Updating Ireland’s national average indoor radon concentration using a new survey protocol
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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.
Updating Ireland’s national average indoor radon concentration using a new survey protocol

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Executive Summary
A National Radon Survey (NRS) of Ireland was carried out between 1992 and 1999 (Fennell et al., 2002). The survey characterised areas of Ireland in terms of their radon risk and one of the key findings was that the geographic weighted national average indoor radon concentration at that time was 89 Bq/m$^3$. Since then, a number of developments have taken place in Ireland that are likely to have impacted on the national average radon concentration. These include the introduction of amending Building Regulations in 1998 requiring radon preventive measures in new buildings in High Radon Areas (HRAs), and the increase in the rate of building since 2000 when the number of dwellings in Ireland grew dramatically.

To re-assess the national average indoor radon concentration, a survey protocol was required that would measure radon in a sample of homes which were representative of radon risk and geographical location. This new national average could then be used to assess the effectiveness of the measures that have impacted on this metric since it was first established in the 2002 NRS.

In 2014, a national radon control strategy (NRCS) for Ireland was adopted by Government. The NRCS aims to minimise the exposure to radon gas for people in Ireland through the implementation of some 30 actions. The Strategy called for the development of appropriate metrics to help monitor the effectiveness of the implementation of these actions. These included the compilation of baseline data, including an updated national average indoor radon concentration.

To monitor the progress of the NRCS over its lifetime, the national average indoor radon concentration was identified as a key metric and a survey was required that could be repeated as required to track progress. Therefore a new survey protocol was developed; one that could be implemented over no more than one year and that could be repeated at intervals of about 5 years. The development and implementation of this protocol are reported in this study.

The results 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. This figure of 77 Bq/m$^3$ is now a baseline metric for the NRCS. Furthermore, a comparison of the average radon concentrations for homes built before and after the introduction of the amending building regulations in 1998 show a significant difference in average indoor radon concentration. For homes built prior to the introduction of the building regulations the mean radon concentration was 86 Bq/m$^3$ compared to 64 Bq/m$^3$ in homes built after the introduction of the building regulations.

This survey also sought information on the building characteristics of the homes surveyed by asking participants to complete a short questionnaire. The purpose of the questionnaire was to investigate if links between indoor radon concentrations and building characteristics could be established. Analysis of the data found that the mean radon concentration in two storey homes was approximately 29% lower than radon concentrations in bungalows. An increase of 34% in mean radon concentration was noted between homes where insulation measures had been added when compared to homes where no insulation had been added.
Introduction
1. Introduction

The 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. As the results of that survey were published in 2002, for ease of reference the report will now be referred to as the 2002 NRS hereafter. Based on the 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 are 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 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
- The growth in the rate of building between 1999 and 2014 when the number of dwellings in Ireland dramatically rose by an estimated 47% (DOHPCLG, 2016)
- 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.
The primary aim of this survey was to produce the current mean indoor radon concentration for homes in Ireland. A secondary aim was to investigate the effect of selected house characteristics on mean indoor radon concentration. In addition to carrying out a radon test in their homes, participants were asked to complete a short questionnaire which was designed to gather information on the building characteristics of the homes tested. Participants were asked about their house type, its age, the type of floor construction on the ground level, the type of windows and whether insulation had been added. In addition the occupants' smoking status was requested. This information when linked with radon concentrations would be used to build a picture of the type of buildings in Ireland that may be prone to elevated radon concentrations while smoking status information points to individual radon risk factors.

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. This report describes the survey protocol designed to establish 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 overtime.
Methodology
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/m³. The design of the survey protocol should take into account that it is not feasible to repeat the large number (11,319) 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.

Since completion of the 2002 NRS, the Environmental Protection Agency (EPA\(^1\)) has completed approximately 60,000 measurements on behalf of volunteer householders (EPAa, 2016). For the most part, this database consists of tests carried out in HRAs following targeted EPA radon awareness campaigns (EPAb, 2016). Burke and Murphy (2011a) have shown this dataset is subject to bias and is unrepresentative due to over-sampling in high radon areas. Furthermore, the lack of a post code system in Ireland made the identification of the precise location of these measured houses difficult and therefore it is effectively impracticable to test for geographic bias in this dataset\(^2\). For these reasons, the existing volunteer measurements could not be used to estimate the current national average and new radon measurements in a random selection of Irish dwellings would be required.

To ensure that the results of this survey would be comparable with the 2002 NRS, the Irish National grid consisting of 10 x 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/m³.

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\(^1\) The Radiological Protection Institute of Ireland (RPII) merged with the EPA on the 1st August 2014.

\(^2\) A post code system for Ireland (Eircode) was introduced in July 2015 which could be utilised in future surveys.
Five risk categories were identified. They are listed in Table 1 and are also displayed on the map of Radon in Irish Dwellings (EPAc, 2016). From the 2002 NRS, it is possible to calculate the fraction of grid squares corresponding to each risk category ($f_{RCi}$). These fractions are set out in Table 1.

Table 1 – Radon risk categories derived from the National Survey

<table>
<thead>
<tr>
<th>Risk Category (i)</th>
<th>% of dwellings predicted by National Survey to be above 200 Bq/m³</th>
<th>Fraction grid squares in risk category ($f_{RCi}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 1%</td>
<td>0.41</td>
</tr>
<tr>
<td>2</td>
<td>1%–5%</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>5%–10%</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>10%–20%</td>
<td>0.16</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 20%</td>
<td>0.13</td>
</tr>
</tbody>
</table>

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 grid squares. A study by Burke and Murphy (2011b) 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 ($f_{GRj}$).

Table 2 – Geographic regions defined by Burke and Murphy (2011b)

<table>
<thead>
<tr>
<th>Region</th>
<th>Counties included in region</th>
<th>Fraction of land mass covered by region ($f_{GRj}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Donegal, Cavan, Monaghan, Louth</td>
<td>0.12</td>
</tr>
<tr>
<td>2</td>
<td>Sligo, Mayo, Galway, Clare, Roscommon</td>
<td>0.28</td>
</tr>
<tr>
<td>3</td>
<td>Leitrim, Longford, Westmeath, Meath, Offaly, Laois</td>
<td>0.15</td>
</tr>
<tr>
<td>4</td>
<td>Dublin, Kildare, Wicklow, Carlow, Wexford, Kilkenny, Waterford</td>
<td>0.17</td>
</tr>
<tr>
<td>5</td>
<td>Tipperary, Limerick, Kerry, Cork</td>
<td>0.28</td>
</tr>
</tbody>
</table>

An excel model was developed to select 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 \(i\), \(q \times f_{RCi}\) grid squares were selected randomly from the \(837 \times f_{RCi}\) 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 \(n_i\) 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:

\[
Z = \sqrt{\sum_{j=0}^{5} \left( f_{GRj} \frac{n_i}{q} \right)^2}
\]

- The model was then run repeatedly until \(Z\) was < 0.05. This set of grid squares was then selected.

