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Ingredients for a Dutch radon action plan, based on a national survey in more than 2500 dwellings

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ABSTRACT

A new Euratom directive demands that Member States establish a national action plan for indoor radon. Important requirements are a national reference level for the radon concentration in dwellings, actions to identify dwellings with radon concentrations that might exceed this reference level and the encouragement of appropriate measures to reduce the radon concentrations in dwellings where these are high. This paper provides ingredients and recommendations for a national action plan for radon in dwellings, applicable to the Netherlands. The approach presented here, which may serve as a model for other countries or regions with a comparatively favourable indoor radon situation, is based on the analysis of radon data from a national survey in more than 2500 Dutch dwellings, built since 1930. The annual average activity concentration of radon in dwellings in the Netherlands equals 15.6 ± 0.3 Bq m^{-3}. The 50th and 95th percentiles were found to be 12.2 and 38.0 Bq m^{-3}, respectively. In 0.4 per cent of the dwellings we found values above 100 Bq m^{-3}. Radon concentrations showed correlations with type of dwelling, year of construction, ventilation system, soil type and smoking behaviour of inhabitants. The survey data suggest that it is feasible for the Netherlands to adopt a national reference level for radon in dwellings of 100 Bq m^{-3}, in line with recommendations by WHO and ICRP. We were able to predict dwellings with a moderate probability for radon concentrations above 100 Bq m^{-3} by applying a combination of three selection criteria: location, type of dwelling and manner of ventilation. Of the existing 6.2 million dwellings in the Netherlands (built since 1930), approximately 23–24 thousand are suspected to exceed this level. Some 80% of these are found in the group of naturally ventilated single-family dwellings in either the southern part of Limburg (approx. 13 thousand) or the Meuse-Rhine-Waal river delta (approx. six thousand). This selected group of dwellings represents 7% of the housing stock. In contrast to many other countries in Europe and elsewhere, radon concentrations in dwellings above 200 Bq m^{-3} are very rare in the Netherlands. As a result, relatively simple and inexpensive measures in existing Dutch single-family dwellings will be sufficient to reduce indoor radon concentrations above the proposed national reference level of 100 Bq m^{-3} to values well below.

1. Introduction

Indoor radon (Rn-222) in dwellings is by far the most important source of exposure of the public to naturally occurring ionising radiation. UNSCEAR reports a value of 40 Bq m^{-3} for the arithmetic mean of radon concentrations in dwellings worldwide, but large variations between and within countries are observed. Even within Europe, we find countrywide average values ranging from 10 Bq m^{-3} in Iceland to values well over 100 Bq m^{-3} in countries such as Finland, Sweden, Albania and the Czech Republic. Regional average concentrations in radon prone areas are even higher (UN, 2006). Many countries with substantial radon prone areas have already developed their own national radon policy in order to limit the exposure of their population to indoor radon. Such policies often include a national action level for radon in dwellings, a national monitoring programme and a set of dedicated measures to mitigate the situation. However, most of the world's population lives in areas with low to moderate radon levels and if we assume that the linear no-threshold model (LNT) is valid, the majority of lung cancer cases due to radon exposure can be seen to occur in these areas (WHO, 2009). But in countries without specific radon prone areas, such as the Netherlands, national policies on radon are

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often less explicit. In the Netherlands, this will change in the near future since a recent Euratom directive requires all Member States to develop a national action plan addressing long-term risks from indoor radon (Euratom, 2014). As part of this plan, a national reference level for the annual average activity concentration of radon in dwellings must be established, which should not be higher than 300 Bq m^{-3}, but can be substantially lower. Member States must promote actions to identify dwellings with radon concentrations exceeding the national reference level and encourage appropriate measures to reduce the radon concentrations in these dwellings. The Member States must comply with this directive by 6 February 2018.

The aim of this paper is to present a scientific approach to the implementation of that part of the Euratom directive into Dutch legislation that deals with radon in dwellings. First, we will present the results of a recent national survey on radon in Dutch dwellings. Based on an analysis of data from this survey we propose a value for a national reference level of radon in dwellings, applicable to the Netherlands. We subsequently present a set of selection criteria to predict dwellings where radon concentrations might exceed this level. Finally, a set of radon mitigation techniques are mentioned which we consider appropriate to reduce radon concentrations in existing Dutch dwellings that are above the proposed reference level to concentrations well below. The approach presented here may be applicable in other countries or regions with similar radon concentrations in dwellings.

