



**World Health Organization**

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**The 1<sup>st</sup> Meeting of National Experts  
for WHO's International Radon  
Project**

**17-18 January 2005**

Meeting report prepared by J. M. Zielinski and Z. Carr

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## Table of Contents

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Participants.....	1
Background .....	2
Session 1: Justification for the WHO Radon project and need for global action on radon	4
Session 2: Current science in support of developing sound radon policy .....	10
Section 3: WHO methodology for burden of disease assessment .....	13
Session 4: Current regulatory environment for radon across the world .....	17
Session 5: Mitigation measures and national snapshots .....	19
Session 6: Shaping the WHO Radon project .....	22
Appendix A. Discussion leading to consensus statements .....	32
Appendix B. Management of the Project: Working Groups, Timelines.....	37

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## **Background**

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Radon occurs in significant amounts in the ground. Documentary evidence from as far back as the 16<sup>th</sup> century indicates that elevated radon exposure was probably responsible for excess lung cancer mortality of miners in some Central European mines, such as the silver mines in Germany and Bohemia.

Initially scientists thought natural radiation was of little health significance for the general population in most countries. However, that view began to change in the mid 20<sup>th</sup> century—the change became dramatic in the 1970s and '80s as it was discovered that some houses in a number of countries had indoor radon levels at significant concentrations. Then, in 1984, the issue surged to US national attention when a construction worker set off a radiation monitor on entering the Limerick Nuclear Generating Station in Pennsylvania. The plant was not yet generating fission products, which suggested that his home was the source of contamination.

It is now understood that in areas where the natural radon level is high, the lower air pressure in houses results in an inward flow of radon-rich air through cracks in the bottom slab and cellar walls.

In response to the need for information on risks from indoor exposure, epidemiologic studies were directed at the general population in the 1970s and 1980s. The first studies were largely ecological in design and provided mixed findings. Case-control studies of lung cancer were also implemented in the US, Europe, and elsewhere. Some of these first studies did not actually measure indoor radon, relying on surrogate measures such as the type of housing construction, so the resulting data could not provide quantitative estimates of risk. By the mid- to late-1980s, more sophisticated studies with larger sample sizes were undertaken. Some of these studies have suggested an association between elevated levels of radon in homes; others, including the study conducted by Health Canada in Winnipeg, have not. Overall, these results have failed to provide conclusive evidence of elevated lung cancer risk.

As studies were implemented and planned, the challenge of providing the certainty sought by policymakers became apparent. To produce results that can set policy direction requires a more demanding study design than to simply show that indoor radon probably causes lung cancer.

In the late 1980s, members of the Biological Effects of Ionizing Radiation (BEIR) IV Committee and the Committee on the Biological Effects of Ionizing Radiation reviewed the published and planned case-control studies. The potential limitations of sample size and the plausible levels of measurement error were immediately evident. They proposed pooling individual studies, and easily convinced founders — US Department of Energy and the Commission for European Communities—to support planning for eventual pooling of the world case-control studies of indoor radon and lung cancer. The investigators in question participated eagerly and established continuing North American

and European collaborations, which will eventually be pooled.

The uncertainties around radon and lung cancer that first prompted case-control studies have been reduced by the many scientific advances. It is now accepted that tens of thousands of lung cancer deaths each year are linked to radon exposure. The consistency of the data and the analysis points to a need for action. To reduce radon risk, national authorities must have methods and tools based on solid scientific evidence and sound public health policy.

WHO has had the foresight to have been working towards development of guidelines. In 1993 it published a report containing several conclusions and recommendations covering the scientific understanding of radon risk and the need for countries to take action in the areas of risk management and risk communication.

The Radiation and Environmental Health Programme within WHO's Sustainable Development and Healthy Environments Cluster evaluates health risks and public health issues related to environmental and occupational radiation exposure. The programme promotes research and provides recommendation for emergency medical and public health responses to radiation accidents and terrorist acts and provides advice to national authorities.

The WHO Residential Radon Risk project will develop a programme on the public health aspects of exposure and identify resources for its implementation. The programme will include:

- a world-wide database on national residential radon levels, radon action levels, regulations, research institutions, and authorities;
- public health guidance for awareness-raising and mitigation;
- estimation of the global burden of disease (GDB) associated with residential radon exposure.

GDB is a tool for national public health authorities to quantify the burden of disability and mortality for major diseases or disease groups associated with specific risk factor. WHO has been assessing GDB for some 20 major risk factors, but never for ionizing radiation risk factors.

WHO is encouraging its member states to create programmes towards such objectives as issuing advisory levels, issuing guidelines for identifying radon risk areas, checking for radon risks prior to new construction, establishing mitigation programmes, and increasing public awareness.

WHO has formed a network of key partner agencies around the world working on radon in homes and is proceeding with the International Radon Project (IRP), with completion expected in late 2007.

At this point in time, the development of a global policy for radon and the process to establish a GDB for radon centre around the following questions:

- What are the benefits of an international action agenda for radon?
- What actions could WHO take to move an action agenda forward?
- What are some key opportunities to raise visibility for the action recommendations?
- What are the first steps for development and implementation of a step-by-step process?

The 1<sup>st</sup> meeting of the WHO IRP was held in Geneva, Switzerland, January 17-18 2005. This meeting report was prepared by the rapporteur J.M. Zielinski (Health Canada) and Z. Carr (Project Manager, WHO). The report contains the collective views of an international group of experts, and does not necessarily represent the decisions or the stated policy of the World Health Organization.

## **Session 1: Justification for the WHO Radon project and need for global action on radon**

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**Co-chairs: M. Repacholi, H. Walker**

### **Welcome Address**

**Margaret Chan, Director, Protection of the Human Environment, WHO**

Margaret Chan welcomed participants to the First Meeting of the Expert Group for the WHO Radon Project, on behalf of WHO Director General, J.W. Lee.

She observed that exposure to radon, either at home or in the workplace, is one of the greatest risks of ionizing radiation, and causes tens of thousands of deaths from lung cancer each year. How can WHO work with international experts to help member states formulate good public health policies in this area based on the best available science?

This meeting is well-timed, said Chan. Findings from recent case-control studies on lung cancer and exposure to radon have been completed in many countries and allow for substantial improvement in risk estimates. The pooling of data from these studies brings risk estimates to a new level of sophistication. The consistency of these findings enhances understanding and strengthens the robustness of estimates.

To reduce radon risk, national authorities must have the tools and methods to develop good policies, and this is where WHO can play an active role as the international lead agency in health.

To fulfill WHO's mandate in helping member states develop sound policies on radon, WHO is planning to develop a program that would have several key elements:

- a better estimation of the global burden of disease associated with exposure to residential radon;

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- instruments (guidelines, tools, and methodologies) that would help member states or national authorities formulate policies, strategies, and implementation methods for radon mitigation.

The network of experts gathered at this meeting will form the backbone of this radon project and will guide future work.

## **International Residential Radon Project: WHO Objectives**

### **M. Repacholi (WHO, PHE/RAD)**

M. Repacholi outlined the PHE/RAD (Protection of the Human Environment/Radiation Program) mandate and gave some background information on radon risk factors and WHO/RAD ionizing radon projects. The goal of the International Radon Project is to establish a global project, with all key international and national partners participating, to identify and promote programs that reduce the health impact of exposure to residential radon. This will involve assessing the global burden of disease, identifying and promoting policy options and mitigation programs, raising public and political awareness, and reviewing mitigation measures to ensure effectiveness.

## **Discussion on worldwide action on radon**

### **Moderator: Barnes Johnson, Deputy Director, Office of Radiation and Indoor Air, US Environmental Protection Agency (EPA)**

Barnes Johnson cited radon risk assessments—BEIR VI and the new EPA risk assessment—that confirm the seriousness of the problem. He noted that these risk numbers are consistent with earlier assessments. The consistency of data and analysis points to a need for action.

Past WHO actions lay the groundwork for moving forward. In 1993, a WHO Working Group from the European Regional Office published a report entitled *Indoor Air Quality: a Risk-Based Approach to Health Criteria for Radon Indoors*.

This report contained several conclusions and recommendations and called for countries to take action in the areas of risk management and risk communication.

The goals for this meeting include beginning the process of establishing a global burden of disease (GBD) for radon, and using this group's collective influence to affect global radon policy.

Johnson guided the discussion with four key questions.

### **1. What are the benefits of an international action agenda on radon?**

A participant expressed concern about the possibility of having a big variation. In

particular, there are very “hot” areas with high radiation rates, and this makes it difficult to compare regions/countries. People should be made aware that there are still some unresolved issues that are the subject of ongoing research worldwide.

Another speaker answered the question, “What are the benefits?” by saying that there should be more public and political awareness raising, because most people still do not know what radon is.

Discussing risk communication, a participant commented that this process should not be started until there is a baseline understanding of present public attitudes: “We need to find out what the public actually thinks, and use that to adjust our communication tools.”

One of the benefits of an international agenda would be consistency and uniformity across countries and organizations, and within countries, said a participant. By setting minimum criteria, the worst cases could be improved (where there is hardly any control or regulation). WHO’s stature would help in making this a priority.