Using this procedure, grid squares representative of radon risk and geographical location were identified. The next step was to determine the required number of grid squares and homes in each square to be invited to participate in the survey.

### 2.1.2 Monte Carlo simulation to determine required number of grid squares and dwellings

As mentioned previously, the sampling protocol requires a number \(p\) of sample homes selected randomly from \(q\) grid squares, where the \(q\) squares were selected using a stratified random sampling method. To do this an Excel based Monte Carlo simulation was developed to determine the values of \(p\) and \(q\) necessary to re-estimate the national average to a level of accuracy comparable to the 2002 NRS. The simulation was run for different values of \(p\) and \(q\) to determine the optimum values for the current survey.

The 2002 NRS data demonstrated that the distribution of indoor radon concentrations in any grid square could be modelled as a lognormal distribution with an offset of 6 Bq/m\(^3\) to allow for background ambient radon (Gunning et al., 2014). The 2002 NRS reported the geometric mean (GM) and standard deviation (GSD) for 751 grid squares. These values were used to simulate \(p\) measurements for each of \(q\) grid squares as follows:

- \(q\) grid squares were selected using the stratified sampling model described above.

- For each of the \(q\) grid squares, \(p\) simulated radon concentration values were produced by generating random numbers according to a lognormal distribution with the NRS GM and GSD values for that grid square. Each simulated value was then corrected for ambient radon by adding 6 Bq/m\(^3\). Thus a set of \(p,q\) simulated measurement values were generated, which were then averaged to give a single corrected value per simulation run.

- For each set of \(q\) values the simulation was repeated 20 times and a standard deviation calculated across the 20 runs as a simple measure of spread. The standard deviation was considered appropriate as Q-Q plots demonstrated that the simulation repeats approximated well to a normal distribution.
For each value of $q$ the standard deviation was plotted against $p$ and the results are presented in Figure 1.

Figure 1 – Determination of required number of grid squares and radon measurements for survey protocol

From Figure 1 it can be seen that beyond certain values of $p$ and $q$ “diminishing returns” apply whereby acquiring additional samples leads to only a very modest improvement in accuracy in the determination of the national average indoor radon concentration. Based on Figure 1, it was decided that a $q$ value of 60 and $p$ value of 10 would provide a sufficient level of accuracy, namely a standard deviation of 3.5 Bq/m$^3$, to estimate the national average indoor radon concentration.

To summarise, this survey methodology requires radon measurements in 600 randomly selected homes chosen from grid squares representative of radon risk and geographic location be carried out. This methodology is appropriate on the basis that the 2002 NRS was a comprehensive geographical based survey with measurements carried out in each of the 10 km grid squares of the Irish national grid. This survey protocol is appropriate to estimate the current national average indoor radon concentration to a level of accuracy comparable to the 2002 NRS methodology. It should be noted that the design of this survey protocol is such that the sample size chosen is representative of radon risk and geographical location nationally. The limitation of this smaller sample size is that no comparison can be made between mean radon concentrations at grid square level in this survey and the 2002 NRS. The grid squares selected for the 2015 survey are highlighted in Figure 2.
Figure 2 – Grid squares selected for 2015 national average radon concentration survey
2.1.3 Selection of dwellings invited to participate

A number of specific precautions were taken in designing the survey protocol to avoid volunteer bias by ensuring to the extent practicable homes were selected randomly. Firstly no survey specific advertising or media publicity was undertaken in order to minimise the impact of bias caused by influencing the acceptance rate. It was considered that householders in high radon areas might be more influenced by such publicity. Secondly all measurements were made free of charge to householders thereby eliminating any bias due to either ability or willingness to pay.

The response rate for the NRS was found to be typically 21%, ranging from 17–36% depending on the county. Assuming a similar response rate in this survey, invitations were issued initially to a maximum of 50 addresses in each of the 60 selected grid squares. The addresses were randomly selected from An Post’s Geodirectory (Geodirectory, 2016). The Geodirectory is a commercially available database of Irish address identified by geographical coordinates. For each grid square, a list of all available addresses was extracted from the Geodirectory. The addresses were then randomised in Excel and invitations were issued to the first 50 addresses. It should be noted that less than 50 addresses were available in 8 of the selected grid squares. The number of available addresses in these grid squares ranged from 2 to 47 with all being invited to participate.

Each year, a small number of radon detectors are not returned to the EPA’s laboratory for measurement. Over the three year period from 2012 to 2014, data from the EPA’s measurement service found that approximately 7% of detectors issued annually are not returned (Personal communication, 2016). While a minimum sample size of 10 dwellings per grid square was deemed appropriate for this survey, to allow for non-return of detectors, where possible, at least 15 participants were sought in each grid square.

Between July and August 2015, a total of 3878 invitations to participate in the survey were delivered. It should also be noted that this includes a second round of invitations which targeted grid squares where the initial response rate was less than 10 and where more addresses were available. A total of 864 responses were received and 755 were accepted. A number of responses (109) were not accepted as they were in grid squares that were oversubscribed or they were returned from measurement addresses outside the required grid square. Overall the survey response rate was 22% ranging from 7 to 50% depending on the grid square.

2.2 Radon Measurement

The next phase of the survey was to carry out radon measurements in the accepted homes. It is widely reported that radon concentrations in homes can vary considerably with season. Burke et al. (2010) produced a set of seasonal correction factors for indoor radon levels which could be used to calculate a seasonally adjusted annual average radon concentration from measurements made at different times of the year. The approach adopted in this survey was to make all measurements at the same time of year but to select the measurement time when the seasonal correction factors set out in the EPA’s protocol for the measurement of radon in homes (EPAe, 2016) are close to unity. Taking these factors into consideration, measurements for the survey were scheduled for the three month period between September and November inclusive. The seasonal correction factor for this period is 0.96.
Each of the 755 accepted participants were issued with two radon detectors along with instructions to place the detectors in a main living area and a main bedroom for 3 months as described in the EPA's measurement protocol. Approximately four weeks before the radon detectors were due to be returned to the laboratory for analysis, a reminder to return detectors was sent to each participant along with a one page questionnaire containing 6 short questions. The main purpose of the questionnaire was to gather information on the build date of the home so that the impact of building regulations introduced in 1998 could be examined. In addition, questions on other building characteristics of the home that may influence radon concentrations were also included. A copy of the questionnaire can be found in Appendix 1.

On return to the laboratory, the detectors were analysed using the EPA's Radon and Radiation Measurement Services test procedures which are accredited to ISO 17025 by the Irish National Accreditation Board (INAB). To compare radon measurement results for homes with the national Reference Level of 200 Bq/m$^3$, the radon gas concentration must be determined in accordance with the EPA's measurement protocol summarised below:

- The annual average radon gas concentration for a home is determined using two radon gas measurements, one for the main living area and one for the main bedroom.

