Journal of Environmental Radioactivity 169-170 (2017) 1–8

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Update of Ireland's national average indoor radon concentration – Application of a new survey protocol

A. Dowdall [a, *], P. Murphy [b], D. Pollard [a], D. Fenton [a]

[a] Environmental Protection Agency, 3 Clonskeagh Square, Clonskeagh Road, Dublin 14, Ireland
[b] School of Mathematical Sciences, University College Dublin, Belfield, Dublin 4, Ireland

ARTICLE INFO

Article history:
Received 12 July 2016
Received in revised form
30 November 2016
Accepted 30 November 2016

Keywords:
Radon
National survey
National average indoor radon concentration
National radon control strategy
Survey protocol

ABSTRACT

In 2002, a National Radon Survey (NRS) in Ireland established that the geographically weighted national average indoor radon concentration was 89 Bq m^{-3}. Since then a number of developments have taken place which are likely to have impacted on the national average radon level. Key among these was the introduction of amending Building Regulations in 1998 requiring radon preventive measures in new buildings in High Radon Areas (HRAs). In 2014, the Irish Government adopted the National Radon Control Strategy (NRCS) for Ireland. A knowledge gap identified in the NRCS was to update the national average for Ireland given the developments since 2002. The updated national average would also be used as a baseline metric to assess the effectiveness of the NRCS over time.

A new national survey protocol was required that would measure radon in a sample of homes representative of radon risk and geographical location. The design of the survey protocol took into account that it is not feasible to repeat the 11,319 measurements carried out for the 2002 NRS due to time and resource constraints. However, the existence of that comprehensive survey allowed for a new protocol to be developed, involving measurements carried out in unbiased randomly selected volunteer homes. This paper sets out the development and application of that survey protocol. The results of the 2015 survey showed that the current national average indoor radon concentration for homes in Ireland is 77 Bq m^{-3}, a decrease from the 89 Bq m^{-3} reported in the 2002 NRS. Analysis of the results by build date demonstrate that the introduction of the amending Building Regulations in 1998 have led to a reduction in the average indoor radon level in Ireland.

1. Introduction

The first National Radon Survey (NRS) of Ireland was carried out between 1992 and 1999 (Fennell et al., 2002). One of the key findings of that survey was that the national average indoor radon concentration (arithmetic mean) at that time was 89 Bq m^{-3}.

The 2002 NRS was a geographically based survey which used the 10 km grid squares of the Irish National Grid as the unit area. Radon measurements were carried out in 11,319 randomly selected houses throughout the country. The results of this survey were published in 2002 and for ease of reference, the report will hereafter be referred to as the 2002 NRS. Based on the results of the 2002 NRS, the percentage of houses in each grid square with radon levels in excess of the national Reference Level of 200 Bq m^{-3} was predicted. Grid squares in which this prediction exceeds 10% or more were designated High Radon Areas (HRAs). These predictions have since been used in connection with Irish Building Regulations, which require enhanced levels of radon protection in new houses being built in HRAs (Stationery Office, 2008).

Since 1997, Irish Building Regulations have required that reasonable measures be taken during the construction of new buildings to avoid danger to health due to radon (Stationery Office, 2008). Specific technical guidance published by the Department of the Environment, Community & Local Government (DECLG) states that all homes built since July 1st 1998 be fitted with a standby radon sump, which can be activated at a later stage to reduce any high radon concentrations subsequently found. In addition, a radon membrane is required for homes built in HRAs. A radon membrane is a fully sealed membrane that meets the specifications set out in the technical guidance document in terms of radon permeability as

* Corresponding author.
E-mail address: a.dowdall@epa.ie (A. Dowdall).

http://dx.doi.org/10.1016/j.jenvrad.2016.11.034
0265-931X/

well as other physical parameters. When installed correctly a radon membrane should ensure that the radon concentration in the occupied homes is significantly lower than it would be in homes without a membrane. International studies of the efficiency of radon membranes by Holmgren and Arvela (2012) found that the typical reduction ranged from 0% to 90%.