Referring to the fact that radon levels are very different in different countries, G. Kendall (UK) noted that it would be logical for different countries to have different action levels and radon policies. That is a problem, because it is not possible to set a standard level for all.

B. Field (US) suggested aiming for consensus within this group of experts regarding the need for further education and research—or at least, that radon is a serious problem that should be addressed. Disagreement among scientists can seriously lower the level of risk perception in the public, he warned.

A participant noted that although this is a very multidisciplinary area (involving a range of experts, including building, environmental, and health authorities), the key role is for health authorities, therefore WHO is needed.

M. Repacholi reviewed the way in which WHO works, noting that the organization is good at gathering people together, convening meetings among experts, and generating conclusions and recommendations for key topics. That is what is being done at this meeting: WHO is present to take advice and compile the information into documents like fact sheets, press releases, and authoritative reports—based on agreement among the consultants. For radon, WHO will really need help from the specialists to be able to provide the information needed for the fact sheets. WHO fact sheets are an effective communication tool: they are translated into 15 different languages and posted on the website. Such fact sheets would be very useful for radon, but the risks must be communicated effectively. Repacholi also acknowledged the need to understand the current public perception of the risks and work from there. The aim is to compile a set of solid scientific information based on peer-reviewed literature and by consensus within meetings such as this.

He acknowledged that countries want support for their national programs, and need to



increase political awareness of the problem. WHO can put all this into a very simple format. This project is an opportunity to be able to promote programs domestically with WHO support.

E. Ettenhuber (Germany) asked about the availability of WHO information papers in other languages. Repacholi said that information documents are generally taken to the department of health within a country. If that country does not use one of the normal seven WHO languages, WHO asks the Department of Health within that country to provide an authenticated translation.

## **2. If recommendations were developed to encourage more risk reduction from radon, what would they say?**

G. Kendall noted that it is really too late to try to control radon in a building, once that building is up. It is much better to put in anti-radon measures when the building is being constructed. It is much more expensive to retrofit. He suggested addressing radon issues within a country's building code, noting that the approach may vary from country to country.

G. Piller (Switzerland) added that every professional builder should know what radon is and what measures exist for remediation of high concentrations, including preventive measures. This is not always easy to do, because programs for training and education in this profession are already full. To add radon into such programs would mean making very clear statements. It would help if WHO issued a statement indicating that radon is a very serious health problem. With such statements, it would be easier to get training programs to accept radon content.

S. Darby (UK) commented that most regulations on radon concentrate on the upper end of the scale. Also, in most countries the distribution of residential radon is skewed: there are many more people with medium radon concentrations than with high radon concentrations. Because of that, the vast number of radon-induced lung cancers do not occur at the very high radon concentrations; they occur at medium concentrations. If one's concern is public health, one needs to develop measures that will concentrate on where the radon-induced lung cancers are happening.

In addition, she noted that the vast majority of radon-induced lung cancers occur among smokers. Sometimes radon measures have been considered in isolation from smoking, but perhaps the two issues should be brought together.

H. Paretzke (Germany) agreed that most lung cancers occur in relation to lower radon exposures, but cautioned that this group should be careful to state in reports that they do not know whether a particle from radon actually causes any cancer. At higher concentrations, it can be proven that radon causes cancers; but this group should be more cautious in discussing the impacts of lower doses of radon. This important action should not be weakened by a discussion as to whether very low doses cause any harm.

M. Tirmarche (France) agreed on the need to focus on all lung carcinogens present in indoor air. For practical reasons, focusing only on radon may not be sufficient because

many people are now involved in measuring other pollutants in the house. Situating radon close to asbestos and other measurements that are more or less obligatory from one country to another would give the impression that WHO is handling the whole problem, not just one of the pollutants separately.

Secondly, she posed a question: “How can we convince smokers to act on radon, if they are not convinced that tobacco is dangerous for them?”

The moderator acknowledged the importance of the first point, and referred to the Vilnius Declaration, an effort by WHO Europe to look at whole building environments collectively. That declaration mentions radon, along with asbestos, lead, mold, asthma, and all the other indoor air health issues. In the US, the strategy is to deal with radon along with other indoor air issues, collectively.

J. McLaughlin (Ireland) expressed support for the recommendations made regarding building codes. In Ireland, since 1996, there has been a building code that all new dwellings must have radon protection built into them. If there is such a code, there should be a follow-up requirement of a measurement to confirm that the technique worked.

T. Strand (Norway) said that the radon concentrations in the Norwegian housing stock have increased significantly over the last 25 to 30 years. In fact, data shows that the radon concentration today is approximately 75 per cent higher than it was 25 years ago. This is mainly due to the use of aerated concrete in the foundation walls, and is extremely difficult and expensive to mitigate. Something should be done about this problem in the future. He added that there are significant geographical variations in radon levels: in some municipalities, more than two-thirds of the housing stock exceeds 200 Becquerels per cubic metre (Bq/m<sup>3</sup>). In others, it is much less. These issues must be considered when communicating with the public.

H. Arvela (Finland) expressed support for a focus on healthy indoor air, noting that in Finland concentrations are higher in newer houses.

D. Chambers (Canada) said that there is a practical problem in countries like Canada, where people may put their whole savings into building a house. If someone builds a house and does everything properly, but still has a problem, how do they fix it if they have no more money? This is an issue that would be on people’s minds when considering assessing their houses for radon: a radon problem would mean that it would be harder to sell the house.

D. Krewski (Canada) summarized some of the main points raised: It is better to install mitigation devices at the time of construction rather than retrofit; and building codes provide a natural point of intervention for the control of residential radon. He added that radon testing and mitigation might be required when a building is sold. This is required in some US states, but it does raise problems for those who do not have the money to mitigate the radon problem. Nevertheless, this is an option that could be considered when looking at control measures.

The moderator noted that progress on radon in the US depends upon a vital testing and mitigation industry. He asked for comments on the capacities, either public or private, to provide the testing services and address the problems mentioned by Chambers.

B. Field (US) agreed that the availability of detectors within a country is important, but added that there should be follow-up to ensure that the detectors are accurate and precise. The moderator agreed about the need for quality assurance in testing, installation, and follow-up testing—the whole cycle.

D. Fenton (Ireland) suggested that the issue of public confidence in radon testing could be addressed by working with companies that have ISO accreditation. One could also look for a radon testing company to participate in international comparisons. But measurement is only one aspect: information is also needed on mitigation tools and measures. And, of course, there must be measurement again following remediation. He added that, although the vast majority of lung cancers are caused by medium levels of radon, policymakers need a figure above which the risk is too high, and in most of Europe that figure has been set at around 200 Bq/m<sup>3</sup>— even though the majority of cancers occur at concentrations that are known to be lower.

Addressing the concerns around stigma when selling a house contaminated by radon, K. Brand (Canada) said that the public needs information that can help in interpreting results. For example, in Canada most of the radon-related deaths from lung cancer have involved smoking. A way of putting this into perspective for the public is needed, and the Global Burden of Disease initiative might provide an avenue for that, given that it is doing burden of disease assessments for other environmental agents.

Kendall said that the perception in the UK is that radon measurements are not really a problem: it is possible to get a reliable radon measurement done, and one large lab can measure many households; whereas mitigation would involve a number of local builders. The quality of radon measurements in the UK may have been driven up because there is a national scheme for improving radon measurement laboratories. He added that many people would want to take a short-term radon measurement, because it is quicker. But because radon levels are so variable, one cannot get a good handle on the long-term radon levels from a one-week measurement. Consideration should be given to how one should interpret a short-term measurement.

A. Söderman (Sweden) said that Sweden has an extensive radon program, with a target that all dwellings should have a radon level of under 200 Bq/m<sup>3</sup> by 2020. This means that about half a million dwellings will need to be mitigated. Sweden has a grant system to cover half the costs, but mitigation is still very expensive. Now, following the European Union (EU) study, Sweden is questioning whether the best approach is to force everyone to mitigate. An alternative may be to focus on smokers. Söderman suggested that WHO project should include this topic.

**3. What are some key opportunities for WHO and us to raise visibility for such recommendations?**

**4. How can we get started to develop and implement a step-by-step process?**

Going beyond these questions, the group made final comments on a broad range of considerations.

J. Tschiersch (Germany) said that another nuclide of radon—radon 220, or thoron—could influence instrument readings if it is present at about the same concentration in indoor air, and may skew results for radon measurement. Housing in most developing countries has higher-than-expected levels of thoron. Some recommendations should be made regarding this nuclide as well.

J. McLaughlin (Ireland) expressed doubt that there is any measurement of radon using alpha track detectors where thoron is not making some contribution. Under these circumstances, radon risk may be higher.

Y. Yamada (Japan) argued that thoron should be taken into account because in areas of low radon concentration, thoron exposure gives equal effects. It was noted that, with a sealed detector, where the gas takes some time to diffuse into the detector (e.g., the NRPB detectors) thoron will not be detected.