- The radon gas concentrations are measured using a CR-39 detector held in a two-part polypropylene holder. The holder acts as a simple radon diffusion chamber, excluding radon decay products and dust, limiting access of moisture but allowing the entry of radon gas. The composition of the detectors is polyallyldiglycol carbonate.

- The average radon gas concentration for a home is calculated as the arithmetic mean of the measured values for the main living area and the main bedroom corrected for seasonal variation. Equal occupancy between the two locations is assumed.

- The alpha particles emitted following the decay of radon in the detector chamber leave tracks on the CR-39 detector. On return to the laboratory, the detectors are chemically etched in 6.25 M sodium hydroxide at 98°C for 1 hour. The track density is then counted and converted to radon concentration.

Each participant received a test report containing their radon measurement results. Where a result was found to be above the national Reference Level of 200 Bq/m$^3$, advice regarding radon remediation was also provided.
Data Analysis
3. Data Analysis

3.1 Outlier detection

Of the 755 accepted participants, 80 failed to return detectors for analysis. A further 26 participants returned detectors but were excluded from the survey as described below:

- 14 householders returned one detector
- 7 householders returned the detectors too early
- 5 householders did not place the detectors correctly

Therefore a total 649 radon measurements were therefore accepted for use in the survey analysis.

To identify any outliers in the data, a box plot of the 649 log transformed measurements was produced. It should be noted that a background concentration of 6 Bq/m$^3$ was subtracted from the indoor radon levels before the data were log transformed. While it is well established that the distribution of radon levels in homes approximates a log-normal distribution (CEC, 1987), previous studies of radon levels in Ireland demonstrate that there are deviations from log normality. These deviations are due to outliers observed as a small number of extreme radon measurements (Organo and Murphy, 2007).

In a boxplot, outliers were classified as those which lie further than 1.5 interquartile ranges from the upper and lower quartiles. As can be seen from figure 3, a small number of outliers are observed in our data. On this basis, further statistical analyses to determine whether these values should be treated as outliers were warranted.
3.2 Tests for log normality

Graphical checks to test for log normality of the data were carried out using a histogram and a normal quantile QQ plot. The histogram and QQ-plots of the data set again with a background concentration of 6 Bq/m$^3$ subtracted show a good fit to a log normal distribution (figures 4 and 5). A small deviation from a normal distribution is noted but it is not extreme. It is similar to that observed in previous Irish radon data such as the 2002 NRS.
Figure 4 – Histogram to check for normality of the data

Figure 5 – QQ plot to check for normality of data
To verify the graphical checks of log normality, a Kolmogorov-Smirnov hypothesis test for normality of the log-transformed background-corrected data was performed and gave a p-value of 0.1047. This p-value indicates that we cannot reject the hypothesis that the data is log normal. From this we can conclude that there is no reason to treat the values highlighted by the box plots as outliers and the entire data set of 649 measurements can be analysed.

### 3.3 Test for bias due to measurement duration

The EPA’s measurement protocol requires a measurement period of 90 days. A preliminary analysis indicated that there was a substantial variation in the time that detectors were present in the houses tested. Therefore it was considered prudent to determine whether detectors that were present in homes for a period significantly different than the 90 days originally specified could lead to biases in the analysis. A total of 57 measurements were identified with a duration of 140 days or longer. One measurement was carried out for less than 60 days. To investigate any bias in the data set introduced by these measurements, the mean indoor radon level was calculated for two data sets, one being the full dataset and the other excluding the 58 measurements of longer and shorter duration. This step in the analysis was carried out to determine if the mean indoor radon concentration was different for the two data sets and if the longer and shorter measurements were biased towards grid squares identified as HRAs in the 2002 NRS.

When the mean indoor radon concentration for the full data set of 649 measurements and for the truncated data set containing 591 measurements was calculated, each data set had a mean of 82 Bq/m$^3$. This indicates that there is no significant difference in these two datasets and that no bias was introduced by the detectors which were in homes for significantly longer or shorter than the recommended 90 day period.

Using the 2002 NRS data as a proxy, the mean radon concentration for the full data set of 649 measurements and the truncated data set of 591 measurements was calculated. To do this each radon measurement in the current survey was assigned to its grid square. The 2002 NRS mean radon concentration for that square is then used as a proxy mean for each measurement in the full and truncated dataset. The mean radon concentration using these proxy values was then calculated for both datasets. Using this procedure, the mean radon concentration for the full dataset and for the truncated data set using the 2002 NRS data were both found to be 95 Bq/m$^3$. This clearly indicates that there is no significant difference in these two datasets and that no bias was introduced by the detectors which were in homes for significantly longer or shorter than the recommended 90 day period or by these homes being biased towards HRAs. Therefore the full dataset of 649 measurements was included in the analysis.
3.4 Weighting of data

This survey protocol was designed to produce a stratified random sample of houses which would be as representative as possible. The primary goal of this survey is to produce a national average radon level which could be compared with the national average from the 2002 NRS. However as with any sampling procedure it is important to assess how representative the sample is. The 2002 NRS was a comprehensive survey where radon measurements were carried out in homes throughout the country using the 10 km grid square of the Irish national grid as the basis for sampling. The availability of that 2002 NRS data set enables us to apply a weighting procedure to the current survey data to ensure that our final estimate of the current national average radon level is as accurate as possible. Weighting of data is a standard statistical practice and is often used to produce unbiased estimates of the population (Nguyen and Murphy, 2015).

For each of the 60 grid squares in the survey we know the mean indoor concentration obtained for that grid square in the 2002 NRS. These concentrations can be used to compute an estimate of the 2002 NRS national average concentration based on the 649 homes included in this survey. To do this, each of the 649 homes in the current survey was assigned a proxy radon concentration from the 2002 NRS, namely the mean radon concentration for the grid square it is located in.

If the 649 homes selected for this survey were truly representative of the homes in the 2002 NRS then the average computed from the 649 proxy mean radon concentrations using the 2002 NRS data should match the national average of 89 Bq/m$^3$ obtained in the 2002 NRS. If it does not match, then weighting is required to ensure an unbiased estimate of the current national average. Using the 2002 NRS dataset, the national average for the 649 homes in the current survey was estimated to be 95 Bq/m$^3$.

This shows that the 649 homes selected produce an estimate of the 2002 national average that is higher than we would expect to obtain if the sample was truly representative. In fact the estimate is too large by a factor equal to the ratio of 95 to 89 or by a factor of 1.07. Therefore the current estimate of the average indoor radon concentration obtained from the 649 homes cannot be directly compared with the NRS national average until it has been weighted by a factor of 1.07.
Results
4. Results

4.1 Radon Measurement Results

Radon measurements were completed in a total of 649 homes. A summary of the radon results for each grid square is presented in Appendix 2. A total of 53 of the homes surveyed had radon concentrations exceeding the 200 Bq/m$^3$ national Reference Level. The maximum concentration measured was 1001 Bq/m$^3$ in a home in Co. Wexford. The house is a two storey home built in a HRA but built prior to the introduction of building regulations requiring radon preventive measures in homes built since 1998.

