Evaluation of radon survey, setting a national reference level

Presented by
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A basic consideration

**Radon, radon decay products, dose to the lungs, risk**

- Radon decay products (RnDPs) deliver a quite higher dose to the lungs than radon itself.
- However, the dose to the lungs is better correlated with radon concentration than to the concentration of RnDPs.
- This is due to the large impact (on the dose) of the size distribution of aerosols to which RnDPs attach themselves and to the fraction of unattached RnDPs, besides the concentration of RnDPs itself.
- Therefore it is appropriate to evaluate the radon concentration distribution in dwellings in order to estimate the dose to the lungs and the related health risks.
The objective of a radon survey

• To estimate the average exposure of the population to indoor radon and the distribution of the exposures

• To identify those areas within the country where high indoor radon concentrations are more likely to be found (radon-prone areas)

• To identify those building characteristics within the country where high indoor radon concentrations are more likely to be found (radon-prone buildings)
Representative survey

• **To estimate the distribution of radon exposures**
  • is there a radon health risk in a country? if yes, to what extend?
  • for implementation of national radon policy (national reference level (RL), estimation number of homes above RL, estimation of the cost of the programme, etc.)
  • this can be done through a **population-weighted survey** by measuring indoor radon levels in randomly selected homes

• **To identify radon prone areas (radon map)**
  • more extensive survey; some thousands of detectors, depending on population and area of the country
  • this can be achieved with **geographically based survey** (where homes are randomly selected to obtain a minimum density of measurements per area unit chosen - e.g. a grid square, an administrative unit etc).

A carefully designed survey can, in principle, meet the requirements and objectives of both types of surveys
Aim of this survey:

- to determine the radon exposure distribution of the population, in particular:
  - to estimate the average exposure (related to the total health burden)
  - to estimate the percentage of dwellings exceeding reference levels.

Measured homes have to be representative of the total building stock → random selection.

Representativeness can be achieved by choosing homes randomly from a complete list of the residential dwellings (e.g. houses and flats, list of inhabitants) in the country.

It is important to obtain statistical advice - many biases can distort the results.
Population-weighted survey – issues to be considered

- Sampling scheme (random selection of households)
- Sample size
- Monitored rooms
- Number of detectors per household
- Duration of measurement (seasonal variation and correction factors)
- Detector type
- Detector placement
- Contacting householder, detector deployment and collection
- Measurement protocol
- Questionnaire
- Quality assurance
- Data analysis and reporting results
- National database
Population-weighted survey – issues to be considered

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Sample (design and size)

- Simple sample
  - Random sample from the list of all dwellings or inhabitants
  - Deviations from full randomness can cause biases
    - measurement only for volunteers, high number of refusals

- Stratified sample – Multistage sampling
  - Target population is partitioned into separated groups (strata)
  - Distribution of sampled units is then under control in the strata

- Sample size depends on
  - Bias and uncertainty that is acceptable (larger sample may somehow decrease the bias and uncertainty)
  - Population of the country and resources
  → usually hundreds to several thousands of dwellings are measured
Dwellings and householders

It is equivalent to consider housing units or the householders as the target population of the survey (all inhabitants of each dwelling are exposed to about the same radon concentration).

Choice depends on the availability of complete lists from which the sample units could be randomly selected (complete list of inhabitants often easier to have than of dwellings)
Randomness, completeness, bias

• Need a sample which is representative of the population exposure → select a random sample of dwellings (or inhabitants) from a complete list

• If not (e.g. sample of volunteers or a large number of refusals to participate) → probable/possible bias

• For practical reasons often surrogate of complete list used (e.g. list of telephone numbers) and often a significant number of refusals occurs → need to check representativeness (e.g. compare certain parameters in the actual sample with corresponding values in the last census)
Volunteers and bias

An example from Ireland

- Representative national survey: average=89 Bq/m³
- Survey on volunteers: average=161 Bq/m³

(Burke and Murphy, J.Radiol.Prot. 2011)
Population-weighted survey – issues to be considered

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Data processing

• Check the representativeness
  • due to refuses to participate in measurement (and, to a minor extend, detectors losses) it is necessary to check the representativeness of the actual sample (compared to the planned sample).

