Lessons Learned from Surveillance: General procedure for controlling occupational exposure to radon

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1. Abstract

Radon can be a matter of concern in a wide range of workplaces, and protective measures have to be taken into account for many cases. According to the recommendations of the ICRP, workplaces should be included in the institutional control when the exposures incurred at work are the result of situations that can reasonably be regarded as being the responsibility of the operating management.

Such workplaces do not only occur in underground mines being in operation, closed-out mines open to visitors, tourist caves and other underground workplaces, but they can also occur in above ground working areas such as in spas and waterworks. The exposure levels cannot be projected. They can vary in wide ranges because of the complex mechanisms affecting the radon concentration in the working areas. Therefore, in the first place, a national authority will need to arrange for surveys to get a sound overview of the situation, in particular of the patterns and levels of exposure. This information is the basis for discussion of the national scope and scheme of regulatory control.

Based on the results of surveillance carried out for many years the authorities in Germany evolved a system of radiation protection control for occupational exposures to radon within which the optimisation principle is of great importance.

2. Occupational exposure to radon in the system of radiation protection control

In the past workers employed in jobs involving incidental radiation exposure due to natural radiation sources were not included in the control system of radiation protection although the exposures in doing these jobs are in the same order of magnitude or, in many cases, higher than the exposures of workers in practices. It was generally considered not possible or not desirable to control a radiation exposure due to a natural radiation source. This understanding has completely been changed. There is an international consensus that only sources and exposures such as K-40 contained in the human body, cosmic radiation prevailing at ground level or above ground exposure to radionuclides present in the undisturbed earth's crust are not amenable to control and that they should therefore stay out of the system of

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protection [1]. All other natural occurring radiation sources and exposures are regarded as amenable to control.

The most important component of radiation exposure at work due to natural sources is the exposure to radon.

Nowadays there is a consensus that the radon risk is real and substantial at lower exposure levels, too. Consequently there is an overall need to keep the exposure to radon at home and at work as low as reasonable practicable. In only a few cases is exposure to radon not amenable to control, e.g. working outdoors. These situations should be excluded *a priori*. In all other cases, however, the exposure to radon at work should generally be an issue of concern. However, we have to distinguish between exposures to radon at work that can be treated as being due a practice and exposures being comparable to exposures at home. If there is no distinction, all workplaces must be included in the protective system and unnecessary protective measures involving great expenses would be the consequence. After due consideration the ICRP recommended in [2] that *the system of protection for practices should be applied at work only when the exposures incurred at work are the result of situations that can reasonably be regarded as being the responsibility of the operating management.*

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3. Occupational exposure to radon – The history of survey in Germany

3.1 Radon in uranium mining

In 1946, intensive mining of uranium started under the directive of the USSR government in the traditional mining regions of Saxony, e.g. in Schneeberg, Aue and Johanngeorgenstadt where already in the 30ies high radon concentration levels in pits had been measured. Although the relation between lung cancer and the exposure of miners to radon was commonly accepted at that time, no attention was paid to the radiological protection of workers. The same attitude was observed in other countries where uranium ores were mined and milled. At that time, under the post-war conditions, it was the primary goal to produce uranium as quickly and as much of it as possible. However, it was also believed that the radon levels in the reconstructed mines or new mines were significantly lower than in the old mines. Measurements intended for exposure assessments were not taken. Only gamma

radiation measurements were carried out in order to detect uranium ores suitable for exploitation.

Nowadays we are faced with a specific problem. In the post-war time up to 100 000 workers were employed in the mines and their radiation exposures were very high. As a result, numerous workers contracted lung cancer. For several purposes, in particular for the occupational disease adjudication processes of workers formerly exposed, for determining subsequent occupational medical care and for epidemiological studies retrospective assessments of exposure are necessary. For lack of measurements, these assessments are very difficult. Therefore, comprehensive studies were carried out n the 90's in order to develop methods for the retrospective assessment of exposure [3]. Firstly, all available data that was suitable for drawing conclusions on the radiation exposure of miners were systematically analysed. In addition, mining and working conditions of the early years were reconstructed and radon and other exposure components were measured considering typical situations in the pits. In this way, a lot of important information on the former exposure of workers was obtained and first assessments were verified. The historical records, the measurements and data on the ore deposits, information on exploitation, ventilation techniques, engineering control and last but not least data on the uranium production served as the basis for the development of models (job-exposure matrix). In developing the models, data gathered from the Czech uranium mining industry in the Ore Mountains were taken into account, too. Applying these models, retrospective assessments of the exposure levels were estimated more precisely for the early time of uranium mining [3].

