# 11 Ionising radiation (radon)

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## 11.1 Natural radiation exposure

Human beings are constantly exposed to low levels of ionising radiation from natural radiation sources. This natural background radiation exposure has the following main origins:

- Inhalation of radioactive substances and above all of radon and its derived products
- Nutritional intake of radioactive substances (food and drink)
- Radiation from the environment, e.g. from the building materials of surrounding walls and ceilings
- Radiation from space

The average radiation exposure of the population in Germany to natural radiation sources is roughly 2.1 millisievert (mSv) per year. The inhalation of radon and its derived products accounts for about half of this. Natural radiation exposure is supplemented by a dose of another approximately 2 mSv per year due to the use of artificial radiation sources, mainly in medicine. The population‘s mean radiation dose changes only very little over the years. The radiation dose of individuals, however, can deviate greatly from the mean value – firstly, due to regional differences in the natural background radiation, but above all due to medical treatment and diagnosis. The Bundesumweltministerium (Federal Ministry of the Environment) publishes a report on the current radiation exposure of the population every year [1].

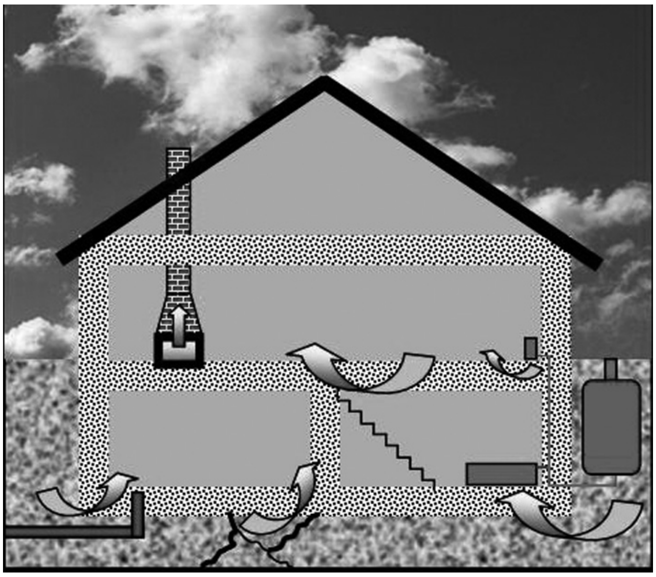
## 11.2 Radon

The lion‘s share of the dose from natural radiation sources is contributed by the radioactive noble gas radon and its derived products. Radon is not only odourless but also otherwise imperceptible to the human sense organs. In our surroundings, i.e. also in offices or office-like rooms, it is constantly present in greater or lesser concentrations. Radon is part of the natural decay chains of uranium and thorium. The concentrations of uranium and thorium (and hence also of radon) in the ground depend on the ground‘s geological structure. A high activity concentration in the soil air is encountered in certain areas of the Ore Mountains, Bavarian Forest and Black Forest, for example.

Under normal ambient conditions (temperature and pressure), radon is gaseous. It can also be carried over long distances dissolved in water. Due to convection and diffusion from the soil, it can enter the atmosphere, yielding the small share of radon in the air. The Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) has published a general map of radon concentrations in the soil air [2]. The values are typically of the order of a few kilobequerel per cubic metre (kBq/m³).

Radon gas can enter not only the ambient air, but also the cellars of buildings (see Figure 23). Due to low pressure differences, occurring particularly during the heating period, radon can rise out of cellars into the storeys above.

Figure 23:
Penetration of radon from the ground into cellars and upper storeys.
Source: German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors, Radiation Protection Group



In the rooms of a building, the magnitude of the radon concentration depends among other things on the following factors:

- Geology of the ground

  The radon concentration increases with increasing uranium and thorium content in the ground. The mobility of radon in the ground depends on its fissuration

- Storey on which the room in question is located

  The radon concentration decreases with height above the cellar level.

- Mode of construction

  Radon penetrates into buildings via leaks in the base slab and cellar walls (e.g. via penetrations for pipes and cables) and via joints.

