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Note

Radon from building materials

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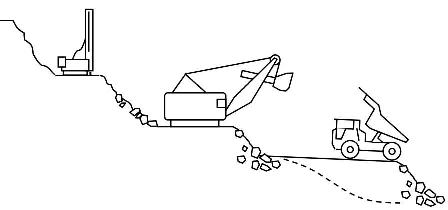
New sampling guidelines established by NGU (Geological Survey of Norway) and NRPA (Norwegian Radiation Protection Authority, Norwegian: Statens strålevern) will help to ensure that materials with high uranium content are not used in the construction industry, where they might otherwise have contributed to elevated indoor radon concentrations.



1. INTRODUCTION

Radon (radon-222) is a colourless and odourless radioactive gas which is formed by the decay of radium-226. Radon and radium are parts of the uranium-238 decay series, one of several naturally-occurring radioactive series, and many rocks and minerals – and hence building materials - contain uranium and uranium progeny. Radon's gaseous nature and its radioactive half-life of less than four days means that it is able to escape rocks and building materials, and can, in certain circumstances, reach considerable concentrations in homes and workplaces. When radon and its alpha-emitting progeny are inhaled, they can lead to damage to lung tissue and to lung cancer. It has been estimated (Darby et al. 2005) that radon is responsible for around 2% of cancer deaths in Europe, which would correspond to more than two hundred deaths a year in Norway alone.

In common with other radiation authorities, the NRPA have established recommended upper levels for radon concentrations in homes: concentrations should not exceed 200 Bq/m^3 (maximum level), and homes where concentrations exceed 100 Bq/m^3 (action level) should be considered for radon-reducing measures, where practical (Statens strålevern 2009). In Norway such high radon concentrations are not unusual, with average indoor radon concentrations not far under the action-level of 100 Bq/m^3; concentrations as high as several thousand Bq/m^3 are not unknown (Strand et al. 2003).

Although the source of most indoor radon is the bedrock and soils under and around buildings, uranium-rich building materials are another possible source and can result in elevated indoor radon concentrations even in areas where relatively little hazard from the natural surroundings is anticipated. In Norway for example high uranium concentrations can be found in many granites; crushed-rock quarries operating in such areas may be supplying uranium-rich materials to the construction industry today.

To guard against importing a radon problem through building materials, a number of recommendations based on radium-226 activity levels exist, among them the *Gamma Index I*, where I is defined as a weighted sum of the activities of the uranium and thorium decay series, together with potassium-40:

$$I = \frac{C_{Th}}{200} + \frac{C_{Ra}}{300} + \frac{C_K}{3000} \qquad (1)$$

Here C_{Th}, C_{Ra} and C_K represent the mass activity concentrations (Bq/kg) of thorium-232, radium-226 and potassium-40 respectively. European Union guidelines (EU 1999) recommend that $I < 1$ for building materials. This recommendation is based on keeping the exposure to gamma radiation below reasonable levels, and it does not specifically address the radon problem; however adopting $I < 1$ ensures that radium-226 concentrations cannot be higher than 300 Bq/kg and in practice will often be lower, given that some potassium and thorium will normally also be present.

The above guideline applies to building materials in general, and does not give any particular consideration to potentially high-permeability drainage layers where strong advection currents driven by underpressure in the building may lead to radon transport into the dwelling space. An earlier recommendation by NRPA - made when recommended indoor concentrations were a factor two higher than today, but since withdrawn - specified an upper radium activity level of 300 Bq/kg for transported material used under or around new buildings (Statens strålevern 1995).

While the gamma index is used by some suppliers of constructions materials in Norway, its use is not enforced, and there is little guidance provided to the industry regarding suitable sampling and measurement methodology; nor is any central recording of sample data carried out.

In 2010 NGU and NRPA began working together to address some of the above issues with the aim of producing measurement and sampling guidelines - including a suitable safe recommended threshold level - which the construction industry could adopt to prevent usage of high-uranium content building materials. The project focussed on crushed rock used as drainage material under and around new constructions, and has included a comparison of measurement methodologies, the establishment of a recommended activity level for drainage materials, and the development of a sampling methodology for adoption by the industry (Watson et al. 2013).

2. MEASUREMENT METHODS

The project involved performing in-situ measurements and lab-based measurements on samples collected from several crushed-rock quarries in south-eastern Norway. A variety of measurement methods were investigated and compared in the study, including:

- hand-held in-situ gamma spectrometry
- lab-based gamma-spectrometry
- lab-based ICP-MS
- lab-based radon gas exhalation measurements

Each of the above methods have different characteristics with regard to cost, time, accuracy, and how directly or indirectly they measure radon exhalation. The likelihood of radon gas exhalation from material is dependent on the source activity (radium-226) together with the radon exhalation factor – a measure of what fraction of radon produced from radium-226 decay is likely to be available for transport out of the material. While gas measurements can measure radon exhalation directly, reliable and standardised procedures are relatively complex, time-consuming, and expensive. Gas measurements were performed as part of this project but were rejected as a possible final measurement method on the grounds of time and cost.