Since 1955, radon measurements have been carried out increasingly applying simple techniques available at that time. Air samples were taken in the mines and the radon concentrations were measured in laboratories by scintillation cells etc. Later on instruments and methods were developed for measurements of the concentrations of the short-lived radon decay products (strictly speaking the potential alpha-energy of these decay products). Several types of so-called 'Working Level Monitors' were used for monitoring. The measurements (short-term measurements) were carried out at the workplaces. Primary objective of the investigations was the provision of data to increase the effectiveness of the mine ventilation with regard to the reduction of the radon concentrations and the concentrations of other harmful substances in the air in underground working areas. Step-by-step, working conditions were improved and the radiation exposures of workers were lowered.

Since the early 1970's, a systematic monitoring of the radiation exposure of workers was carried out in the mines and mills [4]. All measurements and other investigations were specified in monitoring programmes. Now as before the measurements were used to adapt the ventilation system to the changing conditions in the pit and for operational radiation protection at the face, in particular for decision-making on protective measures (e.g. closing off workplaces with excessive radon concentrations). The measurements were also used for assessing the individual exposures of workers. Measurements of the potential alpha energy of the short-lived radon decay products were the major component of these programmes. The frequency of the measurements (short-term measurements) was orientated to the radon concentration levels at the workplaces and their variation.

The individual exposures of workers were estimated based on the assumption that the short-term measurements carried out at a workplace were representative for a defined working time and for all workers staying during this time at this place. The other components of exposure (external exposure and internal exposure due to inhalation of long-lived alpha radionuclides) were assessed by means of screening measures. However, during the exploitation of uranium ores the exposure to radon and its decay products is the decisive factor for the total exposure. The measurements and data required for exposure assessments as well as the calculated figures of individual exposures were registered in a company internal file. Since then, the limits of radiation exposure having been specified meanwhile in several regulations were kept.

This approach to assess the occupational exposure of uranium miners – measurement of the concentration of radon and the potential alpha energy of the short-lived radon decay products at the workplaces - 'workplace monitoring' - was retained up to 1991. In that year, it was decided to close and to remedy the mines, mills and waste management areas. Because of the broad variety of practical situations to be monitored in the course of this work, monitoring individual exposure by applying 'personal dosemeters' was initiated. All components of the radiation exposure of workers (internal exposure due to short-lived radon decay products, internal exposure due to long-lived alpha nuclides of the uranium decay chain and external exposure) were measured [4]. 'Workplace monitoring' has been continued in several working areas for both purposes operational radiation protection and comparisons with the measurements using personal dosemeters.

3.2 Radon at workplaces other than uranium mines

Because of the geological conditions in the uranium mining areas, increased concentrations of radon had to be expected in other working areas, too. Therefore, since the 1970's, investigations of the exposure to radon have been made in non-ferrous ore and mineral underground mines, at shaft construction work, and at work carried out to protect abandoned mines against mechanical damages (e.g. surface breaks, subsidences). In mining areas, show caves and tourist mines, radon spas, and waterworks have also been included in the investigation. As in uranium mining, the potential alpha-energy concentrations have been measured and Working Level Monitors have been used for measurements at the workplaces. If the limits specified for occupational exposure in practices and that also applied to exposure to radon at work were exceeded measures were taken to reduce the exposure of workers. In the course of time the exposures have been decreased considerably.

In spite of the measures, exposures remained high at numerous workplaces. These workplaces were included in the radiation protection control system and 'workplace monitoring' programmes were carried out in order to assess the exposure of workers systematically. The individual exposures of workers were estimated taking into account the working hours at the place monitored. The authorities supervised protective measures and monitoring programmes.