• Log-normality test
  • the frequency distribution of radon concentration tends to have a log-normal shape
  • the log-normality (normality of the logarithms) should be tested before further analysis by chi-square or Kolmogorov test or (better) by the Q-Q plot (which allows to evaluate where deviations from L-N occur)

• Analysis depends on sampling scheme
  • simple sampling → simple analysis (no weighting of results)
  • complex sampling schemes (e.g. stratified sampling) → results have to be calculated separately for each stratum and then be combined (weighted) in a proper way.
Data processing

• Parameters of the radon concentration distribution
  • If the frequency distribution of radon concentrations has a log-normal shape, then the distribution can be described by two (*) parameters: **geometric mean** (GM) and **geometric standard deviation** (GSD)
  • Based on the knowledge of GM and GSD it is possible to estimate the proportion of dwellings above any reference level (RL)

\[ k = \frac{\ln(RL) - \ln(GM)}{\ln(GSD)} \]

with \( k \) taken from statistical tables of the area under the standardised normal curve.
Data processing

- Parameters of the radon concentration distribution (cont.)
  - (*) in many cases, the additive contribution of outdoor Rn conc. produces some deviation from L-N distribution
    => 3-parameter L-N distribution
  - Neglecting this effect can lead to underestimate the GSD and therefore to underestimate the proportion of dwellings exceeding RLs
    - e.g. in UK:
      uncorrected GSD=2.2
      corrected GSD= 3.6
  - The observed average is not biased by the outdoor contribution from outdoor Rn concentration
Population-weighted survey – issues to be considered

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- National database
Who (and how) should get the results?

- How to present the results to the homeowner – official protocol with results and interpretation
- Ownership of the results and confidentiality
- Be prepared on how to deal with dwellings with high (elevated) radon concentrations → civil engineers should be involved in radon issue from early beginning!
National database

- To store results from radon measurements at national level
- Radon database is an important tool for National Radon Action Plan (for both planning and evaluation of actions)
- Related issues:
  - Who will enter the results into the database – everyone incl. private companies? National/regional laboratories only? – obligation should be introduced in relevant regulation.
  - Who will have access to the database – national authority only? municipalities?
  - Consider carefully what information should be stored in the database – only results of radon measurements? To get a real benefit of the radon database information from the questionnaire on building characteristics etc., information on corrective actions (type, cost, radon concentration before/after), information on preventive measures (type, cost, radon concentration should be also collected for further analysis.
  - Consider confidentiality of (some) data?
Radon measurements in UK

- A national survey carried out in the early 1980s provided results of gamma ray dose rate and radon concentration measurements in more than 2000 dwellings selected systematically according to postal codes.
- The mean radon level from the survey was 20.5 Bq/m$^3$.
- The same study also reported data from studies carried out in regions of the UK with elevated uranium mineralization.
- The regional surveys showed average radon levels of up to 300 Bq/m$^3$ for areas of south-west England.
Radon measurements in France

- Indoor radon measurements were performed using passive dosimeters left in place for 2 months in the main room.
- A questionnaire was completed regarding housing characteristics.
- In total the survey included 12,621 radon measurements distributed over the whole country.
- Corrections for seasonal variations and housing characteristics were applied.
Radon measurement in Czech Republic

- A national representative survey was performed with 2000 flats in 1992-1993
- Bare solid state nuclear tracks detectors, 1 year exposure, 2 detectors per flat
- The average radon concentration found was 118 Bq/m³
- Approx. 2-3% of houses (50,000) were estimated to be above intervention level 400 Bq/m³
- 1st step - Targeted radon survey was started based on the results to identify those high level houses – 150,000 measured flats, 20,000 high radon flats identified, development of maps
- 2nd step – focus on radon awareness, education and cost free long term measurement (2 months in heating season or 1 year)
Radon measurements in USA

• A major survey of radon concentrations in US homes measured radon levels in homes in 125 counties in 50 states.

• Approximately 6.1% of the homes surveyed exceeded the US Environmental Protection Agency (EPA) action level of 148 Bq/m³.

• Distribution of radon concentrations in homes could be reasonably described by a log-normal distribution.