Addressing questions two and three, A. Gray (UK) commented that policy makers often have enough recommendations but lack the resources to act on them. He suggested that the cost-effectiveness of WHO's recommendations should compare favorably with other things that could be done. It is also wise to look at radon remediation within the same type of conceptual framework used to evaluate other health interventions. This type of argument would help to raise visibility this area.

## **Session 2: Current science in support of developing sound radon policy**

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**Co-chairs: B. Field, Y. Yamada**

### **Summary of US Residential Radon Case-Control Studies, and Narrowing the Gaps in Knowledge**

**Bill Field, University of Iowa, US**

Bill Field reviewed residential radon studies done in several US regions. He identified the following gaps in research:

- What is the global distribution of radon exposure potential?
- What is the shape of the dose-response curve for radon-induced lung cancer?
- Does prolonged radon exposure cause other types of cancer?

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- Does prolonged radon exposure cause other adverse (non-cancer) health outcomes?

He also identified the following gaps in knowledge as narrowing:

- Does prolonged residential radon progeny exposure increase lung cancer risk?
- Is the excess relative risk for smokers the same as that for nonsmokers or never smokers?
- Does residential radon progeny exposure increase the incidence of specific lung cancer morphologies over others?
- What genetic polymorphisms are related to lung cancer incidence?

### **Pooling of North American residential radon case-control studies**

**Daniel Krewski, University of Ottawa, Canada**

Daniel Krewski presented a combined analysis of seven North American residential radon case-control studies conducted from 1989 to 2004. He highlighted the following conclusions:

- The analysis of all data revealed no overall association between residential radon and lung cancer risk. Only the Iowa study showed a positive association.
- Analysis of restricted data indicated a positive association overall.
- The odds ratio increased with completeness of monitoring in the 5- to 30-year exposure time window.
- The odds ratio increased using BEIR VI weights in the 5- to 30-year exposure time window.
- In the restricted data set, odds ratios were similar for males and females, and higher (although not significant) with proxy as compared to subject interviews.
- Odds ratios were significantly different depending on age at recruitment.
- There was no significant effect of educational attainment on odds ratios.
- There was no clear effect on odds ratios related to ever/never smoking, duration or intensity of smoking, or smoking cessation.

### **Pooling of European residential radon case-control studies**

**S. Darby, University of Oxford, UK**

Sarah Darby presented a collaborative analysis of individual data from 13 European case-control studies on radon in homes and lung cancer risk. Based on studies of miners, the researchers assumed that the important period of exposure for radon risk was the 30-year period ending five years before diagnosis for cases of lung cancer.

After stratification for study, age, sex, broad region of residence within study, and detailed smoking history, researchers estimated that lung cancer risk increased by 8.4 per cent per 100 Bq/m<sup>3</sup> increase in measured radon concentration (averaged over the 30 year

period of interest). This is a highly significant increase, but it is very dependent on detailed stratification for smoking.

After detailed stratification for smoking history, and also correction for the dilution from random uncertainties in measuring radon, lung cancer risk was estimated to have increased by 16 per cent per 100 Bq/m<sup>3</sup>. The data are consistent with a multiplicative model for radon and smoking rather than an additive model.

### **New United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report on health effects of radon**

**Douglas Chambers, Specialists in Energy, Nuclear and Environmental Sciences (SENES), Canada**

Douglas Chambers explained that The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was established in 1955, and is composed of scientists from 13 countries. This committee has published numerous reports on the health effects of ionizing radiation. It has a UN mandate to assess and report on levels and effects of ionizing radiation, and provides a scientific basis for the development of radiation protection standards. The next UNSCEAR report series will include a “sources to effects assessment for radon in homes and workplaces.” This report will look at sources and levels of radon exposure, dosimetry, experimental studies, epidemiological studies of miners and of residential exposure, and implications for risk assessment.

Chambers summarized the implications for risk assessment, explaining that miner studies provide the preferred basis for dose-response estimation. Models such as BEIR VI, which incorporate effect modifiers such as TSE, are preferred. Biologically based models will see increasing use in the future.

### **Thoron problems with GBD evaluation in the WHO Radon project**

**Yuji Yamada, National Institute of Radiological Sciences (NIRS), Japan**

Yuji Yamada explained that high thoron concentrations of over 200 Bq/m<sup>3</sup> are often observed in China. The dose conversion factor for thoron decay products is over four times larger than that for radon decay products. Therefore, thoron should not be neglected in the evaluation of the global burden of disease.

Some radon monitors are affected by the presence of thoron, and radon concentrations measured in some past studies might have been overestimated. More attention should be paid to thoron's interference with radon measurements.

Thoron concentration is strongly dependent on distance from the source and thus there may be no representative thoron concentration for each dwelling. A constant equilibrium factor should not be used for thoron in dose evaluation. EETC measurements should be made for each dwelling.

## **Section 3: WHO methodology for burden of disease assessment**

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**Co-chairs: J. M. Zielinski, M. Tirmarche**

### **Concept and methods for GBD assessment**

**A. Pruess, WHO, PHE/OEH**

Environmental burden of disease is the quantification of health impacts caused by various environmental risk factors at a population level, using a comparable framework, definitions, and outcome measures.

The estimation of environmental burden of disease is a comparative and consistent method for quantification of health risks. Many environmental levels are currently not “safe,” and will not be so in the near future. Increasingly, government agencies are looking for information that compares the action taken in a mitigation program with the health gains that would be achieved. Estimating environmental burden of disease can raise public awareness, serve as a basis for setting advisory levels, and help government agencies understand the cost effectiveness of interventions.

To estimate the disease burden for a country, one needs to establish a number of hypotheses regarding the exposure distribution in the population and the relationship between exposure and response. For every quantification of the burden of disease, it is necessary to do a full review of the evidence base.

An equation is then used to calculate the impact fraction. This is multiplied by the disease burden estimate per disease, resulting in the disease burden attributable to the risk factor.

### **Radon exposure assessment issues and implications for the GBD project**

**Dan Steck, US**

If cell damage cannot be measured directly, what is the best surrogate measure for radon-related lung cancer risk?

Currently, dose rate is the gold standard, and radon gas or radon progeny concentrations are commonly measured. In addition, new technologies now allow for the measurement of radon progeny activity size distribution.

The idea of the dose conversion factor is that the dose rate estimate could be improved with information about the airborne radon progeny concentration and its size distribution (because the smaller progeny are more effective at delivering dose, and different atmospheres have different mixtures of small and large progeny).

Factors that greatly influence dose conversion factor include aerosols, air movement, and air exchange and ventilation. Within homes in the upper American Midwest, researchers found a factor of two variation in effectiveness in translating from the radon concentration to the dose delivered.

A new measurement approach measures both the total airborne radon progeny fraction and the progeny size. The only conversion needed is a dose model to go from activity distribution to the dose.

There are two approaches to measuring the activity size. The more complex method involves pumping directly onto a filter or screens to sample the temporal variation over time. An alternative approach is to make indirect measurements that look at the progeny deposited on surfaces to determine what is in the air.

In summary, radon progeny size distribution information can improve the accuracy of risk predictions that are based on radon and working level (WL) measurements. Those estimates based on dose conversion factors are an attractive surrogate for global burden of disease risk assessment.

## **Results of the WHO pilot study on assessment of the radon burden of disease in Canada**

**J. M. Zielinski, Health Canada / University of Ottawa, Canada**

Epidemiologic studies of uranium and other underground miners have consistently shown miners exposed to high levels of radon to be at increased risk of lung cancer. Recent pooled analysis of all North American case-control studies of residential radon have provided direct evidence of an association between residential radon exposure and lung cancer, a finding predicted by downward extrapolation of epidemiological data on underground miners exposed to higher levels of radon, and consistent with toxicological results from animal and in vitro studies.

The pilot study applied the BEIR VI exposure-age-concentration model to Canadian population and exposure data to compute annual lung cancer burden due to radon. The computations were based on data on Canadian population mortality from all causes and from lung cancer, smoking prevalence, relative risk for all-cause mortality and lung cancer due to smoking, and residential radon distribution. The residential radon risks were characterized using the life years lost (LYL), the lifetime risk ratio (LRR), and population attributable risk (PAR). Results were stratified by gender (females, males) and smoking status (ever versus never).

The impact of radon on life years lost (LYL), as represented by the mean LYL, is in the order of 40 days per person. The impacts are higher among ever-smokers (52 days for females, and 58 days for males), and lower among never-smokers (21 days for females, and 16 days for males). The estimates are subject to considerable variability, with over



300 days of life lost for some individuals.

The PAR estimates (representing the fraction of Canadian lung cancer deaths attributable to residential radon) for never-smokers are higher (average PAR of 0.163 for females, and 0.161 for males) than for ever-smokers (average PAR of 0.095 for females, and 0.081 for males).

In 1998, there were 16,268 lung cancer deaths in Canada. The study estimated that 1574 of those deaths can be attributed to residential radon. Thirty per cent of these deaths are preventable.

### **European project on the assessment of burden of lung cancer attributable to radon**

**S. Darby, University of Oxford, UK**

The objective of this study was to present, for each European country, an estimate of the number of lung cancer deaths caused each year by residential radon alone, and by residential radon in conjunction with cigarette smoking. Sarah Darby presented sample calculations for the UK, based on the risk estimate from the collaborative analysis of data from European case-control studies.