In the 80's, additional investigations were started in other parts of Germany in order to complete the information on radiation exposure due to radon at work [5,6]. Several underground workplaces, workplaces in waterworks and not least workplaces in spas were the matter of these surveys. At the beginning Working Level Monitors were

used, later other methods and measurement techniques such as measurements of radon concentration using monitors and measurements of time-integrated concentration of radon using track-etch detectors were also used in order to get experience with several techniques.

Remedial measures were carried out, if necessary.

4. Lessons learned from surveillance

4.1 Workplaces of radiation protection concern

Radon can be an issue of concern in a wide range of workplaces other than uranium mines. Radon concentrations that cannot be disregarded from the radiation protection point of view have generally to be expected at underground workplaces. The investigations made there have clearly shown that, because of numerous parameters affecting the radon concentrations at underground workplaces, geological parameters and information on underground structures alone are mostly not sufficient to make reliable predictions of the radon concentrations at the workplaces and the exposure of workers.

Particular attention should be directed towards abandoned mines where temporary work is carried out to avoid surface breaks, subsidences and other mining damages. In these underground working areas the radon concentrations vary considerably from place to place and remarkable concentrations can occur. Similar situations occur in caves or closed-out mines open to visitors, too.

Although in Germany the majority of people working in underground workplaces is employed in coal mining, these workplaces are not very important. Only a small number of workplaces is of interest since the ventilation systems of the coalmines are very effective and provide mainly constant and good working conditions. Also, from the radiation protection point of view [7] the situation can be regarded as optimised and additional protective measures are not necessary.

Salt mines can generally be left out of consideration since there the concentration levels are always very low.

Workplaces in waterworks drawing groundwater can be an issue of concern, not only in mining regions like Ore Mountains or other radon prone areas. High concentrations of radon in the groundwater drawn can be an indicator for relevant workplaces. Because of other parameters also affecting the radon concentrations in working rooms, e.g. dimensions of the room, technology of water treatment, the concentration levels at the workplaces cannot be predicted reliably. The investigations carried out in the past have shown that the concentrations in the working rooms can vary considerably. Concentrations up to some hundred thousand Bq per m^3 were measured in extreme.

Workplaces in radon spas can also be of concern. The relevant workplaces are mostly in the treatment areas of the spa. However, operating and maintenance staff can also suffer exposures that cannot be disregarded from the radiation protection point of view.

Although underground mining, except coal and salt mining, and other underground works, waterworks and radon spas are work activities, which are generally of concern, we learned from the surveillance that the exposure levels can vary from place to place and over time. Radon concentrations are low bat numerous places because of the small radon flow into the working rooms, the effective ventilation system or both. Additional measures can cause considerable costs and give a small benefit only. Therefore, the situation at these workplaces can be accepted as optimised from the radiation protection point of view. These workplaces should not be included in the control system.

In the working areas generally being of concern, systematic investigations have to be made in order to identify these workplaces for which, in addition to the measures of occupational health and safety, measures of radiation protection have to be considered. Employers who are responsible for the occupational health and safety should investigate themselves the situation at the workplaces by measurements and other actions. They have competent knowledge of the working conditions and other details required for proper exposure assessments and so they are in the position to carry out the exposure assessments in an optimised way. However, in many cases the employer is not yet well acquainted with the problems of radiation protection and does not have experience in radon measurements. Therefore, the employers should have access to laboratories from which they can commission measurements of radon concentrations at the workplaces and exposure assessments for the workers. The authorities should support the employers in planning sound arrangements for investigations.

Additionally the authorities should specify the exposure level - action level- above which measures of radiation protection are necessary.