Gamma-spectrometry and ICP-MS methods make indirect measurements of radium-226, the former by measuring the activity of radon progeny, and the latter by measuring the amount of the parent isotope (uranium-238) of the decay series. Both methods rely on assumptions of radioactive equilibrium – assumptions that are however often valid. Under equilibrium conditions, a measurement of one member of the decay series can be used as a proxy for another; in the case of uranium-238, a concentration of 1 ppm (part per million) uranium is equivalent to around 12.4 Bq/kg radium-226 activity.

Interpreting these radium activity levels as a measure of potential radon hazard requires further assumptions regarding the radon exhalation properties of the material. Radon exhalation properties of materials have been studied by many workers over the years, and while there can be considerable variation, it is possible to make assumptions about likely exhalation factors from building materials, allowing us to use radium activity alone as a reasonable measure of radon gas potential.

In-situ gamma spectrometry has the advantage of giving immediate results in the field, but off-the-shelf hand-held spectrometer systems may suffer from calibration problems and may be sensitive to the high uranium background present in some quarry environments. Our studies have suggested that hand-held in-situ measurements may suffer from an over-estimation of radium activity when compared with laboratory measurements of the same sample material. Laboratory gamma-ray spectrometry and ICP-MS methods gave consistent results, with ICP-MS methods having the advantage of reduced costs and quicker measurement turnaround relative to laboratory gamma-ray spectrometry.

3. A RECOMMENDED ACTIVITY LEVEL

To estimate a suitable activity level NGU has undertaken modelling studies of the propagation of radon gas from drainage layers into homes. Using the radon model of Andersen (2000, 2001) as a starting point, we have investigated the likely radon flux and resulting indoor radon concentrations with a variety of material properties and slab-on-grade building geometries. Our studies found that using a 40 cm drainage layer depth and radon exhalation factor of 0.4, together with high surrounding soil permeabilities, indoor concentrations as high as 100 Bq/m^3 (i.e. the action level in Norway) could be attained with drainage layer activities of 118 Bq/kg radium-226. Using a 20 cm drainage layer, 0.2 exhalation factor and more typical soil permeabilities, drainage layer radium activities could be more than 800 Bq/kg before leading to indoor concentrations above the action level. The above results consider the contribution only from drainage materials, and use only simple model house geometries. But considering typical building geometries and material properties, we suggest that drainage layers are unlikely to contribute significantly to elevated indoor radon levels if the uranium-238 concentrations are under 10 ppm uranium, equivalent to around 124 Bq/kg radium-226 activity (Figure 1).

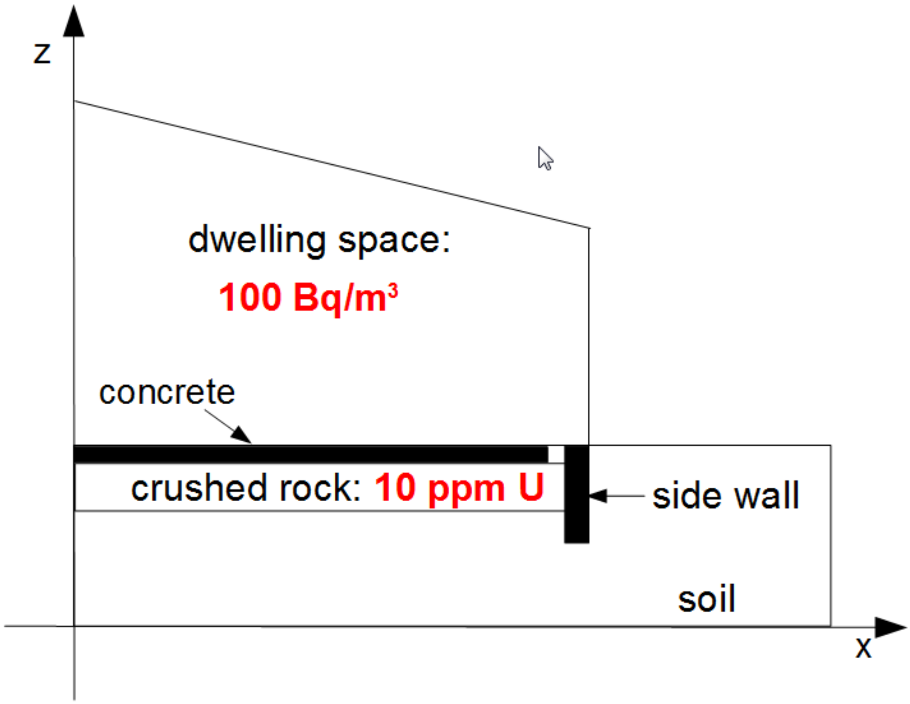


Figure 1. Modelling the contribution of a drainage layer to indoor radon concentrations, after Watson et al. (2013) and Andersen (2000).

