EXPERIENCE FROM RETROSPECTIVE RADON EXPOSURE ESTIMATIONS FOR INDIVIDUALS IN A RADON-EPIDEMIOLOGICAL STUDY USING SOLID STATE NUCLEAR TRACK DETECTORS.

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The relation between an increased risk for lung cancer and exposure to indoor radon is assessed in epidemiological studies. Both the quality and reliability of smoking data and the radon exposure data are of primary importance. Contemporary measurement of radon concentration in the dwellings of the individuals in a case-control study is traditionally used to assess the past radon history. These assessments contain large uncertainties since the contemporary measured radon concentration might not be representative for the situation a long time ago. The measurement of the long-lived decay products from ²²²Rn remaining on indoor hard surfaces, such as glass, presents another possible way to assess the exposure to indoor radon.

At the Swedish Radiation Protection Institute, a combination of two different solid state nuclear track detectors has been developed to assess the ²¹⁰Pb activity implanted in glass surfaces by measurement of ²¹⁰Po alpha activity. This detector (a RETRO detector) is used in the Swedish radon epidemiological case-control study of non-smokers where the objectives with these measurements are to provide an alternative estimate of individual radon exposure, to estimate the radon exposure when no other data are at hand and to evaluate the usefulness of RETRO measurements.

For this study we followed a pre-determined plan which gives guidance on how to choose the objects, what information should be noted etc. The objects chosen for RETRO measurement were personal objects, which had been in the person's possession for more than 20 years. If possible, two different objects were measured for each individual. In addition, a contemporary radon measurement was undertaken during the three-month period during which the RETRO measurement was made.

Of the 419 persons contacted, we made at least one RETRO measurement for 344 of them, 9% had no suitable object and 9% refused to allow measurements. A total of 576 different objects were found and 568 were measured. For 225 persons we measured two personal objects that had been in the same person's possession for more than 20 years. The standard deviation of the estimated mean radon concentration obtained from these two objects had a median value of 13 Bq/m³ indicating a precision of exposure estimation of about 20 %.

The correlation between ²¹⁰Po surface activity measured earlier and mean values of measured radon concentrations in a number of Swedish dwellings is applied to estimate the historical average radon concentration. This average correlation factor seems also to be valid for the measurements in the non-smoker epidemiological study.

Measurement of surface implanted ²¹⁰Po activity in personal objects can provide information on individual radon exposure which is of value in a radon epidemiological study. Additional information using room-models will improve the accuracy of the assessed exposure.

INTRODUCTION

The relation between increased risk of lung cancer and exposure to indoor radon is assessed in epidemiological studies. Quality and reliability of smoking data as well as radon exposure data are of primary importance. Contemporary measurement of radon concentration in the dwellings of the individuals, in a case-control study, are traditionally used to assess the past radon history. The results are then time-weighted using the length of occupancy in each home to obtain a cumulative
estimate of the past exposure. This calculated exposure is uncertain for many reasons. The radon concentration measured today in the dwellings may not be representative for past situations. Data for some of the past dwellings is lacking due to failure to find the dwellings or refusal to permit measurement. The measurement of the long-lived decay products from $^{222}\text{Rn}$, starting with $^{210}\text{Pb}$ ($T\frac{1}{2}$ 22.3 years), and remaining in the dwelling poses an alternative method to assess the cumulative past indoor radon exposure.

Two different techniques are presently being investigated. In "volume traps" the $^{222}\text{Rn}$ diffuses into the interior of a porous material, such as foamed material, where the radon progeny from decayed $^{222}\text{Rn}$ inside the material will remain and accumulate. Knowing the age of the porous material and the volume concentration of $^{210}\text{Pb}$, an estimate of the $^{222}\text{Rn}$ exposure to the material can be made (Oberstedt et al., 1996). The usefulness of the method for large-scale studies is limited due to difficulties in finding suitable materials and the laborious analysis of the materials that are also destroyed.

A part of the radon progeny in indoor air will plate out on surfaces in a room. In the alpha decay of the short-lived progeny plated out on hard surfaces such as glass, a part of the decay product formed will, by recoil, be implanted in the surface ("surface trap") deep enough to remain there and accumulate. Knowing the age of the surface material and the surface activity of $^{210}\text{Po}$, an estimate of the indoor radon exposure of the object can be made (Samuelsson 1988; Lively et al., 1987).

Under laboratory conditions, good correlation exists between radon exposure and implanted $^{210}\text{Po}$ surface activity on glass. In an indoor environment this correlation is influenced by a number of factors and the historical-average airborne activities can be assessed using semi-empirical models. (Cornelis et al., 1992; Knutson, 1988; Porstendörfer, 1994).