Researchers used data from the American Cancer Society on mortality rates by age and sex to obtain the total number of lung cancer deaths each year, and the total number of lung cancer deaths each year excluding those caused by active smoking. To calculate the proportion of lung cancers caused each year by radon, the researchers needed to know the mean usual radon concentration in Bq/m<sup>3</sup> and the proportionate increase in risk per Bq/m<sup>3</sup>.

The number of deaths not caused by active smoking can be subdivided into the proportion caused by tobacco and the proportion not caused by tobacco. Researchers assumed that the relative risk of lung cancer increases by 16 per cent per 100 Bq/m<sup>3</sup> increase in usual radon concentration, regardless of smoking status.

Researchers found that 3.2 per cent of lung cancer deaths in the UK involved radon, with the vast majority being caused jointly by radon and by active smoking. Forty-six per cent of lung cancer deaths caused by radon in the UK involve low ranges of residential radon concentrations.

### **Radon burden of lung cancer in the United States based on the EPA 2003 model**

**B. Johnson, EPA, US**

Researchers at the EPA assessed risk from radon in homes using the BEIR VI age-concentration model, with slight modifications: the model was scaled to yield numerical results midway between the age-concentration and age-duration model results.

The primary measure of risk was the probability of a radon-induced lung cancer death from an exposure to one working level month (WLM). A constant exposure rate was assumed throughout one's lifetime at an occupancy factor of 0.7.

Changes made in the BEIR VI model and by the EPA essentially doubled the risk per working level month compared to EPA numbers from 1992. Results showed that most of the deaths from radon occurred in the ever-smoking category, and the risks are much higher to smokers than they are to never-smokers.

If the ever-smoking prevalence in the population were to decrease, one would see a linear reduction in the probability of fatal lung cancer—but there would still be a fairly high risk. The proportion of radon-induced lung cancers is fairly insensitive to the proportion of ever-smokers, until the number of ever-smokers falls 30 per cent. At that point, the proportion of radon-induced lung cancers shoots up.

Radon-induced lung cancers appear earlier in life and have greater impact on years of life lost. This may also be relevant to global burden of disease estimates for radon in other countries: if a country has different life expectancies, this may affect the results.

While radon mitigation measures are expensive, they do appear to be quite cost-effective when viewed socially in aggregate.

### **BEIR VI projections “on the back of an envelope”: insights for sensitivity analysis and mitigation analysis**

**K. Brand, University of Ottawa, Canada**

Kevin Brand discussed BEIR VI projections for residential radon, presenting an overview of methods and some insights for sensitivity and mitigation analysis.

It is useful to think of the BEIR VI algorithm in two components: predicting excess rate ratio (how radon amplifies age-specific risk); and translating excess rate ratio into an index of lifetime detriment. Factors that determine the excess rate ratio include potency, weighted exposure, dose rate effect, attained age, smoking status, and the mode of extrapolating the dose (K-factor).

Most inputs have unit elasticity with regard to excess rate ratio and index of lifetime detriment. For example, a doubling of potency, weighted exposure, or dose rate effect would simply double excess rate ratio. Two inputs are more complicated: the impact of attained age; and exposure weighting factors.

Perturbation of excess rate ratio input will exert a proportional change in average excess

rate ratio (with the two exceptions noted above), and this translates into a proportional change in several impact indices: excess lifetime risk ratio (ELRR), life years lost (LYL), risk of exposure induced death (REID). Knowing which uncertainty drives excess rate ratio thus tells researchers which uncertainty drives these indices. Mechanistic insight also helps to interpret smoking-specific indices, identify key determinants of difference between US and Canadian analyses, and extrapolate to different populations.

## **Session 4: Current regulatory environment for radon across the world**

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**Chair: H-E. Wichmann**

Appendix A provides background information on the current regulatory environment for radon across the world.

### **UK national radon policy**

**Gerry Kendall, NRPB, UK**

There are two threads to the UK Domestic Radon Programme: remediation of high levels of radon in existing homes; and preventive measures in new houses. UK policy is based mainly on a UK national survey carried out in the early 1980s, which measured about 2100 households. More recent measurements have been more targeted, and estimates of the UK average are still based on this survey. On the basis of this survey, the UK set a radon action level that was 10 times the UK average.

A 1993 survey has suggested that 10 to 20 per cent of householders actually take remedial measures. A new radon program in the UK involves local authorities much more heavily. This approach can bring benefits, although success is very dependent on local commitment. For example, there has been a higher uptake of measurements (25–35 per cent in areas where the local people are interested). The new approach also increases the availability of advice on remediation, and increases the proportion of people who tend to remediate.

### **Swiss radon policy**

**Georges Piller, BAG, Switzerland**

Research conducted by the Swiss program on radon has found that soil is the main source of radon there. Building materials in Switzerland do not produce elevated concentrations of radon. The contribution from domestic water is low.

Swiss radon policy has two main objectives: to reduce radon levels in buildings with the highest concentrations; and to lower the mean value by ensuring that no new buildings are constructed with elevated radon concentrations. Goals of the Swiss radiological protection ordinance include: avoiding elevated concentrations; preventing contamination in new buildings; making a clear delimitation between living and working areas;

establishing remedial programs; and ensuring good collaboration between the confederation and cantons.

Piller outlined the tasks of the Swiss Federal Office of Public Health and the responsibilities of the cantons. The cantons are expected to perform sufficient radon measurements, make plans available to the public regarding radon areas, issue construction specifications, and control radon concentrations after completion of the construction work.

Two new instruments will soon be put in place: the assessment of attributive risk, based on BEIR VI and the new pooling of European studies; and the implementation of recommendations based on an evaluation.

### **A review of national radon policies in Europe and Ireland's policy on and experience of radon**

**David Fenton, IRII, Ireland**

Ireland participated in the European Radon Research and Industry Collaboration Concerted Action 2 (ERRICCA 2) project, aimed at heightening awareness of radon in Europe and providing a mechanism for the coordination and dissemination of scientific and technical knowledge of radon related issues. The project involved 20 participating countries and addressed a number of topics including the mapping and measurement of radon.

Thirteen countries in Europe have set reference levels for radon in homes. Most are between 200 and 400 Bq/m<sup>3</sup> and are advisory (except for Sweden and Finland, where the 200 Bq/m<sup>3</sup> level is mandatory). Switzerland and the Czech Republic have higher mandatory levels of 1000 Bq/m<sup>3</sup> and 4000 Bq/m<sup>3</sup>, respectively.

Reviewing policy on radon in homes in Ireland, Fenton noted that Ireland had established an advisory reference level of 200 Bq/m<sup>3</sup> in 1990. Since 1998, Irish building regulations require that all new houses must have a radon sump, with a barrier required in high radiation areas. Surveys suggest that the public seems indifferent to radon, although this may be changing. Several public awareness initiatives have been tried, including writing directly to people, advertising and placing articles in newspapers, supplements, and professional magazines. So far, the most success has been achieved by engaging with the press and media.

## **Session 5: Mitigation measures and national snapshots**

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**Co-chairs: G. Kendall, Q. Sun**

### **EC's experience on identifying effective mitigation measures and raising public awareness: opportunities for international cooperation**

**Hannu Arvela, Radiation and Nuclear Safety Authority—STUK, Finland**

Speaker presented information from the European Radon Research and Industry Collaboration Concerted Action 2 (ERRICCA 2) project, including case study examples, information on generic solutions, and a summary of radon activities carried out in participant countries.

Good technical knowledge in mitigation is needed before launching into major publicity activities. Media experience has shown that newspaper articles need to be written carefully and should tie in with national campaigns. Articles targeting specific authorities and professional audiences are important. The impact from TV campaigns is variable.

Radon awareness activities in Europe include a guide to buying and selling homes in radon-affected areas of Europe. Progress in building public awareness is the result of long-term efforts by numerous authorities, organizations, companies, and citizens. These efforts include regulatory work; guidance, training, and communication; and research.

Qualified guidance and handbooks on radon mitigation are already available in Europe. The challenge is the application of this knowledge in the new construction environment. In the case of radon resistant new construction, the US has detailed information, including a step-by-step guide called "Building Radon Out." Challenges include the variety of regulations and the building code. There is a need for cooperation with construction experts.

### **Economic analysis and radon remediation**

**Alastair Gray, Health Economics Research Centre, Department of Public Health, University of Oxford, UK**

Alastair Gray discussed the cost effectiveness of radon prevention and remediation, explaining that these measures are undertaken primarily to address health risks and concerns. There is a wide consensus in a number of countries that a cost-effectiveness analysis is the type of methodology that should routinely be used for economic evaluation of health interventions.

Gray reviewed radon remediation costs and outcomes and explained the data inputs used to determine cost effectiveness. Radon remediation was compared with other interventions such as smoking cessation and prevention of heart disease. Smoking cessation appears to be more cost-effective measure than radon mitigation measures in the buildings.

