Indoor Radon

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Abstract

The naturally radioactive but chemically inert gas, radon, is formed from the radioactive decay of radium which is part of the uranium series. Radon gas, which has a half life of 3.8 days, must escape from soil particles through air-filled pores in order to enter the atmosphere following the decay of radium. The concentration of radon in the atmosphere varies, depending on the place, time, height above the ground and meteorological conditions. It is thus an inescapable source of radiation exposure, both at home and at work.

The potential hazards posed by exposure to radiation from indoor radon gas and its daughter products are of great concern worldwide. Noting of an excessive lung cancer risk among several groups of underground miners exposed to radon and its daughter products, studies on radon concentrations in the workplace and in dwellings have been conducted in many countries. The results have shown that the distribution of radon concentrations are approximately lognormal from which population weighted; the arithmetic mean of radon concentration of 40 $Bq.m^{-3}$ has been adopted worldwide for dwellings and workplaces.

The principal methods for reducing a high indoor radon concentration are: reducing the radon supply by reversing the pressure difference between the building and the soil; raising the resistance of the foundations to soil gas entry; removing the radon sources such as water or underlying soil; diluting the concentration by increasing the ventilation rate; and reducing the concentration of radon progeny by filtering and increasing the circulation of indoor air.

Buildings which have a radon concentration higher than 200 $Bq.m^{-3}$ should be investigated by the national authorities concerned; meanwhile, householders should be advised to take simple temporary precautions, such as increasing ventilation, until a permanent remedy can be effected.

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Humans spend at least 60 per cent of their lives indoors, and their exposure to indoor radiation is computed to be up to 50 per cent of their total exposure to natural radiation sources. During the past 35 years, there has been a considerable increase in interest in the level of natural radiation to which people are exposed. The external gamma radiation dose arising from terrestrial and cosmic sources has been the subject of numerous studies and surveys since the 1950s. However, the importance of the contribution of environmental radon (^{222}Rn) to the natural radiation dose has only recently been realised and it has since become the subject of extensive studies. It is now recognised that inhaled radon contributes about one half of the total natural environmental ionising radiation dose to the world population[1].

WHAT IS RADON?

Radon (^{222}Rn) is an inert, colourless radioactive gas formed during the disintegration of the element radium (^{226}Ra), a fifth generation of the uranium (^{238}U) decay series. Radon itself also decays into a series of solid isotopes (i.e., polonium, bismuth and lead), referred to as "radon daughters", "radon progeny", or radon decay products. Uranium and radium are universally present in varying amounts in almost all rocks, soils and water; thus radon is ubiquitous in nature as a result of its continuous discharge from the Earth's crust.

Radon normally refers to the isotope ^{222}Rn, whereas, thoron (^{220}Rn), which is part of the thorium (^{232}Th) decay series, is encountered naturally in negligible amounts because it is extremely short-lived with a half-life of 55.6 seconds. Radon's half-life is 3.8 days but its decay products in solid form, especially polonium-210 and lead -210 have half-lives as long as 138 days and 21 years, respectively (data taken from: Table of Isotopes and USNRDL-TR-802).

Indoor Radon

Radon enters buildings from different sources, such as the soil or rocks under or surrounding the buildings, building materials, water supplies, natural gas and outdoor air.

Radon can be transported into a building from the underlying soil *via* diffusion or *via* the pressure-driven flow of air through the structural elements. In the case of a cracked slab of concrete of thickness 0.2 metre only a small percentage of the activity emitted from the soil is transmitted, presenting about one-half of that from the concrete itself. The corresponding radon entry rate in the reference house can be estimated as 1.7 $Bq.m^{-3}.h^{-1}$.

The presence of cracks in a concrete slab may considerably increase the transmission of the diffusive flux from the soil. Using a mathematical model of a cracked slab, Landman[2] determined that 25 per cent of the flux from uncovered soil would penetrate the slab by diffusion if a gap of 1 cm existed for every metre of slab. In the case of pressure-driven flow, radon-bearing air through structural elements is believed to be an important mechanism for radon entry[3]. It is often a predominant source of radon in dwellings which have elevated concentrations, especially if the building is in direct contact with the ground[4]. Flow through an intact concrete slab is likely to be negligible in comparison to the flow through cracks, holes and other avenues of penetration. In dry soil with a density of $1.6x10^3$ $kg.m^{-3}$, porosity of 20 per cent, ^{226}Ra activity mass concentration of 25 $Bq.k^{-1}$ and an emanating power of 20 per cent, the calculated equilibrium radon concentration in soil gas is 40 $kBq.m^{-3}$. If it is assured that 0.25 m^3 of soil gas enters a building per hour, representing about 0.1 per cent of the total air exchange rate, the radon entry rate from that source is 40 $Bq.m^{-3}.h^{-1}$.

