A SURVEY OF INDOOR EXPOSURE TO RADON IN SOUTH AFRICA

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1. INTRODUCTION

Radon is a noble gas which is naturally radioactive. Isotope ^{222}Rn decays with a half-line of 3.8 days to a series of radioactive daughter products which exist as respirable sized particles. Radon in itself poses few health problems, since it is not absorbed by and does not attach to surfaces when inhaled. The particulate daughter products are electrically charged and will attach to the surfaces of the respiratory organs where they decay by alpha particle emissions, imparting intensively ionising radiation to the surrounding tissue. Alpha rays cannot penetrate the outer layer of the skin and are therefore only a cause for concern if deposited internally.

Radon concentrations in air are measured in Bequerel per cubic metre (Bq/m^3). When radon is in radio-active equilibrium with all its short-lived daughter products, it is called an equilibrium equivalent concentration (EEC). It is seldom true that full equilibrium is achieved and the measured radon concentration has to be corrected with an equilibrium factor which has a value between 0 and 1, and is equal to the ratio of potential alpha energy for the actual daughter concentration present to the total potential alpha energy of an equilibrium mixture of radon and daughters. The radon concentration is also expressed in working levels (WL). One WL equals 3700 Bq/m^3 (100 pCi/1) of radon in equilibrium with its daughter products. Exposure to 1 WL for 170 hours (the number of working hours in a month) is called a working level month (WLM).

2. SOURCES

Radon is a product of the natural decay of uranium which is present in variable concentrations in the environment. In chemical terms, the concentrations of radon in nature are negligible, but, because of its radioactive properties, it can be detected at levels of 1 Bq/m^3, which is equivalent to 2×10^{-16} g/m^3.

Radon originates from its parent nuclide present in the soil and building materials, and, because of its gaseous nature, diffuses through the pores in the media into the atmosphere. The large volume of soil underneath a house is usually the primary source of radon entering the house.

Out of doors, the radon is rapidly dispersed and diluted in the free air. Indoors, however, radon is confined and concentrations are significantly higher than outdoor concentrations, typically by a factor of ten. Materials or soils rich in uranium or radium such as certain granites and wastes from uranium mines are prime sources of radon.

3. HEALTH EFFECTS

Human health is affected by intense radiation dose to lung tissue. These were first observed in the uranium miners in Czechoslovakia and later also in the USA and Canadian miners. The exposure-effect relationship was uncertain due to the fact that actual radon exposures were not well documented. The long and uncertain latent period (5-15 years) between exposure and the development of radiation induced cancers, and the effect of smoking and the role of other synergistic agents in the mine such as diesel smoke, are complicating factors.

The values of the risk rate, derived from improved epidemiological studies amongst miners[1], cover a range from 2-20 cases per year per million miners exposed to 1 WLM. The range is partly due to an observed age dependency, i.e. a decrease in risk coefficient with a decrease in age. Assuming a mean manifestation period of 30 years, the International Commission on Radiological Protection (ICRP) suggests a total life-time risk for lung cancer of between 150 and 450 cases per WLM per million occupationally exposed persons[1]. The public is at a lower risk per unit exposure than miners, due to their breathing less contaminated air. It has been suggested[2] that the life-time risk of the general population is 100 deaths for a collective exposure of 10^6 WLM.

Lung models are used to convert radon exposure (WLM) or concentration (Bq/m^3) to a radiation dose expressed in Sievert (Sv), which is the energy imparted to the lung tissue by the alpha radiation (1 Sv = 0.001 joules/g). As different physical and biological parameters are used, a range of values for the dose to the lung of between 0.03 and 0.04 Sv/WLM is obtained[3]. Expressed in terms of a ^{222}Rn concentration, 1 Bq/m^3 (^{222}Rn ECC) results in 0.8 mSv/yr to the lung which is an effective dose equivalent of 0.1 mSv/yr to the whole body[1].

4. MEASURING TECHNIQUES

Radon concentrations in indoor air are dependent on changes in the emanation rate from soil,

which again is determined by atmospheric pressure, temperature and wind speed and usually shows a diurnal concentration profile. Changes in ventilation conditions, due to the opening of windows and doors, will drastically affect the concentration levels. In addition, climatic changes can result in seasonal variations. In order to obtain representative concentrations, it is necessary to perform integrated measurements over days or even months.

Measuring radon is simpler and more convenient than measuring the radon daughter products. The former requires a correction for the equilibrium condition of the radon. Under average indoor conditions, an equilibrium factor of 0.45 is representative[3]. Radon can be measured through passive sampling, which is significantly less complicated and cheaper than active sampling of the daughter products which requires a power-driven pump. Two types of passive samplers were employed, namely track etch samplers and charcoal canisters. The track etch samplers[4] are exposed for a period of two or more months and the time integral of the radon concentration is determined by electro chemical etching of the polyester film and by counting the tracks. An automated counting system has been developed and calibrated for use at the AEC. Integrated concentrations in excess of 37 Bq.month/m^3 can be measured.