The action level for the exposure to radon at workplaces is given in [9] as a yearly average concentration of 1000 Bq/m^3. We learned from numerous investigations carried out in the past that this concentration level is applied in all situations irrespective on the occupancy at the workplace of concern and the specific exposure conditions, e.g. the equilibrium factor. However, it should be noted that this concentration level is based on an assumed equilibrium factor between radon and its short-lived decay products of 0.4 and an annual working time of 2000 hours. For these conditions the radon concentration of 1000 Bq /m^3 equates an annual effective dose of 6 mSv. Therefore, the authority should specify a time-integrated radon concentration as action level. In this way unnecessary protective measures can be avoided at workplaces where staff stay only for a short time e.g. for inspections.

4.2 Investigations at workplaces

Unfortunately, we do not have a magic bullet for measurements at workplaces. The goal of investigations will determine the measuring strategy as well as the measuring method. The reasons for performing measurement include:

- identification of workplaces for which mitigation measures must be considered or which must be included in the institutional control,

- measurement in conjunction with mitigation measures and

- measurements for monitoring exposure of workers in order to comply with the limits specified in the regulations.

Since the action level should be specified as a time-integrated radon concentration (commonly termed radon exposure) and the radon concentration in a workplace of concern vary with time, long-term measurements of the radon concentration over a period of one year, at least over several months are preferable to short-term measurements.

Several workplaces are occupied only during a short time, e.g. for inspections or maintenance purposes. On the basis of long-term measurements, the exposure of workers can be overestimated. Nevertheless, long-term measurements should be made for these workplaces, too. The overestimation of exposure will change in planning remedial works if the work patterns of the staff have to be taken into account in exposure assessment that have to be made as realistic as possible. For large working areas with many rooms or workplaces the measurements have to be made at a number of locations that is sufficient in order to make a reliable assessment of the exposure. Outlining our experience, we concluded that programmes designed to identify the exposure levels at workplaces always require the deployment of numerous detectors. Since the cost and the possibility of placement of the detectors are important factors in planning optimised programmes, passive radon detectors measuring the time-integrated radon concentration are applied in the majority of cases.

For several reasons reliable data on the radon concentrations have to be available as soon as possible and instantaneous or short-term measurements have to be made. The conditions for short-term measurements, e.g. time periods of the measurements and the frequency, have to be considered carefully in order to avoid misinterpretations. In these situations radon monitors are normally applied that record the variation of radon concentration in time.

If the action level is exceeded, measures have to be planned and implemented in order to reduce the exposure below the action level. The reasons for elevated radon concentrations have to be found. Measurements are absolutely necessary for it. In selecting the optimal method for an individual case, the circumstances at the workplace of concern have to be considered. In more complex situations measurements applying radon monitors are indispensable for a proper assessment of the exposure situation and for operational radiation protection, if required, and they should be operated continuously during the working hours.

After completion of the mitigation, re-testing should be made in order to confirm that the aim of mitigation has been achieved. Intervals should be specified at which the situation at the workplaces should be re-tested. An approach generally applicable cannot be recommended. Re-testing is always necessary if changes are made or occur influencing the protective measure, e.g. the ventilation, or if the radon level after applying the measure is just below the action level.

In cases where the radon concentration still exceeds the action level after the remedial measures the workers should be subject to an appropriate regime of

radiation protection and their exposure has to be monitored systematically in order to document the current exposure and to make sure that the exposure limits given by law are not exceeded. Measuring strategies and methods are discussed in the paper. “Lessons learned from the surveillance: Measuring methods and monitoring strategies”.

4.3 Remedial measures

Remedial and other protective measure should result in exposure levels being reliably below the action level. Therefore, the employers should have access to expert advice on mitigation. The authorities should support the employers by publication of guidelines in accordance with the national standards of occupational health and the national building practices. Ventilation has proved to be the most effective protective measure. By systematic ventilation, radon concentrations at the workplaces can be reduced in all cases. Ventilation systems producing a small overpressure have proven to be very effective. However, in planning the ventilation system it has to be considered that parameters affecting the concentrations vary and are specific to each situation. Extensive measurements can be necessary in planning the systems as well as for improving ventilation conditions. At several workplaces, e.g. workplaces in waterworks in which the workers stay only for a short time period, intensive airing before starting work (e.g. inspections or maintenance) can be sufficient to provide acceptable working conditions.