One advantage of using the long-lived $^{222}\text{Rn}$ decay products to assess a person's radon history is that a single $^{210}\text{Po}$ measurement of one personal object which has been in the person’s possession for a long time will replace a number of contemporary measurements in the dwellings in which the person has been living.

Autoradiographic alpha-track methods for assessing the $^{210}\text{Pb}$ activity implanted in glass surfaces by measurement of $^{210}\text{Po}$ alpha activity have been used successfully (Lively et al., 1989; Mahaffey et al., 1993; Trotti et al., 1996) and the different techniques investigated are all suitable for large-scale studies.

**METHODS**

**Detector design**

At the Swedish Radiation Protection Institute (SSI), a combination of two different solid state nuclear track detectors has been developed to assess the $^{210}\text{Pb}$ activity implanted in glass surfaces by measurement of $^{210}\text{Po}$ alpha activity. When the $^{210}\text{Po}$ activity on the glass surface is low, the intrinsic background alpha activity in the glass, which varies between glasses, will limit the detectable $^{210}\text{Po}$ activity. Laboratory measurements show that nearly all the alpha particles emitted from implanted $^{210}\text{Po}$ have an energy close to 5.3 MeV, in contrast to the alpha background activities in the glass, which show a continuous energy spectrum.
Two different alpha track detectors are used simultaneously to separate the $^{210}\text{Po}$ alphas from the background alphas. The KODAK LR-115 (cellulose nitrate) detector is sensitive to alpha particles with energies within the energy range 1.2-4.8 MeV, while the CR-39 (polyallyldiglycol carbonate) detector is sensitive to alpha particles with energies from 1 MeV up to more than 20 MeV. Since the alpha particles from $^{210}\text{Po}$ emitted from the glass surface have an energy close to 5.3 MeV they will not be detected by the LR-115 detector, while they will be detected by the CR-39 detector. By placing these two detectors side by side directly in contact with the glass surface the LR-115 will have tracks from background alphas only and the CR-39 will have tracks from both background and $^{210}\text{Po}$ alphas. This combination of detectors is called a RETRO detector.

The RETRO detector is calibrated against a number of glasses with different known implanted $^{210}\text{Po}$ surface activities (Falk et al., 1996).

**Correlation between past indoor radon concentration and $^{210}\text{Po}$ glass surface activities.**

In a study with 31 dwellings where radon concentrations had earlier been measured, the correlation between radon exposure and $^{210}\text{Po}$ surface activity was investigated. The surfaces selected for a RETRO measurement had to have been in the dwelling for more than 20 years. With other constraints the most suitable objects were selected. About three months measuring time was used for the RETRO detector and for the contemporary radon concentration measurement in the same room. By normalising the $^{210}\text{Po}$ surface activity to 20 years of exposure for the object, taking into account build-up and decay, the relation between the measured surface activity and the best estimate of the past mean radon concentration, calculated as a mean between the contemporary value and previous, is shown in Figure 1. The frequency distribution of this relation is found to be close to log-normal, with a median value of 42 and a $\sigma_g$ of 2.0. This broad distribution is due to a combination of many factors affecting the two different methods to assess mean indoor radon concentrations during the last 20 years or more. The contemporary and earlier $^{222}\text{Rn}$ measurements may not be representative for that period, and the implanted $^{210}\text{Po}$ surface activity on the object is affected by a number of parameters which are different for the different dwellings and objects.

For Swedish dwellings we assume that the median value is the best estimate between $^{210}\text{Po}$ surface activity and past mean radon concentration. It means that an object that has been in a dwelling for 20 years with a constant $^{222}\text{Rn}$ concentration of 42 Bq/m³ will have a $^{210}\text{Po}$ surface activity of 1 Bq/m².

**The pre-determined plan for RETRO measurements**

In the ongoing Swedish radon epidemiological case-control study of non-smokers, in addition to traditional $^{222}\text{Rn}$ measurements, we are applying measurements with the RETRO-detectors. The objectives of these measurements are to improve the estimate of individual radon exposure, by providing an alternative individual radon exposure and to give an estimate of the radon exposure when no other data are at hand. The usefulness of RETRO measurements will be studied as well as the comparison of estimated exposure, using RETRO measurements with contemporary radon measurements.