Transport of radon into a building through convection flow has been observed in countries where a number of dwellings have unusually high radon concentrations such as Sweden and the United Kingdom. The radon entry rate through connective flow is simply the product of radon concentration in soil gas and the infiltration rate from the soil. The radon concentration in soil gas depends on the activity mass concentration of radium in the soil, its emanating power and the porosity, permeability and moisture content of the soil. Investigations of radon concentration in soil gas in Sweden have shown that there is usually no-long distance transport of radon in the soil and that the radon concentrations in soil gas can be explained by assuming an emanating power of 10-30 per cent[5].

The infiltration rate from the soil depends on the degree to which indoor air is coupled to the soil; that connection, in turn, depends on the design and construction of the building, meteorological parameters influencing radon movements in

the soil and the living habits of the occupants, all of which can affect the air exchange rate in the building.

Mechanisms of radon transport from the soil into buildings comprising various structures have been investigated. Experimental investigations in a house with a vented crawl space[6] showed that a higher temperature difference, including an increasing infiltration rate, corresponded to a higher indoor radon concentration. This suggests that the increased infiltration rate is more than compensated for by an increase in the radon entry rate; it also suggests that the infiltration rate from the soil into the house was, in this case, more important than the infiltration rate from the walls. It was found that a high wind speed tended to reduce the indoor radon concentration, presumably by increasing the cross-ventilation of the crawl space and the infiltration rate of the living space. For this particular house, as well as for two other houses with vented crawl spaces which were investigated during the study, it was found that perhaps 50 per cent or more of the radon that was released into the crawl space from the soil beneath the house entered the living space. The floor of a crawl-space house, which is usually built of wood, is likely to have a greater infiltration rate than the floor and walls of a basement, which are usually built of poured concrete and concrete blocks.

Another extensive investigation of radon entry through the soil was conducted in a single-family house with a basement; rate-time measurements were performed on the indoor radon concentration, the air exchage rate, source-related parameters and meteorological factors for a period of five months[7]. The radon entry rate was calculated from the measured radon concentration and air exchange rate; the results were obtained during one week of the experiment with regard to the radon entry and the radon concentration in the soil adjacent to the house and in the basement sump, which collected rain water *via* a drain tile system surrounding the house at a level near that of the basement floor. The clear correlation between the sump activity and the radon entry rate suggested that the sump was an important pathway for radon entry into the house, although it could not account for the total radon activity[7]. The main conclusion derived from the study was that the radon entry rate could have two components; one might be independent of the air exchange rate, acting in a way which was similar to entry by diffusion; the other component might be proportional to the air exchange rate, behaving in the same way as pressure-driven entry[7]. The corresponding radon entry rates in the house were calculated to be about 2 $Bq.m^{-3}.h^{-1}$ for the diffusion process and about 60 $Bq.m^{-3}.h^{-1}$ for the pressure-driven force[7].

Information on the mass exhalation rate, the diffusion length, the emanating power and the ^{226}Ra activity mass concentration in building material is presented elsewhere. Concrete and brick are probably the two most widely used building materials, at least in the temperature latitudes, even though the ^{226}Ra concentrations in concrete seem to be lower than those in brick. The ^{226}Ra mass exhalation rates appear to be higher for concrete than for brick. This is because of the high values of the emanating power of concrete, with or without fly ash, in comparison to those for brick. Cement and fly ash have low emanating powers, probably due to their crystalline nature. Differences in the moisture content of the materials studied may also account in part for the wide disparity in the results of exhalation measurements from different countries[3]. It should be noted that the exhalation rate from concrete should not be derived from the emanating power of its constituents, as chemical changes occur during manufacturing.