At some of the underground workplaces, a decrease in the radon concentrations was also achieved by covering the mine drainage system and by hermetic sealing of abandoned tunnels. Partitioning of rooms within which staff are stay for longer time during the working day have been proved to be very effective to reduce the exposure of workers in water works, too.

Remedial measures that have to be considered in some cases for in caves are an special problem. The ventilation, that is successfully applicable in other underground workplaces, can modify the climate, e.g. the humidity in the cave, and the formations in the cave can be destroyed. In these cases, the restriction of the working time for the tourist guides in the cave is the only option in order to reduce the occupational exposure.

The restriction of the working time at a workplace with elevated concentration is always an effective protective measure. Therefore the work processes of concern and the patterns of work should be revised and optimised with regard to the radiation exposure before other measure of mitigation are considered.

4.4 Workplaces to be subject to control of radiation protection

Although effective remedial or protective measures were developed and tested, we have to recognise that the exposure cannot be reduced below the action level in all cases since the measures are ineffective or, considering the relevant circumstances, they are unreasonably difficult.

These workplaces are subject to radiation protection control. The system of radiation protection applied for practices has to be applied for workers exposed to radon, too.

Considering the optimisation principle the authority should decide whether the complete protection system for practices has to be applied or only parts of it.

5. Radiation protection regulations in Germany

5.1 Basis

The ICRP recommendations on control of exposures to radon [2], the International and European Basic Safety Standards [9,10] are the basis for national regulations of radiation protection that are specified in the in the Radiation Protection Ordinance - Strahlenschutzverordnung (StrlSchV) [11]. According to the European Basic Safety Standards [10], the area was extended within which the Ordinance is operative. Human activities involving the presence of natural radiation sources, which can lead to a significant increase in the exposure of workers or members of the public ('work activities'), are now included.

According to the standards in the ordinance, regulations were specified to identify work activities of concern, to implement corrective measures to reduce exposures and to apply radiation protection measures pursuant to the requirements for practices.

5.2 Identification of work activities

Based on the studies described before, working in underground mines, shafts, tunnels closed-out mines open to visitors (tourist mines) and show caves were identified as work activities of concern as well as working in waterworks and in radon spas. These work activities are generally included in the system of radiation protection control outlined by the Ordinance.

Although most of the workers exposed to radon during their work are employed in above ground workplaces such as small factories, shops, offices etc. these workplaces are not included in the protection system by the Ordinance. According to [2] exposures at these workplaces are not regarded as being the responsibility of the operating management.

5.3 Action levels and limits

In the Ordinance the radon exposure (P_{Rn}) of $2 \cdot 10^6$ Bq·h·m^{-3} is specified as the action level. The authority can establish other action levels of exposure if the relevant equilibrium factor is significantly different from 0.4.

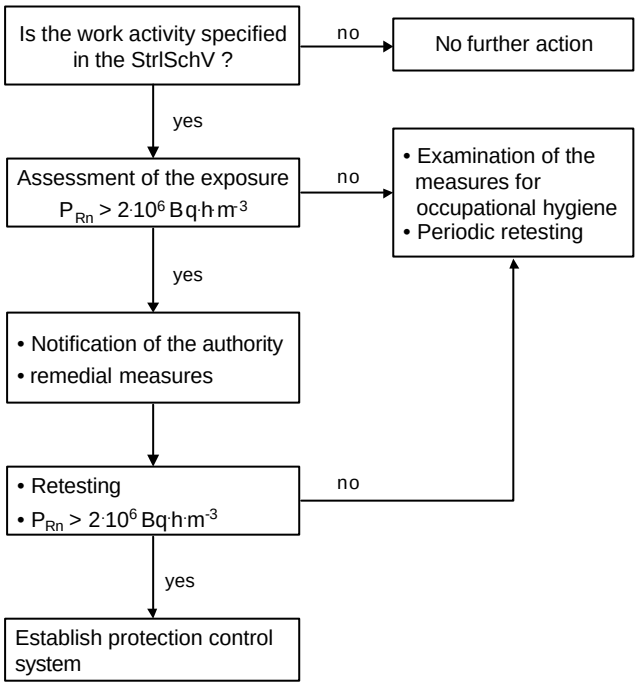
The dose limits specified in the Ordinance for practices are in force for work activities, too. For practical purposes and, assuming an equilibrium factor of 0.4, the annual effective dose limit of 20 mSv can be equated with the radon exposure (P_{Rn}) of $6 \cdot 10^6$ Bq·h·m^{-3}.