• Overall GM of the radon concentration data was 25 Bq/m³ with a GSD of about 3.1.
Radon measurements in Japan

- Several Japanese studies showed significant differences.
- The first survey of more than 7,000 houses, using passive radon detection (KfK radon detector), reported a mean radon concentration of 29 Bq/m$^3$.
- To investigate potential confounding by thoron, a survey of 900 houses used a detector that could discriminate between radon and thoron. The mean radon concentration from the second survey was 15.5 Bq/m$^3$. 
Radon measurements in China

- In the 1980s and 1990s, two nationwide surveys of indoor radon were performed in China using grab sampling measurements or short-term measurements.
- The arithmetic mean (AM) was 24 Bq/m\(^3\) and the GM was 21 Bq/m\(^3\).
- A new survey of indoor radon in 26 cities and regions during 2001 and 2005 used alpha track detection (exposure period of 3–6 months). The AM was 44 Bq/m\(^3\) and the GM was 34 Bq/m\(^3\).
- The latest results are significantly higher than those of previous surveys.
- Results of grab sampling will never represent the real situation (see the chart of radon concentration variation).
Example – Sweden, Gammadata (Landauer Nordic)

- Need of large number of measurement in dwellings to identify all dwellings above 400 Bq/m³ (200 Bq/m³)
- **Prerequisite** – municipalities do not have enough money and man power to carry out / manage all measurements →
- Radon laboratories buys addresses to single-house owners in selected areas.
- The local authority, in cooperation with the laboratory, makes an information letter which is sent in the inquiry.
- Postage pre-paid answering letters can be sent directly to the laboratory or homepage can be used.
- The laboratory takes all costs and administration for the inquiry. No direct costs for municipality authorities.
- The result of the measurement is sent to the homeowner and the municipality

Source: Presentation of Henrik Stranning, MSc. Gammadata Mätteknik AB, 2010
Example – Sweden, Gammadata (Landauer Nordic)

- Relatively high answer rates (up to 30%) in local regions with large radon problems and where there is an active radon program since many years.
- Bad publicity has a large effect.
- “Official” information important. Interest inquiries sent out in the name of Gammadata gave about 10% answer rates.
- Information letter clearly noting backing of municipality.
- Well written information letter
- The inquiry could be sent in the envelope of the local authority.
- Additional positive information from local authorities through e.g. media.

Source: Presentation of Henrik Stranning, MSc. Gammadata Mätteknik AB, 2010
Radon surveys – Summary

- Define the aim of the survey → select appropriate type of survey
- Design the survey very carefully, consider all issues
- Data analysis and check for representativeness is very important, involve statistical services at an early stage
- It is not easy to organize a „truly“ representative survey (subsample of total sample, not possible to enforce measurements in private homes, etc.) → a careful planning is needed and some compromise may be necessary!
Radon survey in buildings with public access

• If the survey in dwellings is not possible for different reasons, the buildings with public access can be used for the 1st step of radon survey.

• Primary schools and kindergartens should be primarily selected rather than hospitals
  - Usually easy to access through municipality
  - Positive public perception of the measurement (protection of children)
  - Classrooms are occupied with predictable pattern BUT nights, weekends and holidays the building is unoccupied → the average radon concentration for the whole exposure period may be higher than during occupation

• Hospitals has very specific user conditions, ventilation rate is higher than in usual dwelling and cellar or storage rooms are not appropriate to describe the exposure of public.
An affordable proxy of representative national survey on radon concentration in dwellings: design, organization and representativeness evaluation

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Introduction

• International recommendations and regulations require the set-up and implementation of a National Radon Program
  • e.g. WHO Handbook on Indoor Radon (2009), International Basic Safety Standards (2012), European Basic Safety Standards (2012)

• A representative national survey on radon in dwellings is a basic element of a NRP, allowing to evaluate correctly the distribution of radon concentration in a country, and to plan appropriate actions accordingly.

• However, carrying out a true representative national survey on radon in dwellings can be quite difficult and expensive

• An affordable proxy survey on going in Italy will be described

• Similar methods could be used in other countries
Representative National Surveys: key factors and feasibility

• A complete list of individuals (or families) is needed to extract randomly a sample representative of the whole population

  • Generally not available. Registries of residents are often available at local level only (=> multi-step sampling strategy). Some national lists could be used as proxy for residents (mail, telephone, etc).