4.2 Estimation of the current National Average Radon Concentration

The unweighted estimate of the national average indoor radon level based on the 649 homes in the current NRS was 82 Bq/m$^3$. However this estimate has now been shown to be biased because of the lack of complete representativeness of the 649 homes in the survey.

Applying the weighting factor of 1.0691, the weighted estimate of the national average indoor radon level based on the 649 homes in the current NRS is 77 Bq/m$^3$.

This estimate of 77 Bq/m$^3$ is the best estimate of the current national average indoor radon concentration. It can be directly compared with the NRS national average of 89 Bq/m$^3$. The national average indoor radon concentration has decreased by 12 Bq/m$^3$ since the 2002 NRS. The 95% confidence interval for the national average indoor radon concentration was calculated using the data from the 649 homes and was found to be 71 Bq/m$^3$ to 83 Bq/m$^3$.

The upper confidence limit of 83 Bq/m$^3$ is lower than the 2002 NRS national average of 89 Bq/m$^3$ indicating that we can be confident that the true geographic weighted national average concentration in Ireland has reduced in the years from 2002 to 2015. Furthermore, the confidence interval for the 2002 NRS national average of 89 Bq/m$^3$ was calculated to be 88 to 91 Bq/m$^3$.

4.3 Comparison with 2002 NRS results

A comparison of key metrics from the 2002 NRS and the current survey is presented in Table 3. The number of homes exceeding the 200 Bq/m$^3$ Reference Level was found to be 8% in this survey, compared with 9% in the 2002 NRS. This indicates very good agreement between the two surveys and is further justification of the new survey protocol. As mentioned previously, the national average indoor radon concentration has decreased by 13% since the 2002 NRS. The maximum concentration measured in this survey was 1001 Bq/m$^3$ for a home in Co. Wexford compared with 1924 Bq/m$^3$ measured in a home in Co. Kerry in the 2002 NRS.
Table 3 – Comparison of NRS and 2015 national average indoor radon concentration survey key metrics

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of homes measured</td>
<td>11,319</td>
<td>649</td>
</tr>
<tr>
<td>No. of homes &gt;200 Bq/m³</td>
<td>9%</td>
<td>8%</td>
</tr>
<tr>
<td>Minimum concentration measured (Bq/m³)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Maximum concentration measured (Bq/m³)</td>
<td>1924</td>
<td>1001</td>
</tr>
<tr>
<td>Arithmetic mean (Bq/m³)</td>
<td>89</td>
<td>77</td>
</tr>
<tr>
<td>Geometric mean (Bq/m³)</td>
<td>57</td>
<td>51</td>
</tr>
<tr>
<td>Geometric standard deviation (Bq/m³)</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

4.4 Building Characteristics data

Completed questionnaires regarding the building characteristics of the homes tested were received from 573 participants. A total of 548 had also completed a valid radon test in their home and this dataset was used to investigate if links between indoor radon levels and building characteristics could be seen.

4.4.1 Analysis of data by build date

The first question on the building characteristics questionnaire asked householders the build date of their home. The purpose of this question was to investigate the effectiveness of radon preventive measures introduced in 1998 when all homes built in HRAs are required to have a radon barrier installed. It can be seen from table 4 that the majority of homes surveyed were built prior to the introduction of these building regulations and it is assumed that these homes were constructed without radon preventive measures installed. For homes built post 1998, it is assumed that the homes were constructed with radon preventive measures installed. Analysis of the data by build date shows that the mean radon concentration in homes built post 1998 has decreased to 64 Bq/m³ when compared with homes built before 1998 where it is 86 Bq/m³.

Table 4 – Distribution of houses by build date

<table>
<thead>
<tr>
<th>House build date</th>
<th>Number of homes</th>
<th>Weighted mean radon concentration (Bq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-98</td>
<td>345</td>
<td>86</td>
</tr>
<tr>
<td>Post-98</td>
<td>197</td>
<td>64</td>
</tr>
</tbody>
</table>
4.4.2 Analysis of data by house type

The second question asked householders about the type of house they lived in. The responses showed that the most common type of home was a two storey home followed by one storey bungalows. The mean radon concentration found in two storey homes was 69 Bq/m$^3$ while in one storey bungalows, it was significantly higher at 97 Bq/m$^3$ (Table 5).

Table 5 – Distribution of homes by type

<table>
<thead>
<tr>
<th>Type of home</th>
<th>No. of homes</th>
<th>% of total</th>
<th>Weighted mean radon concentration (Bq/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single storey bungalow</td>
<td>156</td>
<td>29</td>
<td>97</td>
</tr>
<tr>
<td>Two storey house</td>
<td>299</td>
<td>55</td>
<td>69</td>
</tr>
<tr>
<td>Ground floor and upper storey apartment</td>
<td>10</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>Dormer bungalow</td>
<td>38</td>
<td>7</td>
<td>83</td>
</tr>
<tr>
<td>Other</td>
<td>39</td>
<td>14</td>
<td>76</td>
</tr>
</tbody>
</table>

This result is not entirely unexpected as the main source of radon in homes is from the underlying soil. In the case of one storey bungalows, both rooms tested are closer to the ground and therefore the source of radon. In addition radon is heavier than air so levels of radon measured in first floor rooms are generally lower than ground floor rooms. For example, in the UK, radon levels were found to be typically 35% lower on first floor bedrooms compared to ground floor living rooms (Wrixon et al., 1988). In this survey, the mean radon concentration in one storey homes where both rooms tested are on the ground floor is 41% higher than that in two storey homes where it is assumed that the main living area is on the ground floor and the main bedroom is on the first floor.

A significant number of respondents (38) specifically noted that they lived in dormer bungalows and did not assign this house type to either a one storey bungalow or a two storey house. This indicates that there was some uncertainty when categorising this house type and any future questionnaires should be revised to take this house type into account. A dormer bungalow is a one storey bungalow which has a second storey built into a sloping roof, usually with dormer windows. It is also referred to as a one-and-a-half storey home. With regard to radon concentrations, no significant difference between dormer bungalows and two storey homes was noted. Other house types reported included ground floor apartments, upper storey apartments and other. The numbers of respondents with these house types was low so no conclusions could be made between these house types and their indoor radon concentration.
4.4.3 Analysis of data by floor type

The third question in the survey asked householders what type of ground floor was in their home and the responses are summarised in table 6. Over half the respondents (58%) indicated that they have a concrete ground floor while 7% have a suspended timber floor and 11% have a mix of timber and concrete. The mean radon concentration in homes with a concrete floor was found to be 68 Bq/m$^3$.

