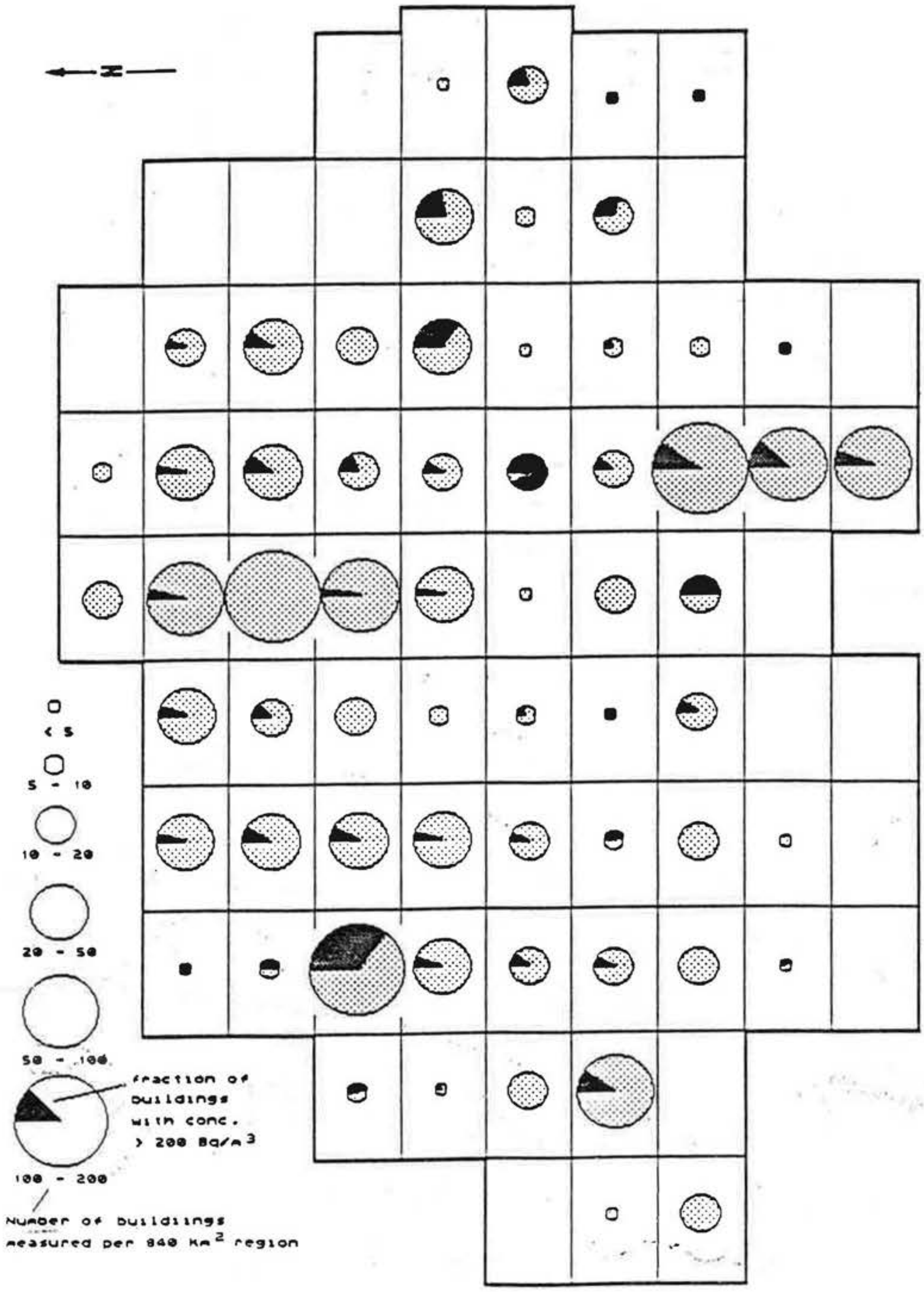

Figure 3. Regional distribution of radon measurement results

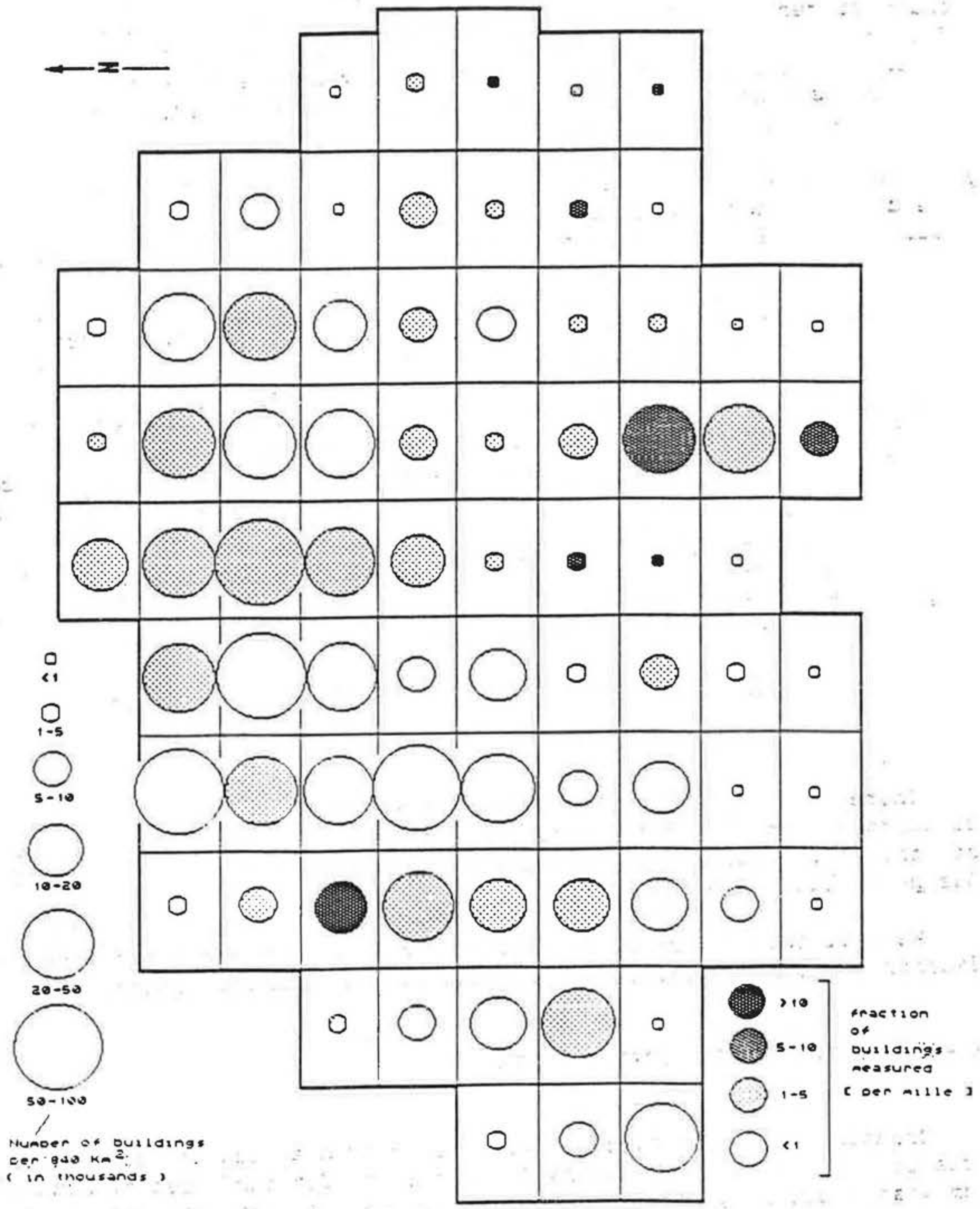

Figure 4. Fraction of buildings measured

We consider radon levels exceeding 200 Bq/m^3 in this type of rooms as an indicator for a possible radon problem. The fraction of homes with at least one room exceeding this level is shown in this figure for each of the regions. The division into regions is the one used for the 1:50000-scale maps. Each rectangle measures 24 km times 35 km (840 km^2).

There are at least two regions in Switzerland with clearly enhanced radon concentrations : the Jura Mountains in the west and the Upper Rhine Valley in the east. Geological aspects of the radon problem in these two regions are discussed below. Enhanced levels are present in the south-eastern part of Switzerland too. The Swiss Plateau where most of the Swiss live is essentially free from radon problems.

The more than 1500 homes measured so far represent 0.15 % of the residential housing stock in Switzerland. This may be sufficient to calculate a Swiss average but as can be seen from figure 4 many regions are not well represented. We don't really know what "well represented" means. What percentage of homes has to be measured per 840 km^2 unit until one can declare it as "affected" or "safe" ? A hint comes from a recent survey in the southern part of Switzerland (Ticino) that nearly doubled the number of homes measured in this region. From a comparison of the frequency distributions of the radon values before and after this survey we conclude that a representative sample has to contain at least 1 % of the residential buildings. Another hint comes from the now best covered region (3.5 % of the 6000 homes are sampled) where we have been measuring for more than 8 years. The frequency distribution changed slightly over the years and now has become quite stable. We don't expect any surprise from further measurements. We therefore recommend to sample 1 to 3 % of the housing stock before any region can be declared as safe or affected.