He presented initial results on the cost effectiveness of remediation of new homes,

cautioning that the figures were only illustrative. Much more work is required on the relationship between exposure levels and lung cancer and on factors such as uncertainty, quality of life, action levels, remediation rates, policy options, and differences between countries. He concluded, however, that this type of exercise throws light on the options—adding that it is difficult to make policy recommendations that do not refer to economic arguments.

## **National Radon Activities**

### **Brazil**

Although Brazil has a tropical climate (ventilated houses), high residential radon concentration can be observed, mainly due to high uranium content in soils and construction materials. Recently, a national regulation was approved to recommend remediation actions at workplaces with radon concentration above 1000 Bq/m<sup>3</sup>. A national project is being undertaken to assess radon concentration in non-uranium underground mines.

### **China**

China has implemented national standards on radon, with action levels of 200 Bq/m<sup>3</sup> for new buildings, and 400 Bq/m<sup>3</sup> for existing buildings. China plans to join in the WHO Radon project but requires technical assistance from other countries to carry out its plans for indoor radon mapping.

### **Finland**

In Finland, health authorities are responsible for surveying local indoor radon concentrations and for informing and advising homeowners on radon mitigation. Radon regulations in the National Building Code of Finland have made authorities and homeowners more aware of radon and have helped to improve practices.

### **France**

In 1999, France launched a national plan focusing on those “departments” having an average exposure higher than 100 Bq/m<sup>3</sup>. Radon measurements are performed in buildings receiving the public (such as schools and hospitals). Radon risk management is one of the priorities of the national plan, “santé-environnement,” established by the government in June 2004.

### **Germany**

Epidemiological studies in Germany suggest that protective measures should not be focused only on areas of high exposure: exposures should almost always be kept as low as reasonably achievable. The target value should be specified as 100 Bq/m<sup>3</sup>. Areas should be specified in which protective measures are necessary; and in planning

protective measures, all circumstances have to be taken into account.

### **Greece**

Greece has no specific regulations for dwellings but follows the EC recommendation that action levels be set at 200 Bq/m<sup>3</sup> for new houses and 400 Bq/m<sup>3</sup> for existing houses. There is a regulatory framework for workplaces. Workplaces now under investigation include the fertilizer industry, spas, schools, mines, and underground workplaces such as the Athens METRO.

### **Italy**

Regulations in Italy are only for occupational exposure, where the action level is set at 500 Bq/m<sup>3</sup> (with control activities required for levels between 400 and 500 Bq/m<sup>3</sup>). There are no obligations with regard to residential exposure. Guidelines on all indoor health protection and promotion were established by the Ministry of Health and the Regional Health Authorities. A radon national action plan has been formed, but there is currently no funding.

### **Japan**

In Japan, residential radon has not been considered an urgent issue, and the Japanese government has just started discussing radon regulation. A 2003 report by the Radiation Council suggested that intervention on residential radon is necessary. Discussion is ongoing in an ad hoc government committee, which has suggested a new survey of 2000 dwellings with high radon concentration. At present there is neither a reference level nor an action level in Japan.

### **Norway**

Radon concentrations have been measured in Norwegian dwellings, kindergartens, schools, and drinking water. Approximately 8000 homes were identified as having levels higher than 200 Bq/m<sup>3</sup>, and so far 3000 have been mitigated. Building regulations specify an “upper level” of 200 Bq/m<sup>3</sup>. The mean level in future housing stock should be significantly less than the mean level in current housing stock, and preventive measures are recommended for all new buildings.

### **Poland**

Poland originally encountered problems with radon in relation to occupational exposure of miners, and still measures radon levels in mines. Measurements have also been taken in spas, and were taken in about 3000 dwellings, with an average value found of about 44 Bq/m<sup>3</sup>. Higher concentrations were found in dwellings located in a specific region with existing high levels or specific geology.

### **Russian Federation**

The maximum permissible levels of radon daughters concentration in Russia are 200 Bq/m<sup>3</sup> for existing dwellings and 100 Bq/m<sup>3</sup> for new dwellings. Radon studies in Russia should be conducted by scientific organizations in close cooperation with the regional centres of sanitary epidemiological control. Measurements should take into account concentrations of thoron daughters, as well as the correlation between radon concentrations and other characteristics (e.g., geology).

## **Spain**

The Spanish radon program began in 1988, and good information on radon in Spain has been gathered. However, the radon program is too dependent on the Spanish Nuclear Safety Council and has a very low budget. Researchers at the university are working to ensure quality control by developing common protocols for the evaluation of the different parameters involved. Measurement of radon has been carried out in numerous locations including mines, caves, schools, and offices, but there is no remediation program in Spain and the new building code regarding radon has yet to be passed.

## **Sweden**

Swedish regulations set the action level for new houses, existing homes, and public premises at 200 Bq/m<sup>3</sup>. The action level for workplaces is 400 Bq/m<sup>3</sup>. Water levels must be less than 100 Bq/litre for water to be fit for consumption. Interim targets for radon were adopted by the Swedish Parliament in 1999.

## **Session 6: Shaping the WHO Radon project**

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**Co-chairs: B. Johnson, D. Krewski**

Appendix B provides background information on the policy implications of residential radon.

### **Shaping the WHO Radon Project**

*In this session, D. Krewski offered a summary of the program's main elements, reviewed the original objectives, and presented highlights of the discussion so far. The group discussed some unresolved issues and questions, and established a number of consensus statements. Finally, they reviewed a potential work plan and set up work groups.*

### **Main program elements**

Science:

- Risk models: Develop WHO model for projecting radon lung cancer risk (build on BEIR VI and European and North American combined analyses, including the joint effects of tobacco smoking).
- Radon database: Develop global database on indoor and outdoor radon levels;



## 1<sup>st</sup> Meeting of the WHO International Radon Project – Jan 17-18 2005 Geneva

describe spatial variation in radon levels using mapping techniques.

- Population health impact: Estimate global burden of disease for radon.

Policy:

- Exposure guidelines: Develop WHO guidelines for residential radon exposure levels.
- Cost effectiveness: Conduct economic analyses of alternative mitigation strategies.

Measurement and mitigation:

- Measuring residential radon: Recommend measurement methods for indoor radon.
- Radon reduction: Recommend technologies for reducing indoor radon levels.

Communication:

- Communications: Develop communications materials to promote the WHO program to the public and to national public health agencies.

Program evaluation:

- Effectiveness monitoring: Track reductions in indoor radon concentrations related to radon mitigation.
- Reporting: Complete annual project reports.

## Discussion

Repacholi clarified that the suggestion is that WHO guidelines be developed on radon in various situations, including new and existing homes. These could be similar to the drinking water guidelines. He asked for feedback on this idea.

Kendall noted that they had traditionally observed that radon levels in different countries are so disparate that it is not necessarily appropriate to recommend one target level.

McLaughlin asked if there are guidelines within WHO on the range of risks WHO can recommend for members of the public. He asked if WHO would restrain a group like this from moving outside the normal ranges given as guidelines for other toxicants. He also cited a WHO document called *The Right to Healthy Air*, which states that people who are going to be exposed to substances have a right to be informed of the risks. He explained that giving a number to the public representing the level of radon contamination would mean nothing to them; instead, they should be given information on the risk level. In summary, he suggested that, to harmonize with other WHO activities, there may be a need to quantify the risk.

Repacholi indicated that he did not see a problem with this, as it would be included under “risk communication.”

Another participant noted that radon is not really a concern for nonsmokers, and he wondered if quantifying the risk would create a false perception of the dangers for nonsmokers.

Darby referred to the morning's presentation by A. Gray, which suggested that the most cost-effective health measure would be smoking prevention programs; the next most cost-effective measure would be radon prevention in all new homes. She asked Gray to comment on whether this would generally be the case in all countries, and if so, whether this observation could flavor the guidelines.

Gray responded that it would be possible to estimate cost effectiveness with some basic information from each country: distribution of radon, cost of remediation, and some life tables and lung cancer incidence rates. What will vary from one country to another are the opportunity costs. In a low-income country with more competition for health dollars, the situation will be very different than it will be in a country like Canada.

Strand said that a 2003 cost-benefit analysis done in Norway found the cost of mitigation would be approximately \$270,000 per life saved. The average life extension was approximately 14 years, at a cost of approximately \$20,000 per year of life. He noted that radon levels in Norway are higher than in the UK. These numbers apply to both existing and future homes. It was not necessarily more cost-effective to intervene for new homes only.

H. Walker (UK) spoke from the point of view of a government official in a public health department, discussing what she would like to see from a WHO document. "What we need to have is the information in order to make our own decisions," she said. Useful information would cover the range of risks, possible remediation measures, measurement information, and the global burden. The only information that will work on a global level will be guidelines and protocols that can be used by individual member states.

## **Project scope and objectives**

Scope: establish a three-year global project, with all key international and national partners participating, to identify and promote programs that reduce the health impact of exposure to residential radon.

Objectives:

- Estimate the global health impact of exposure to residential radon.
- Create a global database of residential radon exposure.
- Identify effective measures to reduce radon's health impact.
- Promote sound policy options and mitigation programs to member states.
- Raise public and political awareness about the consequences of exposure to radon.
- Monitor and periodically review mitigation measures to ensure effectiveness.
- Provide annual reports.