Table 6 – Distribution of homes by ground floor type

<table>
<thead>
<tr>
<th>Type of ground floor</th>
<th>No. of homes</th>
<th>% of total</th>
<th>Weighted mean radon concentration (Bq/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended timber floor</td>
<td>39</td>
<td>7</td>
<td>81</td>
</tr>
<tr>
<td>Concrete floor</td>
<td>315</td>
<td>58</td>
<td>68</td>
</tr>
<tr>
<td>Combination of timber and concrete</td>
<td>62</td>
<td>11</td>
<td>91</td>
</tr>
<tr>
<td>Don’t know</td>
<td>104</td>
<td>19</td>
<td>93</td>
</tr>
<tr>
<td>No reply</td>
<td>22</td>
<td>4</td>
<td>101</td>
</tr>
</tbody>
</table>

In homes with a suspended timber floor it was found to be 81 Bq/m$^3$ while in homes with a mix of timber and concrete, it was 91 Bq/m$^3$. These results appear inconclusive in that if floor type is a contributing factor to indoor radon levels, then this should be evident when the group of homes with concrete floor is compared to those with timber floors followed by the homes with a mix of timber and concrete. In fact, the biggest difference is seen between homes with concrete floors and those with a mix of timber and concrete. This would suggest that the question may have been misunderstood and householders may have given information for timber floor covering as opposed to floor construction type. This assumption is supported by the significant number of respondents (23%) who responded that did not know what type of ground floor they had, again suggesting that the question was not understood.

4.4.4 Analysis of data by window type

The next question asked about the window type in the homes surveyed. The questionnaire responses show that the majority of homes (89%) have double glazed windows and the mean radon concentration found in these homes is 78 Bq/m$^3$ (Table 7). The number of respondents with triple glazed windows was only 1%. As this is too small to be representative, no comparison could be made between double and triple glazed windows. A small number of homes (9%) replied that their window type was “other”. As no other information was requested, it is assumed that these windows are single glazed. No significant difference was found between the mean radon concentration of 79 Bq/m$^3$ found in this group of homes and those with double glazing at 78 Bq/m$^3$. While this suggests that glazing alone does not influence indoor radon levels, more data, particularly on triple glazed windows is required to investigate this further.
Table 7 – Distribution of homes by window glazing type

<table>
<thead>
<tr>
<th>Type of windows</th>
<th>No. of homes</th>
<th>% of total</th>
<th>Weighted mean radon concentration (Bq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double glazed windows</td>
<td>483</td>
<td>89</td>
<td>78</td>
</tr>
<tr>
<td>Triple glazed windows</td>
<td>7</td>
<td>1</td>
<td>124</td>
</tr>
<tr>
<td>Other</td>
<td>46</td>
<td>9</td>
<td>79</td>
</tr>
<tr>
<td>Don’t know</td>
<td>5</td>
<td>1</td>
<td>35</td>
</tr>
</tbody>
</table>

4.4.5 Analysis of data by retro-fitted insulation

Question 5 asked householders if they had retro-fitted insulation to their home. The responses found that 47% of householders had added insulation to their homes while 49% had not. The mean radon concentration in homes with added insulation was 90 Bq/m³ as opposed 67 Bq/m³ for those with no added insulation. These results are presented in Table 8.

Table 8 – Distribution of homes with added insulation

<table>
<thead>
<tr>
<th>Retro-fitted insulation</th>
<th>No. of homes</th>
<th>% of total</th>
<th>Weighted mean radon concentration (Bq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>254</td>
<td>47</td>
<td>90</td>
</tr>
<tr>
<td>No</td>
<td>266</td>
<td>49</td>
<td>67</td>
</tr>
<tr>
<td>Don’t known/no answer given</td>
<td>22</td>
<td>4</td>
<td>60</td>
</tr>
</tbody>
</table>

It should be noted that the questionnaire did not gather information on the types or numbers of insulation measures added to homes. Therefore, no correlation could be made between house age and insulation type(s) in this survey. However, a study of some Irish local authority homes that had been previously tested for radon and then energy retrofitted and retested found on average that retrofitting measures were having no impact on radon levels. Furthermore, in a small number of homes where measures such as replacing or sealing windows and doors are combined with other measures there appears to be a greater effect on radon levels (EPA, 2016f). While very few studies have been carried out internationally investigating the impact of thermal retrofitting on radon levels in homes, findings do show that retrofitting such measures can increase radon levels by between 26% and 56% particularly where multiple measures are installed (Goyette Pernot and Pampuri, 2014 and Milner et al., 2014). Recognising the knowledge gap in this area, the NRCS recommended that research be carried out to investigate the relationship, if any, between increased air tightness and elevated radon levels. Research funded by the EPA under the framework of the NRCS is currently being carried out to investigate the relationship if any between increased air tightness and indoor radon levels.
These results re-enforce advice from Sustainable Energy Authority of Ireland (SEAI) that radon concentrations can increase in existing houses as a result of greater airtightness and it is therefore recommended to carry out a radon test after significant energy efficient measures have been undertaken (SEAI, 2016). Similarly the EPA advise that a house be re-tested for radon following any work that could in theory open up new entry routes for radon or prevent radon escaping from the house (EPAg, 2016).

4.4.6 Analysis of data by smoking status

The survey also included a question on the smoking status of participants. This question is included as the risk to smokers from radon is 25 times greater than to non-smokers and from a public health perspective, information on the levels of radon that smokers are exposed to is of interest. Over half of the respondents (57%) replied that they are non-smokers, 27% are ex-smokers and 13% are smokers. These results are presented in table 9. As expected, smokers are exposed to the similar levels of radon as the general population.

Table 9 – Distribution of respondents by smoking status

<table>
<thead>
<tr>
<th>Smoking status</th>
<th>No. of respondents</th>
<th>% of total</th>
<th>Weighted mean radon concentration (Bq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoker</td>
<td>70</td>
<td>13</td>
<td>72</td>
</tr>
<tr>
<td>Ex-smoker</td>
<td>145</td>
<td>27</td>
<td>83</td>
</tr>
<tr>
<td>Non-smoker</td>
<td>311</td>
<td>57</td>
<td>75</td>
</tr>
<tr>
<td>No answer given</td>
<td>16</td>
<td>3</td>
<td>77</td>
</tr>
</tbody>
</table>
Discussion
5. Discussion

To establish the national average indoor radon concentration a survey protocol was required that could be implemented over a one year period and repeated at regular intervals over the lifetime of the NRCS. The 2002 NRS measured radon concentrations in houses selected at random in each 10 km grid square of the national grid. The resulting data was used to estimate the then national average indoor radon concentration and also to establish predicted radon risk categories for the country.

