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RADPAR

FINAL SCIENTIFIC REPORT

Radon Prevention and Remediation

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Table of Contents

FOREWORD

The RADPAR Project is a joint European effort to expand knowledge on the human response to radon, and on this basis create principles for reliable information and recommendations on radon prevention and remediation. The Project's consortium, which includes 12 associated partners from 10 EU countries, ensures wide geographical coverage and reflectance of different EU situations and building practices.

Exposure to radon contributes significantly to the incidence of lung cancer in EU Member States. Based on European case-control epidemiological studies it has been estimated that radon causes circa 20000 lung cancers per year in the EU. Exposure to radon is therefore clearly of public health concern. The RADPAR project is important in this context as its main objective is to help national authorities improve and develop national radon control policies and strategies.

Considerable variability in the effectiveness of building protection techniques is observed. Bad installation and poor adherence to the relevant building code guidelines are the major contributors to this problem in some MS. This could be due to the poor knowledge of the professionals involved and the inappropriate or of poor efficiency materials used. Also, in recent years, the rising ecological awareness and the rising energy costs have stimulated the development of the so-called low energy and passive houses. In this context, it is important to assess the compatibility of such design with the radon protection. Radon remediation and prevention require the commitment of scarce resources, in order to obtain health benefits measured in terms of lung cancer. It is therefore appropriate to assess the cost-effectiveness of existing and potential radon prevention and remediation strategies in the EU.

The key findings of the Project are:

- The assessment of the health burden from radon for all the EU MS.
- The identification, on the basis of experience gained in several EU countries and of information collected through questionnaires from 26 European countries, of key points on the prevention and remediation policies on radon and the development of corresponding recommendations to improve such policies.
- In some MS coherent national radon control policies were well developed and long established while in others they were either non-existent or at a very embryonic stage.
- In many MS radon control policies were not very effective. The biggest problems facing the authorities were (1) to encourage the public to test their homes for radon and (2) to remediate their homes if the radon level was found to exceed the national radon reference level which in the EU MS is typically in the range 100 to 300 Bq/m^3. For future dwellings in the EU the situation was more promising.
- Because of the strong synergism between cigarette smoking and radon exposure it seems sensible from a public health perspective to link radon control policies to smoking cessation policies in the EU. A key finding in this regard by the RADPAR project was that such a linkage was almost non-existent in most MS and where it did exist it was very weak.
- Exhaustive state of the art on building protections against radon and their impact on the energy consumption.
- State of the art of new building characteristics and systems associated with an analysis on their impact on indoor radon exposure.

- Definition of the protocol for the characterisation of materials used on building protection (membranes, sealants).
- Definition of the frame of courses for professionals training.
- The development of a spreadsheet-based model with sufficient flexibility to permit different MS to evaluate the cost effectiveness of a range of possible radon prevention and remediation strategies.
- Design of a training course to encourage the use of the spreadsheet model. The results indicated that basic radon prevention measures in new homes are usually cost-effective unless average radon levels are low. Remediation of existing homes requires careful design and targeting.
- The RADPAR Recommendations, which are an outcome of the RADPAR Deliverables and all the work done in the framework of the RADPAR Project.

The results of the Project are intended and expected to be used to tailor future communications on radon risk to the public and decision makers. Also they are expected to help pave the way towards a scientifically based development of a harmonized radon policy and legislation in European countries. An important aspect of RADPAR is the transfer of its results and recommendations to new and accession Member States, where strategies to reduce radon exposures are presently almost nonexistent.

The results should be of value to those responsible for radon control, to public health departments, to building professionals and to householders. If all or some of the RADPAR recommendations are adopted by the relevant EU authorities the ultimate beneficiary would be the general population resulting from a reduction in the incidence of lung cancer of the general population.

The main targets of the RADPAR project were decisions makers in national authorities and to a lesser extent the general public. In the case of national authorities RADPAR has encouraged them to critically examine its recommendations in the context of their national situation and where appropriate to adopt them. The project has demonstrated that in future they should design radon prevention and remediation policies taking account of their cost-effectiveness. The works undertaken could be used for the amelioration of professional practices (installation of building protection, compatibility with energy efficient building, better characterisation of products, and training of professionals).

Some of the recommended actions have been already carried out in some EU countries. Moreover, several EU countries have just started to deal with radon problems and therefore will largely benefit from the whole set of the RADPAR outcomes and recommendations.

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Keywords
Radon, Air Pollutants, Radioactive, Carcinogens, Environmental Prevention & control, Environmental Remediation, Cost-Benefit Analysis

1. EXECUTIVE SUMMARY

The RADPAR (Radon Prevention and Remediation) project (2009-2012) is part of the Second Programme of the European Community Action in the Field of Health and within the aegis of the Executive Agency for Health and Consumers (EAHC), of Directorate General SANCO. It commenced in May 2009 and is coordinated by the University of Western Macedonia, Kozani, Greece. Its partners are from health, radiation protection and related institutions, in 15 European countries as well as the World Health Organization.

Objectives

Its main objectives were the following:
(a) The accurate assessment of the health burden to the general population from exposure to radon;
(b) The improvement of radon prevention and remediation strategies that are currently in place;
(c) The development of radon risk communication strategies and approaches for different population target groups in the EU;
(d) The standardization of measurement procedures for radon sources and control technologies;
(e) The assessment of the cost-effectiveness of existing and potential radon prevention and remediation strategies in the EU;
(f) The improvement of the effectiveness of radon control strategies through the design and use of training courses for radon measurement, prevention, remediation and cost-effectiveness analysis;
(g) The assessment of the potential conflicts between energy conservation in buildings, and reduction in radon exposure

Improving policies and strategies to promote effective radon prevention and remediation

The health burden from radon was estimated – in terms of attributable risk, i.e. the fraction and the number of lung cancers attributable to radon exposure – for all the 27 EU Member States. The combined effect of radon and smoking was evaluated by calculating attributable fraction and number of lung cancers separately for: i) current smokers, ii) former smokers, and iii) never smokers.
Data on radon policies and strategy were collected through questionnaires (both the RADPAR Master Questionnaire and three specific WP4 questionnaires); moreover, all recent (including drafts) recommendations, regulations and other reports of international organizations (WHO, IAEA, ICRP, European Commission, Nordic Countries) were considered. This information was reviewed and discussed both in general and specific meetings, in order to prepare the RADPAR recommendations, which are the results of the collaboration of all associated and collaborating partners.
The attributable fraction ranges from 3% to 16% of all the lung cancers. Most of the lung cancers attributable to radon are expected to occur among current and former smokers, due to the combined effects of radon and smoking. This has to be taken into account by

coordinating policies against radon and those against smoking. A total of specific 66 recommendations on radon policies and strategy were prepared, covering 33 issues grouped in 11 arguments. These recommendations take into account the previous experience and evaluation of effectiveness and should be useful for all European countries, to an extent that depends on the current level of radon policy development.

Radon Risk Communication

The development of radon risk communication strategies and approaches for different population target groups in the EU essentially consisted of three main components which were:

1. The compilation and analysis of the existing activities of the relevant national MS authorities in radon risk communication. The acquisition of information on existing activities was by means of a Master Questionnaire which was developed jointly within the RADPAR Project.
2. The design, execution and analysis of public radon risk awareness studies in a number of partner countries (Belgium, Czech Republic, Germany, Greece, Norway and Switzerland).