## **Highlights of discussion regarding questions 1–4**

*Question 1: What are the benefits of an international action agenda on radon?*

- Provide scientific consensus on radon health risks.
- Promote public awareness of health risks associated with residential radon.
- Promote action at the national level.
- Increase homeowner compliance with voluntary/advisory radon guidelines.
- Set minimum criteria for radon risk management (but allow for country-specific needs).

*Question 2: If recommendations were developed to encourage more risk reduction from radon, what would they say?*

- It is better to install mitigation devices at the time of construction, rather than retrofit.
- Building codes provide a natural point of intervention for control of residential radon (radon levels have increased substantially in Norway because of the use of aerated concrete in foundations; indoor radon levels are also increasing in Finland).
- Radon testing and mitigation might also be required when an existing home is sold.
- Control measures should focus on medium exposure levels, which contribute most to the overall radon lung cancer burden.
- Since the vast majority of radon-related lung cancers occur in smokers, consideration should be given to the role of tobacco smoking in radon risk reduction programs.
- Unburned brick and open floors in homes in developing countries can lead to elevated thoron levels.
- Since resources will be required to implement radon risk reduction measures, it is important to demonstrate the cost effectiveness of such measures (cost effectiveness will vary with radon levels).
- Consideration should be given to both guidelines (as is the case for homes in Britain) and enforceable regulations (as is the case for workplaces in Britain).
- Both voluntary and enforceable guidelines may be useful for residential exposure (as is the case in Switzerland, where homes exceeding 1000 Bq/m<sup>3</sup> must be mitigated).
- Should mitigation focus on new homes only, or include existing homes?
- Radon-affected areas with high radon levels (defined as those areas in which one percent of homes exceed the action level in Britain) might be selectively targeted for testing.
- Government grants might be used to support radon mitigation actions in cases of need (may require a means test to administer this type of public support for mitigation).
- Should schools be identified as an environment that requires special consideration for radon mitigation?
- Should workers be included within the scope of this project?
- Should thermal spas with high radon content in the water be included?
- Should new buildings have a more stringent radon reference level than existing buildings? (Some EU countries have two reference levels, with a lower level for new buildings.)
- All new homes constructed since 1998 are required to have a radon sump in Ireland (nonetheless, 10 per cent of new homes still have radon levels above the action level

## 1<sup>st</sup> Meeting of the WHO International Radon Project – Jan 17-18 2005 Geneva

of 200 Bq/m<sup>3</sup>).

Krewski asked the group for feedback on whether schools, workers and thermal spas should be included in the scope of this project.

Walker replied that all three categories should be included.

H. Landfermann (Germany) said that schools should be treated like normal living spaces. For workers, there are two kinds of places: a workplace like a factory or another kind of space (such as the workplace of water workers). Thermal spas are not a normal workplace, so there should be special conditions for these workers.

E. Ettenhuber (Germany) recommended specifically addressing the radiation exposure of workers in environments that can be influenced by operation and management. All other workers should be treated like the general public.

Because the scope of the project was extending beyond initially planned one, the group agreed to rename the project title into "**International Radon Project**".

Commenting on the issue of schools, one participant noted that the issue of childhood exposure to radon and its role in lifetime risk is still unclear. A participant commented that more research is needed to determine whether radon can be linked to health problems other than lung cancer (e.g., leukemia). Kendall agreed that it would be nice to have epidemiological information on the risks of long-term exposure.

Darby pointed out that the term “reference level” and “action level” are equally used. In the past these terms have been misunderstood, because people have assumed that anything under those levels is “safe.” There can be very cost-effective intervention levels below the levels that had been quoted, and suggested some slightly different terminology such as “maximum reference level” or “maximum action level.” She added that the WHO-2000 guidelines for Europe give a limit of 1000 Bq/m<sup>3</sup>. This is not a recommended level but a “no go” area where immediate action must take place. She urged putting the word “maximum” before all numbers.

*Question 3: What are some key opportunities for WHO and us to raise visibility for such recommendations?*

- Information programs could be developed describing radon as a public health issue.
- Future (open) meetings could be held to develop the WHO International Residential Radon Project.
- Education materials are available in a number of countries: these might be used to develop an “international” radon information kit.

*Question 4: How can we get started now to develop and implement a step-by-step process?*

## 1<sup>st</sup> Meeting of the WHO International Radon Project – Jan 17-18 2005 Geneva

- Complete a consensus report from the present meeting.
- Draft an action plan for the WHO residential radon project.
- Obtain international residential and outdoor radon levels from UNSCEAR.
- Reference levels for radon in 20 European countries have been tabulated as part of ERRICCA 2 (advisory levels are largely between 200 and 400 Bq/m<sup>3</sup>).

### **Communication**

Krewski presented a number of issues that had come up in the general discussion that relate to communication:

- Information should be made available to the public on how to determine radon levels in their homes, and on ways in which radon in homes can be reduced.
- There is a need to put residential radon lung cancer risk in perspective, perhaps by comparison with other agents included in the WHO GBD program.
- Studies have indicated that people may not elect to take voluntary action to reduce radon in their homes, although this depends on the level of knowledge that they have on radon health risks.
- Radon is the largest source of environmental exposure to ionizing radiation (approximately 40 per cent of total exposure in Switzerland).
- Radon is the second leading contributor to the global lung cancer burden, after tobacco smoking.
- Tools developed by the ERRICCA 2 Project should be considered: websites, public awareness, protection of new buildings, mitigation, mapping, and measurement.

Krewski suggested that the WHO Europe communications guidelines with respect to radon could be used as a resource when developing the communications program for this project.

1993 WHO Europe Communications Guidelines:

- Countries should collect baseline information on existing attitudes and perceptions about radon before initiating a risk communication program.
- The goal of the radon communications program should be to provide accurate scientific information to reduce radon health risks.
- Continuous evaluation and improvement of the risk communication programs should be undertaken in order to achieve the overall communications goals.
- For special target audiences, appropriate (and possibly different) radon risk communication messages should be prepared.
- Radon risk communication efforts should be linked to key issues, such as the availability of qualified radon contractors and testing services.
- Messages should be repeated and reinforced; a one-time message will not result in behavioural change.
- Countries should be encouraged to share information and discuss new findings in the

area of radon risk communication.

## **Measurement issues**

Krewski highlighted the following issues related to measurement:

- Although homeowners may want quick monitoring results based on short-term measurements, it is difficult to determine long-term exposure levels on the basis of short-term measurements.
- Adjustment for residential radon exposure measurement error results in increased estimates of the lifetime relative risk. What are the implications of exposure measurement error for estimating the population attributable risk?
- Spatial patterns in radon concentrations may be related to geographical characteristics, which may help in identifying “radon affected areas.”
- Twenty EU countries have carried out radar mapping to some extent under the ERRICCA 2 Project (by measuring indoor radon gas concentrations, by soil gas measurements, by geological mapping, and by other radiological techniques).
- Maps can be used to plan radon campaigns, to distribute radon dosimeters, for radon prevention in new buildings, and to increase public awareness.
- Mapping studies have designated one third of Ireland as “high radon areas” (HRAs). Such information will be very useful in assessing the global impact.
- Identification of high radon areas by direct measurement may take some time (10 years in Switzerland).
- Can measurements of less than one year be used reliably to predict annual residential radon concentrations (possibly using seasonal adjustment models developed by Pinel et al., 1995, and Krewski et al., 2004)?

## **Modeling issues**

Krewski highlighted the following issues related to modeling:

- Develop updated radon risk protection models based on BEIR VI (considering recent modifications by US EPA).
- Develop updated risk projection models based on combined analysis of residential studies, including the ongoing combining of European and North American studies.
- Consider the use of simple approximations to these models, which provide insight into how different indices of risk are interrelated, and on how to extrapolate results among different conditions.
- Characterize sources of uncertainty in radon risk projections.

Regarding the suggestion to just adopt the BEIR VI models, Krewski said that there are some limitations to this approach: built into those models is a strong inverse dose rate effect. The inherent embedding of an inverse dose rate effect (because the numbers are

based on miner-level exposure data) may be inappropriate for residential levels.

Another issue is the interaction with tobacco smoke even at low levels of radon exposure. Development of the WHO model may involve some tweaking of the existing models.

Regarding the information on European miners, Tirmarche said that there are now updated values—more informative than those sent as data for the BEIR VI models. She added that the European program shows no inverse dose rate effect; but with more precise information on individual miners' exposure, there is an increase in the risk coefficient in comparison to what was there in the past. She expressed support for some updating, if possible.

Krewski said that if updated data is available, it will be easy to update the analysis done in BEIR VI and beyond. He added that some modification of the existing suite of models, taking the best of all possible worlds and using some updated data, is probably the best approach for this project.