GEOLOGICAL ASPECTS OF THE RADON SITUATION IN SWITZERLAND

There are mainly three factors that determine the radon risk of a building ground : 1) ^{226}Ra activity concentration in the soil, 2) Fraction of the ^{222}Rn produced that is available for transport (emanation) and 3) Gas permeability of the soil.

We will show the range of values found in Switzerland for these three factors and discuss geological aspects of two high risk sites.

RA-226 ACTIVITIES IN ROCKS AND SOILS

Uranium data for Swiss rocks, taken from a recent compilation by Schärli (7) are shown in figure 5. The term "Uranium" used by Schärli is somewhat misleading for the quantity measured has been the ^{222}Rn daughter concentration. He neglects any disequilibrium in the ^{238}U series down to the ^{222}Rn daughters. We therefore call his "Uranium" values ^{226}Ra taking a conversion factor of 12.3 Bq/kg per ppm U. From this figure it is obvious

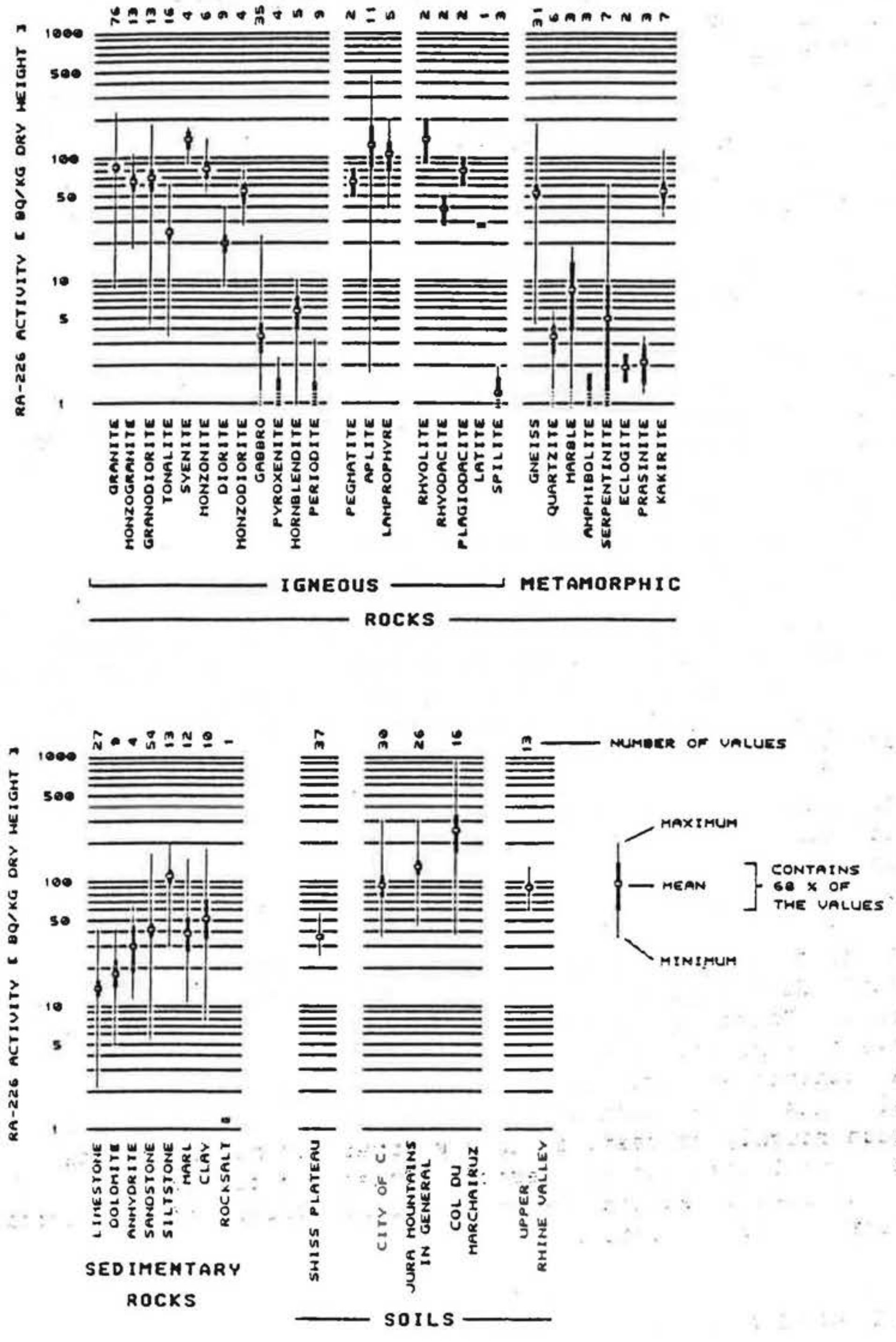

Figure 5. Ra-226 activities in Swiss rocks and soils

that "granite" is not synonymous with "high activity".