1.1. Previous radon surveys

The first national survey on radon in dwellings in the Netherlands was conducted in the early eighties of the previous century (Put et al., 1985). The results of this survey indicated that radon levels increased in dwellings built between 1960 and 1980, which was assumed to reflect changes in building methods and the use of building materials. Subsequent surveys were restricted to newly built houses (Bader et al., 2010; Stoop et al., 1998). The most recent survey of these two, conducted in dwellings from the period 1994–2003, yielded concentrations which were typically half of those seen in the previous two surveys: the measured average radon value dropped unexpectedly from 25 Bq m^{-3} found in dwellings built in the early nineties (second survey) to 12 Bq m^{-3} observed in dwellings constructed in the late nineties and in the first years of the current millennium (third survey). Thorough investigations showed that the radon detectors used previously were also susceptible to thoron (Rn-220). Moreover, a pilot study indicated that thoron may contribute significantly more to the radiation exposure in Dutch dwellings than was thought before (Blaauboer, 2012). This suggested that concentrations previously reported as radon concentrations were in fact a combination of radon and thoron concentrations. Unfortunately, the contribution of each of the two gases to the concentrations measured cannot retrospectively be determined. Consequently, we found ourselves in a situation where both radon and thoron concentrations in the majority of Dutch dwellings was unknown. It was therefore decided to conduct a new nationwide survey of both radon and thoron progeny in a representative group of Dutch dwellings. In this paper, we present the results of the radon measurements.

2. The national radon survey 2013–2014

For the survey 2013–2014, we initially drew a random selection of approximately 10.000 dwellings, representative for the group of Dutch dwellings built in the period 1930–2012. At the time of the survey, dwellings built before 1930 represented approximately 15% of the total housing stock. Pre-1930 dwellings form a very heterogeneous group, ranging from grand 16th century canal houses in Amsterdam to poorly built dwellings from the beginning of the 20th century. These dwellings are seldom in an original state and reliable information about construction period, building characteristics and reconstruction work is often lacking. It is therefore very difficult to draw a representative sample of this group, to relate radon data from this group to 'typical characteristics' of these dwellings and to formulate appropriate measures, if needed. Moreover, the relative number of dwellings in this group is declining. In particular, many poorly built dwellings from the early 20th century are currently replaced by new dwellings. For these reasons, the Ministry of Economic Affairs, which at the time was in charge of radiation protection, commissioned RIVM to conduct this survey only in newer dwellings.

The residents of some 2900 dwellings responded positively to a request to participate in this survey. In 2013, they received two small passive detectors, one radon detector and one thoron progeny detector, as well as an instruction where and how to mount these detectors in their houses. The radon detector (Radtrak, manufactured by Landauer Nordic, Sweden) is a CR-39 based alpha track detector (Durrani and Ilic, 1997). The thoron progeny detector (from FLONEX, Japan) applies four CR-39 chips covered with an aluminium-vaporized Mylar film, detecting exclusively the 8.78 MeV alpha particles emitted by Po-212 (Miroslaw et al., 2013). Later on we sent all participants in the survey a questionnaire on details about their house (type of ventilation system, room where the detectors were mounted) and their behaviour (for instance, do they regularly smoke in the house or not). We asked the householders to mount the detectors in a typical living area. About 96% of the participants that provided us with an answer (93%) had chosen the living room. After a period of at least one year, both detectors were sent back to RIVM. The survey yielded 2562 valid recordings of annual averaged radon concentrations in Dutch dwellings, built in the period 1930–2012. Completed questionnaires were available for almost 95% of these.

2.1. Representativity

At the time of the survey, there were approximately 6.2 million dwellings in the Netherlands constructed during the period 1930–2012 (BZK, 2013). Fig. 1 shows the relative number of houses in given construction periods in the random sample of the radon survey (i.e. the 2562 valid recordings) and stockpile data (rounded on full percentages) obtained from the Dutch Ministry of the Interior (BZK). We notice a small underresponse in our survey for dwellings built before 1971, and a slight overresponse for dwellings constructed after 1970. This is explained in part by the fact that stockpile data also include dwellings that are (temporarily) uninhabited. The average number of vacancies was some 5–6% in the period when the radon survey took place, but vacancies were not randomly distributed. They occur typically twice as often in old dwellings as in relatively new houses, and twice frequently in multi-story dwellings as in terraced and detached houses. High vacancy rates of approx. 12% are found in multi-story dwellings older than 1945 (CBS, 2014). Fig. 2 shows a comparison of both datasets for various types of dwellings. Here we notice an underresponse for multi-story buildings and a small overresponse for detached dwellings and the category 'remainder'. This is partly due to differences in the definition of the term 'remainder' and partly due to a different percentage of vacancies. In addition, it is probable that some societal bias in the process of finding participants and the return of detectors after a long period of exposure has occurred. However, in spite of some remaining nonconformities, we did not correct for deviations, mainly because results for different building periods are quite similar and differences between stockpile data