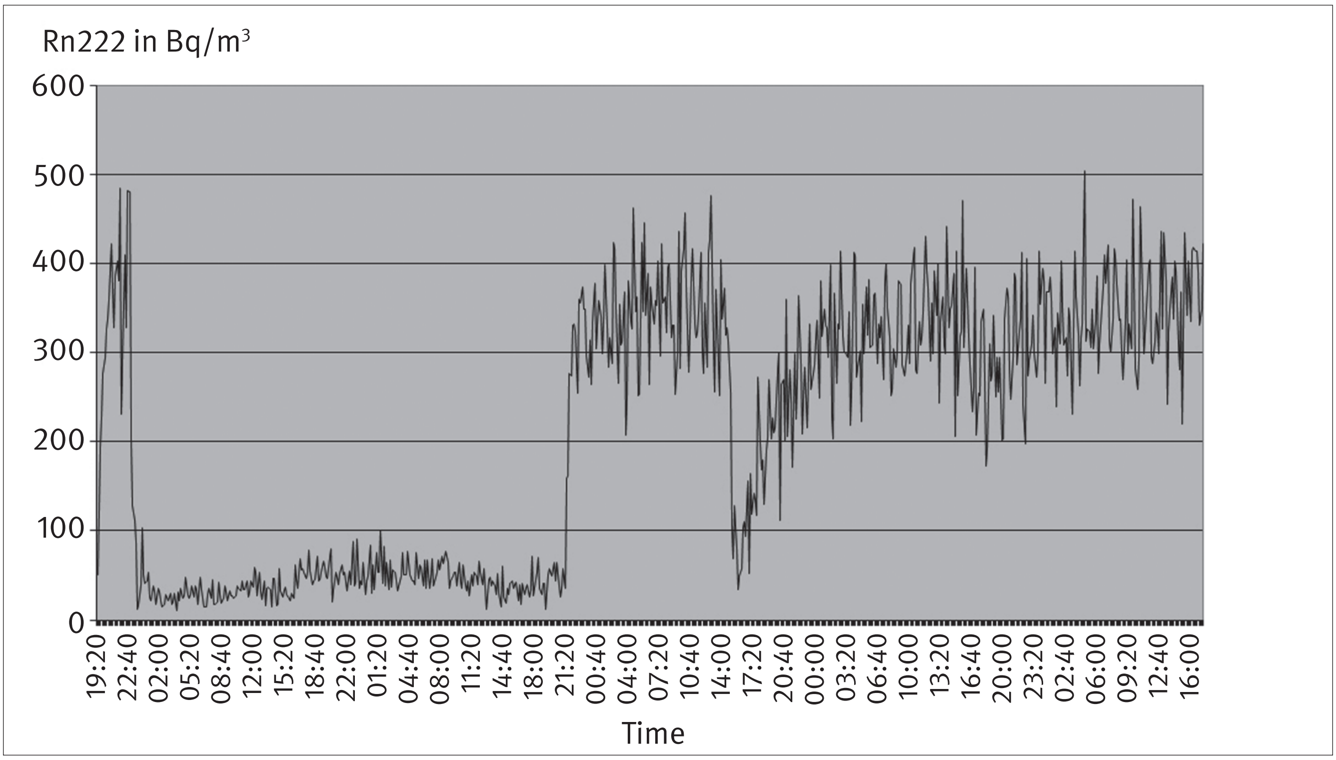
- Ventilation

  Lower radon concentrations can be expected in artificially ventilated than in naturally ventilated rooms.

The radon concentration in a room shows addition seasonal and daily variations. These depend on such meteorological parameters as temperature, humidity, wind speed and wind direction.

The values in buildings range typically from a few Bq/m³ to several hundred Bq/m³. An example of the change in radon concentration in an office room over several hours is presented in Figure 24. The effect of ventilation is clearly visible. The radon concentration drops from an initial roughly 450 Bq/m³ to an average of approximately 50 Bq/m³ after the windows are opened. When the windows are closed, the concentration increases relatively quickly back to the original value.