Activities in Swiss soils are shown in the figures 5 and 6. The ^{226}Ra concentrations in figure 5 have been determined by high resolution gamma spectrometry on dried soil samples. The data given in figure 6 are from in situ gamma spectrometry measurements (8). Contrary to the laboratory measurements the poor statistics for in situ measurements exclude a precise determination of the ^{235}U or the ^{234}Th concentrations. The ^{235}U contribution to the 186 keV ^{226}Ra line has thus to be calculated assuming perfect equilibrium down the ^{238}U series. This leads to an underestimation of the ^{226}Ra activity in soils with a ^{230}Th (and thus ^{226}Ra) excess. A ^{230}Th excess is present in Jura Mountains soils. When comparing activities in figures 5 and 6 one has also to take into account that the laboratory data are for dried samples whereas the in situ values refer to the undisturbed wet soil.

The complex nature of the Swiss geology and the important impact that Quaternary had on our country makes it very difficult to find any correlation between the regional activity distribution in figure 6 and geological or tectonic maps. Soils in many parts of Switzerland are not derived from the underlying bedrock. The most striking example is found in the Western Swiss Jura Mountains where ^{226}Ra activities of up to 880 Bq/kg dry weight are present in soils covering Jurassic or Cretaceous limestone having only about 20 Bq/kg of ^{226}Ra.

A peculiarity of these soils is that ^{230}Th and ^{226}Ra are largely in excess of ^{238}U (determined quantity is ^{234}U), the latter being present in "normal" quantities (30-50 Bq/kg dry weight). There is still no explanation for this widespread anomaly. The watch industry, being very prominent in the Jura Mountains has used large quantities of radium-activated luminous paint but we can hardly blame them for this "contamination". The ^{226}Ra and it's natural precursor ^{230}Th are nearly at equilibrium even in soil samples taken close to a former radium processing workshop. In samples of luminous paint from this workshop the ^{230}Th activity is orders of magnitude lower than the ^{226}Ra activity.

A hint for the origin of the enhanced activities may come from the regional distribution of the ^{226}Ra activity and it's dependence on the altitude. There is a general trend for higher activities towards the southwest (the main wind direction). Enhanced (> 100 Bq/kg dry weight) ^{226}Ra activities are abundant at high altitudes (figure 7) and no Ra anomaly has been found so far below about 900 m above sea level. This altitude roughly corresponds to the upper ice margin of the Rhone glacier during the latest glacial period. These two observation are consistent with the idea by Pochon (9) of an aeolian origin of an important part of the Jura Mountains' soils.

RADON EMANATION

The few emanation measurements on Swiss Plateau soils (mainly glacial till) show that for these soils about 30% of the radon produced can escape