• Selected persons have to be contacted to ask them to participate the survey

  • Time-consuming and expensive by phone, or mail, or direct contact

• Fill in of questionnaire and data entry of questionnaire data

  • Time-consuming and expensive
Need of a new representative National Survey in Italy

- Previous national survey in Italian dwellings was carried out in 1989–1999, involving ~5600 dwellings in 232 Municipalities
  - All the 50 big cities (≥ 10^5 inhabitants) were involved, whereas (for feasibility reasons) a random sample of 182 less populated Municipalities was selected to represent all the ~8000 similar Italian Municipalities (clustered sample)
  - Therefore radon distribution was evaluated at regional level only, for all the 21 Regions
- More detailed surveys have carried out in few Regions only
- An updated and more spread representative national survey on radon in dwellings was considered useful to better plan actions to reduce radon risk all over the country
Need of a new representative National Survey in Italy

21 Regions

110 Provinces

Rn = ?
A new national survey was designed and organized by the ISS (Italian National Institute of Health) in collaboration with an Italian telephone company (Telecom-Italia).

Objective: a survey which could be representative of the population exposure in all the 110 Italian Provinces, by using an affordable approach.

Telecom employee homes and workplaces are distributed all over the country (covering all the 110 Provinces).

- 54,000 employees, working in 1,028 sites distributed in 536 Municipalities, with homes distributed in ~4,200 Municipalities.
An affordable approach for a ~representative NS

Key factors

• A **complete list** of all the Telecom employees was available as a PC file, containing their **workplaces and home address**
  • => easy and ~free to design, test and implement a sampling scheme

• Each employee has a **work email address** and can access the Telecom intranet
  • => easy and not expensive: i) **contacting employees** by automatic emails, ii) **sending them information** though emails and web pages, and iii) **receiving from them information and files** through web pages connected to a database

• Telecom has a mail service connecting all the working sites
  • => easy and inexpensive to send/receive detectors to employees
An affordable approach for a ~representative NS
Basic assumption

• A random sample of Telecom employees can be considered representative of the radon exposure of the general population, if we assume that dwellings and living habits are similar for general population and Telecom employees, so that radon distributions are similar as well.

• **This assumption has to be verified (see later)**

• Besides a potential (hopefully small) bias (i.e. a significant difference of radon distribution average), we can expect a smaller width of radon distribution for employee dwellings
An affordable approach for a ~representative NS

Key factors (cont.)

- A questionnaire was prepared, both in pdf and excel format, and sent to all the participants, that were asked to return the filled excel file
  - => no cost (and time) for printing and sending questionnaire
  - => no cost (and time) for data entry of questionnaire data
- The pdf questionnaire contains examples and figures to facilitate understanding of questions
- The excel file contains tools and controls to facilitate data entry and to highlight wrong and missing values
An affordable approach for a ~representative NS Questionnaire
Stratified Sampling Scheme

- A goal of ~7000 employees (= dwellings) to be selected
- All the employees were stratified into 114 strata (i.e. 110 Provinces + the 4 big cities with ≥ 1 million inhabitants), randomly sampling within each stratum
- The sample size for each stratum was not proportional to population, but chosen considering:
  - a requested minimum precision for the average (=> ≥30, if available)
  - expected Rn levels (=> increased sample size in high Rn areas)
  - availability of previous data (=> reduced sample size)
# Selected and actual sample

<table>
<thead>
<tr>
<th></th>
<th>All Italian dwellings</th>
<th>All Telecom employees</th>
<th>Selected sample of Telecom employees</th>
<th>Actual initial sample (employees accepting to participate)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total number</strong></td>
<td>~20 millions</td>
<td>54,168</td>
<td>7,120</td>
<td>6,809</td>
</tr>
<tr>
<td><strong>Number per stratum: median (range)</strong></td>
<td>378k (58k–4,100k)</td>
<td>190 (10–12,833)</td>
<td>61 (8–333)</td>
<td>58 (5–317)</td>
</tr>
<tr>
<td><strong>Total number of towns</strong></td>
<td>8,100</td>
<td>4,198</td>
<td>2,069</td>
<td>2,063</td>
</tr>
<tr>
<td><strong>Number of towns per stratum: median (range)</strong></td>
<td>60 (6–315)</td>
<td>32 (6–184)</td>
<td>18 (5–55)</td>
<td>17 (4–53)</td>
</tr>
</tbody>
</table>
## Effectiveness in contacting the selected sample