Since the 2002 NRS, a number of developments have taken place in Ireland that are likely to have impacted on the national average radon concentration. These developments include:

- The introduction of amending Building Regulations in 1998 requiring radon preventive measures in new buildings in HRAs as described above
- The growth in the rate of building between 1996 and 2011 when the number of dwellings in Ireland dramatically rose by approximately 32% (CSO, 2012)
- Changes in distribution of house types
- Increased energy efficiency in homes
- Public awareness efforts which have targeted HRAs and therefore increased the number of measurements in those areas in comparison to other parts of the country

In 2014, a National Radon Control Strategy (NRCS) was adopted in Ireland which aims to reduce the overall population risk and the individual risk for people living with high radon concentrations (DOELG, 2014). The national average indoor radon concentration is a key metric that will be used to monitor the effectiveness of the strategy over time. To update this metric over the lifetime of the strategy, a new survey protocol was required that could be implemented over approximately one year and that could be repeated at intervals of about 5 years. Furthermore, homes selected for the survey were required to be a random sample stratified by radon risk as described in the 2002 NRS and also by geographical location. By meeting these criteria, the survey targets randomly selected householders representative of a sample of the national housing stock in terms of radon risk and location.

This report describes the survey protocol designed to establish the national average indoor radon concentration in Ireland and its implementation over a one year period. It presents the current national geographically weighted average indoor radon concentration for Ireland and sets an initial baseline against which future progress of the NRCS can be measured over time.

The geographic weighted national average indoor radon concentration is a useful metric in assessing the effect of any intervention to reduce radon levels. By comparing the mean indoor radon concentration pre intervention to those post intervention, an assessment of the effectiveness of that intervention can be easily made. By comparing mean radon concentrations in homes built before and after the introduction of the amending Building Regulations in 1998, the effectiveness of the requirement to install a radon membrane in homes built since then in HRAs can be evaluated.

2. Methodology

2.1. Design of survey protocol

The primary objective of the survey was to determine the current national geographically weighted arithmetic mean indoor radon concentration in Ireland. To do this, a survey protocol was required where the outcome would be comparable to that of the original NRS which established this metric to be 89 Bq m^{-3}. The design of the survey protocol should take into account that it is not feasible to repeat the large number (11,319) of measurements carried out for the 2002 NRS due to time and resource constraints. Indeed the existence of such a comprehensive survey allowed for a new protocol to be developed involving measurements carried out in unbiased randomly selected volunteer homes.

To ensure that the results of this survey would be comparable with the 2002 NRS, the Irish National grid consisting of 10 × 10 km grid squares were again used as the basis for sampling by taking a number p of sample homes selected randomly from q grid squares, where the q squares were selected using a stratified random sampling method. The approach adopted was to:

1) Define the methodology for selection of the grid squares to be sampled
2) Use Monte Carlo simulation to determine the required number of grid squares and dwellings
3) Select the grid squares from which the dwellings will be randomly chosen
4) Select the actual dwellings to be invited to participate by randomly selecting from a commercially available database of Irish dwellings in the q grid squares selected. In each grid square the number of invitations issued should be sufficient to give a minimum of p measurements where possible.

2.1.1. Methodology for selection of grid squares to be sampled

The 2002 NRS reported radon risk predictions for all 837 grid squares of the Irish National Grid. This risk was quantified as the percentage of dwellings in each grid square predicted to have seasonally adjusted annual average radon concentrations in excess of the national Reference Level of 200 Bq m^{-3}. Five risk categories were identified. They are listed in Table 1 and are also displayed on the map of Radon in Irish Dwellings (EPA, 2016a). From the 2002 NRS, it is possible to calculate the fraction of grid squares corresponding to each risk category (fRCi). These fractions are set out in Table 1.

Only those grid squares with more than 5 radon measurements in the 2002 NRS were included in the stratification process. This gave a total of 751 grid squares that were stratified by these radon risk categories. In addition, geographic region was also taken into account in the selection of q grid squares. A study by Burke and Murphy (2011) examined regional variation of seasonal correction factors for indoor radon levels in Ireland. Having identified 5 regions in Ireland consisting of counties with similar geology and climate, they calculated mean seasonal correction factors for each of these 5 regions and concluded that these were different from the mean national seasonal correction factors. The 5 defined geographic regions are presented in Table 2 together with the fraction of the national landmass represented by each region (f_{GRj}).

An excel model was developed to select q grid squares from the 751 grid squares so that these represent both the risk category distribution set out in Table 1 and the geographic distribution set out in Table 2.

The model steps are as follows:

- For each risk category i, q x f_{RCi} grid squares were selected randomly from the 751 x f_{RCi} grid square grid squares falling into the risk category RCi (where i = 1 to 5).
- The model then assigned a geographic region to each of the q grid squares selected and calculated the number n_j of squares in each geographic region j. To ensure that the selected grid squares were representative, the goodness of fit between the distribution by geographic region and the risk category distribution presented in Table 1 was then tested by calculating a Z value as follows: