Radon in Workplaces

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SUMMARY

The radiological assessment of the results of radon measurements in dwellings is not automatically applicable to workplaces, due to different forms of utilisation, constructional conditions, time of exposure, heating and ventilation conditions, additional aerosol sources, aerosol parameters, chemical substances, etc.

In order to investigate the peculiarities of the radon situation in workplaces located inside buildings, compared with the radon situation in dwellings, long-time recordings of radon, attached radon progeny and unattached radon progeny concentrations (218Po, 214Pb, 214Bi) have been carried out at several categories of workplaces (e.g. offices, public buildings like schools and hospitals, different rooms in factories, workshops, kitchens, agricultural facilities). 36 workplaces have been investigated. There have been carried out at least 2 to 3 long-time recordings for each workplace during different seasons. At the same time the gamma dose rate, meteorological conditions, aerosol particle concentrations have been registered. Many parameters of the workplaces and the buildings have been recorded. Activity size distribution of the aerosol-attached and unattached fraction of short-lived radon decay products have been determined in 20 workplaces.

The investigations show differences in the assessment of the radon situation in dwellings compared with that in workplaces. The special conditions in the workplaces have a considerable influence on the radiation dose of the workers.

INTRODUCTION

The first safety measures against radon in workplaces have been taken already in the forties. At that time control measurements of the radon concentration in underground mines in Germany have been carried out and measures in order to decrease the radon concentration have been introduced (especially the improvement of ventilation). Radon limits also have been set (1). However, more experience and knowledge with respect to the health risk through radon have been gained later in the frame of the global uranium mining. For the first time the experience concerning underground mines has been applied to buildings above ground (especially to dwellings) in the fifties in Sweden. Recently the interest of research of workplace in buildings above ground has grown. This interest has been intensified especially through relevant international recommendations (ICRP 65, 1994; IAEA 115 1995; EURATOM 96/29, 1996) to include radon exposed workplace in the radiation safety control.

In order to record the features of the radon situation in workplaces in buildings, the German Ministry of Environment has initiated the research project „Investigations of Radiation Exposure through Radon and Radon Progenies in Workplaces in Buildings“. The Technical Inspection Agency of Southern Germany (TÜV Süddeutschland) participates together with the firm Sarad GmbH, Pesterwitz and the Isotope Laboratory for biological and medical research of the University of Göttingen in carrying out this project. In the frame of this project, funded by the German Federal Office for Radiation Protection, we have investigated radon in workplaces. This project will be finished by the end of 1999.

The investigations have been carried out in the district of Weißeritz, in the south of Dresden, from 1997 until 1999. In this area the radon concentrations in dwellings and workplaces are very high due to the geogenic radon potential.

At the time when this manuscript was written, the evaluations of the measurement results have not been finished yet. Therefore, no extensive and systematic assessments could be done yet. In the present paper the content of the project „Investigations of Radiation Exposure through Radon and Radon Progenies in Workplaces in Buildings“ and first results of our work are presented.

GOAL OF THE PROJECT

Compared with dwellings and due to different using conditions, different construction of the rooms, possibilities of ventilation etc. it is not simply possible to apply a radiological valuation of radon measurements in dwellings to that in workplaces.
In the frame of this plan it is investigated to which extent constructional, technical and using peculiarities have influence on the radiation exposure through radon and its decay products in workplaces inside buildings. By means of measurements, the range risk relevant factors as for instance potential alpha-energy concentration of the short-lived radon decay products (PAEC), unattached fraction of the PAEC ($f_p$), size distribution of the attached and unattached activity, should be determined. The influence of these factors on the dose has been calculated.

On the basis of obtained measurement data, radiological recommendations for the identification, classification, assessment and control of the working places should be deduced. In this respect, the method for measurement and assessment of the radon exposed workplaces is of substantial importance.

MEASUREMENT PLAN AND MEASUREMENT QUANTITIES

The investigations took place in real workplaces during the normal working process. The search of appropriate measurement objects has been effected after extensive investigations and radon short-time measurements. Workplaces in 36 different working rooms have been investigated.

In connection with each investigated object, extensive data has been recorded (e.g. duration of stay in a workplace, working processes, materials, ventilation, relation between volume and surface, aerosol sources).

For each measurement object, long-time recordings of one month have been effected twice or three times per year (in different seasons) as well as spot measurements. The measuring quantities which had to be recorded in this respect are shown in table 1. The recordings have been effected in a two-hours-resolution and accompanied by an additional passive measurement system.