In addition to the limits for the annual effective dose, the working lifetime dose is limited to 400 mSv.

5.4 Demands on employers

If a workplace of concern can be classified as a type of workplace specified in the Ordinance, it is, in principle, subject to control and the employer has to fulfil the legal obligation of radiation protection. However, the measures necessary for radiation protection depend on the level of exposure. A stepwise approach to control the radon exposure at work is stipulated (see Figure 1).

Figure 1: Controll of radiation exposure at work activities



At first the employer has to determine the possible radon exposure taking into account measurements and occupancy times. If the exposure is below the mentioned action level, in normal cases, specific measures to reduce radiation exposures are not necessary, since the measures being already in place for normal occupational hygiene reasons may usually provide sufficient radiological protection. If the action level is exceeded the employer has to take measures suitable to keep radiation exposure as low as possible taking into account all circumstances. Should the situation arise the authority can demand additional measures. Experience has shown that in many cases remedial measures are successful in reducing radon concentrations below the action level.

If, in spite of all measures, exposure cannot be decreased below the action level, the employer has to adopt an appropriate system of radiation protection for both workplaces and employees in accordance with the requirements specified for practices. Minimum demands are specified in the Ordinance. A major component of the control system is the monitoring of the exposure of workers in order to document that the current exposure is below the limit. Further the employer is obliged to record the monitoring results, to calculate the annual effective dose and to hand over the results to the authority and to the governmental dose register. However, details of the approach to monitor the exposure, the calculation of the effective dose and the report to the register are not specified in the Ordinance. In order to qualify the employers in doing properly the protection of workers and the monitoring, technical instructions and information letters have been published.

Taking into account the circumstances the authority can lay down the type of measurements to be applied and, if necessary, that the measurements have to be implemented by qualified laboratories.

6. Conclusion

Based on experience with the surveillance of occupational exposure to radon for many years and considering the international recommendations and standards a pragmatic approach was developed in Germany to decrease the exposure of workers to radon at work. It is specified in the current regulations of radiation protection. It is focused on the decrease in high exposures to radon incurring incidentally at work within which the exposure can be regarded as being the responsibility of the operating management. The work activities of concern are specified in the regulations. Taking into account the specified action level, the individual workplaces have to be identified in which interventions should be undertaken to reduce radon exposures. Only if exposure cannot be decreased below the action level, a control system has to be established for the workplaces and the exposed workers. Although workers in these cases are regarded as ‘occupationally exposed persons’, the actual measures of control can be adopted to the specific conditions of the work activity taking into account the protective measures specified for practices in the Ordinance. Only minimum demands are specified in the regulations. In this way, unnecessary or unrealistic measures can be avoided.

In the mean time, many employers are aware of the problem and their responsibility and they carried out appropriate measures. These days the monitoring of the occupational exposure to radon is still required only for a small group of workers.

However, taking into account the omnipresence of radon at work and at home it is an overall need to keep the exposure to radon as low as reasonably practicable. Therefore, this approach can be considered only as a milestone on the way to get acceptable conditions regarding the exposure to radon at all workplaces. At normal above ground workplaces such as workplaces in factories, shops, public buildings and offices elevated concentrations of radon can occur and systematic investigations should be carried out. At these workplaces, the exposure conditions are similar to those in rooms people live in. Therefore, these workplaces need another treatment than the workplaces within which exposure can be influenced by the operating management. In order to avoid imbalances between protection against radon at home and at work, the protection concept, action levels etc. developed for the

protection against radon at home should be adopted for the general protection in radiation protection at these work activities. The regulations planned in Germany for the ultimate solution of the radon problem will consider this principle.

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