<table>
<thead>
<tr>
<th></th>
<th>Acceptance (%)</th>
<th>Distribution of acceptance for each contact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial contact (%)</td>
</tr>
<tr>
<td><strong>First series of contacts:</strong></td>
<td></td>
<td>56 (40–83)</td>
</tr>
<tr>
<td>overall (range)</td>
<td></td>
<td>55 (31–78)</td>
</tr>
<tr>
<td><strong>Second series of contacts:</strong></td>
<td>51 (25–83)</td>
<td>49 (0–100)</td>
</tr>
<tr>
<td>overall (range)</td>
<td></td>
<td>51 (25–83)</td>
</tr>
<tr>
<td><strong>Both series of contacts:</strong></td>
<td>54 (37–83)</td>
<td>53 (32–76)</td>
</tr>
<tr>
<td>overall (range)</td>
<td></td>
<td>53 (32–76)</td>
</tr>
</tbody>
</table>
Check of representativeness

Principles

• Representativeness of a sample respect to the population of interest should always be checked, especially in case of proxy

• Here we are interested to radon concentration in dwellings

A) Check of radon concentration

• Compare radon concentration distribution in the actual sample and in a “true” representative sample

B) Check of sample characteristics which could be related to Rn

• Compare distribution over the country (radon prone areas)
• Compare sample characteristics with official national ones (if available), or with those of a true representative sample (if available)
Check of representativeness
in this survey

A) Check of radon concentration

• Radon concentration results of this survey will be compared with results of representative surveys available for some Regions

B) Check of sample characteristics which could be related to Rn

• Sample dwellings are spread over ~2000 towns

• Some data on dwellings (comparable with those collected in national census) were included in the questionnaire and will be compared with n.c.
  • Dwelling location (within a town, in a village, isolated house)
  • Building size (number of dwellings and of floors above ground level)
  • Dwelling size (number of floors in the dwelling)
  • Building age
  • Number of family components
Rn concentration measurements

- Radon measuring device: 1 CR-39 in a small diffusion chamber
- Read-out system: automatic system with high reproducibility
- Exposure duration: a single exposure of 12 months
  - Ageing and fading being evaluated through a supplemental survey
- Monitored rooms: 2 (1 living room and 1 bedroom)
- Number of devices per room: 1
  - Duplicate devices in the supplementary survey only
- Supplementary survey to evaluate uncertainties
  - In ~60 dwellings distributed in all the Regions
  - Devices exposed for 3, 6, 12 months
  - Duplicate devices
Conclusions

- Realization of a potentially good proxy of a population representative survey by measuring radon concentration in dwellings of a sample of employees of a national company distributed all over the country is feasible and quite affordable.
- Contacting selected employees by automatic systems (email + web pages connected with databases) is very convenient and more effective than by mail (although less than door-to-door).
- Actual representativeness respect to the general population (as regards radon in dwellings) can (and shall) be checked.
An affordable proxy of representative national survey on radon concentration in dwellings: Design, organisation and preliminary evaluation of representativeness

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HIGHLIGHTS
- In Italy a new national survey was designed and organised.
- A new approach for a proxy of a representative national survey was used.
- The aim is to estimate the frequency distribution of indoor radon concentration in all the 118 Italian Provinces.
- The realisation of this survey was feasible and affordable.
- Preliminary evaluation of sample representativeness was performed at national level.

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ABSTRACT
Representative national surveys in dwellings are important to unbiasedly evaluate the exposure of the general population to radon. In Italy, a national radon survey was conducted (1989 to 1991), which involved about 5000 dwellings in 230 towns (after six regions were selected because of detailed surveys, but a national survey in dwellings is necessary in order to obtain a more thorough estimate of radon concentration distribution over the entire country). The need to make this survey at an affordable way led to implement a new approach based on the collaboration between the Italian Supervision di Sicurezza PSR and a national company with workplaces and employees’ homes throughout the country. The intent is to carry out a proxy of a population representative survey by measuring radon concentration in the homes of a random sample of the company employees. The realisation of this survey was affordable, thanks to the availability of corporate e-mail for each employee, internal services and company internal mail survey. A dedicated web procedure and questionnaire allowed to automatically manage the contract with employees and to collect their data, which were then sent and processed. Using this novel contact approach, 3/4 of interested employees consented to participate in the survey. Radon concentration passive measuring devices were distributed in about 7800 dwellings, using about 14000 CR230 detectors (two measured reams per dwelling). In order to reduce costs, the detectors were exposed for 12 months instead of two consecutive 6-month periods (as with the former national survey). A first checking of the actual representativeness of the sample was done by comparing characteristics of dwellings and occupants in the sample with corresponding data from the Italian National Census. This was accomplished thanks to the fact that the questionnaire in the survey questionnaire were tailored to the categories adopted for the Census questionnaire. A preliminary comparison showed that, at national level, the Italian dwellings are quite well represented by the sample.© 2012 Elsevier Ltd. All rights reserved.
SETTING NATIONAL REFERENCE VALUE
The concept of the Action Level (AL) was used in many countries prior to the Reference Level concept (introduced with the publication of the 2007 recommendations of ICRP).