Air exchange between outdoor and indoor environments brings some outdoor radon into a building. Air exchange arises from natural ventilation through open doors and windows, mechanical ventilation and infiltration, and the uncontrolled leakage of air through cracks in the building envelop. Outdoor radon can play a significant role in the indoor radon entry rate if a house is poorly sealed.

Radon contained in water is, to some extent, transferred into room air as a result of agitating or heating. Radon concentrations are, as a rule, much lower in surface water than in ground water. In water-saturated soil with a density of 1.6×10^3 $kg.m^{-3}$, porosity of 20 per cent and an emanating power of 20 per cent, a ^{226}Ra activity mass concentration of 2.5 $Bq.kg^{-1} \times 1.6 \times 10^3$ $kg.m^{-3} \times 0.2/0.2 = 4 \times 10^4$ $Bq.m^{-3}$. In surface water, radon concentrations are expected to be similar to those of ^{226}Ra, that is, about 10 $Bq.m^{-3}$.

The release of radon from water into air depends upon the circumstances in which the water is used, as the degassed fraction increases considerably with temperature[8]. Studies of radon transfer from tap-water to indoor air reported a use-weighted transfer efficiency of 0.5-0.6 and an average water use of 0.2-0.4 m^3 per day and per person. Degassing of radon from tap-water has been found to lead to elevated indoor radon concentration. Taking the air-to-water concentration ratio to be typically 10^{-4}[9], an indoor air concentration of 400 $Bq.m^{-3}$ is obtained if the radon concentration in water is by a factor of about 100[10].

Natural gas is sometimes mentioned as a potentially significant source of indoor radon. The radon concentration in natural gas at production wells varies from undetectable values to levels of about 50 $Bq.m^{-3}$[11]. The industrial processing of natural gas involves the removal of impurities and the separation of hydrocarbons. Some of these hydrocarbons are bottled under pressure for sale as liquefied petroleum gas (LPG) while others may be used for fuel. Some of the radon activity contained in the processed natural gas decays during the transit time between processing and use, or while it is stored in the bottles. When natural gas is burned in-house for cooking or space heating, the radon that is released may enhance the indoor radon level if the appliances are unvented. If the concentration products are vented outside the house, this radon source is negligible. Radon concentrations in natural gas and LPG have mainly been measured in the United States, where the average radon concentrations in either natural gas or LPG have been found to be about 1,000 $Bq.m^{-3}$[12,13]. For a consumption rate of 2 $m^3.d^{-1}$ in unvented appliances, the radon entry rate in the reference house is estimated to be about 0.3 $Bq.m^{-3}.h^{-1}$. The corresponding contribution to the radon concentration is 0.3 $Bq.m^{-3}$.

There is, in fact, an essentially universal agreement that the radon concentrations decrease as the number of floors, of a multi-storey building increase, especially between the basement, and first and second floors[2,14,15]. However, it is worth noting that in the upper storeys of high-rise buildings, the radon concentration does not always decrease as the number of storeys increases[15]. The presence of direct routes, such as lift shafts and service ducts between the basement or subbasement levels and higher storeys, can distort the radon concentration gradient. The air exchange rate is subject to important variations as it is a function of human activities, such as opening or closing doors or windows, and turning ventilation systems on or off, as well as meteorological conditions. The radon concentration may experience significant changes in the course of even one day owing to variations in the different radon sources discussed above.

MEASUREMENTS OF INDOOR RADON[16]

Some special techniques are required for measuring low-level radon in a living environment because radon is chemically inert. Therefore, since we cannot concentrate radon chemically, one useful technique utilyses physical concentration such as adsorption to activated carbon or tuluene.

The radon measurement can be classified from the viewpoint of energy supply into active and passive measurements, and from a viewpoint of time into grab, continuous and time-integrating measurement. In any case, a reliable measurement of radon is not easy because of changes in daughter composition and concentration as time lapses. Key points in selecting measuring devices include the environmental condition of the target location, the available timelength of the measurement and the survey scale.

Details of various methods for measuring indoor radon can be obtained elsewhere.

WORLDWIDE SURVEY OF INDOOR RADON

1. Australia

In 1989 the ARL carried out an Australia-wide survey of indoor radon in about 3,000 homes. The results showed that in Australian homes the average activity concentration of ^{222}Rn was 10.9 $Bq.m^{-3}$ with a standard deviation of 11.8 and geometric mean of 7.9 $Bq.m^{-3}$. These values are approximately half of the world average value for indoor radon[1].

2. France[14]

IPSN/DPS/SHR/SEAPS/LES have been conducting a survey since 1981. About 1,000 homes had been surveyed by 1988, using passive monitor (with the partial use of active monitor). The results ranged from 20 to 100 $Bq.m^{-3}$, and the mean indoor radon level was 44 $Bq.m^{-3}$.

3. Republic of Korea

According to a national survey, an indoor radon surveillance programme in 1990, covering 340 houses in 12 residential areas, the annual geometric mean of indoor radon concentration appeared to be 50 Bq.m^{-3} (range: 34-62 Bq.m^{-3})(17).

Measurement of indoor radon concentrations in 340 houses in 12 residential areas in the Republic of Korea, using the CR-39 plastic radon cup measurement technique, during the period April-October 1990, showed an average concentration of 59 $\pm$ 54 Bq.m^{-3}. The excess lung cancer risk factors derived in the study were 0.022 per WLM for males, 0.009 per WLM for females, and 0.016 per WLM for both sexes; the life excess lung cancer for the Korean population was estimated to be 230 per 10^6 WLM(18).

4. People's Republic of China

Beijing

In a 1987 report(19): passive integrating activated carbon detectors were used to study the regional distribution and temporal variation of radon in dwellings in the Beijing region. Measurements were made in 537 dwellings which were either detached houses or multi-family apartments. The city-wide study was completed in 1985. The distribution was approximately log-normal, with 90 per cent of the dwellings having a radon level of less than 60 Bq.m^{-3}. The weighted average ^{222}Rn concentration was found to be 22.4 Bq.m^{-3}. Averages for detached houses and multi-family dwellings were 25.9 and 15.2 Bq.m^{-3}, respectively. Assuring an equilibrium factor of 0.5 and occupancy factor of 0.8, the average equilibrium equivalent concentration of ^{222}Rn progeny was calculated at 11.2 Bq.m^{-3} and the annual average effective dose equivalent at 1.1 mSv.

A 1991 report(20): the average indoor radon concentration of 30 Bq.m^{-3} was determined in different types of dwellings in the Beijing area using activated carbon detectors. The results showed that the underlying soil and building materials are important sources of indoor radon.

Yunnan(21)

Indoor radon and soil levels were measured in the Gejiu area of Yunnan Province by the SSNTD method during the period 1990 to 1996. The results indicated widespread high indoor radon levels in that area (29 -1,146 Bq.m^{-3}; n = 143); only 7 out of 143 buildings had subthreshold concentrations (i.e. <148 Bq.m^{-3}). There was a positive correlation between mortality from lung cancer and certain indoor radon levels (radon concentrations of <100 Bq.m^{-3} no cancer mortality (CM); 100 to 200 Bq.m^{-3}, CM 23%; 200 to 300 Bq.m^{-3}, CN 45%; 800 Bq.m^{-3} and over, CM 100%).

Hong Kong

Guan et al(22) in 1991 reported the mean value for indoor radon concentrations in Hong Kong to be about 45 Bq.m^{-3}; the high value of indoor gas was attributed to the poor exchange of indoor air with the outside air owing to the practice of keeping windows closed all the time. Another factor is the relatively high values of radium contained in building materials (especially granite ballast and brick imported from other parts of China). These factors combined have produced high indoor radon concentrations in Hong Kong(23).

The annual dose equivalent received by the Hong Kong population due to radon exposure has been calculated to be 1.34 mSv, of which 1.11 mSv comes from indoor air and 0.23 mSv from outdoor air(24); this value is slightly higher than the global average value of 1.06 mSv.

From the relative risk model, about 13 per cent of all lung cancer deaths among Hong Kong people during the years from 1973 to 1986 could be expected to be attributable to radon exposure(25). With the population of Hong Kong being 5.5 million in 1986, the estimated number of radon-induced cancer deaths per year would be about 280.

5. India

Based on data accumulated from all over the world, a UNSCEAR 1988 report(1) disclosed that in Bombay, India, 19 Bq.m^{-3} with an equilibrium factor of 0.43 was reported for normal areas.

