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Determining the mean year value of radon in the indoor air

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Abstract. This paper describes how Denmark has implemented the directive 2013/59/EURATOM, laying down basic safety standards for protection against the dangers caused by exposure to ionising radiation. Ionising radiation develops from radon. Furthermore, the paper describes a procedure to determine the value of the mean year concentration of radon based on short-term measurements. Procedures are described both for radon measurements in the indoor environment of buildings used for accommodation and buildings used for other purposes such as workspace, day-care for children and schools. In addition, the paper argues for the described requirements that short-term measurements should follow in order to be used for estimating the concentration of radon indoors as the mean year value.

1 Introduction

Radon-222 develops from the radioactive decay of radium-226 and has a half-life of 3.8 days. This noble gas infiltrates through soil into buildings and, if it is not evacuated, there can be much higher exposure levels indoors than outdoors [1, 2], which is where human exposure occurs [3]. In this way, radon affects occupants through the indoor climate.

The World Health Organization recommends states to introduce requirements for the maximum concentration of radiation from natural sources in the indoor air. These recommendations are the result of the World Health Organization's evaluation that radon is responsible for 3-14% of lung cancer incidents, depending on the average radon exposure in different countries [4]. Results show radon to be the second-largest cause of lung cancer (tobacco smoking is still the primary cause). Radon exposure must be taken seriously in the struggle against radon-induced lung cancer due to the large number of people who are exposed daily in buildings and especially in residential buildings [4]. If people spend their whole life in a house with an average radon concentration in the indoor air that exceeds 200 Bq/m³, their risk of getting lung cancer is higher than 1%. This is far too high and higher than what in other contexts is acceptable for a single-factor risk [5]. Therefore, it is crucial to ensure a low radon concentration in the indoor air and to prevent radon from infiltrating into buildings.

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Since 2010, Danish buildings must be constructed to ensure that the radon concentration in the indoor air is below 100 Bq/m^3 as the mean year value [6]. For all buildings constructed before 2010, it is recommended that the mean year value for the radon concentration in the indoor air does not exceed 100 Bq/m^3 . Since 2018, workspaces with a radon concentration in the indoor air exceeding 100 Bq/m^3 as the mean year value, must implement radon-reducing measures reaching an acceptable radon concentration in the indoor air. The acceptable radon concentration in the indoor air is expected to be defined by the Danish Health Authority based on the mean year value of the radon concentration in the indoor air, the health-risk of workers and the costs of performing the necessary radon-reducing measures [7]. By implementing the same requirements for the mean year value of the radon concentration in the indoor air in the Danish Building Regulations as for workspaces, a national reference level was defined following the council directive 2013/59/EURATOM of 5th December 2013, laying down basic safety standards for protection against the dangers caused by exposure to ionising radiation. Radon exposure in workspaces is limited to the hours used by workers while the exposure of occupants in buildings is defined as 24 hours a day.

The paper describes how to determine the mean year value of the radon concentration in the indoor air. To do so, measurements of the radon concentration in the indoor air must fulfil a number of requirements. If the mean year value of the radon concentration in the indoor air is to be estimated by short-term measurements of the radon concentration in the indoor air, even more requirements must be fulfilled.

The paper argues for the requirements that must be followed and be fulfilled by short-term measurements in order to be used for estimating the concentration of radon in the indoor air representing the mean year value.

2 Mean year radon concentration in the indoor air

The estimated mean year value of the radon concentration in the indoor air seeks to determine the concentration of radon in the indoor air that occupants are on an average exposed to, inhaling air from the indoor air in a particular building over a year. The estimated mean year concentration of radon in the indoor air represents the average exposure over one year and is estimated from measures carried out over a period of less than one year [8].

Within the measuring period, homes are defined as being occupied 24 hours a day, all year around. The indoor air in workspaces, and other buildings used part-time can be evaluated according to the use of time by workers (humans). Periods of time when a building is used by workers will be periods of time when humans are in the building for work. For a building used as an office, this typically includes office hours, hours maintaining and running the office such as cleaning, security and reception functions involving humans. Areas in a building are divided into individual units e.g. a dwelling, an office or a firm. For each unit e.g. a dwelling or a workspace, the estimated mean year value of the radon concentration in the indoor air, given as one value, is determined from short-term measurements of the radon concentration in the indoor air, and intended to quantify the mean year value of the radon concentration in the indoor air.

2.1 Units on one level

The estimated mean year value of the radon concentration in the indoor air is equal to the calculated arithmetic average value of all the measures made in the unit [8].