With AL, remediation work (corrective actions) was considered only at radon concentrations above the AL.

Since that gave the inaccurate impression that radon levels below the AL were safe, the term Reference Level now is used to represent a level above which corrective actions are always recommended.

Reference Level is related with optimization: optimization (and therefore corrective actions) can be done also below RL.

In the US, however, the term “Action Level” is still in use and EPA has set an Action Level of 4 pCi/L. At or above this level of radon, the EPA recommends that action be taken to reduce exposure to radon gas.
Prior the reference levels

TARGET LEVEL: This is a radon concentration that national authorities should strive to achieve in particular in future houses. A number of European countries have set 100 Bq/m$^3$ as their Target Level while at the same time they may have a Reference Level in the range 200 to 300 Bq/m$^3$.

In 2004 the Radon Act 51 was passed by the U.S. Congress. It set 0.4 pCi/L (or approx 15 Bq/m$^3$) based on outdoor levels as the Target Level for indoor radon. Unfortunately two thirds of US dwellings are estimated to be above this target level.

DESIGN LEVEL: The recommendation 90/143/EUROATOM from 1990 emphasize that indoor radon is controllable in the physical and engineering sense thus the preventive measures are required for future constructions. The design level is as the aid to relevant authorities in establishing regulations and codes of construction practices.
Introduction to the concept of reference levels

1.24. (International BSS)

- Reference levels are used for optimization of protection and safety in emergency exposure situations and in existing exposure situations. They are established or approved by the government, the regulatory body or another relevant authority.

- For occupational exposure and public exposure in emergency exposure situations and in existing exposure situations, a reference level serves as a boundary condition in defining the range of options for the purposes of optimization in implementing protective actions.

- The reference level represents the level of dose or the level of risk above which it is judged to be inappropriate to plan to allow exposures to occur, and below which the optimization of protection and safety is implemented.
1.24. (International BSS) cont.

- The value chosen for the reference level will depend upon the prevailing circumstances for the exposures under consideration.
- The optimized protection strategies are intended to keep doses below the reference level.
- When an emergency exposure situation has arisen or an existing exposure situation has been identified, actual exposures could be above or below the reference level. The reference level would be used as a benchmark for judging whether further protective measures are necessary and, if so, in prioritizing their application.
- Optimization is to be applied in emergency exposure situations and in existing exposure situations, even if the doses initially received are below the reference level.
1.29. (International BSS)

The system of protection and safety required by these Standards includes criteria for protection against exposure due to radon which are based on the average level of risk to a population with typical but various smoking habits.

Because of the synergistic effects of smoking and exposure due to radon, the absolute risk of lung cancer resulting from unit dose due to radon for people who are smokers is substantially greater than for those who have never smoked.

Information provided to people on the risks associated with exposure due to radon needs to highlight this increased risk for smokers.

Reference levels should not be seen as a dividing line between safety and harm. Rather they should be used as guidance values for adopting corrective actions to lower exposure due to $^{222}\text{Rn}$. 

IAEA
What are the recommendations?

• Following an assessment of public exposure to radon based on appropriate surveys the national authority should choose and adopt a Reference Level for radon in dwellings.

• Taking into account prevailing social and economic factors the chosen Reference Level should, in general, not exceed an annual average value of 300 Bq/m$^3$.

• In its Handbook on Indoor Radon, the WHO proposes a reference level of 100 Bq/m$^3$ to minimize health hazards due to $^{222}$Rn exposure indoors, stating that “if this level cannot be reached under the prevailing country specific conditions, the chosen reference level should not exceed 300 Bq/m$^3$.”
What are the recommendations?

• An activity concentration of 300 Bq/m$^3$ is taken to correspond to an annual effective dose of 10 mSv (based on epidemiological studies at the beginning of 90ties; estimates based on current results are higher) on the assumption of an equilibrium factor of 0.4 and an occupancy of 7000 hours/year. But based on last updates from ICRP (based on dosimetric models), it is expected that the actual effective dose is near 20 mSv.