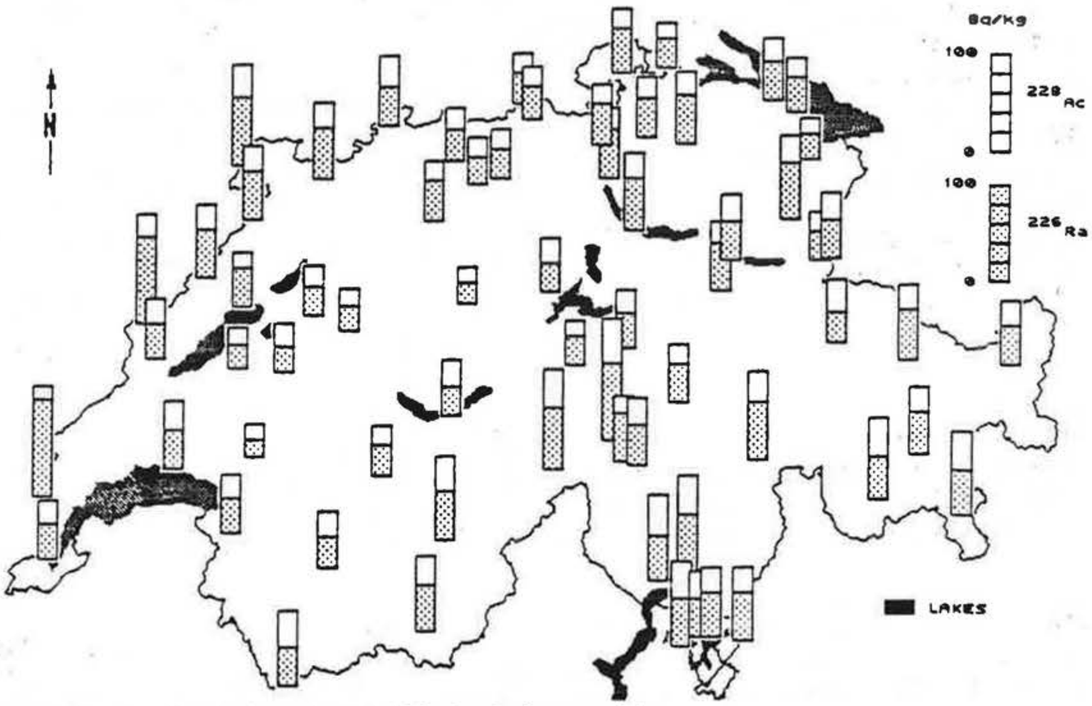

Figure 6. Ra-226 and Ac-228 in Swiss soils.
Determined by in situ gamma spectrometry

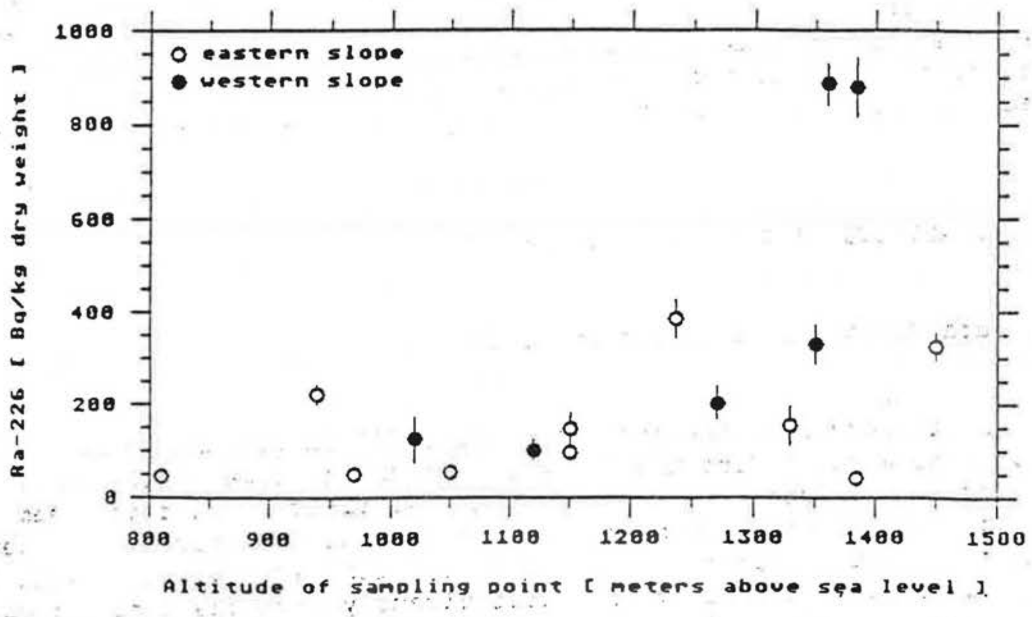

Figure 7. Soil samples Col du Marchairuz

to the pore space and is thus available for transport. This fraction is far higher (about 70%) for "high radium" soil samples from the Jura Mountains. An example is shown in figure 8. The ^{226}Ra values given in this figure have been determined using the 186 keV gamma line. The ^{235}U contribution to this line is calculated from the measured ^{234}Th activity assuming equilibrium between ^{238}U and ^{234}Th and taking the "universal" $^{235}U/^{238}U$ activity ratio of 0.046.

GAS PERMEABILITY OF THE SOIL

Our soil gas sampling apparatus (figure 9 and (6)) allows for the simultaneous measurement of the gas permeability. Values from $10^{-14}m^2$ to $>10^{-10}m^2$ i.e. variations of at least four orders of magnitude have been found in Swiss soils. The highest values show badly consolidated rockslides.

High radon concentrations in the soil gas only present a radon risk if the permeability of the soil is sufficiently large to allow for an efficient radon transport to the foundation of a house. Even "normal" radon levels in the soil gas may lead to a considerable radon risk if the gas permeability of the soil is very high.

Therefore the product of the radon concentration in the soil gas times the soil's gas permeability may be a better measure of the radon risk than the bare radon concentration. This "radon availability" is plotted in figure 10 for several regions in Switzerland. The envelopes have been generously drawn around the respective data sets. Individual data points are not shown in this figure. In the regions TI and FR we could not find homes with high indoor radon concentrations whereas the regions RA and SI are characterized by high indoor levels. Measurements in the region SI include gas samples taken in unconsolidated rocks. Despite the large scatter of the data points there is some evidence that building grounds with radon availabilities larger than 10^{-7}Bq/m to 10^{-6}Bq/m present a radon risk.