The availability of these radon risk categories along with work carried out identifying geographical variations of seasonal correction factors by Burke et al. allowed a new survey protocol to be developed. The new survey protocol required radon measurements in 600 randomly selected homes to provide an updated estimate of the national average indoor radon concentration be established. The survey protocol was implemented by the EPA between July 2014 and February 2015 when radon tests were completed in 649 homes located throughout the 60 selected grid squares. As a result of the smaller sample size in this survey, reductions in the number of invitations issued, radon detectors required and staff resources were achieved. Measurements for the 2002 NRS were conducted over a 7 year period compared to the new survey protocol where radon measurements were completed within 6 months. The number of measurements used to calculate the 2015 national average radon concentration was 6% of that required in the 2002 NRS.

The results of the survey found that the current geographically weighted national average indoor radon concentration for Ireland was 77 Bq/m$^3$ with a 95% confidence interval of 71 Bq/m$^3$ to 83 Bq/m$^3$. This is a 13% reduction in the national average radon concentration since it was first reported in the NRS in 2002.

This reduction demonstrates the overall impact of changes that could influence indoor radon levels since the 2002 NRS. A key change was the introduction, in 1998, of Building Regulations that require reasonable precautions be taken during the construction of new buildings to avoid danger to health due to radon.

To examine the specific effectiveness of these Building Regulations, the homes surveyed were analysed by build date. By comparing the national average indoor radon concentration in homes built prior to 1998 when no radon preventive measures were required with those in homes built post 1998 when it is assumed that a radon preventive measures are installed in new homes built in High Radon Areas, a significant reduction of 26% is observed (Table 4).

A total of 64% of the homes surveyed were built prior to 1998 and the average indoor radon concentration in these homes was 86 Bq/m$^3$. It is noted that this is in good agreement with the national average indoor radon concentration of 89 Bq/m$^3$ reported in the NRS where the dataset consisted of homes tested between 1992 and 1999 and therefore, it can be assumed built prior to the introduction of the Building Regulations. The remaining 36% of homes in the current survey were built post 1998 when radon preventive measures were required and the average indoor radon
concentration in these homes was found to be 64 Bq/m$^3$. These results indicate that the introduction of radon preventive measures in new buildings since 1998 have significantly reduced the national average indoor radon concentration and have been beneficial in reducing the exposure of the Irish population to radon gas (Table 4).

Previous studies have been carried out to assess the effectiveness of the building regulations by comparing mean radon concentrations in homes built prior to 1998 to those in homes built from 1998 onwards. In 2012, a study of the effectiveness of radon preventive and remedial measures in Irish homes was carried out using radon measurements from local authority homes in county Cork (Long et al. 2013). A reduction of 55% in the mean radon concentration in homes built since 1998 relative to those built before that date was reported. Prior to this, smaller studies had been carried out on private homes in Ennis, Tralee and Kilkenny between 2003 and 2006 (Organo and Synnott 2006). Similarly, these studies reported that the provision of a radon membrane in homes in high radon areas had a beneficial effect in reducing average radon concentrations by about 30 to 50%. It should be noted that these smaller studies were confined to limited geographical areas.

The national average indoor radon concentration of 77 Bq/m$^3$ established in this survey sets a baseline for this metric for the NRCS. The NRCS sets out over 30 actions aimed at minimising the exposure to radon gas for people in Ireland. These include actions to improve radon preventive measures in new buildings, and recommendations that the relevant Technical Guidance for homes construction should be amended and strengthened to take account of experience with the existing guidance and more recent research on radon prevention be carried out. This survey protocol can be repeated periodically to track changes in the national average indoor radon concentration and thereby assess the effectiveness of actions in the NRCS as they are implemented.
Conclusions
6. Conclusions

Using the newly designed survey protocol described in this report, the current national average indoor radon concentration for homes in Ireland was estimated to be 77 Bq/m$^3$. This represents a 13% reduction from 89 Bq/m$^3$ reported by the NRS in 2002. This figure of 77 Bq/m$^3$ will be used as a baseline metric against which the effectiveness of the NRCS will be measured over time.

Analysis of the data by build date indicates that the significant factor effecting a reduction in the national average is the building regulations introduced in 1998. This can be seen when the mean radon concentration in homes built prior to 1998 is compared to homes built post 1998. Homes built prior to 1998 have a mean radon concentration of 86 Bq/m$^3$ which is comparable to the 89 Bq/m$^3$ national average reported in the 2002 NRS. For homes built post 1998, the mean radon concentration is 64 Bq/m$^3$.

Compilation of the survey questionnaires on building characteristics found significant difference in mean radon concentration was found between these two house types. The mean radon concentration found in two storey homes was 69 Bq/m$^3$ while in one storey homes it was 97 Bq/m$^3$. This difference in mean radon concentration between one and two storey homes is not unexpected given that both rooms tested in a one storey home are closer to the source of radon.

The majority of homes surveyed had double glazed windows. No significant difference in indoor radon concentration was noted between homes with double glazed and other glazing types. The data on floor construction type and indoor radon concentration is inconclusive and suggests that better information could be obtained by better explanation of this question in any future surveys.

Insulation had been retro-fitted in 47% of the homes surveyed and these homes were found to have higher indoor radon levels than those with no added insulation. This finding highlights the advice that a house be re-tested for radon following any work that could in theory open up new entry routes for radon or prevent radon escaping from the house. Information regarding the types and number of insulation measures added to the homes was not requested in this survey. To address the knowledge gap in this area, research funded by the EPA is currently being carried out to investigate the relationship if any between increased air tightness and indoor radon levels.

The 2002 NRS reported both the geographic weighted mean of 89 Bq/m$^3$ and the population weighted mean of 91 Bq/m$^3$. The aim of this study was to re-assess the geographic weighted mean and examine the effectiveness of the Building Regulations since their introduction. A survey to update the population weighted mean will be completed by the EPA in 2017. Updating the population weighted mean will allow a revised estimation of the number of lung cancer cases currently linked to radon gas in Ireland.
References
7. References


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EPA, 2016d. Estimation of number of detectors not returned to EPA radon testing service. Personal communication. 31 May 2016


Goyette Pernot J and Pampuri L. Indoor air quality in new or renovated energy-efficient buildings – Preliminary results of radon measurement campaigns in French and Italian parts of Switzerland. ROOMS 2014, Bad Ischl, Austria. 2014


Appendices
8. Appendix 1 – Householder invitation and questionnaire

The Householder
Address 1
Address 2
Address 3
Address 4
Address 5
Date:

Dear Householder,

RPII’s Research survey on average level of radon gas in Ireland

I am writing to invite you to participate in the Radiological Protection Institute of Ireland’s research survey of radon levels in homes in Ireland. The survey will begin in September and by taking part you will be helping us update our knowledge about the health risk from radon in Ireland.

We are looking for householders throughout the country to carry out a radon test in their homes. The radon test is simple, completely free of charge and all done by post: so no one will call. We will then use these test results to update the national average indoor radon level for Ireland which is a key factor in determining the number of lung cancers caused by radon in homes in Ireland. Each year some 250 lung cancers are linked to radon. Further information about radon gas, the RPII and our survey is enclosed.