Another report at the Regional Workshop on Radon Monitoring, held at Hengyang Institute of Technology, Hunan Province, China, October 11-19, 1993, the results of radon measurements in some dwellings along the central sector of the Singhbhum Thrust Belt (STB) were on the average 23 Bq.m^{-3}. Most houses were built with mud walls and floors, and roofs made of thatch or baked clay tiles.

6. Japan

In 1985-1987, NIRS begun a nation-wide survey by two different methods. One group used an electrostatic integrating monitor. Another group used cup monitor. The former measured both indoor and outdoor concentrations at 250 homes every two months. The mean indoor concentration was about 10 $Bq.m^{-3}$ and the mean outdoor concentration, 5 $Bq.m^{-3}$. The latter group measured the indoor concentration of more than 6,000 homes every six months, for which the mean concentration was 28 $Bq.m^{-3}$. Currently, a new nation-wide survey is being conducted with collaboration between JCAC and NIRS, using a new type of cup monitor with polycarbonate film.

A separate report[26] on a measurement in a traditional wooden house in Kyoto indicated that indoor thoron concentration increases exponentially as the interior mud (or plaster coated) wall is approached. A soil-based plaster commonly used in Japanese wooden houses to fill walls (or as a surface coating on the wall) is the probable source of indoor radon.

7. Pakistan[27]

Both the external and internal dose equivalent rates in houses under consideration are less than the background dose equivalent rate value given by UNSCEAR.

8. The Philippines

At the Regional Workshop on Radon Monitoring, held at Hengyang Institute of Technology, Hunan Province, China, October 11-19, 1993, Theofilo Y. Garcia of the Philippine Nuclear Research Institute, reported on radon measurements in various parts of the Philippines, using CR-39 (allyl diglycolcarbonate) passive alpha track detectors deployed in houses. The completed survey assessed 200 different sites from which the indoor radon levels were reported to be 16.42 ± 8.86 $Bq.m^{-3}$. The low value of indoor radon was attributed to the design of the houses which allowed free air flow within the house; because windows were normally open most of the time, radon did not build up inside the houses.

9. Romania

In Romania, studies on indoor radon were started not later than 1986. C. Milu[28] recently reported the results of determinations in 119 houses that the CEDE values for indoor exposure, including thoron daughters contribution of about 20 per cent, to be 1.41 mSv/year in rural areas and 1.22 mSv/year in urban areas.

10. Sweden

In Sweden, surveys of radon concentrations in dwellings have been undertaken since 1965, and in mines and other workplaces, including quarries and other rock workings since the end of the 1960s. The first national survey of dwellings, representative of the 1976 building stock, was carried out in 1980/1982. The results of the studies did not differ significantly, and an arithmetic mean of 108 $Bq.m^{-3}$ with a confidence interval of 95 per cent was observed[29].

11. Thailand

Wattananikorn et al[30,31] were the first to investigate indoor radon in Thailand. It was during the period 1987-1988 that they carried out measurements of radon in dwellings close to uniferous fluorite mines. They found the annual indoor radon concentration to be 89 ± 22 $Bq.m^{-3}$.

A second group, Polpong et al conducted research on indoor radon under the IAEA research contract (1990-1994), and later launched a nation-wide survey aiming at covering the whole country, which revealed concentrations ranging from 1 to 1,974 $Bq.m^{-3}$. The results were reported elsewhere[32-40].

12. United Kingdom of Great Britain and Northern Ireland[14]

In the UK, surveying has been undertaken mainly by NRPB (and partly by IEHO). The device used was a passive one incorporating a CR-39 detector. The results by 1988 showed that 20,000 homes exceeded 400 $Bq.m^{-3}$ and 2,000 homes (about 10% of the total) had been found to exceed 1,000 $Bq.m^{-3}$. The arithmetic mean concentration in normal areas of the UK was 20.5 $Bq.m^{-3}$, while the median was 13.6 $Bq.m^{-3}$.

13. United States of America[1]

The Environment Protection Agency/ Department of the Environment (EPA/DOE) began a survey of public exposure to radon in 1986. It has been estimated that about 5,000 - 12,000 lung cancer deaths each year are due to the inhalation of radon and its daughters. EPA had surveyed 10

States by 1988 and found that 21 per cent of 11,600 homes exceeded the EPA screening level of 148 $Bq.m^{-3}$. In Colorado, 39 per cent of homes exceeded that level, with the highest being found in Alabama with a concentration of 6,600 $Bq.m^{-3}$. The risk of lung cancer incidence would increase by 100 times at such high levels. In addition, a report by Teradex Company on the nationwide survey in the U.S.A. which covered 60,000 individual indoor measurements, showed a population weighted arithmetic mean of 140 $Bq.m^{-3}$ and a geometric mean of about 70 $Bq.m^{-3}$.

14. Vietnam

At the Regional Workshop on Radon Monitoring, at Hengyang Institute of Technology, Hunan Province, China, October 14, 1993, Phan Quang Dien and his colleagues from the Radiation Protection Centre, VAEC, reported the results of an indoor radon survey in 300 Hanoi dwellings in 1992, using the urban cup with policarbonate Inpyron S-22 detectors, which indicated that the long-term average indoor radon concentration was 27 $Bq.m^{-3}$. There were only a few dwellings where radon concentrations reached 100 $Bq.m^{-3}$.

RISKS FROM RADON INHALATION

Irradiation from radon and thoron decay products arises from inhalation[41] and takes place in the respiratory tract. The actual dose delivered to the various anatomical structures depends on the relative fraction of attached and free daughter products, the size of the aerosol particles to which they are attached and pulmonary function. On average, the dose from radon daughter products to the bronchial basal cell layer is a factor of 5 to 8 times higher than the dose to the pulmonary region. It should be pointed out that, in temperate latitudes, the dose indoors is about 15 times higher than outdoors, because concentrations of the radioactive gases are higher inside the houses and because people usually spend more time inside than outside[7].

Human epidemiological data have been obtained from groups of underground metal-ore miners mainly in the United States (Colorado Plateau), Canada (Ontario and Eldorado), Czechoslovakia, Sweden (Malmberget), Newfoundland and the United Kingdom. The studies have been reviewed by NCRP[42,43], NIOSH[44], ICRP[45], NAS[46], DOE[47] and EPA[48].

The current estimates for lung cancer risk from radon exposure indoors are based on an averaging of the results of the BEIR IV and ICRP 50 analyses with slight modification (EPA[48,49]). EPA has accepted the BEIR IV conclusions that the dose and risk per WLM exposure in residences and in mines are basically identical. The Swedish Radiation Protection Institute estimated that between 300 and 1,500 lung cancer cases per year, with a most probable figure of 900 cases, could occur in the Swedish population of 8.6 million, as a result of radon exposure in dwellings. That means 1.2×10^{-6} per $Bq.y.m^{-3}$ (0.4-2.0). This value is about 30 per cent lower than recommended by ICRP: $65,1.55 \times 10^{-6}$ per $Bq.y.m^{-3}$. Results from the miner studies, as modeled by international organisations and from radon epidemiological studies in dwellings, were used as the basis for the Swedish estimation. ICRP, on the other hand, based its estimate only on data from miners converted to the conditions in dwellings by model[29].

The EPA risk estimate was adjusted for an assumed background exposure of 0.25 WLM/year; the average radon exposure rate was based on 1980 US vital statistics and the distribution estimate of radon in residences[50].

EPA estimated the excess lifetime risk in the general population as a result of constant low-level lifetime exposure, based on an average of the BEIR IV and ICRP 50 estimates and modifications discussed above, at 550 and $190/10^6$ WLM for males and females, respectively, or a combined risk of 360 lung cancer deaths/10^6 WLM, with an estimated range of 140 to 720 lung cancer deaths per 10^6 WLM[48].

The occupancy factor of 0.75 is based on studies by Moeller and Underhill[51] and Oakley [52], which estimated radiation exposure and population dosage in the United States which was supported by more recent reports. An equilibrium factor of radon with its progeny of 0.50 was estimated[53], and EPA estimated that 10,000 pCi/l radon in water would contribute, on average, about 1 pCi/l to the air of a house[54].

In estimating the dose from exposure for a reference Thai adult, it was assumed that such an adult residing indoors for 6,000 $h.y^{-1}$ with a constant breathing rate at 0.75 $m^3.h^{-1}$, an equilibrium factor of 0.4, a reference dose conversion factor of 1.7×10^{-4} mSv ($Bq.h.m^{-3}.^{-1}$) for the lung expo-

sure and 1.0 x 10^{-5} mSv ($Bq.h.m^{-3-1}$) for whole-body exposure, as proposed in ICRP Publication 50 (45). Using this estimate, the annual dose equivalent to the lung and resulting effective dose equivalent for the Thai population would be 5.53 $mSv.y^{-1}$ and 0.33 $mSv.y^{-1}$, respectively; by using the fatality coefficient of 3 x 10^{-4} per WLM for the public, as recommended by ICRP Publication 60, lung cancer cases from chronic exposure of the public in Thailand (population 60 million) would be between 317 and 15,634 cases, with an average of 1,073 cases.

The limit for the radon concentration in existing buildings is 400 $Bq.m^{-3}$ and for newly constructed buildings, 200 $Bq.m^{-3}$ was recommended by Swedish Radiation Protection Institute. These levels are valid for both dwellings and workplaces with exception of rock workings and its concentration is also recommended that the concentration be reduced to less than 200 $Bq.m^{-3}$ whenever possible(29).

REMEDIAL AND PREVENTIVE MEASURES

The principal remedial methods(55) for reducing high radon concentrations indoors are to:

(a) Reduce the radon supply by reversing the pressure differential between a building and the soil, often called soil depressurisation. This is most easily achieved by using a small fan to withdraw the radon from the region under the floor, either in a porous area under (or close to) the dwelling or in the space under the suspended floor.

(b) Reduce the radon supply by raising the resistance of the foundations to soil gas entry or by treating building materials to reduce radon escape. However, it is difficult to make this sealing process effective in existing buildings because there are many routes of entry for radon from the ground.

(c) Remove the radon source, which is probably feasible only for the water supply and, in extreme cases, solid materials such as the underlying soil.

(d) Dilute the radon and its progeny by increasing the ventilation rate. The effectiveness of this process is limited because the ventilation rate in most buildings is already as high as required by the occupants; in addition, further ventilation will increase heating or cooling costs. Also, some forms of ventilation will decrease the pressure in the building, thus increasing the radon input.

(e) Reduce the concentration of radon progeny, e.g., by filtration or by increased movement of indoor air to enhance the deposition of radon progeny.

Some of the above remedial measures, e.g., (a) and (d) depend on continued expenditure if they are to be effective. Local circumstances and the source materials of radon will influence the choice of methods.

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ก๊าซเรดอน ในอาคาร

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เรดอน เป็นก๊าซกัมมันตรังสีที่พบในธรรมชาติ, เกิดจากการสลายตัวของธาตุเรเดียม ในอนุกรมสลายตัวของธาตุ ยูเรเนียม ซึ่งมีอยู่ทั่วไปในดินในหินและในน้ำ. ก๊าซเรดอน (มีอายุกึ่งชีพ 3.8 วัน) เมื่อเกิดขึ้นบางส่วนจะเข้าสู่บรรยากาศทั่วไป หรือแทรกเข้าไปในอาคารตามช่องทางต่าง ๆ. ในสองสามทศวรรษที่ผ่านไป ได้เริ่มมีความสนใจกันมากเกี่ยวกับศักยภาพของก๊าซเรดอน ที่พบปรากฏในอาคาร ที่มนุษย์ต้องหายใจเข้าไปอย่างหลีกเลี่ยงไม่ได้ ในการเป็นปัจจัยเสี่ยงที่สำคัญอย่างหนึ่งของการเกิดมะเร็งปอด. รายงานจากฝ่ายสาธารณสุขของสหรัฐฯ แจ้งว่าชาวอเมริกันเสียชีวิตจากมะเร็งปอดที่มีสาเหตุจากก๊าซเรดอนในอาคารถึงปีละประมาณ 5,000–12,000 ราย, พร้อมกับได้ให้คำแนะนำว่าอาคารบ้านเรือนใดที่ตรวจพบว่ามีความเข้มก๊าซเรดอนสูงเกิน 200 เบคเคอเรล/ลูกบาศก์เมตร สมควรได้รับการสอบสวนและดำเนินการแก้ไข. วิธีการลดความเข้มก๊าซเรดอนในอาคารมีหลายวิธี ซึ่งต้องเลือกวิธีที่เหมาะสมเป็นกรณีกรณีไป.

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