<table>
<thead>
<tr>
<th>Long-time recordings</th>
<th>Spot-measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rn-222 (inclusive Rn-222 integral)</td>
<td>• Rn-222</td>
</tr>
<tr>
<td>• PAEC attached</td>
<td>• Po-218, Pb-214, Bi-214 attached</td>
</tr>
<tr>
<td>• PAEC unattached</td>
<td>• Po-218, Pb-214, Bi-214 unattached</td>
</tr>
<tr>
<td>• Po-218, Pb-214, Bi-214 attached</td>
<td>• Activity size distribution</td>
</tr>
<tr>
<td>• Po-218, Pb-214, Bi-214 unattached</td>
<td>• attached activity (10-10.000 nm)</td>
</tr>
<tr>
<td>• Temperature, air pressure, humidity</td>
<td>• unattached activity (0,5-10 nm)</td>
</tr>
<tr>
<td></td>
<td>• Aerosol particle concentration</td>
</tr>
<tr>
<td></td>
<td>• Chemical substances</td>
</tr>
<tr>
<td></td>
<td>• Gamma dose rate</td>
</tr>
</tbody>
</table>

Approximately 100 objects have been roughly investigated, while 36 of them have been investigated by means of long-time observations and 20 through additional special spot measurements.

Table 2 shows the mainly measurement systems which have been used.

<table>
<thead>
<tr>
<th>Measurement systems</th>
<th>Producer</th>
</tr>
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<tbody>
<tr>
<td>Radon- and Radon Progeny Monitor EQF 3020</td>
<td>SARAD GmbH, Germany</td>
</tr>
<tr>
<td>Alpha-Track Radon Detectors</td>
<td>BfS Berlin, Germany</td>
</tr>
<tr>
<td>Screen Diffusion Batteries with Different Screens</td>
<td>University of Göttingen, Germany</td>
</tr>
<tr>
<td>Low-Pressure Cascade Impactor</td>
<td>Typ Berner, USA</td>
</tr>
<tr>
<td>Condensation Nuclei Counter</td>
<td>General Electric, USA</td>
</tr>
<tr>
<td>PAEC-$f_p$-Rn-Monitor</td>
<td>University of Göttingen, Germany</td>
</tr>
</tbody>
</table>
The spot measurements contained also the determination of the activity size distribution of aerosol attached (AMAD > 10 nm) and unattached (AMAD < 10 nm) short-lived radon progenies during typical working conditions.

In the range of 10 nm to 16000 nm the aerosol attached activities have been collected with an impactor according to the particle size. The measurements have been carried out with a low-pressure cascade impactor (typ Berner), which consists of eight stages and a back-up filter. The collection efficiency of this impactor was determined with monodisperse test aerosols. A tube diffusion battery (length = 45m) with a 50 % cut-off diameter of 3.5 nm at the entrance of the impactor removes the unattached activities (3).

For the range of 0.5 to 10 nm the diffusion deposition is used for the separation of unattached fraction. The measuring equipment which has been used consisted of five parallel screen diffusion batteries and a reference filter using the differential method. Through impaction and interception deposited activities (particles > 10 nm) have been corrected (4,5).

The size distributions have been approximated by means of a sum of log-normal distributions.

RESULTS

As a result of measurements, many features of the radon-concentration with time, the equilibrium factor F, the unattached fraction fₚ and the activity size distribution could be determined. These amounts are influenced mainly by the working conditions and the working intervals.

Some of the tendencies which derive from the measurement results already obtained, are presented in the following.

Figure 1 shows the directly measured quantities of the long-time measurements in three neighbouring working rooms of wood- and metal-processing factory. The different rooms are: joinery, paint shop and locksmith’s shop.

The reduction of the radon decay products concentration (compared with the radon gas concentration) caused by deposition processes can be clearly recognised. The short-lived decay products can be determined through measurements as free or unattached fractions and as an aerosol attached fraction. In rooms the unattached fraction is lower than the attached fraction in general.

Through measurements the continuous determination of these quantities with a time resolution < 2 hours are not negligible: many measuring chambers and detectors as well as a high memory capacity are needed.

Through the example in figure 2 it is shown that different use even in neighbouring rooms can lead to significant differences in the radon- and radon decay product concentrations. Specific room conditions and first of all ventilation habits lead to the fact that the concentrations differ very much. The differences are extremely high during night; they begin to become smaller in the morning and in the afternoon the concentrations in the three rooms have about the same low level. This kind of features have to be taken into account in the frame of the exposure assessment of workplaces.
Figure 1. Typical course of time of radon and radon decay product concentrations in a workplace

Figure 2. Typical concentrations through different using forms in neighbouring rooms of a manufacturing plant

Figure 3 shows by an example of a bakery daily averages: average concentration of equilibrium factor (F) and unattached fraction (f_p) are not room constants. The reason for the differences of these quantities is mo-
stly the actual concentration of the aerosols (Z). In this respect there is a formula: \( f_p = \frac{400}{Z} \) [Z in cm\(^3\)] (2).

\[ \text{Unattached fraction of potential alpha energy } f_p \text{ and equilibrium factor } F \]

Figure 3. Contrary course of \( F \) and \( f_p \)

In figure 4 the determined quantities \( F \) and \( f_p \) are compared. In order to verify the influence of the aerosol concentration on \( f_p \), figure 5 shows separate average values of \( f_p \) during working hours and non-working hours. During the non-working hours there is no dust and we found higher \( f_p \) values. In the periods free of dust out of the working hours there can be measured lower \( f_p \) values. These are important results for dose assessment in workplaces.

\[ \text{Equilibrium factor } F \text{ as function of unattached fraction of potential alpha energy } f_p \]

Figure 4. \( F \) as a function of \( f_p \)
Figure 5. Average $f_p$ values separated according to the phases of use of the rooms

The $F$ and $f_p$ values shown in figure 3, figure 4 and figure 5 are not corrected yet (e.g. no correction with regard to screen deposited aerosol-attached activity). Due to experience, the $f_p$ values seem to be a little bit too high. As the present paper is focused on the variation of concentrations and relative changes, these values were taken without corrections.

The investigations which have been carried out show that a characterisation of the workplaces in view of relevant dose assessment parameters, for instance PAEC, $f_p$, AMAD, can be based on parameters influenced by room use such as aerosol concentration.

As already mentioned, detailed measurements have been carried out in selected workplaces, especially activity size distributions have been determined. The measurement results indicate significant differences of these distributions regarding the position of the resulting modes (AMAD = Activity Median Aerodynamic Diameter), their activity fractions ($f$ = fraction of the mode) and their distribution width ($\sigma$ = geometric standard deviation).

Different distributions have not only been between different workplaces but also in same places and at different conditions. As example in this respect, figure 6 and figure 7 show the size distribution of aerosol-attached activity in a workplace of a gardener at different working hours.

Figure 8 shows the size distribution in a workplace of a guide of a gallery. (1 = nucleation mode; 2 = accumulation mode; 3 = coarse mode).

In the figures 8, 9 and 10 small fractions of particles with big aerodynamic diameters ($> 1000$ nm) can be seen. In contrast to the measuring results in dwellings, a small fraction of the radon decay products are attached on coarse particles. The reason for the coarse mode is possibly the dust in the workrooms. Further evaluations of the measurements will show more detailed information on this coarse mode.
Figure 6. Relative size distribution of aerosol-attached Pb-214 activity measured in a greenhouse (weather: sunny-misty, time: 14:05)

Figure 7. Relative size distribution of aerosol-attached Pb-214 activity measured in a greenhouse (weather: overcast, time: 15:10)

Figure 8. Relative size distribution of aerosol-attached Pb-214 activity measured in a picture-gallery
Figure 9. Relative size distribution of aerosol-attached Pb-214 activity measured in a office

Figure 10. Relative size distribution of aerosol-attached Pb-214 activity measured in a cabinet maker’s workshop

In summary shows table 3 the measured parameters of the activity size distribution of the aerosol attached short lived radon daughter Pb-214 (all measurements of the project).

Table 3. Mean values and ranges of the size distribution parameters of the aerosol attached Pb-214 activity

<table>
<thead>
<tr>
<th></th>
<th>Nucleation Mode</th>
<th>Accumulation Mode</th>
<th>Coarse Mode</th>
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<tbody>
<tr>
<td></td>
<td>AMD₁ [nm]</td>
<td>AMD₂ [nm]</td>
<td>AMD₃ [nm]</td>
</tr>
<tr>
<td></td>
<td>g₁</td>
<td>f₁</td>
<td>g₂</td>
</tr>
<tr>
<td>d [nm]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>1,8</td>
<td>360</td>
</tr>
<tr>
<td>(10–40)</td>
<td>(1,6– 2,2)</td>
<td>(0,2–0,3)</td>
<td>(150–450)</td>
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</table>
CONCLUSIONS

1. The high variation of radon concentration with time, especially the differences between working hours and non-working hours.

2. High variations of aerosol concentrations, equilibrium factors and unattached fractions due to actual working process and working environment.

3. Different types of activity size distributions depending on working conditions have been determined.

4. Relevance and consequences with respect to the dose assessment for radon exposure should be investigated and further sensitive analysis concerning the influence of the variation of several parameters on the dose are necessary.

LITERATURE