2.2 Units of one room

The estimated mean year value of the radon concentration in the indoor air is equal to the calculated arithmetic average value of all the measures made in the unit. An average of at least two measurements are needed. Measurements may be carried out at the same location [8].

2.3 Units including more than one floor

First, the calculated arithmetic average value for each floor is calculated taking into account all measures made on the individual floors. Second, the estimated mean year value of the radon concentration in the indoor air is calculated as the arithmetic average value calculated for each floor [8].

3 Requirements to measures

Measures used for determining the estimated mean year value of the radon concentration in the indoor air must fulfil a number of requirements, see sections 3.1 to 3.9 [8].

3.1 Use of measuring equipment

Evaluations of measures seek to determine the exposure of humans to ionising radiation from natural sources in the indoor environment where radon is the main source. It is from the radioactive decay of radon that ionising radiation, given as Alfa-radiation, develops. Nevertheless, it is the concentration of radon in the indoor air that is used to determine the health risk from radiation. Therefore, the purpose of measuring is to measure the concentration of radon in the indoor air. In Denmark, national measurements of the radon concentration in the indoor air are based on closed passive etched track detectors, made from CR39 plastic film placed inside an antistatic holder. For these measurements, analyses were carried out by ISO 17025 and ISO 14001 certified laboratories that as well follow the EMAS (European Eco-Management and Audit Scheme). These base methods for measurements were accredited according to standards of SWEDAC (Swedish board of Accreditation and Conformity Assessment) that are accepted in 18 European countries by the European Cooperation for Accreditation of Laboratories (EAL).

Using other types of measuring equipment such as electronic measuring devices or open passive etched track detectors, these measurements must be compared with the methods used in the base, using the basic methods. Specially, when using electronic measuring units, their insensitivity to electromagnetic fields during measuring needs to be considered and dispelled e.g. by carrying out parallel measures with closed passive etched track detectors over a period of time. Electronic measuring units allow data processing, which is useful for determining the estimated mean year value of radon concentration in the indoor air e.g. at workspaces.

3.2 Measuring period

Radon must be measured for a minimum of 60 days from 1 October until 30 April. The period between 1 October and 30 April is the heating season. In this period, the daily average temperature outside is lower than +10 degrees Celsius.

Outside, the heating season the temperature difference between the inside and the outside of the building is less, which influences the natural ventilation and infiltration of

radon from the ground. Besides, windows and door are more likely to be open to the outside increasing the air change indoors.

3.3 Placement

Measuring units for radon measurements must be placed and stay on during the entire measuring period. Radon indoors varies over time, i.e. by the hour, day, month and year. Radon also varies from one room to the next in a building. The most reliable estimated mean year value of the radon concentration in the indoor air is calculated from measurements made in the same period in with the unit.

3.4 Measuring location

Measurements must be carried out at locations where the measuring unit is exposed to the concentration of radon in the indoor air; on an average humans are exposed to inhaling air, from the environment.

Measurements are carried out in rooms in a building where humans stay for several hours, usually included in the part of the heated area of a building. If humans stay in a room for more than four hours, measurements are to be carried out in that room. In dwellings this will usually include bed rooms, living rooms, hobby rooms, TV rooms and home office and, for workspaces e.g. offices, showrooms, meeting rooms and reception.

For a single-family house on one level occupied by a family of four individuals including two children, a minimum of four measuring units are required, with three measuring units located in each of the three bed rooms and one measuring unit located in the living room. Does the dwelling have more than four rooms; one measuring unit should be located in every third of the additional rooms. For dwellings of more than one level, a minimum of one measuring unit is needed on each floor. For larger rooms, a minimum of one measuring unit is needed for every 200 m² floor area.

Areas on the lower floor level should get a high priority. Also rooms with pipes going in and rooms next to an elevator, ventilation shaft or an installation shaft should have a high priority.

If the building consists of different constructions as additions to the original building, one measuring unit should be located above each of the different foundations.

3.5 Use of building

Buildings and units need to be used as they are normally used during the measurement period.

It is important that the way the building is used does not change and in that way provides higher ventilation rates, lower the air pressure inside or change the temperature maintained inside, as this can affect the radon concentration in the indoor air. Conditions that change the concentration of radon in the indoor air so that measures do not reflect what occupants or workers inhale, on an average, during normal use of the building or unit.