Figure 24:
Change in radon concentration in an office room over several hours, measurement by the Radiation Protection Group of the German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors




## 11.3 Biological impact

When radon is inhaled as a noble gas, it is not absorbed by the body, but exhaled. The radiation exposure proper therefore comes only to a small extent from radon itself and to a much greater extent from its non-gaseous products of degradation such as polonium 218, lead 214, bismuth 214 and polonium 214. These degradation products attach in the air to superfine aerosols and can be inhaled with them and absorbed by the body. The emission of ionising radiation by radon‘s derived products then exposes the body to radiation, mainly in the lungs. The magnitude of this lung dose also depends on the ratio of radon activity to daughter product activity. Reference is made in this context to the so-called equilibrium factor. This is usually a value of about 0.4, i.e. the activity concentration of the daughter product is about 40 % of radon‘s activity concentration.

This radiation exposure does not cause any direct harm. No acute symptoms occur from the inhalation of radon and its derived products. However, delayed radiation damage and above all lung cancer can, however, occur. The probability of the occurrence of such damage depends among other things on the magnitude of the activity of inhaled derived products of radon and thus on the radon concentration in the ambient air. The Strahlenschutzkommission (German Commission on Radiological Protection) estimates the risk due to radon as follows: If the radon concentration increases by 100 Bq/m³, approximately 10 % more cases of lung cancer can be expected than without radon [3].

## 11.4 Radon at workplaces

Elevated radon concentrations in the air can be expected at a number of workplaces owing to the special conditions prevailing there. These include workplaces in underground mines, radon spas and water extraction plants. For these workplaces, there is an obligation under the Strahlenschutzverordnung (Radiation Protection Ordinance) [4] to investigate the radiation exposure due to radon and its derived products, to comply with the specified limit values and, if necessary, to take action to reduce the concentration of radon and its derived products.

For workplaces in offices and office-like rooms, there is no statutory obligation to measure the radiation exposure to due radon or to comply with limit values. In general, the expected radiation exposure in offices is low and on the same level as the mean natural background radiation. Nevertheless, there are also cases in which the radon concentration in offices is elevated and above the mean value.

## 11.5 Investigation

If there is any suspicion of an elevated radon concentration in an office or office-like room, this should be investigated more closely. The investigation comprises a preliminary investigation and a measurement.

In the preliminary investigation, it must be ascertained first whether an elevated radon concentration is in fact probable. The following factors should be borne in mind in this connection:

- Activity concentration in the soil air

  If the soil air of the ground on which the building stands has a high radon concentration, a precondition for a high radon concentration in the building is fulfilled. The Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) publishes a map showing the radon concentration in the soil air in Germany [2]. With the aid of this map, it is possible to determine whether the building in question lies in a region with elevated radon activity.

- Position of the room in the building

  The lower the position of a room in the building, the higher the radon concentration is likely to be. This applies, for example, to rooms in cellars or basements and also to rooms on the ground floors of buildings without cellars. The higher a room in a building, the lower the radon concentration. In the upper storeys of a high-rise building, the radon concentration tends to be low.

- Room ventilation

  The radon concentration may be higher if the room is only naturally ventilated. The lack of openable windows also hampers the movement of air and increases the radon concentration. In artificially ventilated rooms, the radon concentration in the room tends to be low.

If the preliminary investigation suggests an elevated radon concentration or at least the impossibility of excluding such a concentration, the radon concentration should be precisely determined by measurement and the result assessed by comparison with the guide values. Instructions for the measurement of radon can be found in a brochure published by the Strahlenschutzkommission (German Commission on Radiological Protection) [5].

## 11.6 Assessment

The International Commission on Radiological Protection (ICRP) has published recommendations for the maximum permissible radon concentration. On this basis, the German Commission on Radiological Protection has repeatedly issued its own recommendations for the limitation of radiation exposure due to radon. The recommendation of 1994 contains „Radiation protection principles for the limitation of radiation exposure due to radon and its degradation products in buildings" [6]. The guide values contained in them for radon concentrations in homes are given as mean values over the period of a year:

- A radon concentration of 250 Bq/m³ marks the upper end of the normal range of the radon concentration in residential buildings in the Federal Republic of Germany. If the values are within the normal range, no action is considered necessary.