## **Cost issues**

The following issues arose with respect to cost:

- Who (government, homeowners) should pay for the costs of radon mitigation programs, both in terms of testing and mitigation?
- Cost-effectiveness analyzes can be used to help choose among alternative radon mitigation strategies.
- Other economic analysis approaches include cost-utility analysis and cost-benefit analysis (which identifies costs to health outcomes).
- Cost-benefit analyzes conducted by the US EPA suggest a favorable cost-benefit ratio for radon mitigation of about five-fold (valuing a lung cancer death at about \$4 million)
- Costs include: testing, remediation, maintenance, medical treatment and program administration.
- Smoking cessation programs are notably more cost effective than radon mitigation (based on Alistair Gray's analysis).
- Norwegian analysis indicated a cost-effectiveness of \$270,000 per life saved, and \$20,000 per life year saved; LYL were estimated to be 14 years.

## **Consensus statements**

*Before arriving at these consensus statements, the group worked from a list of draft statements which they discussed at length. This discussion is recorded in Appendix C.*

The following consensus statements were established:

- For many people, radon represents the largest source of exposure to ionizing radiation in humans.
- Radon is a known cause of lung cancer in humans.
- Radon is an important contributor to the human lung cancer burden, after tobacco smoking.
- Radon is considered to be responsible for some 10 percent of the human lung cancer burden in developed countries/worldwide (will differ between developed and undeveloped countries).
- The BEIR VI Report estimated that there are approximately 22,000 deaths annually from radon in the United States alone. [*Add European results here.*]
- Radon related lung cancer risk is affected by tobacco smoking, with most radon related lung cancers occurring in smokers; however, radon is one of the leading causes of lung cancer in nonsmokers.
- Radon should be a priority public health issue for national environmental and radiation safety programs.
- There is a need to carefully evaluate the costs and benefits of national and international radon mitigation programs.
- Based on existing knowledge of geological conditions and building types, and consideration of the total lung cancer burden, countries should consider developing cost-effective national or regional policies on testing and mitigation.
- Where appropriate, countries should build capacity within the public and/or private sectors to provide testing, mitigation and radon-resistant new construction.
- Where appropriate, countries should issue and widely disseminate statements that address the importance of radon risk reduction and the steps that can be taken to reduce such risks.
- Countries should explore ways to address radon health risks in a cost-effective manner, considering both the installation of preventive measures in new buildings and remediation of existing buildings.
- National governments should team with other stakeholders to ensure radon risk communication messages are delivered from multiple sources.
- Governments should strive to include radon health messages and action steps with other national efforts on green buildings, housing policy and the built environment.

### **Towards the WHO radon guideline**

The group discussed the following possibilities for WHO radon guidelines:

- Immediate remedial action should be taken at levels exceeding 1000 Bq/m<sup>3</sup>.
- A guideline should be established of a maximum of 400 Bq/m<sup>3</sup> for existing homes.
- A guideline should be established of a maximum of 200 Bq/m<sup>3</sup> for new homes.
- Efforts should be made to reduce radon to even lower levels, where possible, since there is still some risk of lung cancer below the above guidelines.
- Risks should be given at different proposed guideline levels for smokers and nonsmokers.



1<sup>st</sup> Meeting of the WHO International Radon Project – Jan 17-18 2005 Geneva

- Should the guidelines explain the role of smoking in relation to radon risk?

### **Next steps**

At the end of the meeting, six work groups were set up and a three-year plan for work on the project was discussed (see Appendix D)

## **Appendix A. Discussion leading to consensus statements**

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*The group agreed to keep the first proposed consensus statement: “Radon is a known cause of lung cancer in humans.”*

*The group discussed the statement, “Radon is responsible for some 10 per cent of the human lung cancer burden worldwide.”*

Brand (Canada) suggested that this statement might be misleading, and explained that the numbers to date have generally been from developed countries. Population-attributable risk will be a function of the lifetime risk of getting lung cancer, and this would be different in underdeveloped countries.

The moderator explained that the group wanted to make a statement that this is a significant population health issue. He suggested that a better approach might be to give a few country-specific examples and indicate that there is a fairly significant burden in terms of lung cancer mortality.

A participant suggested rewording the sentence to read: “Radon is considered to be responsible for about 10 per cent of human lung cancer.” He noted that most cases of lung cancer come from much lower doses than are being considered here and it is unknown whether these low doses cause lung cancer.

Kreienbrock (Germany) asked if it would be possible to avoid having extreme numbers in this document. There are different radon exposures in different countries; there are differences between developed and not developed countries; and the number of lung cancer deaths is related to the risk model used in calculations. The percentage of lung cancer deaths could vary, so a more general statement would be better than a concrete number (10 per cent).

It was noted that the fact sheets would have to be lay-friendly, with information presented in simple terms for the press, public, and politicians. The public relations people are responsible for making the science lay-friendly when creating the fact sheets, but drafts will be circulated within this group to ensure that nothing has been lost.

The moderator said that if the figure of 10 per cent was used, there would be some qualification to reflect the uncertainties that had been discussed. If a number is added (like 22,000 deaths in the US), some comparable numbers from other countries should be added to make the statement more international.

A participant from Finland suggested a compromise: state that radon is one of the most important causes of lung cancer after tobacco. This would emphasize its importance, but avoid giving an exact number.

*The group discussed the statement, “Radon related lung cancer risk is affected by*

*tobacco smoking, with most radon related lung cancers occurring in smokers; however, radon is one of the leading causes of lung cancer in nonsmokers.”*

Darby (UK) suggested that the group may have dismissed passive smoking a bit too quickly. This issue has caught the public imagination. She suggested a statement such as “preliminary estimates indicate that radon causes more lung cancer than passive smoking.” Repacholi stressed that the fact sheets must be based on information contained in a publication that is generally accepted.

Tirmarche (France) commented that medical epidemiologists have indicated that the most important information for them is that there is a synergistic effect between a well-known carcinogen—tobacco—and a new carcinogen. She asked if the group could include this information in one of the statements. Repacholi agreed that the synergistic effect should be reflected.

Regarding passive smoking, McLaughlin (Ireland), advised caution, stating that the major health impact of passive smoking is not lung cancer but cardiovascular disease. Emphasizing the impact of passive smoking as being related to lung cancer may go against the passive smoking prohibition that has been imposed in a number of countries. He said that he was in favour of referring to passive smoking, but stressed that the group should be cautious in how it does so.

The moderator expressed concern about referring to passive smoking, since most of the studies had not looked at this issue. Drawing comparisons and including statements about the synergistic effects could cause confusion. He added that the US had done many basic comparative statements regarding radon deaths versus other causes of death (e.g., more people die from radon every year than die from drunk driving). Although this could ultimately be a communication tool, meaning those comparisons within the consensus statements might not be advisable.

Tirmarche (France) suggested that the group needed more information in order to make this decision.

*The group discussed the statement referring to 22,000 deaths annually from radon in the US*

Field (USA) questioned this number and suggested that the group either give the EPA number of 21,000 or the BEIR VI estimate of 19,800. The group discussed how the number 22,000 was derived. It was suggested that ultimately they would quote a number of different figures from a number of different countries in the form of a table in a fact sheet (with footnote references and precise sources). Repacholi agreed that this does not need to be present as a consensus statement.

Gray (UK) commented on a proposed consensus statement that radon should be a priority public health issue for national and departmental radiation safety programs. He suggested that this statement was pre-emptive in light of the fact that the group was

recommending cost effectiveness analyses of programs. There are larger priorities for some countries. Perhaps, instead, the priority should be to assess the costs and benefits of different prevention and remediation programs.

The moderator noted that many of these recommendations, including this one, were taken from the WHO Europe recommendations that were issued in 1993.

Kendall asked if the group should include another consensus statement indicating that for many people radon is the largest source of exposure to ionizing radiation. The group agreed that this would be a good statement to include.

Another participant suggested that the statement beginning “Radon should be a priority public health issue” should be the very first statement and should include reasons.

A participant expressed doubts about the sentence on strong synergistic interaction. He added that if the baseline is multiplicative, then there is no interaction. Another speaker suggested the following wording: “Radon causes bigger absolute risks in smokers than nonsmokers.” A third favored a less technical statement: “Radon-related lung cancer risk is affected by tobacco smoking.”

*The group discussed a statement that radon should be a priority public health issue.*

Piller (Switzerland) proposed that they go beyond radiation protection and include indoor air quality programs.

*The group discussed a statement indicating that countries should develop national or regional policies on testing and mitigation.*

A participant from Germany suggested that the group advise countries to build up protective regulations for buildings.

The moderator noted that the US does not have a regulatory program, and explained that in order to keep the statement more general, the idea was to allow for different mechanisms, depending on the country’s goals.

Krewski suggested that rather than write a bullet suggesting that national agencies develop guidelines for radon exposure, the group should leave room for states to adopt the WHO guideline that it is now developing.

Darby suggested rewording the bullet to include the phrase “consider developing cost-effective national policies based on the total lung cancer burden in a country and cost-effectiveness considerations.”

Another participant expressed support for the comment about total lung cancer burden, because it would be inappropriate to advise some countries to spend a lot of money on radon control if their lung cancer burden is comparatively low in relation to other

problems.