Once the test is completed, we will send you a report explaining your result. If your radon levels are high we can provide further information and offer advice. Please note that the result of the radon test in your home will be treated in the strictest of confidence and will be used only for statistical purposes.

To take part, please complete the form below, sign it and return it to us in the prepaid envelope provided. We will then send you two radon detectors in September along with instructions on how to place these detectors. I look forward to receiving your reply. In the meantime, if you have any queries about this survey, please call our Freephone number 1 800 300 600 or email radon@rpii.ie.

Yours sincerely,

Alison Dowdall  Scientific Officer, Radon section

PS: This is a free offer but please note it is open for a limited period closing once we have 600 replies.

Ref no: Grid Square and UID:

I wish to accept a free radon measurement as described in the letter from RPII (INSERT DATE):

First Name: 
(BLOCK CAPITALS PLEASE)
Surname: 
(BLOCK CAPITALS PLEASE)
Address:

Email: 
Mobile number:

Signature:
RPII’s research survey on the average level of radon gas in Ireland

Who are the Radiological Protection Institute of Ireland (RPII)?

The RPII is a public body under the aegis of the Department of Environment, Community and Local Government. The RPII is Ireland’s expert voice on ionising radiation.

What is radon?

Radon is a naturally occurring radioactive gas formed in the ground by the radioactive decay of uranium which is present in small quantities in all rocks and soils. You cannot see it, smell it or taste it and it can only be measured using dedicated radon detectors.

How can I test my home for radon?

A radon test is carried out by placing two small radon detectors, which are about the size of a biscuit, in your home for three months. One detector is placed in a bedroom the other in a living room. After three months the detectors should be returned to us for analysis to see how much radon they have been exposed to. You will then be sent a report of the measurement indicating the average level of radon in your home and advice on what to do next if it is a high result.

Why is radon harmful?

Radon can cause lung cancer and is in the same group of carcinogens as asbestos and tobacco smoke. Radon causes up to 250 lung cancer cases each year in Ireland. Radon gas affects us all but the risk is greater for smokers. The national Reference Level for long-term exposure to radon in a home, above which the need for remedial action should be considered, is 200 Bq/m³.

What is this survey about?

The last radon survey of Ireland was published in 2002. From the results of that survey, an average indoor radon level in Irish houses was calculated to be 89 Bq/m³, which is amongst the highest in Europe. Since then, there have been a number of developments such as the building boom since 2002, the introduction of amending Building Regulations in 1998 requiring radon preventive measures in new buildings in HRAs, and increased energy efficiency in homes. We now want to assess the impact these changes have had on the national average radon concentration.

Why has my home been selected?

Your address is one of 2500 across the country which has been selected at random for this survey and you are being offered a free radon test. We are looking for at least 600 homes for our survey.

What can I do if I have a high result?

For relatively moderate radon levels, improving indoor ventilation may reduce your level by half, the cost of which is low. For higher levels, a fan assisted sump can be installed which can reduce any radon level by over 90%. The sump can be installed in a day with little disruption to your home. The average cost of this work is €850 with running costs of approx. €100 per year.

Where can I find out more about radon gas, the RPII and the survey?

You can call our Freephone number 1800 300 600 or visit our website: www.rpii.ie
It would be of great help to our research if you could answer the questions below. Any information provided will be treated as confidential. Thank you for your help.

PLEASE RETURN THIS SHEET IN THE FREEMPOST ENVELOPE PROVIDED.

1. When was your home built?

<table>
<thead>
<tr>
<th>Before 1980</th>
<th>Between 1998 and 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   Please state decade:

<table>
<thead>
<tr>
<th>Between 1980 and 1998</th>
<th>After 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Is your home a:

<table>
<thead>
<tr>
<th>Single storey bungalow</th>
<th>Two storey house</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ground floor apartment</th>
<th>Upper storey apartment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   Other please specify

3. Is your ground floor a:

<table>
<thead>
<tr>
<th>Suspended timber floor</th>
<th>Concrete Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A combination of timber and concrete</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Do you have:

<table>
<thead>
<tr>
<th>Double glazed windows</th>
<th>Triple glazed windows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   Other (please specify) | Don’t know

5. Have you had your house retro-fitted with insulation?  

   YES ☐  NO ☐

   If yes, what year was this done?

6. Are you a:

<table>
<thead>
<tr>
<th>Smoker</th>
<th>Ex-smoker</th>
<th>Non-smoker</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For your information, the risk from radon is 25 times greater for active smokers than for lifelong non-smokers exposed to the same concentrations of radon.

QUESTIONNAIRE COMPLETED BY: __________________________

(Please print your name)

If you have any questions about this questionnaire please contact
Alison Dowdall on 01 206 6914 or a.dowdall@epa.ie
Ref No:
9. Appendix 2 – Summary of survey results by grid square