- The range from 250 to 1,000 Bq/m³ is considered the discretionary range for simple measures to reduce exposure to radon. Information is also given on which action can be taken by whom (residents, specialised firms).

- The range exceeding 1,000 Bq/m³ is considered the rehabilitation range. The radon concentration should be reduced here in all cases even if elaborate measures are necessary for this.

For workplaces exposed to elevated natural radiation, the Strahlenschutzverordnung (Radiation Protection Ordinance) contains instructions and legal requirements [4]. As already mentioned, normal office workplaces are not covered. It is nevertheless possible to draw appropriate conclusions by analogy.

Given 2,000 working hours per year and an equilibrium factor of 0.4, a radon concentration of 1,000 Bq/m³ corresponds to a dose of roughly 6 mSv per year. Values above this dose at the workplaces named in Annex XI of the Radiation Protection Ordinance must be reported to the authorities. The group of persons engaged in the work activities mentioned are subject to a limit value of 20 mSv per year. If the annual radon exposure is less than 6,000,000 Bq*h/m³, compliance with the limit value can be assumed [4]. Given 2,000 hours spent at the workplace, this amounts to an average radon concentration of 3,000 Bq/m³.

However, one must also bear in mind that, in areas with elevated radon concentrations, the dose consists not only of the occupationally related radiation exposure due to radon, but also of the radon exposure arising outside work.

To observe the minimisation requirement of the Radiation Protection Ordinance, it is advisable to apply the same yardsticks to workplaces as to homes and not to permit any elevated radon concentration. For workplaces in areas with high radon activity, radon concentrations from 250 to 1,000 Bq/m³ should therefore also be regarded as the discretionary range and radon concentrations over 1,000 Bq/m³ as the rehabilitation range with rehabilitation measures being taken if required .

## 11.7 Measures

Measures to reduce the radiation exposure due to radon can include:

- Changing the use of a room exposed to above-average radon levels

  For instance, rooms in basements could be abandoned as office rooms and – assuming this is possible – converted into storage rooms.

- Gas-tight sealing of base slabs, cellar walls, penetrations and joints
- Improving ventilation by increasing the air change rate

  This includes more frequent and more vigorous airing in the case of natural ventilation and the installation of artificial ventilation.

- Extraction of radon gas on the cellar level or beneath the building (drainage ventilation)

Some simple measures, such as more frequent airing, can be taken by room users themselves and are very effective. For more elaborate measures, specialised firms must be consulted. Which measure is suitable in the given case depends among other things on the level of radon concentration and the building structure and conditions. Detailed instructions on radon protection measures can be found on the website of the Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) [7]. In areas with high radon soil concentrations, suitable measures are to be taken at the design stage for new buildings.

## 11.8 References

[1] Umweltradioaktivität und Strahlenbelastung – Jahresbericht 2009. Published by: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Bonn 2010

[2] Die Radonkarte Deutschlands. Published by: Bundesamt für Strahlenschutz (BfS), Salzgitter. www.bfs.de/de/ion/radon/radon_boden/radonkarte.html

[3] Einfluss der natürlichen Strahlenexposition auf die Krebsentstehung in Deutschland – Stellungsnahme der Strahlenschutzkommission. Published by: Strahlenschutzkommission, Bonn 2008

[4] Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung – StrlSchV) vom 20. Juli 2001. BGBl. I (2001), p. 1714-1836; last revision BGBl. I (2012), p. 212

[5] Leitfaden zur Messung von Radon, Thoron und ihren Zerfallsprodukten. Published by: Strahlenschutzkommission, Bonn 2002

[6] Strahlenschutzgrundsätze zur Begrenzung der Strahlenexposition durch Radon und seine Zerfallsprodukte in Gebäuden – Stellungsnahme der Strahlenschutzkommission. Published by: Strahlenschutzkommission, Bonn 1994

[7] http://www.bfs.de/de/ion/radon

**Further reading**

Radon. Information zu einem strahlenden Thema. Published by: Bundesamt für Gesundheit der Schweiz. EDMZ, Bern 1999

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