Buildings may not stand idle for a substantial part of the measurement period e.g. during vacations, as indoor temperature and ventilation rates usually depend on the building being in operation. The unassigned period may not exceed ¼ of the measurement period.

If necessary, the measurement period can be extended within the heating season. However, the building can be operated as being in normal use in the measurement period.

3.6 Outdoor climate

There can be challenges with the outdoor climate in the measurement period that need to be addressed. The outdoor climate must, as an average, be normal for the heating season. In the period of the measurement period, consecutive periods of ice-cold days may not exceed $\frac{1}{4}$ of the measurement period. Ice-cold days are days where the outdoor temperature does not exceed 0° Celsius. Periods with ice-cold days can affect the radon concentration in the indoor air, as the soil changes in permeability, hydrogeology and diffusion characteristics. If necessary, the measurement period can be extended, within the heating season.

3.7 Vulnerability and free airflow

Measuring equipment based on closed passive etched track detectors, made from CR39 plastic film placed inside antistatic holders, is insensitive to a number of sources. Closed passive etched track detectors should not be exposed to direct sunlight or direct heat. Closed passive etched track detectors may therefore not be placed in direct sunlight or nearby or direct above a heat source e.g. burning stove, radiator or light bole. In practice, closed passive etched track detectors needs to be placed 1.5 m from a radiator, television, lamp or another heat source.

Additionally, measuring should not take place directly on the surface of the floor, the wall or at the sealing but at a distance of 0.5 m above the floor and 0.25 m from the wall and the sealing. However, if the average indoor air can freely pass the measuring equipment and the additional radon exposure from the building material that the wall or sealing is made of is negligible, distance requirements can be compromised.

In addition, measurements should not be affected by air inlet or air outlet. Outdoor air has a low concentration of radon, which is why ventilation by providing outdoor air to the indoor environment can be used to reduce the radon concentration in the indoor air.

The air speed is higher near an air inlet/outlet. In practice, measurements need to be carried out 1.5 m from an air inlet, external door or a window that can open, and 0.5 m from an air outlet.

Electronic measuring units may in addition be insensitive to electromagnetic fields. Besides the other requirements to ensure proper measuring, of the concentration of radon in the indoor air, the insensitivity from electromagnetic fields needs to be shown to be negligible. Both from permanently e.g. electric wires and interim sources e.g. a mobile phone.

3.9 Avoiding additional radon sources

Radon develops from the radioactive decay of radium, which naturally appears in the soil, in some places with a higher concentration than in other places. Building materials made of materials containing or made of substances derived from ingredients that come from the ground may in fact entail a further contribution to the measurement of the radon concentration in the indoor air. Normally, the contribution from building materials to the radon concentration in the indoor air is considered to be around 10 to 20 Bq/m³.

Attention may be put on materials used for table tops, wall cladding and e.g. bearing walls made of e.g. granite or clay. Even if the content of radium in these materials is low, measurements made by detectors placed directly on top will have a strong influence on the measurements, especially if the concentration of radon in the indoor air is low. In practice, the measuring equipment should not be placed on a table top of granite or put in a bowl made of clay. Furthermore, materials based on volcano rocks, with a low PH-value, some types of coal and clay with high content of radium can work as a radon source indoor.

4 Conclusion

The paper describes how to estimate the mean year value of the radon concentration in the indoor air from short-term measurements. To do so, measurements must fulfil a number of requirements i.a. that measurements must be made between 1 October and 30 April; indoor ventilation must work properly; duration of the measuring period must be at least 60 days; location of measurements in the measuring period must be fixed; up to $\frac{1}{4}$ of the measuring period may include abnormal conditions in the way the building has been operated and how the radon concentration in the indoor air is affected by the outdoor climate. Furthermore, requirements to ascertain that the measure can be used to estimate the mean year value of the concentration of radon in the indoor air that occupants, as an average are exposed to, inhaling air from the indoor environment over a year, are addressed.

Evaluating whether short-term measurements can be used to estimate the mean year value of the radon concentration in the indoor air representing an average exposure over a year are outlined, describing both handling of measures and calculating methods. Including assessments of operating units; the placement of the measuring equipment, avoiding the impact of further contribution from building materials, behaviour of humans and abnormal climate conditions. Besides making decisions on the necessary number of measurements in order to be able to determine a representative value of the radon concentration in the indoor air.

Furthermore, a number of requirements need to be addressed with regard to the measuring equipment, measuring laboratories and the used standards, which impact on the estimated mean year value of the radon concentration in the indoor air. See views in [8].

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