*The group discussed a statement that countries should issue statements that address the importance of radon risk reduction and the steps that can be taken to reduce such risks.*

Auvinen (Finland) said that he would not advise making this recommendation to countries like Sudan, Iraq, or Indonesia (i.e., that top officials instruct the country to take action on radon). The question is whether this statement is meant to cover all countries.

*The group discussed a statement that countries should explore ways to address radon health risks in new and existing buildings.*

Kendall remarked that changing building codes effectively means moving towards bringing down the population dose—not looking at the highest risks from radon.

A participant suggested giving an example of a cost-effective measure, such as “installing radon preventative measures in new buildings.” The moderator noted that the housing industry in the US would not consider this cost-effective.

Gray suggested stating that countries should explore ways to address radon health risk in a cost-effective manner. The statement should then set out a range of issues that should be considered, including population and individual risk (which could be addressed through prevention and remediation). It was agreed that they would include this idea in the statement.

Darby suggested that it read “considering both the installation of preventive measures in new buildings and reduction and remediation in existing buildings.” However, it was noted that this phrase does not address exposure levels explicitly.

A participant requested that the group include a statement indicating that when remediation measures are taken, one should attempt to make as substantial a reduction as possible, and not just aim to fall below a target value.

*The group discussed a statement indicating that national governments should team with others on radon risk communication.*

Walker (UK) suggested that the statement be revised to read “national governments should team with stakeholders” rather than referring to “NGOs and other trusted organizations.”

Chambers (Canada) asked if any government agencies in Europe had been involved in lawsuits because of national standards. Is there any issue with liability when promoting these guidelines?

Krewski suggested that a lawsuit could be a possibility: for example, someone in Canada could contract lung cancer and have a probability of causation calculation done

## 1<sup>st</sup> Meeting of the WHO International Radon Project – Jan 17-18 2005 Geneva

suggesting that it may have been related to a high radon exposure. They could then sue the federal government for having a guideline which is five and a half times that of the US. But this issue is not necessarily relevant to this project.

*The group discussed a statement indicating that governments should link radon with other efforts on housing and indoor air quality.*

It was agreed that radon should be seen as part of the larger issue of indoor air quality.

Tirmarche expressed concern that some statements were focusing mainly on new buildings, with the goal of getting radon down to very low levels. She commented that many countries have not yet implemented large-scale campaigns and still have a large number of high-exposure houses. There should also be a campaign that supports the detection of high-exposure situations.

Another participant commented that this points to the need for more comprehensive measurement programs in order to identify the relevant homes. Tirmarche suggested that governments must not just engage in communication—they also have a responsibility to implement large national measurement campaigns.

Repacholi responded that it may not be possible to tell governments what they must do, but they could be advised about what they should do. The moderator said the US approach has been to make this an individual responsibility (i.e., people should test their own homes).

A participant suggested a statement indicating that “homeowners should have the opportunity to obtain measurements of the radon levels in their homes.” This covers all levels of radon exposure.

Kendall said that the point should reflect the need to reduce both the collective dose of radon and the risk to those who are at the highest levels of risk. The last bullet could be modified to read: “In addition to reducing levels generally, those at the highest levels of risk...”

Another speaker noted that homes at all levels of radon exposure should be identified, not just homes with the highest levels of exposure. But a high dose in one country may not be high in another country.

It was suggested that the group reword the bullets to find a balance between focusing on the small number of homes with a very high exposure and focusing on the broader population health impact of homes with intermediate exposure levels. Another speaker argued that even low levels of radon must be included and should be reduced.

## **Appendix B. Management of the Project: Working Groups, Timelines**

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### **Project Building-Blocks**

*Main elements (building blocks) of the International Radon Project include the following:*

1. Science
  - Risk models—develop “WHO” model for projecting radon lung cancer risk (build on BEIR VI and European and North American combined analyzes, including joint effects of tobacco smoking)
  - Radon database—develop global database on indoor (and outdoor?) radon levels; describe spatial variation in radon levels using mapping techniques
  - Population health impact—estimate global burden of disease for radon
2. Policy
  - Exposure guidelines—develop WHO guidelines for residential radon exposure levels
  - Cost effectiveness—conduct economic analyzes of alternative mitigation strategies
3. Measurement and Mitigation
  - Measuring residential radon—recommend measurement methods for indoor radon
  - Radon reduction—recommend technologies for reducing indoor radon levels
4. Communication
  - Communications—develop communications materials to promote program to the public and to national public health agencies
5. Program Evaluation
  - Effectiveness monitoring—track reductions in indoor radon concentrations related to radon mitigation
  - Reporting—annual project reports

According to the main elements above, Working Groups were formed as follows:

1. Risk assessment (including tasks on risk modeling, GBD, and global radon database)
2. WHO exposure guidelines
3. Cost effectiveness (framework + analysis)
4. Measurement and mitigation
5. Risk communication (including education and training)
6. Program coordination and evaluation

[All groups should identify research and information needs as part of their work]

**Working Group composition<sup>†</sup>**

<b>Risk assessment</b>	<b>WHO exposure guidelines</b>	<b>Cost effectiveness</b>	<b>Measurement and mitigation</b>	<b>Risk communication</b>	<b>Program coordination and evaluation</b>
<b>Chairs: J. Zielinski S. Darby</b>	<b>Chair D. Fenton (to be confirmed)</b>	<b>Chair A. Gray</b>	<b>Chairs: B. Field, W. Angel (Measurements – M1 Mitigation - M2)</b>	<b>Chair J. McLaughlin</b>	<b>Chair H. Zeeb</b>
M. Tirmarche H. Paretzke D. Chambers M. Kreuzer L. Kreienbrock K. Brand D. Krewski M. Zhukovsky B. Shang L. Veiga D. Hill M. Pavia E. Wichmann J. Puskin S. Akiba B. Field F. Bochicchio	J. McLaughlin E. Ettenhuber G. Kendall A-L Söderman T. Strand B. Johnson H. Yonehara F. Bochicchio	K. Brand T. Strand B. Johnson Q. Sun I. Makelainen D. Krewski	H. Arvela (M 1, 2) C. Scivyer (M 2) Y. Yamada (M 1) G. Kendall (M 1) T. Strand (M 1, 2) E. Ettenhuber (M 1) G. Piller (M 1, 2) D. Steck (M 1) G. Fisher (M 1, 2) J. Jankowski (M 1, 2) L. Quindos (M 1, 2) J. Tschiersch (M 1) Q. Guo (M 1) W. Zhuo (M 1, 2) B. Shang (M 1, 2) M. Zhukovsky (M 1) S. Tokonami (M 1, 2) I. Chell (M 1, 2) P. Jenkins (M 1,2)	V. Koukouliou A-L. Söderman G. Piller H.H. Landfermann L. Quindos Q. Sun T. Strand B. Johnson H. Walker D. Fenton N. Korol Z. Carr F. Bochicchio	B. Johnson H. Walker M. Repacholi D. Krewski G. Piller H. Paretzke Z. Carr



1<sup>st</sup> Meeting of the WHO International Radon Project – Jan 17-18 2005 Geneva

			D. Chase (M 1, 2) W. Ringer (M 1, 2) F. Bochicchio		
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†As of January 18<sup>th</sup>, 2005

**Timelines and deliverables for 3-year project planning (2005–2007)****Year 1 / Jan 2005–Dec 2005**

- Develop WHO residential radon risk projection model
- Preliminary GBD estimates (based on approximate methods: need average radon concentration, lifetime risk of dying of lung cancer, prevalence of ever-smokers, life-expectancy, geometric standard deviation of indoor radon levels also useful)
- Establish global radon database
- Review current residential radon exposure guidelines, and recommend WHO radon guidelines
- Review current radon measurement methods
- Review current methods of radon reduction
- Outline main elements of communications strategy
- Develop framework for cost-effectiveness analysis
- Consolidate findings into first annual report

**Year 2 / Jan 2006–Dec 2006**

- Conduct GBD analysis for radon
- Map global residential radon levels
- Conduct cost-effectiveness analysis of alternative radon mitigation strategies
- Complete communications strategy and develop communications materials, including radon fact sheets
- Second annual report

**Year 3 / Jan 2007–Dec 2007**

- WHO Radon “Handbook” describing radon as a global population health issue (with input from all workgroups)
- International symposium on WHO Radon Mitigation Program (showcasing WHO Handbook)
- Program evaluation (impact on national public health agencies, changes in building codes, reduction in exposure, other impacts)
- Third annual report

## **Next Steps**

- Prepare WHO meeting report [Jan Zielinski, Zhanat Carr, Dan Krewski, Mike Repacholi, Anette Preuss, Kevin Brand]—due March 31, 2005
- Prepare project work plans [Working Group Chairs] — final, June 30, 2005
- Updated budget to be prepared [WHO Geneva]—end March 2005
- Schedule next annual meeting [WHO Geneva]—January 31–Feb 02, 2006 in Geneva
- Four page fact sheet on radon (what radon is, characterizes health effects, testing and mitigation techniques known and easily implemented, cost effectiveness of exposure reduction, raise awareness, WHO plans) [WHO Geneva] — end March, 2005
- Press conference to for media advise on WHO IRP project [WHO Geneva]—end of May, 2005.