• When setting a reference level, the national authority should consult interested parties. Reference levels should be selected such that the resulting activities are seen to be practicable and manageable - it would be impractical to set a low reference level such that corrective actions would be necessary for the majority of existing dwellings (unless... feasibility, cost, effectiveness, cost/effectiveness).
Selection of the value

1.28. (International BSS)
The selection of the value for the dose constraint or the reference level would be based on the characteristics of the exposure situation, including:

i. The nature of the exposure and the practicability of reducing or preventing the exposure;

ii. The expected benefits of the exposure for individuals and society, or the benefits of avoiding preventive actions or protective actions that would be detrimental to living conditions, as well as other societal criteria relating to the management of the exposure situation;

iii. National or regional factors, together with a consideration of international guidance and good practice elsewhere.
New buildings - reference levels
What is achievable and reasonable?

Building industry is not prepared

Technologies able to achieve indoor radon ~ 10 Bq/m$^3$ exist (e.g. wood house on pillars)

However: modern house Radon < ?? Bq/m$^3$
How to set reference level for new buildings?

Radon from soil still remains the most important source of radon indoors.

Achievable indoor radon concentration ?? Bq/m³

Ventilation rate 0.05-0.8 h⁻¹

Outdoor air 5-10 Bq/m³, specific cases up to 100? Bq/m³

<table>
<thead>
<tr>
<th>Material</th>
<th>Ra-226 (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>40</td>
</tr>
<tr>
<td>Aerated concrete</td>
<td>60</td>
</tr>
<tr>
<td>Clay (red) bricks</td>
<td>50</td>
</tr>
<tr>
<td>Sand-lime bricks</td>
<td>10</td>
</tr>
<tr>
<td>Natural building stones</td>
<td>60</td>
</tr>
<tr>
<td>Natural gypsum</td>
<td>10</td>
</tr>
<tr>
<td>wood</td>
<td>1</td>
</tr>
</tbody>
</table>

Radon concentration 1 kBq – 1 MBq/m³

Transport through cracks in concrete slab, leakages around piping.
How to set reference level for new buildings?

- Reference levels should be selected such that the resulting activities are seen to be practicable and manageable - it would be impractical to set a low reference level such that corrective actions would be necessary for the majority of existing dwellings.
- It is easier to set the higher the reference level on the upper part of the recommended range for the 1st part of the action plan and then to decrease the level in next stage (decade) that to increase the reference level because it is found that this is not manageable.
- It is advisable to set 2 reference levels for NEW and EXISTING buildings in the 1st stage of action plan; in the 2nd stage these levels could be merged into one.
- Existing buildings - buildings built before the legal requirements on protection of the building against radon are/were set.
- New buildings – buildings built after the requirements on radon went into force
# Existing reference levels in some countries

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>REFERENCE LEVEL EXISTING DWELLINGS Bq/m³</th>
<th>REFERENCE LEVEL NEW DWELLINGS Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>BELGIUM</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>FRANCE</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>DENMARK</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>AUSTRIA</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>FINLAND</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>CZECH REP.</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>IRELAND</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>NORWAY</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>UK</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>CANADA</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>USA</td>
<td>148</td>
<td>148</td>
</tr>
</tbody>
</table>
A UK cost-benefit analysis estimated that doubling radon measurement acceptance and remediation rates would increase radon lung cancer deaths averted by a factor of 5. On the other hand, reducing the national Reference Level of 200 Bq/m$^3$ to 100 Bq/m$^3$ would only increase this by a factor of 2.

This analysis suggests that countries with well established radon programmes and Reference Levels in the 100-300 Bq/m$^3$ range should improve their acceptance and remediation rates by giving better advice and support to homeowners and tenants.