Our modelling studies can only be used as a guide; the resulting radon fluxes are sensitive to many model parameters, and more extreme geometries and material properties (for example considerably greater volumes of drainage material) will be more likely to lead to elevated indoor radon concentrations. Nevertheless our suggested activity level of 10 ppm uranium (124 Bq/kg radium-226) is consistent with using a gamma-index threshold of 1, and with a halving of the earlier recommended maximum activity level from 300 Bq/kg (when recommended indoor levels were a factor two higher) to 150 Bq/kg. In the sampling guidelines which follow we adopt 10 ppm as a maximum recommended uranium concentration for drainage material.

4. TOWARDS THE ADOPTION OF A SAMPLING METHODOLOGY

NGU have prepared a measurement and sampling methodology for determining whether or not materials from crushed rock quarries should be approved for use as drainage material in new constructions. The procedure is based on a minimum of 20 samples collected from crushed-rock quarries, and analysed for uranium content by ICP-MS after a defined preparation procedure. Sampling takes place initially from the quarry face, with follow-up sampling from production material if necessary. Initial sampling should be performed whenever a new quarry area is opened up, and whenever there are significant changes in the material being quarried. Quarries where all samples do not exceed 5 ppm uranium are approved for delivering building materials and require no further controls, while quarries where median uranium levels exceed 10 ppm are not approved. Quarries where any measurements exceed 5 ppm require regular sampling from the production stockpile. Figure 2 summarises the procedure in flow-diagram form, and details of the recommendations can be found in Watson et al. (2013).

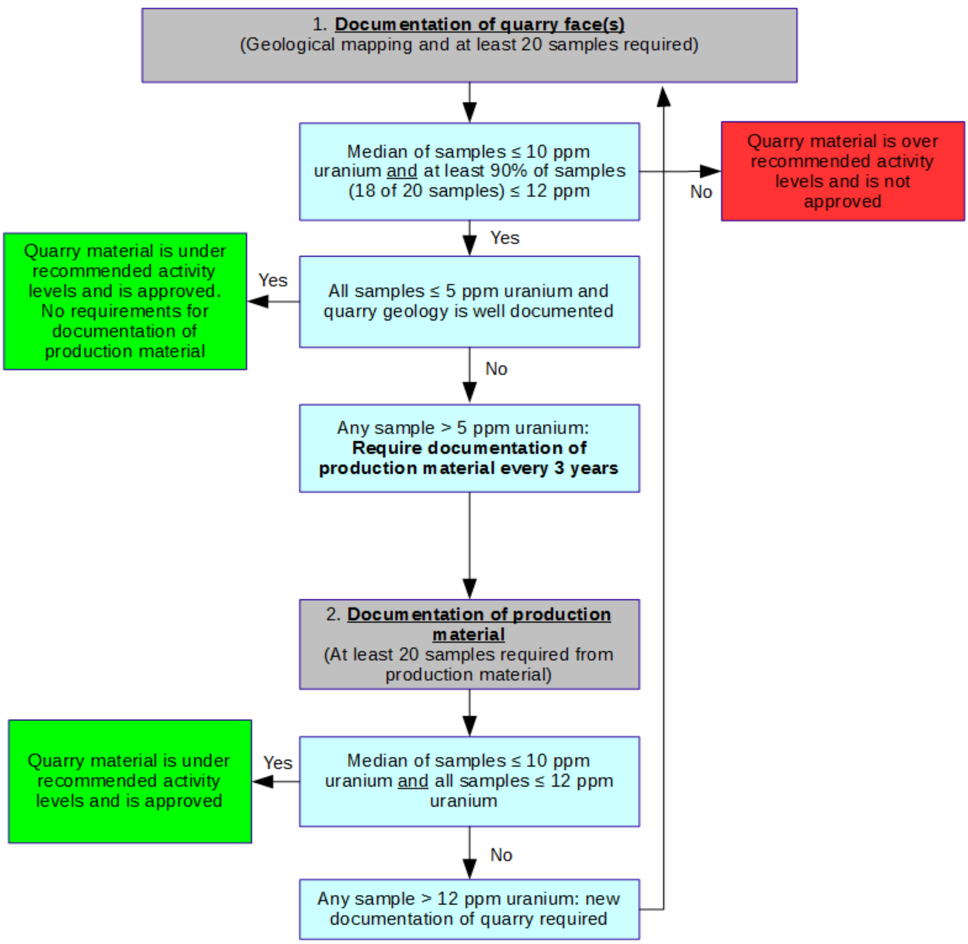


Figure 2. A sampling methodology for quarry material.

It is anticipated that the above procedure will be adopted by the industry during 2015, helping to prevent the use of materials which could otherwise contribute to elevated indoor radon concentrations.

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