RADON IN DWELLINGS: EXPOSURE AND RISK ANALYSIS

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The incentives for interest in the question of indoor radon (and for very substantial work in this area) are clear: a very broad range of concentrations is observed inside buildings, particularly in homes, and even the average concentration has an estimated risk that is large by comparison with most environmental risks. There is estimated to be a chance of about one in a thousand for the average member of the population to contract lung cancer from indoor radon daughters. And significant numbers of people in many countries receive much higher exposures, corresponding to individual risks of lung cancer exceeding one per cent.

There are in fact four broad topics we could address on radon. The first is the question of the actual distribution of radon concentrations inside buildings, particularly in homes. The second is the factors that influence indoor radon concentrations, primarily the source strength for radon entry, ventilation rates, and behavior of the radon decay products. Third is the question of health effects of radon decay products indoors. And fourth is the interesting question of strategies for reducing indoor radon concentrations, which resolves itself into three or more major issues, of which I list three. One is the interesting possibility of geographic assessment as a means for locating a large percentage of those houses that have high radon concentrations. A second question is that of remedial actions that could be taken to reduce concentrations in existing homes and corresponding measures for new homes. The third issue is the regulatory framework for controlling indoor radon concentrations.

A substantial amount of work leads to the conclusion that there is a very wide range of concentrations, which is reasonably well characterized by a lognormal distribution. This extends to rather high concentrations corresponding to large risks. Data from the UK, FRG, Sweden, USA, Canada and many other countries support these conclusions.

For a given source strength the ventilation rate rather directly affects indoor radon concentrations. But taken as whole, measurements indicate that the major factor causing the broad distribution in concentrations observed is the source strength rather than the ventilation rate. Of main interest is radon from soil, although building materials and water in some cases can contribute substantially to the indoor concentration. It appears that the radon from soil is the dominant contributor in most cases, and a principal question is the mode of transport of radon from soil into the house. There is a general agreement based on work from several countries over the past several years that the most important mechanism for radon entry into homes, at least homes having a high level of concentrations, is not diffusion but pressure-driven flow of soil gas that carries radon from the soil into the homes. On the one hand this implies that the same environmental factors that drive infil-

tration (i.e., pressure differences developed because of temperature differences or winds) also drive the flow of radon into homes. The result is that there is not such a nice connection necessarily between ventilation rate and indoor radon concentration as we would like. But on the other hand the importance of pressure-driven flow affords an opportunity for controlling the entry of radon into homes by means such as sealing or depressurizing the understructure of the house.

The discussion of radon decay-product behavior covers a very complex issue, including the behaviour of individual daughters, their charge states, and most importantly their size distribution and unattached fraction. Assuming that these two latter factors, the size distribution and unattached fraction, are within the "normal" range, there seems to be agreement that the potential alpha-energy concentration (PAEC) is a reasonably good measure of effective dose. But if the situation is unusual, for example if air cleaning methods remove particles very effectively from the space, then the PAEC may not give a very effective measure of dose. In particular the fraction of radon daughters removed, as measured by decrease in PAEC, may overestimate the reduction in dose to the lung.

The work on factors influencing concentrations suggests that the most effective remedial or control measures are probably, first, source reduction (with particular attention given to controlling the entry of radon from soil into homes) and secondly, ventilation. Of these source reduction is probably more effective because it has such a strong influence on the rate with which radon gets into homes. Lastly, the effectiveness of air-cleaning removal of particulates as a control measure is somewhat questionable. It appears clear that it does reduce the dose to the lung, but perhaps not as effectively as given by a simple measure of potential alpha-energy concentration.

In regard to health effects, there appears to be general agreement that both epidemiology and detailed dosimetry of the lung lead one to comparable conclusions, i.e., within a factor of about three, the same dose-response factors are found. There is still definite interest in trying to elucidate or confirm these dose-response factors in "environmental" situations, an interest that several groups world-wide are pursuing.

Finally there is the broad question of strategies. The variability observed in source strength from one area to another,or from one type of soil to another, suggests the efficacy of trying to use geographic or geologic assessment as an guide for locating most of the "high radon" houses. This would be based on measures or indications such as radium content of the material surrounding the houses, permeability of the soil, and understructure type. However, it must be recognized that even within a given area there is substantial variability, so that assessment based on these indications has to be confirmed for individual houses. But in spite of this requirement, geographic charactarization might be an effective means for helping to locate most of the houses with high concentrations. As has already being mentioned with respect to control measures, it appears that source control is most effective, but that ventilation (and perhaps air cleaning) can be important components of a control strategy.

With respect to the very important question of regulatory strategies, a major feature of developing frameworks appears to be that two

levels are usually considered. One is the remedial action level applying to existing houses, a level that is usually considerably higher than the average concentration that we observe in houses or that we would find acceptable in new houses. In addition, a lower level may be selected for application in new homes. There would therefore be a two-component structure from the regulatory point of view. The fact is that the radiation protection community is moving very quickly in this area, much more quickly than action on most other questions of indoor air quality. There are still significant questions on selection of specific action levels, on how to identity high houses or high areas, on determination and selection of specific remedial action measures, and - perhaps most difficult - on the question of who is responsible for solving the problem.

Conclusions

1. Many countries have now observed that indoor radon concentrations are approximately lognormally distributed, often with a fraction of the general population exposed to very high levels of radon daughters.

2. The observed range of indoor concentrations among buildings is caused, in order of importance, by variability in the source strength (the rate at which radon enters the interior space), by differences in the ventilation rate, and by differences in removal of radon daughters formed in the indoor atmosphere. Control measures follow approximately the same order of effectiveness, at least in homes with high levels: source control has the greatest influence, ventilation has lesser influence, and air cleaning has questionable effect.

3. The epidemiological and dosimetric evidence forms a fairly consistent picture, yielding dose-response factors for environmental exposures that agree within about a factor of three and implying that - in many countries - thousands to millions of the general public are suffering added risk of lung cancer - due to radon-daughters exposures-exceeding 1% over their lifetimes.

4. Based on present knowledge of the factors affecting indoor concentrations and of the associated health effects, considerable progress is being made in developing strategies to locate and reduce excessive concentrations in existing residences and to prevent such levels in new buildings. These strategies include guidelines for allocation of responsibility and for acceptability of indoor levels, as well as specification of means for identification and control of cases that may have high concentrations.

References

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