For this study we follow a pre-determined plan, which provides guidance on how to choose the objects, what information should be noted etc. The objects chosen for RETRO measurement are personal objects which have been in the person's possession for more than 20 years. The object should preferably have been in the bedroom or living room. Wall-mirrors, glass panes on photos or pictures, on display cabinets, or on doors between rooms are examples of first choice objects.
Windows or objects hidden in a bookshelf etc. are examples of objects that should be avoided. The surface of the chosen object was cleaned prior to the application of the RETRO detector. Information on the object and its history was collected in addition to information such as smoking habits, ventilation, heat sources in the dwelling etc. In a Polaroid photo of the room the location of the object was marked. If possible, two different objects were measured for each individual. In addition, a contemporary radon measurement was undertaken in the same room during the three-month period during which the RETRO measurement was made.

RESULTS

Of the 460 persons, cases and controls, which were selected for RETRO measurements, 419 persons were successfully contacted, and 344 person had at least one RETRO measurement made. For 36 persons (9%) no suitable objects were found and 39 persons (9%) refused to allow measurements. A total of 576 different objects were found and 568 of these were successfully measured. Figure 2 summarises the different types of objects used for the RETRO measurements. Glass panes on pictures or photos are the most frequent objects.

The objects had ages ranging from 18 to 245 years with a median of 44 years, and the number of years it had been in the person’s possession ranged from 10 to 85 years with a median of 37 years.

One single RETRO measurement of one personal object, which has been in the person’s possession during a long time, gives an estimate of the individual cumulative radon exposure. For 225 persons we have two measurements on objects that have been in the same person’s possession for 20 years or more. This will make it feasible for us to estimate the reproducibility of exposure estimates using the RETRO measurement techniques. Figure 3 is a scatter diagram over the two estimated mean radon concentrations during the last 20 years or more for the 225 persons. The mean radon concentration estimates are for the whole age of the objects. As can be seen in the figure, good correlation was found between the pairs of measurements ($r^2=0.6$).

The standard deviation (SD) of estimated mean radon concentration for the 225 pairs of individual objects was calculated. Figure 4 shows the frequency distribution of this SD. The distribution is close to a log-normal distribution with a geometric mean of 13 Bq/m³ and a $\sigma_g$ of 3.8. Since the median $^{222}$Rn concentration in this material is 65 Bq/m³ the precision of the exposure estimates can be estimated to be about 20%.

At present we do not have all the results from the contemporary radon measurements performed in the study, for this reason no comparison has yet been made between individual exposure measurements. But from the three-month contemporary radon measurements made in same room as the RETRO measurements allow us to make a preliminary comparison of the radon history of the room using the two methods. Figure 5 shows the relation between the contemporary radon concentration and the estimated mean radon concentration during a period of 20 years or more for 281 different rooms. The correlation coefficient ($r^2$) is 0.53. These two estimates are both influenced by a number of uncertainties and factors. For example, the contemporary three-month radon value is an uncertain estimate for the mean over more than 20 years, and the RETRO values should be corrected for deposition effectiveness. Despite these uncertainties, the mean radon concentrations for the 281 rooms are very close, 98 Bq/m³ and 92 Bq/m³ from contemporary and RETRO measurements.
CONCLUSION

RETRO detectors were used for the measurement of the surface implanted $^{210}\text{Po}$ activity in personal objects for estimation of individual radon exposure in an epidemiological study. It was possible to find suitable objects to investigate for more than 90% of the contacted persons. Only a small percentage of the measurements had to be excluded, primarily due to the high intrinsic background activity of the objects. These objects were mainly ceramics and porcelain. Estimates of indoor radon history from two different personal objects show that the precision of the estimated mean historical radon concentration can be expected to be about 20% as a mean.

The correlation between earlier measured $^{210}\text{Po}$ surface activity and mean values of measured radon concentrations in a number of Swedish dwellings is applied to estimate the historical average radon concentration. This average correlation factor seems to be valid also for the measurements in the non-smoker epidemiological study.

Measurement of surface implanted $^{210}\text{Po}$ activity in personal objects can provide information on the individual radon exposure and this is of value in a radon epidemiological study. Additional information using room-models will improve the accuracy of the assessed exposure.

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REFERENCES

Figure 1: Relation between the best estimate of average $^{222}\text{Rn}$ concentration, over more than 20 years backwards and measured surface activity, normalised to 20 years of exposure.
Figure 2: Frequency of different objects used for RETRO measurements
Figure 3: Calculated average $^{222}$Rn concentration, for more than 20 years backwards, from RETRO measurements on 225 pairs of personal objects.
Figure 4: Frequency distribution of SD (Bq/m³) for 225 pairs of personal objects.
Figure 5: Comparison between the estimated past average $^{222}\text{Rn}$ concentration in dwellings from contemporary $^{222}\text{Rn}$ measurements and RETRO measurements in the same dwelling. All 281 objects measured have been in the same dwelling for more than 20 years.