For shorter measuring periods, a charcoal canister is used. The canister is exposed for seven days and the radon concentration is determined by a gamma measurement of the radon daughters trapped in the charcoal. The judicious choice of a diffusion barrier[5] allows an integration time of approximately four days. Sealed canisters are counted with a scintillation counter such as sodium iodide. For a count period of 30 minutes, a standard deviation of less than 50% is obtained for a radon concentration of 37 Bq/m^3.

5. TYPICAL CONCENTRATIONS

Other countries: Indoor radon concentrations have been measured in numerous countries and substantial variations have been reported[3]. Concentrations varied from very low values to several hundred Bq/m^3 in individual houses and, in a few isolated cases, several thousand Bq/m^3 have been measured. The global average indoor radon concentration[3] is estimated to be 33 Bq/m^3 or 15 Bq/m^3 equilibrium equivalent concentration (EEC).

Some average indoor concentrations[3] (EEC) for a few countries are given in Table 1. The variations are attributed to different types of subsoil and building materials, and difference in ventilation rate due to the method of construction. Extreme levels were almost always associated with natural geological features such as submerged uranium ore bodies intersected by faults.

TABLE 1: Radon concentrations in different countries. Sample size is given in brackets

USA	60 Bq/m^3 (817)
UK	35 Bq/m^3 (2 000)
Germany	50 Bq/m^3 (5 470)
Nordic countries	100 Bq/m^3 (3 500)

South Africa: Although much can be learnt from overseas experience, local differences warrant an investigation of the South African situation. The South African climate would seem to favour better ventilation conditions, but it is evident that the cold Highveld winters and lack of central heating results in stagnant indoor conditions for certain months of the year. The densely populated region on the Witwatersrand is surrounded by waste from the gold-uranium mines which contains enhanced concentrations of ^{222}Ra from the uranium originally present in the ore. A preliminary study, done in the Western Cape and Witwatersrand, showed average indoor radon concentrations of 20 Bq/m^3 and 40 Bq/m^3 in two small samples of approximately 70 and 100 houses, respectively. Correlations between high indoor radon concentrations and factors such as construction type, geological characteristics and ventilation rate showed that houses with wooden floors are more likely to have high indoor radon concentrations. From the sample of 100 houses which had an average radon concentration of 40 Bg/m^3, all the houses with indoor concentrations higher than 80 Bq/m^3 had wooden floors.

In the case of a house situated in an area underlain by Pretoria shale formation, the outdoor radon concentration averaged 94 Bq/m^3, and indoor radon concentrations averaged 300 Bq/m^3 with maxima of approximately 600 Bq/m^3 in the early morning. Below floor levels, in excess of 1400 Bq/m^3 were measured. Improved ventilation lowered the average indoor concentration by a factor of 3. Factors contributing to the high radon levels were wooden floors, radium content of soil and probably the presence of a major geological fault which requires further investigation.

6. DISCUSSION

Exposure to indoor radon concentrations of 15 Bq/m^3 EEC and outdoor concentrations of 4 Bq/m^3 EEC

results in an estimated effective dose equivalent of 1.2 mSv/yr.

When these potential exposures are compared with those from other natural sources, viz. cosmic rays, earth radiation and internal ^{40}K, which contributes to the order of 1 mSv/yr, the importance of radon is clearly recognised. Further perspective is given by the fact that the dose limit to the public from nuclear installations in the RSA is 0.25 mSv/yr.

Chronic exposure to normal environmental (indoor + outdoor) levels can result in 42 excess cases of lung cancer for every million persons exposed to radon. The incidence rate of lung cancer from all causes is 400 per 10^6 persons. Environmental radon may therefore be responsible for 10% of lung cancer incidences.

According to studies conducted in the USA and Europe, 0.1% of houses measured had radon levels in excess of 200 Bq/m^3. The effective radiation dose from exposures at this concentration is 20 mSv/yr, which is 10 times the average natural dose. The associated risk of lung cancer is 2×10^{-4}/yr and is considered a level at which immediate remedial action should be taken.

There is no simple way of recognising homes with high radon concentrations as many factors, such as soil type, geological faults, building features, ventilation etc., can affect the situation. Certain areas are selected and in these areas homes are taken at random for analysis.

In May 1988, a programme was launched to measured the radon levels in homes in areas where either mine waste or natural granites, known to have high uranium levels, could contribute to unusual radon concentrations. No such homes have been identified as yet, and it will require a much more extensive survey.

7. CONCLUSION

Indoor radon is the major contributor to the natural radiation dose of the general population. Enhanced exposure is caused by the use of mine waste as underfill or building material. Natural geological features, in association with construction practices, can also result in indoor concentrations that create unacceptable health risks. High exposures cannot be readily predicted and have to be determined by measurement.

Action levels, proposed by national authorities for radon concentrations, far exceed the radiation protection standards used in the nuclear industry. This action is justified through the application of radiation optimisation, which requires that a cost-benefit study be performed and that the cost of preventing radiation dose should not exceed the benefit gained from such action.

Radiation risks from the nuclear fuel cycle is controlled by national authorities not to exceed a level of about 10^{-7}/yr in the case of the general population. Proposed levels for remedial action in the case of indoor radon is in the risk range 10^{-5}/yr. In view of the wide impact of indoor radon, urgent attention should be given to quantify the extent of the risk.

8. REFERENCES

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