Based on the outcomes of the above mentioned activities, the development of recommendations aimed at improving the effectiveness of radon risk communication strategies throughout the EU.

Assessment of radon control technologies

The assessment of radon control technologies has three objectives in order to contribute to the evaluation of radon control in buildings, to reduce potential conflicts between energy saving construction and radon reduction, and to form building professionals. To reach these objectives, the work undertaken was to elaborate a specific questionnaire, which was sent to the RADPAR partners and to other European countries in order to state on the current practices used. Literature review on each topic was also realized associated with some specific studies. All this material was analyzed and at the end, recommendations on each topic were proposed. An analysis of current practices on professional courses in European countries involved in the RADPAR program was realized. On the basis of this material, frames of courses for professionals were defined, which could be developed and applied depending on addressed target groups and development of radon management practices in the country.

Potential conflicts between energy conservation and radon control were analysed. Based on different studies undertaken, the main conclusions for new buildings are the following:

- The extremely tight building shell of passive houses is also a good radon protection
- Mechanically controlled ventilation of dwellings plus tight building shell lead generally to very low radon levels
- Mechanically controlled ventilation with an air-soil heat exchanger may draw radon-laden soil gas directly into the dwelling if pipes in the soil are not tight
- Later modifications of the building shell at the foundation by the occupants (e.g. bore holes) can deteriorate the radon situation of a dwelling significantly.

The analysis of the requirements for standard measurement protocols to characterize various building products used to control indoor radon such as membranes, sealing materials, sumps etc was also realised. A protocol for the determination of the radon diffusion coefficient for membranes and sealants was proposed. This last protocol has been proposed to be an international standard and is now currently submitted at ISO level (ISO/WD 11665-10 standard).

Analysis of cost effectiveness and health benefits of radon control strategies

There is a need to evaluate radon control policies using the evaluative techniques that are increasingly used to assess other health interventions. For the assessment of the cost-effectiveness of existing and potential radon prevention and remediation strategies in the EU, a cost-effectiveness tool was developed. A number of participating EU countries was familiarized in the use of the tool, and applied it in five countries using a set of agreed principles and parameter inputs to evaluate a standard prevention intervention and a standard remediation programme.

The results suggest that basic radon prevention measures, such as installing membranes in all new buildings, are likely to be cost-effective even in settings where the average radon level is quite low.

Concerning remediation of existing buildings, the results were less clear-cut, and indicated that cost-effectiveness is highly dependent on the radon level in target areas: such policies need to be carefully targeted. Cost-effectiveness is also strongly influenced by the characteristics of the inhabitants of homes, and is much better for smokers, due to their much higher risk of lung cancer.

The analyses of remediation policies also showed large variations in such things as home measurement invitation acceptance rates, remediation rates in homes found to be over the action level, and the effectiveness and costs of remedial actions. These variations suggest that there are likely to be considerable gains from a better understanding of why they vary so much internationally.

International comparisons of cost-effectiveness of this type are not common and can be complex to set up, undertake and interpret. In future it would be possible to undertake more detailed analyses, such as the cost-effectiveness of installing more complex preventive measures during construction, the cost-effectiveness testing new homes after they have been occupied and undertaking further remedial work where necessary, and the cost-effectiveness of policies to increase home measurement invitation acceptance rates and remediation rates.

Conclusions and Recommendations

Radon Prevention and Remediation is quite limited in the European scale. In some MS coherent national radon control policies were well developed and long established while in others they were either non-existent or at a very embryonic stage. It is clear that only a joint European effort can provide the necessary experience and diversity of circumstances to provide an insight into the complex radon problem and in how to deal effectively with it.

Based on the present work a series of Recommendations have been produced covering areas such as Radon Policy and Strategy, Indoor Radon Concentration Measurements, Radon Risk Communication, Assessment of radon control technologies, Assessment of potential conflicts between energy conservation in buildings and radon exposure reduction, Establishment of measurement protocols for radon control technologies, Design of training courses for radon measurement, prevention and remediation and Analysis of cost effectiveness and health benefits of radon control strategies

These recommendations were included in the overall RADPAR Recommendations document [1].

By means of its deliverables and Recommendations it is expected that the RADPAR project will:

- heighten awareness both of the public and of decision makers of the health burden of radon in the EU and of the technical means available to control radon.
- transfer information to new and accession MS where radon control strategies are presently almost non-existent.

2. TECHNICAL ASPECTS OF THE PROJECT

2.1. Background and project scope

Previous studies have shown the great complexity of the radon problem. Their findings suggest the need for new and greater efforts to understand the subject. It is clear that only a joint European effort can provide the necessary experience and diversity of circumstances to provide an insight into this complex problem and in dealing with it. This project, covering almost all regions of the EU, strived to review the national strategies in dealing with radon, and on this basis create principles for reliable information exemplified in the RADPAR Information web site, which is linked to the main DG SANCO web site dealing with IAQ. The results of the project are expected to be used to tailor future information about radon to the public, maximizing its effect in motivating decision makers for protection against radon, thus promoting a better quality of life. These results are expected to help pave the way towards the scientifically based development of harmonized radon policies and relevant legislation in European countries. An important aspect of this project will be the transfer of this experience to new and accession MS, where such strategies are presently almost nonexistent.

2.2. Main activities carried out including methods and means.

The general objective of this project was to assist in reducing the significant public health burden of radon related lung cancers in EU Member States (MS). The effectiveness of the various existing radon prevention and remediation strategies in the MS was assessed with the objective of improving them. The assessment of potential conflicts between EU energy conservation objectives in buildings and radon control technologies was an important objective of this project.

Existing radon control strategies in EU Member States were reviewed. A model of sufficient flexibility to permit different Member States to evaluate the cost-effectiveness of a range of possible radon prevention and remediation strategies was developed in the project. Radon risk communication strategies targeted at policy/decision makers, the general public and high risk groups such as people in high-radon areas, smokers and former smokers was developed.

By means of its deliverables it is expected that this project will heighten awareness both of the public and of decision makers of the health burden of radon in the EU and of the technical means available to control radon. An important aspect of this project is the transfer of this information to new and accession Member States where radon control strategies are presently almost non-existent.

Previous studies on the response to dealing with the radon problem have shown the great complexity of the issue. Their findings suggested the need for a new and bigger effort to understand this subject. It is clear that only a joint European effort can provide the necessary experience and diversity of circumstances to provide an insight into this complex problem and in how to deal effectively with it.

The Project target groups

The Project target groups are policy/decision makers, radiation protection agencies, housing construction companies, radon remediation companies, environmental protection

NGOs, the general public and high risk groups such as people in high-radon areas, smokers and former smokers.

2.3. Results and key findings

For each of the 27 EU Member States, an assessment of the health burden due to radon exposure was performed using the same methodology for all such countries. This will provide all EU Member States with an evaluation of the extent of the radon problem as regards its health effects, which will be useful to evaluate national policies in order to reduce such heath burden. Moreover, considering that most of the lung cancers attributable to radon have been evaluated to occur among current and former smokers (due to the combined effects of radon and smoking), coordinating policies against radon and those against cigarette smoking are recommended.