<table>
<thead>
<tr>
<th>Grid Square Reference</th>
<th>No. of measurements</th>
<th>Radon concentration range (Bq/m³)</th>
<th>No. of measurements &gt;200 (Bq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>406</td>
<td>7</td>
<td>14–66</td>
<td>0</td>
</tr>
<tr>
<td>610</td>
<td>13</td>
<td>16–437</td>
<td>1</td>
</tr>
<tr>
<td>711</td>
<td>14</td>
<td>21–524</td>
<td>5</td>
</tr>
<tr>
<td>809</td>
<td>13</td>
<td>18–189</td>
<td>0</td>
</tr>
<tr>
<td>830</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>904</td>
<td>11</td>
<td>5–92</td>
<td>0</td>
</tr>
<tr>
<td>1016</td>
<td>13</td>
<td>11–172</td>
<td>0</td>
</tr>
<tr>
<td>1019</td>
<td>11</td>
<td>46–623</td>
<td>3</td>
</tr>
<tr>
<td>1027</td>
<td>2</td>
<td>20–374</td>
<td>1</td>
</tr>
<tr>
<td>1122</td>
<td>14</td>
<td>14–337</td>
<td>2</td>
</tr>
<tr>
<td>1207</td>
<td>13</td>
<td>13–199</td>
<td>0</td>
</tr>
<tr>
<td>1221</td>
<td>6</td>
<td>12–57</td>
<td>0</td>
</tr>
<tr>
<td>1305</td>
<td>11</td>
<td>14–424</td>
<td>1</td>
</tr>
<tr>
<td>1307</td>
<td>13</td>
<td>20–193</td>
<td>0</td>
</tr>
<tr>
<td>1311</td>
<td>10</td>
<td>11–195</td>
<td>0</td>
</tr>
<tr>
<td>1313</td>
<td>13</td>
<td>16–153</td>
<td>0</td>
</tr>
<tr>
<td>1318</td>
<td>12</td>
<td>26–872</td>
<td>3</td>
</tr>
<tr>
<td>1329</td>
<td>13</td>
<td>16–775</td>
<td>1</td>
</tr>
<tr>
<td>1425</td>
<td>14</td>
<td>16–973</td>
<td>3</td>
</tr>
<tr>
<td>1612</td>
<td>13</td>
<td>15–139</td>
<td>0</td>
</tr>
<tr>
<td>1614</td>
<td>9</td>
<td>28–118</td>
<td>0</td>
</tr>
<tr>
<td>1715</td>
<td>13</td>
<td>12–65</td>
<td>0</td>
</tr>
<tr>
<td>1716</td>
<td>11</td>
<td>16–134</td>
<td>0</td>
</tr>
<tr>
<td>1721</td>
<td>9</td>
<td>16–144</td>
<td>0</td>
</tr>
<tr>
<td>1740</td>
<td>1</td>
<td>86</td>
<td>0</td>
</tr>
<tr>
<td>1806</td>
<td>15</td>
<td>26–596</td>
<td>6</td>
</tr>
<tr>
<td>1822</td>
<td>10</td>
<td>33–164</td>
<td>0</td>
</tr>
<tr>
<td>1825</td>
<td>7</td>
<td>21–135</td>
<td>0</td>
</tr>
<tr>
<td>1919</td>
<td>12</td>
<td>16–402</td>
<td>1</td>
</tr>
</tbody>
</table>
### Grid Square Reference | No. of measurements | Radon concentration range (Bq/m³) | No. of measurements >200 (Bq/m³)
--- | --- | --- | ---
1923 | 15 | 15–252 | 1
1930 | 14 | 13–621 | 2
1942 | 1 | 16 | 0
2006 | 8 | 11–45 | 0
2107 | 12 | 24–345 | 2
2108 | 11 | 46–564 | 2
2110 | 11 | 33–113 | 0
2243 | 8 | 13–74 | 0
2311 | 14 | 22–294 | 1
2313 | 13 | 15–223 | 1
2314 | 10 | 15–70 | 0
2340 | 15 | 20–641 | 1
2416 | 10 | 15–210 | 1
2417 | 9 | 15–55 | 0
2420 | 11 | 11–49 | 0
2421 | 10 | 23–90 | 0
2423 | 15 | 15–246 | 1
2514 | 13 | 23–354 | 1
2526 | 14 | 14–253 | 1
2630 | 5 | 38–64 | 0
2633 | 11 | 17–70 | 0
2717 | 12 | 25–368 | 2
2726 | 10 | 17–217 | 1
2732 | 6 | 15–82 | 0
2814 | 9 | 22–553 | 3
3015 | 14 | 52–1001 | 5
3027 | 12 | 8–93 | 0
3126 | 13 | 11–78 | 0
3127 | 12 | 15–158 | 0
3221 | 14 | 19–166 | 0
3225 | 14 | 17–110 | 0
Tá an Gnóiomhairéacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaoil a chomhánú agus a threabhshú mar shocruitheanna luachmhaireachta do mhuintir na hÉireann. Táimid toimtha do dhaoine agus don domhain a chosaint ò úrlí agus ò éifeachtaithe doibhleachála a raithioachta agus an triuiliútha.

Is féidir obair na Gníomhraíochta a roint ina tri phríomhhréime: Rialú: Déanaimid córais éifeachtachta rialaithe agus comhlintaí comhshaoil a chur i bhfeidhm chun tuaisceart maithe comhshaoil a chur i seachtar agus chun díon ó riarthóireachta leis na córais sin. Eolas: Soláthramaid sonrai, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, scothphréinte agus tráthúil chuimhneann eolas agus le faoin gníomheoraíocht ar gach leabhar.

Tacaíocht: Bimid ag saothrú i gcomhrá le gealltaí eile chun tacú le comhshaoil atá glan, tairgiúil agus cosanta go maith, agus le híompar a chúirtí fíor le comhshaoil inbhuanaithe.

Ár bhFreagrachtáí

CEADÚNÚ Déanaimid na gniomhaíochtaí seo a leasana a rialú ó nádúranna is a thabhaltóidh an phobail na domhain:  
• saoráidí draíomhaíochta (m.sh. láithreacha)  
• gniomhaíochtaí tionsclaíoa ar scála mór (m.sh. deántasálaíochta cénas, deántasálaíochta stróighthe, stáisiúin chumhachtach)
• an diantalmhaisíochta leis an maínlúiseachta
eoladóireas an t-údarás áitiúil.
• foinis radaíochta inaúcháin (m.sh. trealamh x-gha, ar daiteine, foinis tionsclaíochta)
• áisearna mór-stórála peitril;  
• scardadh dramhuisce;
• áiseanna móra stórála peitril;  
• úsáid shrianta agus scaoileadh rialaithe Orgánach an t-ádiomhchóir (m.sh. luaithe, éanlaith).  
• gníomhaíochtaí tionsclaíochta ar scála mór  
• saoráidí dramhuisce a bhainistiú.

FORFEIDHMHÚ NAISÍUNTA I LEITH CÚRSAÍ COMHSHAOIL  
• Cloimsíonaí siúnta agus cígraíochta a dhéanamh gach bliain ar shaoiridí agus leis an bhfuil ceadúnas ó nGníomharaíocht.
• Maoríseacht a dhéanamh ar fhearghachtaí comhshaoil na n-údarás áitiúil.
• Gaithsíonn an t-aisteoir le clósadh agus leis na n-údarás áitiúil.
• Obair ar fud cúig bliain ar saoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
• Cabhrú leis an riccheachtaí a thabhairt ar an rialú agus leis an chumhacht.

FORFHEIDHMIÚ NAISÍUNTA I LEITH NGS comhshaoil  
• Tá an ghníomhairéacht um Chaomhnú Comhshaoil (GCC) mar shocruithe a bheith inbhuanaithe.
• Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag táirgiúil agus cosanta go maith, agus leis an chumhacht a chur i bhfeidhm.
• Comhairle agus treoir a chur ar fáil do dhuine agus na hÉireann.
• Feasaíonn an bhreithinthí faoin gcinnteoireacht ar gach leibhéal.
• Feasaíonn an bhreithinthí faoin gcinnteoireacht ar gach leibhéal.
• Feasaíonn an bhreithinthí faoin gcinnteoireacht ar gach leibhéal.
• Feasaíonn an bhreithinthí faoin gcinnteoireacht ar gach leibhéal.

BAINSTÍOCHT UISCE  
• Tuairiscíonn meascnáisiomhaíte acu le cabhrú le cinnteoireacht an rialtais na n-údarás ar an uisce agus ar an dochtúir na hÉireann.
• Tuairiscíonn meascnáisiomhaíte acu le cabhrú le cinnteoireacht an rialtais na n-údarás ar an uisce agus ar an dochtúir na hÉireann.
• Tuairiscíonn meascnáisiomhaíte acu le cabhrú le cinnteoireacht an rialtais na n-údarás ar an uisce agus ar an dochtúir na hÉireann.