GEOLOGICAL ASPECTS OF TWO HIGH RISK REGIONS

Western Jura Mountains, a Limestone Karst Region

As can be seen from the figures 5 and 6 ^{226}Ra concentrations in the soils of the Western Jura Mountains are on the average well above the values for soils from the Swiss Plateau. At first sight this seems to correspond well to the high percentage of increased indoor radon levels found in this region (figure 3). But a closer look at the houses with high concentrations shows that they are built directly onto the bare limestone bedrock. The contact with the soil is limited to a less than 30 cm high zone round the walls. More important than the soil ^{226}Ra concentration seems to be the fact that most of the homes affected in the city of C. are close to karst features like caves and sinkholes. In the basement of one

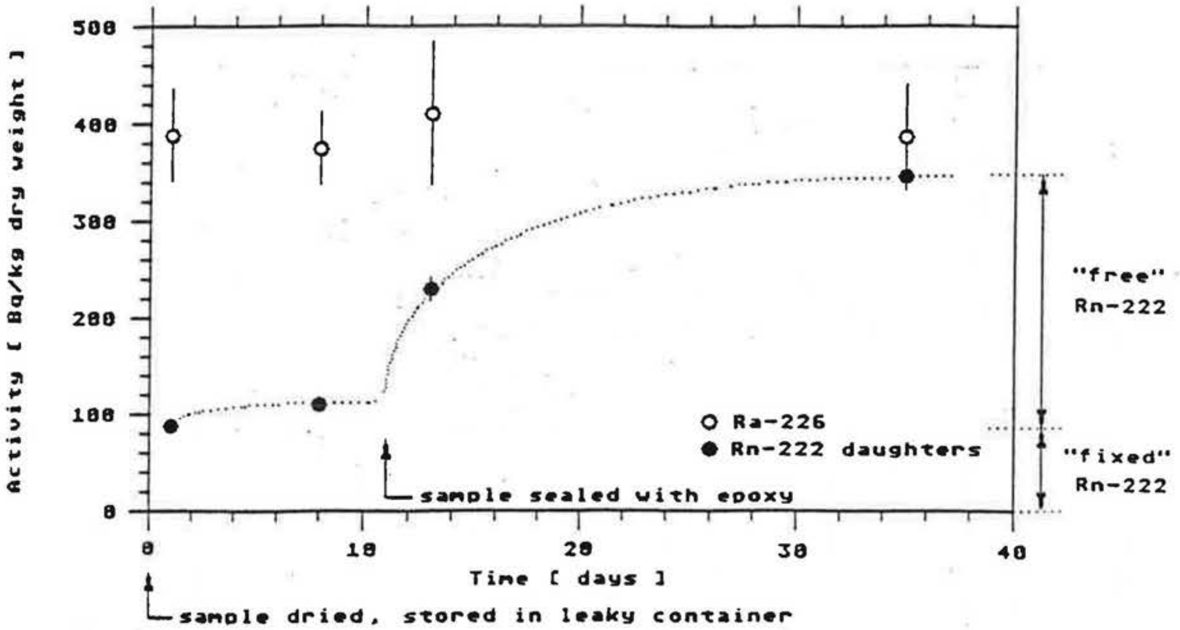

Figure 8. Radon buildup in a Jura Mountains soil sample

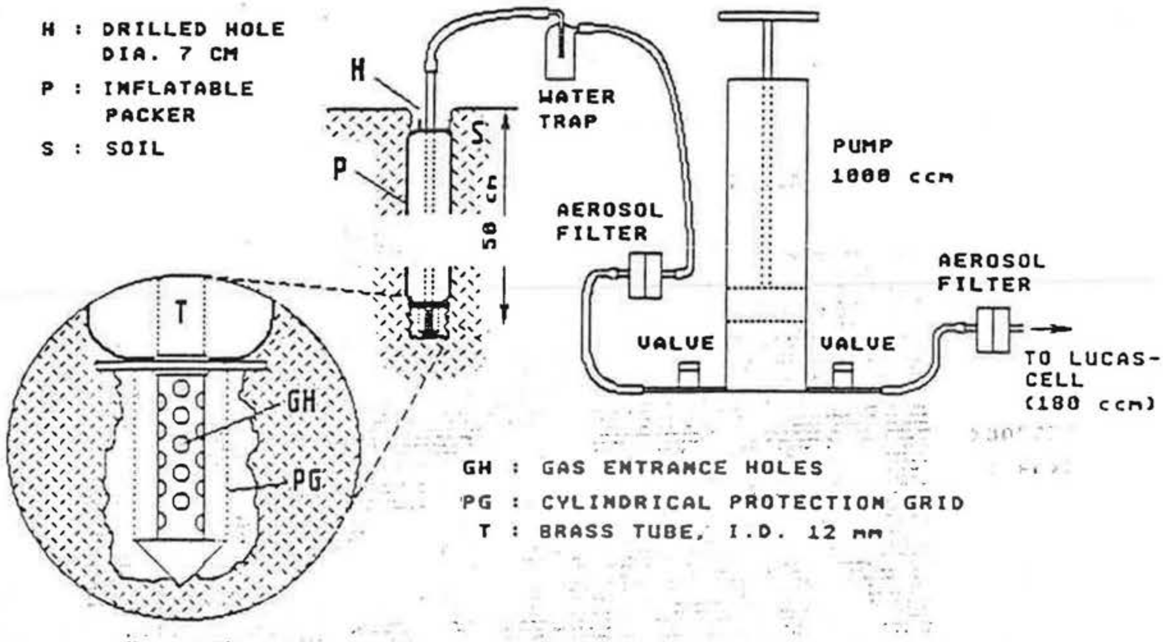

Figure 9. Soil gas sampling equipment. To determine soil permeability we measure the time it takes to pump 1000 ccm at constant pressure into the borehole. Constant pressure is produced by the pump piston's own weight.

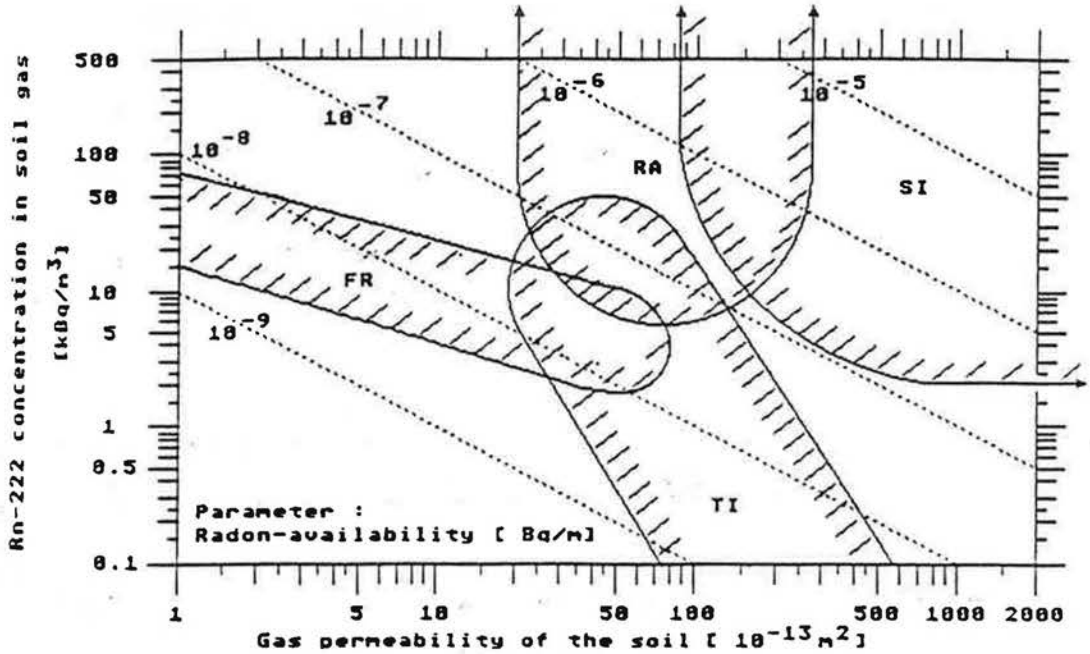

Figure 10. Radon availability in Swiss soils

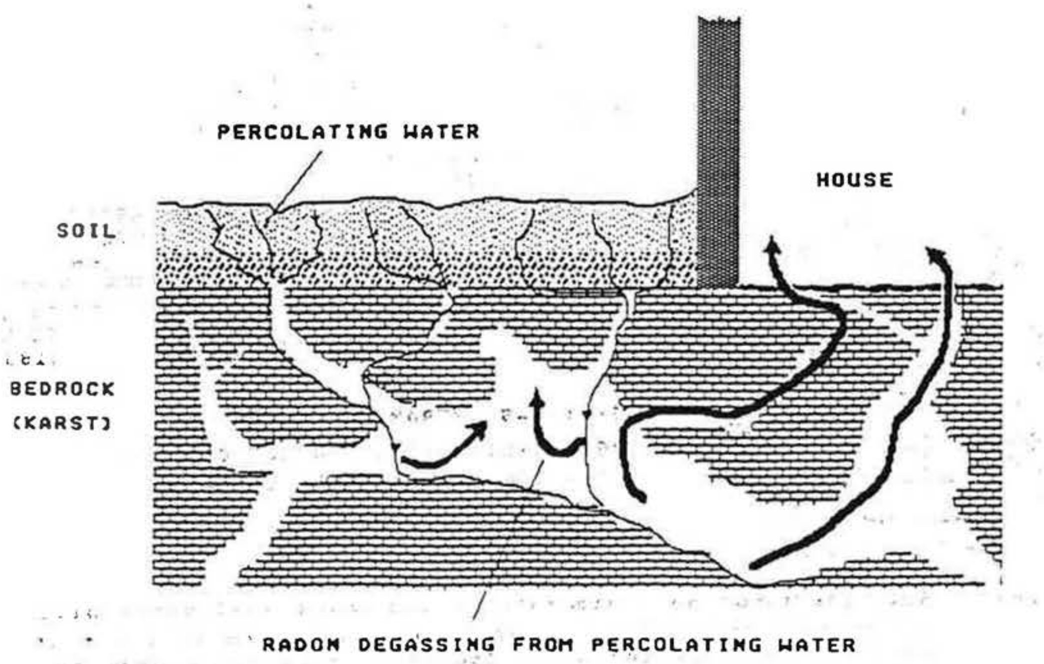

Figure 11. Proposed radon transport in a karst system

of the buildings there is even a visible connection to the karst system.

The radon concentrations in caves below this city are very high (up to 40 kBq/m^3 (10,11)). In combination with the high gas permeability this karst system represents a very powerful radon source. Even small connections to this source are sufficient to supply large quantities of radon to the basement of a house.

There remains to explain the high radon levels in the air of the karst system. The Jurassic limestone contains only about 20 Bq ^{226}Ra/kg, by far not enough to sustain 30 to 40 kBq/m^3 ^{222}Rn in the cave air. We have therefore proposed (12) that percolating water is transporting large quantities of radon from the (high ^{226}Ra) soil to the caves (figure 11).

Rockslides in the Alps

There are many villages in the Swiss Alps built onto badly consolidated rockslide debris. In the Upper Rhine Valley these rockslides contain "Verrucano". In Switzerland the term "Verrucano" means an old clastic sediment frequently showing enhanced ^{226}Ra concentrations. ^{226}Ra values in soils from the Upper Rhine Valley are shown in figure 5. The combination of relatively high ^{226}Ra activities with the extremely high gas permeabilities in these rockslides seems to be the reason for high indoor radon concentrations. Contrary to the situation in the Jura Mountains the homes are built onto the "high ^{226}Ra" material.

MITIGATION

Remedial actions are still in a test phase. Homeowners willing to participate in pilot projects have been offered a substantial financial support by the Federal Office of Public Health that also plans and supervises the work.

Pilot projects carried out so far have shown that passive methods like sealing floors are insufficient. Combining sealing with subfloor suction has lead to the successful mitigation of several homes at still reasonable costs.

The most dramatic reduction (to nearly outdoor radon levels) has been achieved by an air conditioning system that allows for the control of air flow and pressure in the basement. A heat exchanger keeps the energy consumption low. This installation is for research only. It is too expensive for a general use but a scaled down version may give comparable results at reasonable costs.

In a high risk area a future homeowner could be convinced to install a subslab suction system. We hope that he will have considerably lower radon levels in his new home than his neighbour living with the highest radon concentration ever measured in Switzerland (45 kBq/m^3 in winter).

In Switzerland the mitigation technique has not yet passed to the private sector. There is no "radon business" in our country for there is no real public concern about radon. This may be partly due to the lack of limits or recommendations for indoor radon levels but distinctly more important is the general feeling that something natural like radon can't be harmful.

THE NEW DECADE

In the 1980s we have gathered enough data to make a reasonable estimate for the average radon exposure of the Swiss. This average will change only slightly even if we could double the number of buildings measured. What we need more is to find the homes with extreme values, homes really worth remedial actions. Therefore any new survey will concentrate on the search for high risk regions. This search will be guided by the knowledge gained on the correlation between geology and radon concentration. A survey started in November 1990 in the eastern part of Switzerland has already been planned according to this new concept. Etched-track detectors are placed in villages on high permeability grounds (rockslides, karst, clean coarse gravel with low lying water table, important fault zones) and/or close to known or suspected uranium mineralizations.

The new decade will also see recommendations or even limits for safe indoor radon concentrations and an increased engagement and responsibility of local authorities. The federal government will concentrate on research, the search for high concentrations, scientific support and quality control.

We will plead for sensible radon concentration limits. Radon is only one of the many carcinogenic substances present in our environment.

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