A whole set of coordinated 66 recommendations on radon policies and strategy was developed within the RADPAR project in order to improve effectiveness of such policies in EU countries. These recommendations were prepared taking into account previous actions and information on their effectiveness (collected through questionnaire sent to relevant authorities and experts) in all EU Member States. Therefore, these recommendations should be useful for the improvement of radon policies in all European countries.

Detailed questionnaires were sent to national authorities (radiation protection or public health) in all EU Member States (MS) to determine the state of their existing radon control activities. Based on the responses obtained it was found that in some MS coherent national radon control policies were well developed and long established while in others they were either non-existent or at a very embryonic stage. Another key finding was, judged from the perspective of achieving significant reductions of existing public exposure to radon, that in many MS radon control policies were not very effective. The biggest problems facing the authorities were (1) to encourage the public to test their homes for radon and (2) to remediate their homes if the radon level was found to exceed the national radon reference level which in the EU MS is typically in the range 100 to 300 Bq/m^3. For future dwellings in the EU the situation was more promising. A number of MS have introduced building codes aimed at preventing radon entry and thereby reducing the exposure of future occupants. Providing these codes are properly implemented in the construction of new dwellings by the EU building industry this should result over coming decades in a significant reduction in the public health burden from radon. European case-control residential epidemiological studies have clearly shown that there is a linear increase (circa 16% per 100 Bq/m^3 increase in radon concentration) in the relative risk of lung cancer for cigarette smokers when they are exposed to radon. Because of this strong synergism between cigarette smoking and radon exposure it seems sensible from a public health perspective to link radon control policies to smoking cessation policies in the EU. A key finding in this regard by the RADPAR project was that such a linkage was almost non-existent in most MS and where it did exist it was very weak.

Exhaustive state of the art on building protections against radon and their impact on energy consumption was developed. State of the art of new building characteristics and systems associated with an analysis on their impact on indoor radon exposure was also conducted. These works enable the MS that are not aware of these methods to develop the appropriate knowledge for their country.

Definition of protocols for the characterization of materials used on building protection (membranes, sealants) were defined and submitted at ISO level. These rules enable the

characterization of relevant products used in building protection within a common protocol.
Definition of frames of courses for professionals training was carried out. This enables the MS to develop their own courses adapted to their level of advancement in building protection management.
The cost-effectiveness model was successfully adapted for use in the project and was used in 5 countries. A training course was developed and run. A user manual was developed for the model.
The results have already helped influence policy in the UK and Ireland.

2.4. Coordination with other projects or activities at European, National and International level

During the project period fruitful collaboration was established with the Radiation Protection Section of the International Atomic Energy Agency (IAEA). It is to be noted that all EU Member States are also members of IAEA. The collaboration with IAEA has already resulted in scientists from the RADPAR project (from Czech Republic, Ireland and Switzerland) participating in IAEA Technical Cooperation missions on the establishment of radon control strategies in a number of countries including EU Member State Bulgaria. IAEA has also indicated that it will consider the RADPAR consortium to be a pool of technical expertise in the radon field which it will approach for assistance in its future radon related missions.
At international level, the RADPAR project was carried out with the participation of WHO, as collaborative partner. Moreover, a further coordination (and support) of EC, WHO and IAEA would be important to develop specific guidelines and protocols to implement in the EU countries the set of RADPAR recommendations.

2.5. Strategic relevance, contribution to the Health Programme, EU added value and level of innovation.

- A unified method for the determination of the radon diffusion coefficient of barrier materials was prepared in the framework of RADPAR activities. This method was currently submitted at ISO level for standardisation (ISO/WD 11665-10 standard);

- The RADPAR expertise covers many aspects related to the radon issue. This allowed it to prepare a quite comprehensive list of recommendations after a critical review of the state-of-art of the existing radon policies in EU. These recommendations would be quite useful in developing more effective and national radon policies, as will be required by the forthcoming new Directive of Basic Safety Standards for protection against the dangers arising from exposure to ionizing radiation, expected by 2013. Moreover, the collaboration with international organization such as WHO, IAEA and ICRP (which participated in the RADPAR project or were informed about its activities and results) allowed it to take into account the indications from such organizations and to share with them the RADPAR methods and results. It will be very useful to continue such collaboration in the next years, as already proposed elsewhere in this report.

2.6. Dissemination

Dissemination was a horizontal activity and concentrated on disseminating the results of RADPAR project itself to a wide range of existing or potential stakeholders. Carefully designed Newsletters were distributed through the website to the Newsletter mailing list in order to keep our audience informed of the progress of the Project and continue to stimulate their interest. 213 newsletter users have joined this mailing list. Special attention was paid to the RADPAR website which is the main communication channel of the Project. The website allows easy access to information about the project and is continuously updated. The RADPAR website was publicised via the Newsletters, the flyers and via emails sent to potential stakeholders, introducing them to the Project and its objectives. Many of these stakeholders showed great interest in RADPAR and that was ascertained by their joining the Newsletter mailing list and also by their wide participation at the RADPAR Workshop. At the Workshop there were 65 participants from 16 countries and invited speakers from Japan, Germany, Luxembourg, Switzerland, Austria, Belgium, France and the IAEA. The participants were from National Radiation Protection Agencies, the Academic Community, Radon and Building Companies, National Authorities and the IAEA. During the workshop, presentations on the RADPAR Project were made by the members of the RADPAR Consortium, while after that, presentations were made by distinguished invited speakers.

The RADPAR consortium has also prepared a booklet of “The RADPAR Recommendations” in order to disseminate the Project results and raise radon awareness in Member States (both existing and new) and especially where radon exposure control policies are at a preliminary stage of development. Also the members of the RADPAR consortium participated in a number of conferences, forums and workshops where they presented their results, while they are encouraged to also publish their results submission to peer-reviewed journals.

Finally, the Project was widely disseminated via the Radon awareness Surveys conducted in Greece, Germany, Czech Republic, Belgium, Switzerland and Norway and via the project’s questionnaires that were sent to radiation agencies and researchers in all the EU and in some non-EU countries.

3. DESCRIPTION OF THE SCIENTIFIC WORK

3.1. Improving policies and strategies to promote effective radon prevention and remediation

The main objectives of this work were:

1. the development of improved strategies to reduce the health burden from radon to the EU population
2. recommendations for the improvement of existing standards, building codes and guidelines for the control of radon in new buildings in Member States

To achieve these objectives the following activities/tasks were carried out:

A. Assessment of the significance of the health burden from radon to the EU population
B. Critical review and analyses of existing radon control policies and strategies in EU Member States
C. Recommendations for the improvement of existing standards, building codes and guidelines for the control of radon in new buildings in Member States

A) Health burden from radon was produced for all the EU Member countries, including also an evaluation of the combined effect of radon and smoking and a comparison, for some countries, with previous evaluations (whenever available). In particular, the annual fraction and number of lung cancers attributable to radon exposure were calculated for all the 27 EU Member States (and other three European countries) on the basis of the following data:

   i) representative average radon concentration in dwellings, as evaluated by an ad-hoc review of papers and information collected through questionnaires;
   ii) excess relative risk from radon evaluated by the European pooling of 13 case-control studies on lung cancer and residential radon;
   iii) total lung cancer rate data taken from WHO database;
   iv) smoking habits data taken from Eurostat database.

   The attributable fraction ranges from 3% to 16% of all the lung cancers. Moreover, the combined effect of radon and smoking was evaluated by calculating attributable lung cancer rate separately for current smokers, former smokers, and never smokers. Most of the lung cancers attributable to radon were evaluated to occur among current and former smokers, due to the combined effects of radon and smoking. This should be taken into account by coordinating policies against radon and those against smoking.

B) Information on existing radon control policies and strategies were collected through:

   - the RADPAR Master Questionnaire (Section B);

- detailed questionnaires prepared and subdivided in three parts: Part A on radon measurement strategy, Part B on radon measurement protocols, and Part C on radon policy.

On the basis of the review and analysis of the above mentioned questionnaires, recommendations on how to improve policies and strategies which could promote an effective radon prevention and remediation were prepared.

C) Recommendations for the improvement of existing standards, building codes and guidelines for the control of radon in new buildings in Member States' were prepared, on the basis of recommendations and regulations of international bodies related to the topic, and on indications arising from RADPAR questionnaires.

3.1.1. Task Reports

Details for the scientific work performed under this specific objective are given in the following reports.

1) *Database of existing radon control policies and strategy in EU Member States and other countries [2]*.

This deliverable contains data and information collected by questionnaires within the RADPAR project, in particular on: National policies on indoor radon control (Master Questionnaire Section B, with answers from 29 countries); Strategy of radon concentration measurements, Protocols for radon concentration measurements, Radon policy/strategy (WP4 Questionnaire Part A, Part B, Part C, with answers from 23 countries). The deliverable contains both the text of the questionnaires and all the answers to each question were fully reported in tables.

2) *Review and analysis of existing policies and strategies on indoor radon control in EU Member States and other countries [3]*.

Data included in the above database were analyzed and reviewed in this deliverable, with separate analysis for the answers to each of the four questionnaires (Master Questionnaire Section B, WP4 Questionnaire Part A, Part B, Part C). The answers to each question were reviewed and some general comments were also included.

3) *Recommendations for the improvement of existing standards, building codes and guidelines for the control of radon in new buildings in Member States [4]*.

This deliverable contains a deep analysis and discussion of some specific issues related to new buildings, with some corresponding recommendation, based on the data collected through the RADPAR questionnaires and on the analysis of evolution of international regulations.

4) *Health burden from radon for EU Member States and some other European countries (including combined effects of radon and smoking and comparison with other studies) and relevant databases [5]*.

In this document, the number of lung cancer deaths attributable to radon exposure was evaluated and reported for all the 27 EU countries and for other three European countries, with an attributable fraction ranging from 3% to 16%. These evaluations were based on a ad hoc comprehensive review of the radon surveys carried out in dwellings and of their representativeness, and on the available data on lung cancer death rate and radon smoking prevalence for each country. The impact of the multiplicative interaction of radon and cigarette smoking was therefore evaluated through separate estimations of the lung cancer deaths attributable to radon and occurring among current smokers, former smokers and never smokers. All these evaluations were carried out separately for males and females due to the different smoking habits and the different lung cancer death rates.

5) *Comparison of the radon measurement protocols with measurement protocols presently in use in MS for other air pollutants in order to improve the indoor air quality [6].*

The Radon Measurement Protocol is compared with the measurement protocols used for Volatile Organic Compounds (VOC), Formaldehyde (HCHO) and other carbonyls, NO_2, O_3 and CO_2. Some of these air pollutants can be measured both by active and passive sampling (the methods are based either on integral sampling or continuous sampling with data logging. Either short-term or long-term measurements are used, which are accompanied by the respective protocol for each sampling method.
A measurement protocol of an air pollutant is usually used when we want to evaluate the indoor air quality of a building which can be a home, a school, a workplace etc. The significant exposure to air pollutants for most people occurs in indoor environments and this can have an important influence on their health and well-being and affect productivity at school and work. While the measurements of VOC, HCHO and other carbonyls, NO_2, O_3 and CO_2 prevail in air quality assessment in the workplaces, radon became probably the first indoor air pollutant, measured on a large scale in homes**.**
Good knowledge of the variation of pollutant concentrations in buildings is essential for the choice of the right length of measurement time, the number of measurements and period of the year. The short and long term changes of external meteorological factors (temperature, wind, pressure), indoor factors (temperature, ventilation etc), indoor-outdoor pressure gradient etc. play important roles in the variation of pollutants indoors. However, not all important factors are known up to now (and even not all factors could be incorporated in a protocol). As an example: due to the well known fact, that the radon concentration varies not only diurnally but significantly within a year, long term integral measurements of radon concentration are preferred, even up to 1 year measurements are not uncommon (this differs significantly from the measurement methods and protocols for most of other pollutants). For the other pollutants there are short-term measurements varying from a few minutes to hours and long term measurements varying from a few hours to several days.
The protocols were compared with respect to the time length of the measurement, the number of measurements needed, the preferred period of the year for a measurement, the number, the type and the level of monitored rooms, the recommended positions of the detectors, the conditions during a measurement, the simultaneous checking of the ventilation system, the type of the detector/device, the use of any correction factor, the detection limits, the interferences and the main QA/QC requirements. While the radon measurement protocol differs significantly from the other protocols regarding the duration of the measurement, the number and the level of the monitored rooms, the detectors, the interferences and the detection limits, they are similar regarding the positions of the detectors, the conditions during a measurement and the main QA/QC requirements.

3.1.2. Task Recommendations

The final result was a series of specific recommendations on radon policies and strategy, covering 33 issues grouped in 11 arguments: 1) objective of radon policy; 2) overall strategy; 3) national action plan; 4) preventive measures; 5) reference levels for existing and future dwellings and other buildings; 6) surveys and radon concentration distribution; 7) national radon database; 8) use of radon maps; 9) radon prone areas and radon-prone buildings; 10) type of regulations; 11) promoting tools to increase the number of remedial actions.

These recommendations are discussed below (see section 4.2) together with all the other recommendations [1].

3.2. EU Radon Risk Communication

The main objective of this work package was the development of appropriate radon risk communication strategies targeted at both policy/decision makers and at the general population in the EU. In order to achieve its objectives this work was divided into a number of tasks. The first phase of the work was to compile information on relevant existing radon communication activities (e.g. radon risk communication strategies, awareness surveys etc) from national radiation protection and public health agencies in EU Member States (MS). Requests for such information were sent to agencies in all MS. The main tool for obtaining the information was the Master Questionnaire (see Final Technical Report Annexes) developed by all RADPAR partners. The information obtained is summarized in the following table which contains data from both EU MS and from the partner countries of Norway and Switzerland.

TABLE I : Radon Awareness in Europe

Country	**National Survey Status**	**Mean Radon Bq/m^3**	**Risk Communication Campaigns**	**Linked to other Public Health Actions**	**Radon Awareness Surveys**	**Estimated Percent Aware of Radon and its Effects**
Austria	C,PW	102	Y,GP	N	P	0-25%
Belgium	C,GE+GL	52	Y,GP,D,PG	N	Y,NA,R,M	0-25%
Bulgaria	P	--	P for GP,D,PG	--	N	--
Czech Rep	C, GE	118	Y, GP,D,PG	N	Y,NA	50-75%
Denmark	C,GE,PW	77	Y,GP,PG,NA,R,M	N	N	------
Estonia	C,GE	102	Y,GP,D,M	N	Y,M	0-25%
Finland	C,PW	96	Y,GP,D,PG,NA,R,M	N	P	50-75%
France	C	90	Y,GP,D,PG,R	N	---	---
Germany	C,GE,GL, PW	50	Y,GP,D,PG,NA	N	IP	0-25%
Greece	IP,GE	80	Y,GP,PG,NA	N	Y,M	25-50 %
Hungary	IP,GE,GL	93	N	---	N	0-25%

Ireland	C, GE	89	Y, NA,R, GP,D	Y	Y, NA, R	75-100%
Lithuania	C,GL,PW	55	Y,GP,D,PG,NA,R,M	N	N	0-25%
Malta	P	---	N	---	N	---
Norway	C,GE,GL,PW	88	Y,GP,D,PG,NA	N	Y,NA	75-100%
Portugal	C,GE	62	IP,GP,R,M	N	N	0-25%
Spain	C,GE	82	Y,GP,D,PG,NA,R,M	N	P	0-25%
Switzerland	C,GE,GL,PW	75	Y,GP,D,PG,NA,R	N	Y,NA	25-50%
United Kingdom	C,R	21	Y,GP,D,PG,NA,M	Y	N	----

KEY TO TABLE

Y: Yes, N: No
C: Completed, P: Planned, IP: In Progress
GE: Geographical, GL: Geological, PW: Population Weighted
NA: National, R: Regional, M: Municipal
GP: General Public, D: Decision Makers, PG: Professional Groups

As will be noted in the above table it was clear that radon awareness surveys (RAS) had taken place in only a minority of EU MS. In this regard it is to be noted that one of the main objectives was to carry out RAS in a number of countries with well developed radon control strategies and also in a country whose policy on radon control was not yet well developed. In the case of the former countries RAS were carried out by RADPAR partners IBES (Belgium), SURO (Czech Republic), BfS (Germany), NRPA (Norway) and Switzerland (BAG) in their respective countries. Kozani which is a provincial city in central Greece was chosen as the location to carry out a RAS in a country that did not yet have a well developed national policy on radon control. Two RAS were carried out by RADPAR partner UOWM in Kozani during the period 2010-2011. Following the completion of this first RAS a survey of radon levels in local schools was carried out using passive alpha track detectors. This radon survey of schools was well publicised in local media. On its completion a second RAS was carried out in Kozani to determine if radon awareness had changed or improved in the local community. These findings and the results of all the RAS surveys carried out by RADPAR partners are presented and analysed in the RAS Report [7].

Informing the public of the risks from radon is important to raise awareness and to encourage them to take action against it (by measuring their homes and taking remedial action where necessary). The information gathered by RADPAR of the experience in a number of EU countries showed that following a radon risk communication campaign in an area only a small percentage of the public will decide to measure in their homes [8]. It has further been found that not more than a quarter of homes found to have a radon level above the national reference level will take remedial action to reduce it. It may be the case that if the limited resources available to communicate radon information were targeted at decision makers (such as national and local government officials and politicians) it may be more effective at reducing the public health risk due to radon than only targeting the public with such information. A simple example of this is to persuade decision makers to introduce new building codes to ensure improved radon proofing of new dwellings. If properly implemented such an approach should in the long term reduce the national mean indoor radon level and consequently the national health burden from radon. The information obtained by RADPAR from EU MS suggests that studies to compare the relative public health effectiveness of targeting decision makers with radon risk information compared to only targeting the public need to take place. This would form an important input to the national radon strategy planning.

3.2.1. Task Recommendations

Following on the analysis of the information received from MS on their existing radon risk communication strategies twelve recommendations were developed aimed at the improvement of these strategies in the EU.

These recommendations are discussed below (see section 4.2) together with all the other recommendations [1].

3.3. Assessment of radon control technologies

In order to contribute to the evaluation of radon control in buildings, to reduce potential conflicts between energy saving construction and radon reduction, and to form building professionals, the whole work has been performed under the following three specific objectives

1. Assessment of potential conflicts between energy conservation in buildings and radon exposure reduction.
2. Establishment of measurement protocols for radon control technologies.
3. Design of training courses for radon measurement, prevention, remediation, and cost effectiveness analysis.

To reach these objectives, the work undertaken had been at first to elaborate a specific questionnaire, which was sent to the RADPAR partners and to other European countries to state on their current practices. Literature review on each topic had also been realized associated with some specific studies. Analysis of all this material had been conducted. At the end, recommendations on each topic had been proposed.

Studies undertaken yielded three deliverables with different documents presented below.

An analysis of current practices on professional courses in European countries involved in the RADPAR program was realized. On that basis of this material, frames of courses for professionals were defined, which could be developed and applied depending on addressed target groups and development of radon management practices in the country.

Potential conflicts between energy conservation and radon control were analysed. Based on different studies undertaken, main conclusions for new buildings are that:

- The extremely tight building shell of passive houses is also a good radon protection

- Mechanically controlled ventilation of dwellings plus tight building shell lead generally to very low radon levels

- Mechanically controlled ventilation with a air-soil heat exchanger may draw radon-laden soil gas directly into the dwelling if pipes in the soil are not tight

- Later modifications of the building shell at the foundation by the occupants (e.g. bore holes) can deteriorate the radon situation of a dwelling significantly

The analysis of the requirements for standard measurement protocols to characterize various building products used to control indoor radon such as membranes, sealing materials, sumps etc was also realised. A protocol for the determination of the radon diffusion coefficient for membranes and sealants was proposed. This last protocol has been proposed to be an international standard and is now currently submitted at ISO level (ISO/WD 11665-10 standard).

3.3.1. Task Reports

The details of the work are given in the following reports that are annexed to this report.

1) *Design of training course for professionals on radon measurement, prevention and remediation in buildings [9]*.

The main source of indoor radon in most buildings is the subjacent soil gas with building materials in most cases making a smaller contribution. The level of radon in a building is, however, to a large extent influenced by the properties of the building itself and its usage. Critical building parameters are, for example, coupling to the ground, leakage distribution of the building envelope, type of heating/ventilation systems and occupant living comfort preferences.

Present methods for radon reduction in existing buildings and radon prevention in new buildings have been developed over the last twenty years in particular for standard houses. Currently, a good knowledge at scientific and technical level can be noticed. However, it can also be noticed, depending on country, that this knowledge is not shared enough with building professionals and it is needed to spread information on building protection

For a successful development of public protection against radon, three following topics should be developed jointly: regulation, communication to public and professional improvement

In that way, training course for professional is a key point to develop practices and should be linked with professional improvement and more generally the development of regulation and communication to public.

For this reason, the present task of the RADPAR project aimed to design frame of training courses for professionals.

The document produced in this framework [9] is divided in three main parts.

The first part presents frames of courses which could be developed and adapted depending on addressed targets and advancement on country in radon management. Training course for professional is a key point to develop practices and should be linked with development of regulation and communication to public.

The second part corresponds to the analysis of responses on questionnaires developed in the framework of RADPAR program (Task questionnaire and Master Questionnaire).

The aim was to take into account current experiences and practices in that domain from different countries to build frames of courses presented in first part. This experience could differ a lot depending on radon management advancement. Courses are sometimes linked with professional accreditation. In this case, content is more consistent and duration is longer, with better attendance and efficiency. In countries where courses are well running, improved of professional practices is observed.
The third Part presents the RADPAR recommendations on "Design of training course for professionals on radon measurement, prevention and remediation in buildings".

2) *"Potential conflicts between energy conservation and radon control" consists of the following reports:*
2.1. Assessment of current techniques used for reduction of indoor radon concentration in existing and new houses [10].
2.2. Questionnaires: Compilation and Assessment [11].
2.3. Survey of Construction Technologies in Low Energy and Passive Houses in Europe [12].
2.4. Heating and Ventilation Systems in Low Energy and Passive Houses in Europe [13].
2.5. Measurement and Analysis of Radon in Low Energy and Passive Houses in Austria [14].
2.6. Review of Low Energy Construction, Pressure Conditions and Indoor Radon in Finnish Residential Buildings [15].
2.7. Radon and Energy Efficient Construction: Assessment and Recommendations [16].

The building sector is at present responsible for more than 40% of EU energy consumption. New technologies have been implemented in new houses and those are continually under development, which substantially improves the energy performance in buildings, reducing the conventional energy demand in new and existing buildings. New building concepts all aim at a new approach for the design, construction and operation of new and/or refurbished buildings in order to reach a high level of energy efficiency and sustainability. Various terms exist for those building concepts like green building, low energy house, passive house, triple zero house, eco-building, etc.
Radon control technologies aim at the reduction of indoor radon concentrations in existing buildings and in new construction through remedial and preventive measures. The analysis and assessment of current techniques and technologies used to achieve the reduction of indoor radon concentrations in existing and new houses with regard to the reduction efficiency and potential impact on energy consumption (qualitative analysis) is given [10]. A questionnaire was prepared and sent to all RADPAR partners in 14 different countries in order to gather national information about the current remediation and prevention techniques.
The most efficient remediation and prevention method is the active sub-slab depressurization (SSD), for which the reduction in the radon concentration is typically 70–95%. Other methods, such as sealing entry routes and improving ventilation in living spaces, in the cellar or in the crawl space, are less effective: the reduction in the radon concentration is typically 10–60%, although varying national building and remediation practices affect the results. However, widespread use of passive SSD and/or radon-proof membrane in the base floor in new construction can be recommended.
The active SSD increases the energy consumption mainly due to the power consumption of the electrical fan used. The effect of the cooling of the base floor is normally minimal. The impact on energy consumption of passive SSD and passive radon piping is negligible. Sealing entry routes in both remediation and prevention in new construction has a positive impact through reduction of the leakage of cold air from the ground in low

energy and passive houses. Replacing existing natural or mechanical exhaust ventilation with a new mechanical supply and exhaust ventilation system with heat recovery typically reduces energy consumption. On the other hand, other methods increasing ventilation in living spaces reduce the radon concentration, but simultaneously increase energy consumption due to increased air exchange.

The effect of new energy-saving building concepts on indoor radon levels were also investigated in detail. First, the construction, heating, and ventilation technologies used in modern dwellings were identified and subsequently their potential effect on indoor radon was assessed [11-16]. To complement and to verify the findings, a survey in 28 passive houses in radon prone areas in Austria was conducted [14]. In another 9 passive houses more detailed radon measurements were made by means of active devices. In general, the results were below 300 Bq/m³, in the majority of houses even below 100 Bq/m³. However, in a few houses high radon concentrations were found.

The main results of this study are: (i) the high standard of air-tightness of the building shell of new buildings is basically beneficial with respect to low radon levels, (ii) controlled mechanical ventilation has principally a positive effect on radon indoors, (iii) however, certain design features or bad practice may cause high radon levels, e.g. leaky earth tubes of ground-coupled heat exchangers, improper sealing of penetrations of geothermal heat pumps, switching off mechanical ventilation in summer, use of air wells for preheating of outside air.

As a result of this study, recommendations were set up to avoid any adverse effect of these new technologies on indoor radon levels [16].

Finally, a review is made [15] on the low energy construction, pressure conditions and indoor radon on the basis of experiences from Finnish residential buildings. Increased air-tightness of building shells increase the potential to increased pressure differentials in indoor spaces compared with outdoors. Non-balanced ventilation systems and also real conditions in balanced ventilation installation may result in negative pressure differentials which increase the inflow of radon bearing soil gas into living spaces. Minor leakages in the foundation can increase radon concentration even in the case the leakages do not decrease the total air-tightness markedly. Therefore, the foundation must be sealed with special care.

3) *Establishment of measurement procedures for radon control technologies [17].*

The majority of RADPAR partners is convinced that the first priority should be given to testing of radon-proof materials to judge their performance as efficient barriers against radon penetration from the soil. Therefore, the work was concentrated on the development of the test methods for the radon barrier materials and formulation of the guidelines for the design and application of radon-proof courses.

With the aim to increase the accuracy of the tests, to ensure reproducibility and repeatability of the test results and to simplify interpretation of the results, a unified test method has been developed under the framework of the RADPAR project by the Faculty of Civil Engineering of the Czech Technical University in cooperation with the National Radiation Protection Institute in Prague. The proposed method was accepted in April 2011 as a working draft for the international ISO 11665-10 standard "Determination of the radon diffusion coefficient in waterproof materials using radon activity concentration measurement". Radon diffusion coefficient determined according to this standard can be used for selecting materials with sufficient radon barrier properties.

Design and application guidelines stress that the design of radon-proof courses should be a complex procedure, because the barrier materials protect the building not only against radon, but also against soil moisture and underground water. Therefore, not only radon barrier properties but also other very important characteristics, such as material and physical parameters, durability, applicability, chemical resistance, air-tightness of joints and services penetrations, etc. should be taken into account when designing radon-proof courses.

3.3.2. Task Recommendations

The whole effort has led to recommendations on topics such as Assessment of potential conflicts between energy conservation in buildings and radon exposure reduction, Establishment of measurement protocols for radon control technologies and Design of training courses for radon measurement, prevention and remediation
These recommendations are discussed below (see section 4.2) together with all the other recommendations [1].

3.4. Analysis of cost effectiveness and health benefits of radon control strategies

The rationale for this work is that radon remediation and prevention are primarily about health risks / benefits measured in terms of lung cancer.

The objectives of the programme are therefore:

1) to assess the cost-effectiveness of existing and potential radon prevention and remediation strategies in the EU, and

2) to improve the effectiveness of radon control strategies through the design and use of training courses for radon measurement, prevention, remediation and cost-effectiveness analysis.

A spreadsheet model was been developed and adapted to fit different countries, and to facilitate the input of country-specific information on radon levels, costs, epidemiology, demography and other parameter values.

A training course event was planned and took place in Oxford, UK, in July 2011.

Following the training course, which was attended by representatives from 10 countries, participants were invited to take away the model and enter data from their own countries, to then be collated in a report by the WP leader.

In the first round, data were provided for Finland, Ireland, Norway and the UK. In the second draft, additional data were provided for the Czech Republic.

3.4.1. Task Reports

Details of the work under the present task are given in the following reports:

1) *Manual: "Training course in methods of cost-effectiveness analysis" [18]*.

A detailed manual was prepared to help guide users using the cost-effectiveness model, which has been designed in an Excel workbook. The manual is available as a Word document or a pdf.

The manual is 11 pages and 2,300 words, and includes a series of screenshots to assist readers. It is structured in the same way as the model, and includes sections on: 1) an Introduction to the model and manual, 2) background information on the concepts and methods of cost-effectiveness analysis, 3) step by step instructions on opening the model and enabling macros; selecting calculation options; data input requirements; other user choices and model parameter values; a description of the baseline results outputs, the sensitivity analyses, and the use of probabilistic sensitivity analyses; and contact details.
The Manual was developed as a draft and redrafted following comments from actual and potential users and a scientific review.

2) *"Analysis of cost effectiveness and health benefits of radon control strategies" [19]*.

A report setting out in full the work undertaken as part of WP7, and in particular reporting the results of the cost-effectiveness analyses undertaken, was produced in draft form and circulated for comment, then redrafted. The final version is a 51 page document of almost 16,000 words.
The report provides an introduction and background to the work package, a guide to the principle of cost-effectiveness analysis, and then detailed sections on the way in which health benefits are measured in the analysis, the analytical perspective adopted, and the time horizon. The report also sets out the way in which uncertainty has been handled in the analyses.
The report then deals with the data inputs to the cost-effectiveness model, documenting all parameter inputs for the cost-effectiveness analyses of a basic prevention strategy, and for a remediation strategy. In addition to central values, variance and sources of information are reported for each of the five participating countries: Finland, Norway, Ireland, the UK and the Czech Republic. These data sections cover radon reference or action levels, average household size, the proportions of homes accepting invitation to test, and agreeing to remediate if over the reference level, the radon reduction from prevention and remediation measures, the cost of prevention and remediation measures, of test invitations and tests, the health care costs of lung cancer cases and of added life expectancy, smoking rates, lung cancer rates and life table/survival data.
The report then provides results for each country for the prevention strategy in new homes, and then for remediation of existing buildings in target areas. Baseline results are given, followed by sensitivity analyses in which parameter values are changed.
Finally, the report contains a summary and discussion of the results. There is also an Appendix containing detailed technical information from each country.
The report is available as a Word document or a PDF file, and a manuscript based on it is currently being prepared for submission to a peer-reviewed journal.

3.4.2. Task Recommendations

The whole effort has led to recommendations on topics such as the Use of cost-effectiveness information, Evaluation of existing policies, Co-ordination for cost-effectiveness and Information needs and Training for cost-effectiveness. These recommendations are discussed below (see section 4.2) together with all the other recommendations [1].

4. CONCLUSIONS AND RECOMMENDATIONS, SUSTAINABILITY OF THE PROJECT AND LESSONS LEARNED.

4.1. Conclusions

- Radon Prevention and Remediation is quite limited in the European scale
- There is a need to reduce the overall population risk as well as the individual risk for people living with high radon concentrations.
- It is clear that only a joint European effort can provide the necessary experience and diversity of circumstances to provide an insight into the complex radon problem and in how to deal effectively with it.
- By means of its deliverables and Recommendations it is expected that the RADPAR project will:
  - heighten awareness both of the public and of decision makers of the health burden of radon in the EU and of the technical means available to control radon;
  - transfer information to new and accession EU MS as well as other countries (in collaboration with IAEA and WHO) where radon control strategies are presently almost non-existent.

4.2. Recommendations

The RADPAR Recommendations are an outcome of the RADPAR Deliverables and all the work done in the framework of the RAPAR Project. The majority of the RADPAR Consortium has contributed for the production of the Recommendations

These recommendations were sent together with the recommendations from the other RADPAR Work Packages to the relevant health and radiation protection national agencies in all EU Member States and in the RADPAR partner countries of Norway and Switzerland. The agencies in these countries were requested to rank their degree of agreement with each individual recommendation on a 1–5 scale (5=strongly agree, 4=agree, 3=partly agree, 2=disagree, 1=strongly disagree). The agencies were also requested to indicate for each individual recommendation if it would be taken into consideration as part of their radon control strategy. The “consideration” ranking was on a 1–6 scale (6=already part of our radon control strategy, 5=full, 4=large, 3=moderate, 2=little, 1=none).
The analysis of the responses arrived shows that the average feedback was quite positive for nearly all the recommendations.
The recommendations were also presented and discussed in the RADPAR workshop held in Brussels on 23 February 2012.

The detailed recommendations in the final form are given the Overall RADPAR Recommendations document [1].

The Recommendations cover practically all topics of the Project and can be distinguished in the following seven (7) categories:

1. Radon Policy and Strategy;
2. Protocols for Indoor Radon Concentration Measurements;
3. Improving 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, and remediation;
7. Analysis of cost effectiveness and health benefits of radon control strategies.

The RADPAR recommendations are intended and expected to be used to tailor future communications on radon risk to the public and decision makers. Also they are expected to help pave the way towards a scientifically based development of a harmonized radon policy and legislation in European countries. An important aspect of RADPAR is the transfer of its results and recommendations to new and accession Member States, where strategies to reduce radon exposures are presently almost nonexistent.

In order to assess the level of agreement with these recommendations, as well as the consideration to take them into account when producing a radon policy, a special response form was designed. This response form was sent to relevant institutions of 37 countries (all EU Member States and other European countries). Responses, including comments, were received from institutions of 13 countries: Austria, Czech Republic, Estonia, France, Germany, Greece, Ireland, Italy, Lithuania, Norway, Poland, Serbia and Switzerland. For two countries (Czech Republic and Serbia) responses were received from two institutions. The RADPAR Recommendations including the responses of the 13 countries can be seen in Annex I.

RADPAR Recommendations cover a large number of issues related to radon and are therefore numerous and detailed. Core examples of the recommendations included under the above mentioned recommendation categories are given below.

For categories 1 and 2:

- A comprehensive strategy (developed with all stakeholders) has to be implemented by means of National Action Plans, involving also local authorities and expertise, and coordination with other related programs/activities (cigarette smoking, IAQ, energy saving) should be promoted.
- Preventive measures in all new buildings (considerable renovations, extensions) are recommended, unless it can be demonstrated that this is not cost-effective. These preventive measures should be: i) very cheap in order to be cost effective for large scale application; ii) easy to install (i.e. not requiring specialists); iii) properly installed.
- Verification of preventive measure effectiveness should be done, by means of long-term (e.g. 1 year) radon concentration measurements, preferably 1–2 years after construction and when the building is normally occupied. Verification of long-term effectiveness of preventive/remedial measures should also be done.
- As regards remedial actions in existing buildings, an adequate number of persons trained in the necessary skills should be available at local level. Moreover, standards and protocols for preventive/remedial measures should be prepared.
- Surveys should be generally designed to be representative of population exposure, and checks of representativeness should be done on the actual sample included in the survey. Moreover, evaluations of radon distributions and maps should be based on representative data only.
- Radon-prone area can be a useful tool to optimize/prioritize the search for radon levels to be reduced. It should be clear that the final goal is not to find radon-prone areas, but to reduce lung cancers. Protection from radon should not be restricted to Rn-prone areas only, especially if they contain a small fraction of the overall population.

For category 3:

- Radon Awareness Surveys (RAS) should be an essential component of a risk communication strategy.

- Target audiences need to be identified and communication information tailored accordingly.
- Messages should be kept simple but accurate in particular when communicating with the public.
- Radon Focus Groups and attention to regional characteristics should be used to assess and improve communication effectiveness.
- If possible radon information campaigns should be linked to other health or environmental communication campaigns.

For categories 4, 5 and 6:

- The level and type of remediation works to be undertaken depends on the initial level of indoor radon and characteristics of considered building.
- The techniques of radon prevention in new construction should be established in national building codes, regulations and guidelines. Integration of radon prevention in new construction needs to done at early stage of building design.
- Construction elements have to be designed and constructed in a way that entry into the element and movement within the element of radon bearing air is avoided.
- Radon-proof material can be selected from common waterproof materials available on the building market. The radon barrier material must eliminate the convective flow of soil gas containing radon and minimize radon transport by diffusion. Radon diffusion coefficient should be determined according to the ISO/WD 11665-10 standard.
- Training courses for professional are key instruments to develop and improve practices. They should be linked with development of regulation and communication to the public.

For category 7:

- Policy-makers are encouraged to incorporate cost-effectiveness information in their deliberations, and should be encouraged to take steps to undertake and periodically update cost-effectiveness analyses of existing and proposed radon prevention and remediation policies. Cost-effectiveness analyses should be integrated in the radon policy-making process at an early stage, to help select the options being considered.
- Unless it is shown to be not cost-effective, the installation of basic radon prevention measures in all new homes should be incorporated into the relevant building codes. In contrast, for existing homes, the cost-effectiveness of radon remediation is strongly influenced by the average radon levels in the target areas, and by the reference level being used. When reviewing existing policies, the impact of changing these on the cost-effectiveness of remediation policy should be carefully assessed.
- The costs of radon policies, particularly radon remediation, often fall on a wide range of different national, regional and local bodies, including radon mapping agencies, testing, local authorities, housing agencies, environmental agencies, health services and private homeowners. This varies considerably between different countries. Cost-effectiveness analyses should take into account all relevant costs.
- The cost-effectiveness analyses undertaken during the RADPAR project showed large variations in such things as invitation acceptance rates, remediation rates in homes found to be over the action level, and the effectiveness and costs of remedial actions. Countries should assess whether information in these areas is adequate, and if necessary commission further research to address deficiencies.
- Individuals or bodies with relevant training to undertake cost-effectiveness analysis of radon policies will need to be carefully identified. Responsible agencies should contact bodies or project groups such as RADPAR, the WHO International Radon Project, and

national and international Health Technology Assessment agencies, to identify who can help. Where necessary, national agencies should ensure that appropriate personnel is given opportunities to attend such courses.

4.3. Sustainability

The Project has produced significant results including the Project Recommendations and their analyses which should be considered and examined by the National Authorities and the potential stakeholders.

One of the future possibilities of RADPAR is to maintain the RADPAR website even after the end of the project's contract and updating the website with radon news, events, announcements etc.

Also the Project might sustain in a way that includes data bases, testing protocols, issuing guidelines / advice / pre-normative work, cost effectiveness taking into consideration the effects on indoor air quality and energy saving when applying radon control.

The health burden for all the EU Member States and a whole set of recommendations covering many radon issues were prepared in order to assist national authorities to improve their radon policies, with the aim to reduce radon health burden. As already reported in other parts of this final report, it would be important to continue RADPAR activities with a new project, in order to develop specific guidelines and provide assistance to any EU Member State. Moreover, the effectiveness and feasibility of the RADPAR recommendations could be checked and evaluated in such a new project or Concerted Action. In this direction support from the EC to produce an EU Radon Handbook should be sought.

The cost effectiveness model will need to continue to be updated in the future, both in terms of parameter inputs and in terms of its structure as new policy designs are evolved and implemented. This is more difficult and will require further funding from some source to be sustained into the future.

4.4. Lessons learned

It has been very interesting and useful to compare approaches, and related problems, on radon policy of many different European countries. Differences are present not only on experience on radon issues, but also (more interesting) on organizational and sociological aspects of these countries. For example, in some countries a "voluntary/recommendatory" approach of radon policy has been proven to be not very effective, probably because in such countries several people think that a health issue which is only recommended is not very serious, compared with other health issues which are regulated in a mandatory form. On the opposite, in other countries a recommendation is better considered because it gives more responsibility to each person and freedom to decide what to do. Therefore, we learned that an effective radon policy should also take into account the general "attitude" and organization of a country. This was done during the preparation of a detailed list of recommendations on radon policy, which contained the experience of many countries, but was also quite flexible in order to be useful for many different countries.

Another lesson that we learned is that it is very useful to compare practical experience on implementation of radon policy, as well as radon measuring methodology and protocols, and that there is a huge demand of such information from countries which have a limited experience on radon. Therefore, it would be very useful to continue this (or similar) international collaboration, in particular to prepare detailed protocols on such issues.

The dissemination of information on radon and its risks to the general population and other relevant stakeholders has been found to be the first step in the development of awareness of radon and on how to deal with it. Raising awareness should not, however, be seen as an end in itself. In many EU and other European countries considerable effort and expenditure over many years has gone into awareness raising and radon risk communication campaigns targeted mainly at the public. Publications by national agencies and responses to the RADPAR questionnaire make it clear, however, that the reduction of national cumulative radon exposures in existing dwellings as a result of these efforts has been negligible. The biggest problem the radiation protection community faces in dealing with public exposure to radon in existing dwellings appears to be apathy. It is very difficult to persuade members of the public to measure for radon in their homes. Even when informed that the radon concentration in their home is above a national reference level only a disappointingly low percentage of householders will decide to remediate. There are, of course, many reasons (social, economic etc) for this which will not be overcome by simply feeding the public with factual information to raise their awareness regarding radon. To communicate effectively with target audiences (both public and decision makers) the objective should not only be of raising their awareness but also of persuading them to take action (i.e measure for radon and remediate where necessary). This latter and important objective cannot be achieved by the passive dissemination of information but requires the application of social marketing techniques which aim to change people’s behaviour for their own or the common good. Social marketing techniques have been used to persuade people not to smoke in public areas, to use seat belts, to follow speed limits etc. Social marketing is, unfortunately a skill not normally present in the skill set of radiation protection practitioners, epidemiologists, physicists or other scientific experts. Therefore just as non radiation professionals such as architects, builders etc play an important role in dealing with radon social marketing specialists should be involved in radon risk communication.

Knowledge on building protection is not shared enough with building professionals and it is needed to spread this information on building protection. In that way, training courses for professional will become key instruments to develop and improve practices. They should be linked with development of regulation and communication to the public. Referring to systems and materials used for building protection against radon, it is necessary to have common protocols at European or international level to assess their relevance. The most efficient protection method is the active sub-slab depressurization (SSD) and the radon well, for which the reduction in the radon concentration is typically. However, its impact on energy consumption could be significant, mainly due to the power consumption of the electrical fan used and potentially also to a lesser degree due to cooling of the base floor. The impact on energy consumption of passive SSD and passive radon piping is negligible. For new construction, basically, the combination of a highly airtight building envelope and a controlled mechanical ventilation system leads to very low indoor radon levels. Nevertheless, certain features of the new technologies may cause high radon levels. Examples are leaky earth tubes of ground-coupled heat exchangers or bad design of air intakes (e.g. air wells). For these buildings, quality of implementation is crucial, whether for an energy efficiency of the building and for protection against radon. Also awareness of the occupant is crucial to prevent it from disrupting the effectiveness of safeguards in place.

International collaboration in applied research is time-consuming and the attrition rate is quite high – 16 people from 9 countries attended the training course on the cost – effectiveness model but in the end not all were able to provide results from the model, due to pressure on time etc. However, the results are particularly valuable and will form the basis of a good publication.

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