1.4 – **Ref. Lev. for existing and new dwellings and other buildings (6)**

- Ref. Levels for new buildings should be lower than those for existing ones, thanks to compulsory preventive measure
- New buildings should be considered those constructed after introduction of compulsory preventive measures

1.5 - **Surveys and radon concentration distribution (6)**

- Surveys should be generally designed to be representative
- Check of representativeness should be done on the final sample
- Radon distribution and maps should be based on representative data only
1.6 - National Radon Database (NRD) (6)

- A NRD (or archive) is an important tool to support the National Action Plan, aiming to evaluate/verify effectiveness of actions and the overall reduction of risk.
- It should collect all relevant information (on measurements, preventive measures, remedial actions, etc.)
Assessment of risk to the population

- The proven health effect of long-term exposure to radon concentrations is lung cancer (epidemiological studies on miners and residents).
- Dose-response relationship appears to be linear with no threshold.
- There is evidence of risk increase even below 200 Bq/m³.
- The risk of lung cancer
  - Is the highest for smoker exposed to high radon
  - Is the lowest for lifelong non-smoker
- The number of lung cancers caused by radon ($N_{\text{lung Rn}}$) can be calculated knowing total lung cancer rate in a country ($N_{\text{lung}}$) and the average radon concentration in the country ($C_{\text{Rn}}$)

\[
N_{\text{lung Rn}} = \beta N_{\text{lung}} C_{\text{Rn}}
\]

where $\beta$ is the increase of risk per 1 Bq/m³

(according to Darby et al, 2005, excess relative risk is 16% per 100 Bq/m³)
Assessment of risk to the population

- The results of such calculations may be then used:
  - in risk communication
  - evaluation of action plan

Source: EPA, USA
1) The majority of radon related lung cancer deaths occur in active smokers.

2) The majority of these deaths will occur to persons exposed to indoor radon levels well below the commonly used indoor radon Reference Level of 200 Bq/m³ (due to the high number of people in this group).

3) In estimating the lung cancer burden in a country, good data is needed not only on the indoor radon distribution but also on smoking prevalence.
Radon and smoking

Cumulative absolute risk of death from lung cancer to age 75 years*

Risk of Lung Cancer relative to that for Life-long non-smokers*

RADON – ANOTHER REASON TO QUIET

Lung Cancer Risk

Smokers + high radon = 1 in 3

High radon only = 1 in 20

Almost 90% of lung cancer deaths are caused by smoking. Radon exposure is linked to approximately 16% of lung cancer deaths in Canada and is the leading cause of lung cancer for non-smokers.

Radon is a gas that is produced naturally from the breakdown of uranium in the ground and can enter your home undetected. You can’t see it, smell it, or taste it.

Some level of radon can be found in most homes. High levels of radon increases your risk of developing lung cancer.

The risk from radon exposure is long term and depends on 3 things:

1. the level of radon,
2. how long you are exposed, and
3. your smoking habits.
Some documents and reports (1)
WHO Handbook on Indoor Radon

WHO, 2009

Structure

Introduction
1. Health Effects of Radon
2. Radon Measurements
3. Prevention and Mitigation
4. Cost-Effectiveness
5. Radon Risk Communication
6. National Radon Programmes

5 key messages for each chapter

The booklet can be freely downloaded from the WHO website
Some documents and reports (2)
The RADPAR Recommendations

• A number of documents were produced within RADPAR, some of which can be downloaded from


• A major document is a booklet of detailed (and quite comprehensive) recommendations:

The RADPAR Recommendations
(2012)
Some documents and reports (2)
The RADPAR Recommendations

1. Recommendations on radon policy and strategy
2. Recommendations on protocols for indoor radon concentration measurements
3. Recommendations to improve radon risk communication
4. Assessment of potential conflicts between energy conservation in buildings and radon exposure reduction
5. Establishment of measurement protocols for radon control technologies
6. Design of training courses for radon measurement, prevention, remediation
7. Recommendations on analysis of cost effectiveness and health benefits of radon control strategies
Some documents and reports (2)
The RADPAR Project

- The RADPAR (Radon Prevention and Remediation) was an European project funded by the Executive Agency for Health and Consumers (EAHC) of the EU Directorate General SANCO, and carried out in 2009–2012, in the framework of the Health Programme 2008–2013.

- 11 associated partner institutions from 10 European countries (Greece, Germany, UK, France, Italy, Austria, Norway, Finland, Belgium, Czech Rep.)

- 7 collaborating partners from 6 countries (Switzerland, UK, Finland, Spain, Portugal, Ireland) and 1 Int. Organization (WHO)
National and Regional Surveys of Radon Concentration in Dwellings was published in Dec. 2013 in the series *IAEA Analytical Quality in Nuclear Applications, No.33* (IAEA/AQ/33).

It can be freely downloaded from the IAEA website: