Physics

INDOOR RADIOACTIVE POLLUTION DUE TO RADON AND ITS DAUGHTERS

HAMEED A. KHAN*
HASEEBULLAH*

SUMMARY: Indoor radioactive pollutants such as radon and its daughters (Po-218 and Po-214) have been found to pose grave health hazards in the indoor environments. Radium-226, radon's immediate parent is present in significant concentrations in building materials, and recycled industrial waste products (such as cements). Radon, besides being emitted by different building materials, has been found to enter the houses through (a) the underlying soil or rocks and (b) through the water, drainage, and natural gas connections. The inhaled radon has been found to cause radiation damage to the lungs due to its alpha activity. Radon daughters, Po-218 and Po-214 are found to be even more dangerous than radon itself. They attach themselves to dust particles present in air, some of which enter the lungs. A fraction of the aerosols so produced are either retained by lungs or enter the blood stream. Radon and its daughters have been found to contribute at least 60% of the dose received by an individual from the natural radiation sources. The danger of indoor radon and its daughters is even higher in energy-saving houses and those having poor ventilation systems. The present paper gives a brief overview of the health hazards linked to these important indoor radio active pollutants. Some remedial and preventive actions have been described and recommendations for safer designs of new buildings and houses have also been suggested.

Key Words: Radioactive pollutants, radon, radon daughters, lung cancer, ventilation, remedial actions.

INTRODUCTION

The area of Bohemian Alps in the early 16th century, became known to contain a disease called, 'Bergkrankheit' or 'mountain disease' (1). The disease has now been recognized as the 'lung cancer' and is believed to be caused by a 'radioactive gas', emitted by 'uranium ores' or to be more precise by 'radium'. This radioactive gas, now called 'radon' was discovered in 1900 by Ernst Dorn (2), who named it 'Radium Emanation Gas'. It was later renamed as 'nitron'. The present name 'radon' was first used in early 1920s. By 1950, the role of radon as a lung cancer agent became fairly established (1-21).

Almost every material around us contains some uranium impurity (a few parts per million). Uranium undergoes radioactive decay, producing a wide spectrum of daughter products (Figure 1). Radon is the sixth member of the series. It fills the spaces in the host materials (soil, sand, rocks, gravels, etc.). It may succeed in escaping out of the construction material and get mixed with the indoor air. If it escapes to a confined space such as a basement of a building or a room with limited ventilation, the concentration of radon may become fairly high (1-11). It has been estimated that among the natural radiation sources, radon and its daughters contribute the maximum annual dose which may ultimately cause lung cancer (1-20).

It has been established now that we are exposed to airborne combustion products, volatile toxic chemicals, and different types of radioactive pollutants (1-8). The greatest exposure to the above mentioned pollutants does not take place outdoors but rather indoors. Measurements carried out to determine the indoor levels of different pollutants have indicated that the health hazards linked with breathing the indoor air can far exceed the previously

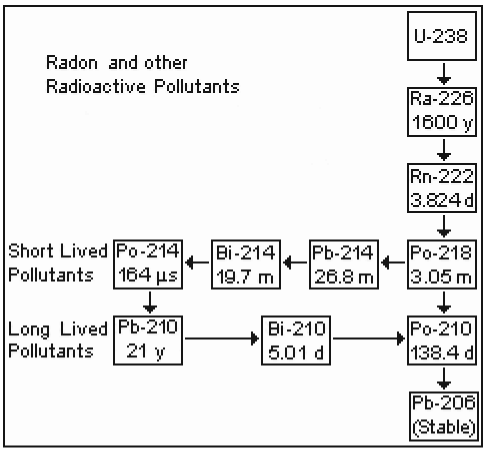
* From IA and Training Division, PAEC Head Office, P.O. Box 1114, Islamabad, Pakistan.

determined limits for controlling pollutants in the outdoor air.

INDOOR RADIOACTIVE POLLUTION

Experience shows that radon (Rn-222) and thoron (Rn-220) along with their daughter products are the most important indoor radioactive pollutants (1-27). Radon-222 is the immediate daughter of Radium-226, produced in the decay series of U-238 (Figure 1). The half-life of radon is equal to 3.824 days. This value though is not enough to allow the transport of radon by diffusion to appreciable distances, it is helpful in radon's partial emanation from building materials and soil. The amount of radon so emanated succeeds in migrating several meters. The influx of radon is a function of parameters such as permeability of the underlying soil and geological-, meteorological- and structure- factors (28-33). 'Stack Effect' is primarily responsible for the movement of radon in a building's shell, its substructure, walls and roof, by infiltrating through various openings, particularly around windows and doors and penetrations along with pipes and wiring (7,8,31). The concentrations of radon daughters depend on the amount of airborne particles and the pattern of air movement in a particular building (7,31), influencing the radiation dose. The variability in entry rates, and ventilation rates is the cause of a very wide range of concentrations for radon and its daughters from a few Bq/m^3 of air to more than 10.000 Bq/m^3 with an average level of about 50 Bq/m^3.

Figure 1: 'Uranium Decay Series', showing radon (the only gaseous member of the series) and its daughter products. The radon family is an important source of indoor radioactive pollution.

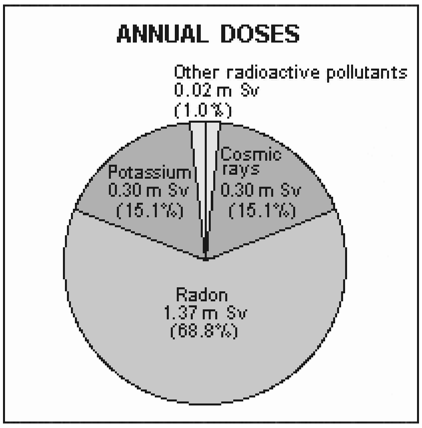


HEALTH HAZARDS

Studies carried out during the last two decades or so indicate that inhalation of these radioactive elements causes severe health problems (34-37). Since radon has a relatively long half life, its health hazard is relatively less than what can be expected from its short lived daughters: Po-218 (half life~3 minutes), Pb-214 (half life~27 minutes), Bi-214 (half life~20 minutes), and Po-214 (half life~164 µs). Po-214, daughter of Bi-214 decays to Pb-210, having a relatively long half life of 22.3 years, is eliminated from the lungs before it decays significantly. Experience shows that most of the radon daughters attach themselves quickly to ambient aerosols (38). Po-218, the immediate daughter of radon at first, exists as a free and highly mobile ion or atom but within about 20 seconds (under normal environmental conditions), it loses its independence and attaches itself to water vapors, oxygen, trace gases, and dust particles (7, 8, 38). The estimates of the risks posed by radon and its daughters to the underground miners were extrapolated to their indoor levels and it was found that the average indoor concentration of radon in USA corresponds to a chance of causing lung cancer of about 0.4 percent. Indeed, hundreds of thousands of people living in houses in some countries that have high radon levels receive as large an exposure of radiation yearly as the people living in the vicinity of the Chernobyl nuclear power plant did in 1986. The average indoor level represents a radiation dose which is about three times larger than the dose most people get from X-rays and other medical products in the course of their lifetimes.

It has been estimated that among the doses received due to natural radiation sources, radon causes the maximum (about 69%) radiation dose (Figure 2). The radioactive pollutants such as radon and its daughters have received considerable media coverage during the last couple of decades. American Press produced headlines such as 'Colorless Odorless Killer', 'Beast in the Basement', 'Buyer Beware Radon Tests', 'Man Gets Free Gas Here', and 'Radon Lawsuits Feared'. The British Press came out with headlines such as, 'Search for Death Houses', 'Cancer Gas Guinea Pigs', 'Action Over Killer Gas', 'No Radon Found In Homes', and 'Watch for Radon Cowboys'.

Figure 2: The annual dose due to different natural radiation sources. It is quite evident that the annual dose received due to radon (and its daughters) is the highest and, thus, a grave health hazard.



MEASUREMENT METHODS OF INDOOR RADIOACTIVE POLLUTANTS (39-61)

Measurement of radon

Grab sampling: This method is based upon the collection of discrete samples of air without radon decay products over a short time, followed by the measurement of its decay products. The concentration is measured by methods such as a scintillation flask, two filters, an ionization chamber, etc.

Continuous monitoring: Air is continuously sampled free of radon decay products and measurements are made continuously at fixed intervals of time using (a) electrostatic convergence of 'Po-218' with scintillators or semiconductor detectors, and (b) continuous flow of the filtered air into a scintillation flask, coupled with a photo-multiplier tube.

Integrating measurements: It is a long term measurement of radon levels in containers in which radon enters free of its decay products. The detectors used include (a) Solid State Nuclear Track Detectors (SSNTD) Figure 3, (b) thermo luminescence dosimeters, (c) activated charcoals, and (d) electrets.

Measurement of radon daughter products

Grab sampling: The technique is based upon the collection of radon daughter products on filters and the measurement of the radiations emitted from them. Most of the methods are used for alpha particle measurements. Some of them are based upon the measurement of gamma rays while very few are used for beta measurements. A brief description of the commonly applied systems is given below.

(a) One-count method: Here the Potential Alpha Energy Concentration (PAEC) is estimated. The uncertainty is usually 10-20%. Such systems are usually applied in underground mines.

(b) Two-count method: The method estimates PAEC in a relatively shorter period of time. It has lower uncertainty than the 'one-count method'.

(c) Three-count method: Here the PAEC is measured much more accurately as compared to both the above mentioned two methods. The three-count method can further be divided into (i) alpha-gross counting and (ii) alpha-spectroscopy methods.

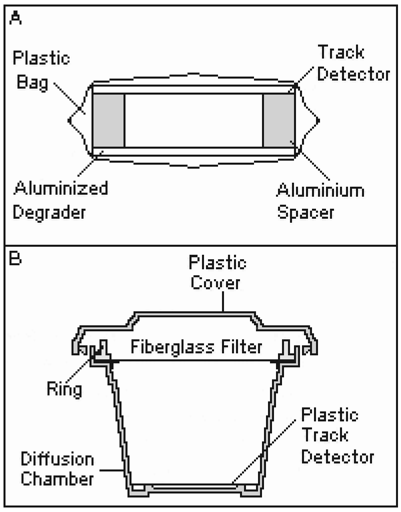
(i) Alpha-gross counting method: This method counts the alpha particles emitted from Po-218 during the specified counting intervals.

(ii) Alpha-spectroscopy method: In this method alpha activity from Po-218 and Po-214 is obtained. It is the most accurate method, however, the instrumentation is relatively expensive.

SOME EUROPEAN SURVEYS FOR THE MEASUREMENT OF INDOOR RADON LEVELS

In the past, a number of countrywide surveys have been carried out for the measurement of radon levels (63-95). The table given below shows some of these values.

Figure 3: A set of two figures showing two passive type dosimeters for radon concentration measurement. (A) shows a polythene bag type dosimeter. Here only radon permeates through the plastic bag while its daughters present in the atmosphere are filtered out. Tracks are produced by radon (and its daughters produced inside the dosimeter) decaying in the volume of the dosimeter. (B) shows the sketch of a permeation sampler having detector positioned at the closed end and a membrane placed on its open end.



Country/(Area)	Radon Concentration (Bq/m^{-3})
Austria (Salzburg)	15
Hungary	26
Denmark-Single Apts.	70
Denmark-Flats	82
Norway	160
Sweden	101
Finland	90
U.K. (Cornwall)	390
U.K. (Devon)	210
Ireland	45
Germany	40
Switzerland	225

(Acceptable Radon Level=50-150 Bq/m^{-3})

MEASUREMENTS IN PAKISTAN

The Pakistan Institute of Nuclear Science and Technology (PINSTECH) developed and employed an environmental system for the measurement of radon in some selected houses of Islamabad and Rawalpindi and the surrounding areas. To start with, a survey plan for radon monitoring was prepared. Then volunteers were invited from various localities of Rawalpindi and Islamabad. Most of the people showed their willingness for monitoring of their houses. The dosimeters (enclosed in plastic envelopes-Figure 3a) were handed over to the individuals and were fixed at the recommended points in the rooms. After an exposure of about 8-10 weeks, the detectors were retrieved and chemically etched for 90 minutes in 6N NaOH, kept at 50°C. Track density was converted into radon concentration (Bq/m^3) by applying the conversion factor for the detectors in the box type dosimeters (93-95).

It was found that the average value of radon concentration in stores was the highest when compared with other category of rooms. The radon concentration in the lounges was lower than that found in the bed rooms. The results agree with the fact that less ventilated places have more radon concentrations. The second highest value of radon concentration was found in a kitchen. In Rawalpindi and Islamabad, people use natural gas for cooking. The natural gas might have transported the underground radon with it. The other sources of radon in kitchen are water and the drainage holes. The kitchen doors and indoors are usually kept closed in winter. Therefore, radon concentration may be on the higher side. In winter, the bed rooms and the sitting rooms are closed at night and are open at day time, showing low radon concentration.

REMEDIAL AND PREVENTIVE ACTIONS

Studies carried out to devise ways and means of controlling the radioactive pollutants has produced some useful results (7, 8, 96-98). Certain types of 'surface coatings' and 'sealing of cracks' in the basement floor and walls can considerably reduce the radon levels. Reductions achievable with different sealants show, that even the easily applied paint coast reduce emanation by 30-70% (latex paint) and 50-90% (epoxy paint). The remedial programmes undertaken on these lines have produced quite satisfactory results. An increase in ventilation is found to be very effective in reducing the concentration of radon and its decay products in the indoor air (7, 8, 96-98). However, increase in ventilation costs in terms of increased heating expenditure. A way out to this problem is the use of a mechanical ventilation system with heat recovery. If the above described measures fail to reduce the indoor radon concentration sufficiently, diversion of soil gas has to be considered. Active soil ventilation can be achieved by the use of a fan to draw or force soil gas away from the home. Some safety measures against indoor radon build up are (7, 8):

1. To avoid the presence of (a) 'cracks' in the walls of the floor and (b) 'leaky skirting'.
2. To avoid 'loose floor-wall' joints and 'loosely-fitted' pipes.
3. To install sewerage pipes through 'effective' water traps.
4. To employ an efficient ventilation system.
5. To employ a system of 'pumping out' the 'sub-soil gas' under the foundation.
6. To employ a piping system for providing 'easy path' to the 'sub-soil gas' from the 'lower earth layers' of the foundation.
7. To 'seal off' the foundation by means of special foils or sheets.
8. To 'employ a degassing system' for 'foundation drainage'.

In order to avoid build up of indoor radon in the new constructions, the following recommendations have been made (7, 8, 98).

1. Building materials with strong radon exhalation should be avoided in the construction of new buildings/houses.

2. Construction on potentially dangerous ground should not be recommended/allowed in any case.

3. The latest experience shows that it should be possible to construct new dwellings such that radon ingress from the ground can be prevented without radical departure from the conventionally followed building practices: a ventilated crawl space is likely to be sufficient in this regard.

CONCLUDING REMARKS

One may draw the following conclusions from the above brief description of indoor radioactive pollutants:

1. The pollution problem in the Islamic world has assumed significant importance. This problem has received recognition throughout the world and the government agencies have become aware of the need to control it. The world summit in Rio de Janeiro will greatly help in finding solutions of this explosive problem.

2. The issue of radioactive pollutants has been a subject of considerable importance for the whole world right from the era of the second world war. Whereas much efforts have been made in controlling pollution emanating from industrial scale waste disposal of radioactive materials, relatively lesser attention has been focused on areas like pollution due to radon and its daughter products.

3. The effect of radon pollution on human health (lung cancer) has been fairly established. Surveys have shown definite relation between lung cancer and elevated radon dose intakes.

4. Presence of radon in households and public places due to a variety of reasons has been discovered and studied. The risk of the continuous presence of radon in usual human dwellings on human health warrants more public awareness. Remedial measures must be adopted to avoid the risk of deaths due to over exposures of radon.

REFERENCES

1. Harting FH and Hasse W : Der Lungenkrebs, die Bergkrankheit in den Schneeberger Gruben, Teil I Eulenbergs Vierteljahrschriftf., Gerichtliche Medizen und offentliches Gesundheitswesen, neue Folge, 30:296, 1879.

2. Bettis C and Throckmorton C : What Teachers Should Know about Radon. The Physics Teacher, 29:338-343, 1991.

3. Nero AV : Earth, Air, Radon and Home. Physics Today, 42:32-39, 1989.

4. Nero AV: Airborne Radio nuclide and Radiation in Buildings: A review, Health Phys, 45:303-322, 1983.

5. Fleischer RL : Radon in the Environment-Opportunities and Hazards. Nucl Tracks Radiat Meas, 14:421-435, 1988.

6. Hopke PK : Radon and its Decay Products: Occurrence, Properties and Health Effects. American Chemical Society, Washington DC, 1987.

7. Nazaroff WW and Nero AV : Radon and its Decay Products in Indoor Air, John Wiley and Sons, New York, 1988.

8. Nero AV : Controlling Indoor Air Pollution Sci American, 258:42-48, 1988.

9. Miles JCH : Indoor Radon and Lung Cancer : Reality or Myth? Report of the Twenty-Ninth Hanford Symposium on Health and the Environment, held in Richland, USA, October 15-19, 1990.

10. Crameri R and Burkart W : The Radon Problem. Radiat Phys Chem, 34:251-259, 1989.

11. Sevic J, Kunz E, Tomesek L, Placek V, Horacek J : Cancer in Man After Exposure to Rn Daughters. Health Phys, 54:27-46, 1988.

12. National Research Council Committee on the Biological Effects of Ionizing Radiation. The Health Effects of Radon and Other Internally Deposited Alpha-emitters (BEIR-IV) Washington D.C. National Academy Press, 1988.

13. James AC : A Reconsideration of Cells at Risk and Other Key Factors in Radon Daughter Dosimeter, ACS Symposium Series 331, Radon and its Decay Products: Occurrence, Properties, and Health Effects; Editor Philip K. Hopke, Univ of Illinois, Published by American Chemical Society, Washington, DC, USA, 400-418, 1987.

14. Donaldson AW : The Epidemiology of Lung Cancer Among Uranium Miners. Health Phsy, 16:563-569, 1969.

15. Holaday DA : History of the Exposure of Miners to Radon. Health Phys, 16:547-552, 1969.

16. Bodansky D, Robkin MA, Stadler DR : Indoor Radon and its Hazards. University of Washington Press, Seattle and London, 1987.

17. ICRP, Limits of Inhalation of Radon Daughters by Workers. Annals of ICRP, ICRP Publication 32, 1981.

18. ICRP, Lung Cancer Risk from Indoor Exposure to Radon Daughters. Annals of ICRP, ICRP Publication 50, Pergamon Press, Oxford, 1987.

19. EPA, A Citizen's Guide to Radon, What it is and What to do About it. Environmental Protection Agency, EPA-86-004, 1986.

20. Jacobi W : Relation between the Inhaled Potential Alpha-Energy of Rn-222 Daughters and the Absorbed Alpha-Energy in the Bronchial and Pulmonary Region. Health Phys, 23:3-11, 1972.

21. OECD/NEA, Dosimeter Aspects of Exposure to Radon and Thoron Daughter Products. Organization for Economic Co-operation and Development (OECD), Nuclear Energy Agency, 1983.

22. Spengler JD and Sexton K : Indoor air pollution: A public health perspective, Science, 221:9, 1983.

23. Indoor Pollutants, National Academy of Sciences, Washington, DC, 1981.

24. McCann J, Horn L, Girman JR, Nero AV : Potential risks from *exposure to organic carcinogens in indoor air. In: Short-Term Bioassays in the Analysis of Complex Environmental Mixtures. Ed by SS Sanbhu, de DM Marini, MJ Mass, MM Moore, JS Mumford, Plenum, New York, in press.*

25. Palmes ED, Gunnison AF, DiMattio J, Tomczyk C : Personal sampler for nitrogen dioxide. Am Ind Hyg Assoc J, 37:570, 1976.

26. Geisling KL, Tashima MK, Girman JR, Miksch RR and Rappaport SM : A passive sampling device for determining formaldehyde in indoor air. Environ Int, 8:153, 1982.

27. Gunning C and Scott AG : Radon and thoron daughters in housing. Health Phys, 42:527, 1982.

28. Steck DJ : Geological variation of radon sources and indoor radon along the southwestern edge of the Canadian shield. In Fourth Int Conf on Indoor Air Quality and Climate, Berlin, August 17-21, 1987.

29. Abu-Jarad F, Fremlin JH, Bull RK : "A study of the radon daughter emitted from building materials using plastic alpha-track detectors". Phys Med Biol, 25:683-694, 1983.

30. Gesell TF : Background atmospheric Rn-222 concentrations outdoors and indoor: A review, Health Phys, 45:289, 1983.

31. Abu-Jarad F and Fremlin JH : "The activity of radon daughters in high-rise buildings and the influence of soil emanation". Environmental International, 8:37, 1982.

32. Abu-Jarad F: "Variation in Long-term radon and daughters concentration with position inside a room". Radiation Protection Dosimeter, 3:227-231, 1982.

33. Abu-Jarad F and Fremlin JH : "Seasonal variation of radon concentration in dwellings". Health Physics, 46:1126, 1984.

34. Jacobi W : Possible lung cancer risk from indoor exposure to radon daughters. Radiation Protection Dosimeter, 7:395, 1984.

35. Hess CT, Weiffenbach CV, Norton SA : Environmental radon and cancer correlations in Maine. Health Phys, 45:339, 1983.

36. Jonhson RH, Bernhardt DE, Nelson NS, Galley HW : Radiological health significance of radon in natural gas. In: Noble Gases, U.S. Energy Research and Dev Admin. Ed by RE Stanley, AA Moghissi. CONF-730915, Las Vegas, NV, p 532, 1973.

37. Ellett WH : Epidemiology and risk assessment: Testing models for radon-induced lung cancer. In: Indoor Air and Human Health. Ed by RB Gammage, SV Kay. Lewis Publishers, Chelsea, MI, p 102,1985.

38. Porstendorfer J : Behavior of radon daughters products in indoor air, Radiation Protection Dosimeter, 7:107, 1984.

39. Budnitz RJ : Radon-222 and its daughters-A review of instrumentation for occupational and environmental monitoring. Health Phys, 26:145, 1974.

40. Nazaroff WW, Offermann FJ, Robb AW : Automated system for measuring air-exchange rate and radon concentration in houses. Health Phys, 45:525, 1983.

41. Bigu J and Kaldenbach R : "A microprocessor based continuous monitor with alpha spectroscopy capabilities for the determination of radon, thoron and their progeny", Radiation Protection Dosimeter, 12:251, 1985.

42. Lucas HL : "Improved low-level alpha-scintillation counter for radon". Rev Sci Instrum, 28:680, 1977.

43. NEA-OECD, Metrology and Monitoring of Radon, Thoron and Their Daughter Products, Paris, 1985.

44. Thomas JW : "Measurement of radon daughters in air". Health Phys, 23:783, 1972.

45. Budnitz RJ, Nero AV, Murphy DJ, Graven R : Instrumentation for Environmental Monitoring. 2nd ed, Vol 1, Radiation WIley, New York, p 395, 1983.

46. Lucas HF : Improved low level alpha scintillation counter for radon. Rev Sci Instrum, 28:680, 1957.

47. Scheibel HG, Porstendorfer J, Wicke A : A device for the determination of low natural Rn-222 and Ra-226 concentrations. Nucl Instrum Methods, 165:345, 1979.

48. Barton TP and Ziemer PL : A simple, inexpensive scintillation cell. Health Phys, 47:93, 1984.

49. Porstendorfer J, Wicke A, Sehraub A : Methods for continuous registration of radon, thoron and their decay products indoors and outdoors. In: Nat Rad Environ III. CONF-780422. Ed by TF Gesell, WM Lowder. US Dept of Commerce, National Technical Information Service, Springfield VA, p 1293, 1980.

50. Alter HW and Oswaild RA : Results of indoor radon measurements using the track etch method. Health Phys, 45:425, 1983.

51. Cohen BL : Comparison of nuclear track and diffusion barrier charcoal adsorption methods for measurement of Rn-222 levels in indoor air. Health Phys, 50:828, 1986.

52. Bedrosian PH : Photographic technique for monitoring radon-222 and daughter products. Health Phys, 16:800, 1969.

53. Scott AG : A field method for measurement of radon daughter in air. Health Phys, 41:403, 1981.

54. Irfan M and Fagan AJ : Measurement of radon daughters in air using gamma spectroscopy. Nuclear Instrum Methods, 166:567, 1979.

55. Groer PG : The accuracy and precision of the Kusnetz method for the determination of the working level in uranium miners. Health Phys, 23:106, 1972.

56. Borak TB, Franco ED, Holub RF : An evaluation of working level measurement using a generalized Kusnetz method. Health Phys, 42:459, 1982.

57. Guggenheim SF, George AC, Graveson RT, Breslin AJ : A time-integrating environment radon daughter monitor. Health Phys, 36:452, 1979.

58. Johnson DR, Boyett RH, Becker K : Sensitive automatic counting of alpha particle tracks in polymers and its applications in dosimeter. Health Phys, 18:424, 1970.

59. Khan A and Phillips CR : Electrets for passive radon daughter dosimeter. Health Phys, 46:141, 1984.

60. Fleischer RL, Turner LG, George AC : Passive measurement of working levels and effective diffusion constants of radon daughters by the nuclear track technique. Health Phys, 47:9, 1984.

61. Fleischer RL : Theory of passive measurement of radon daughters and working levels by the nuclear track technique. Health Phys, 47:263, 1984.

62. Miles JC, Stares EJ, Cliff KD, Sinnaeve J : Results from an international inter-comparison of techniques for measuring radon and *radon decay products. Radiation Protection Dosimeter, 7:169, 1984.*

63. Steinhusler F, et al. : Health Phys, 45:331, 1983.

64. Luis S, et al. : Health Phys, 56:107, 1989.

65. Nero Jr AV : Radon and it Decay Products Indoor Air. Ed by WW Nazaroff, AV Nero Jr, 57:112, 1988.

66. George AC and Hinichiliffe LE : ACS Symposium Series 331. Ed by PK Hopke, p 42, 1987.

67. Stranden E : Health Phys, 38:301, 1980.

68. Hopke PK : ACS Symposium Series 331. Ed by PK Hopke, p 572, 1987.

69. Gesell TF : Health Phys, 45:289, 1983.

70. Crameri R and Burkrt W : Radiat Phys Chem, 34:251, 1989.

71. Cliff KD, et al. : ACS Symposium Series 331. Ed by PK Hopke, p 104, 1987.

72. Mclaughlin JP : ACS Symposium Series 331. Ed by PK Hopke, p 113, 1987.

73. Toth A : Health Phys, 23:281, 1972.

74. Cohen BL : A national survey of Rn-222 in U.S. homes and correlating factors. Health Phys, 51:175, 1986.

75. McGregor RG, Vasudev P, Letourneau EG, McCullough RS, Prantl FA, Taniguchi H : Background concentrations of radon and radon daughters in Candian homes. Health Phys, 39:285, 1980.

76. Swedjemark GA and Mjones L : Radon and radon daughters concentrations in Swedish homes. Radiation Protection Dosimeter, 7:341, 1984.

77. Castren O, Winqvist K, Makelainen I, Voutilainen A : Radon measurements in Finnish houses. Radiation Protection Dosimeter, 7:333, 1984.

78. Sorensen A, Botter-Jensen L, Majborn B, Nielsen SP : A pilot study of natural radiation in Danish homes. Sci Total Environ, 45:351, 1985.

79. Schmeir H and Wicke A : Results from a survey of indoor radon exposures in the Federal Republic of Germany. Sci Total Environ, 45:307, 1985.

80. Keller G and Folkerts KH : A study on indoor radon. In: Indoor Air: Radon, Passive Smoking, Particulates and Housing Epidemiology. Ed by B Berglund, T Lindvall, J Sundell. Vol 2, Swedish Council for Building Research, Stockholm, p 149, 1984.

81. Green BMR, Brown L, Cliff KD, Driscoll CMH, Miles JC, Wrixon AD : Surveys of natural radiation exposure in UK dwellings with passive and active measurement techniques. Sci Total Environ, 45:459, 1985.

82. Put LW and Meijer RJ : Survey of radon concentrations in Dutch dwellings. In: Indoor Air: Radon, Passive Smoking, Particulates and Housing Epidemiology. Ed by B Berglund, T Lindvall, J Sundell. Vol 2, Swedish Council for Building Research, Stockholm, p 49, 1984.

83. Castren O, Voutilainen A, Winqvist K, Makelainen I : Studies of high indoor radon areas in Finland. Sci Total Environ, 45:311, 1985.

84. Hildingson O : Radon measurements in 12.000 Swedish homes. Environ Int, 8:67, 1982.

85. Doyle SM, Nazaroff WW, Nero AV : Time-averaged indoor radon concentrations and infiltration rates sampled in four U.S. cities. Health Phys, 47:579, 1984.

86. Cliff KD : Assessment of airborne radon daughter concentrations in dwellings in Great Britain. Phys Med Biol, 23:696, 1978.

87. Poffijn A, Marijns R, Vanmarcke H, Uyttenhuve J : Results of a preliminary survey on radon in Belgium. Sci Total Environ, 45:335, 1985.

88. Rannou A, Madelmont C, Renouard H : Survey of natural radiation in France. Sci Total Environ, 45:467, 1985.

89. McAulay Ir and McLaughlin JP : Indoor radiation levels in Ireland. Sci Total Environ, 45:319, 1985.

90. Luxin W, Yongru Z, Zufan T, Weihul H, Deqing C, Yongling Y : Epidemiological Investigation in High Background Radiation Areas of Yangjiang, China, paper ICHLNR-MS-110-P8/3, Proc Int Conf on High Levels of Nat Radiat, Ramsar, Iran, 3-7 1990, being published as an IAEA TECDOC.

91. Sunta CM : A Review of the Studies of High Background Areas of the S-W Coast of India, paper ICHLNR-MS-110-P9/10, Proc Int Conf on High Levels of Nat Radiat, Ramsar, Iran, 3-7 1990, being published as an IAEA TECDOC.

92. Sohrabi M : Recent Studies of High Natural Radiation Areas of Ramsar, ICHLNR-MS-110-P11-2, Proc Int Conf on High Levels of nat Radiat, Ramsar, Iran, 3-7 1990, being published as an IAEA TECDOC.

93. Tufail M, Amin M, Akhtar W, Khan HA, Qureshi AA, Manzoor S : Radon concentration in some houses of Islamabad and Rawalpindi. Nucl Tracks, 19:429, 1991.

94. Tufail M, Ahmad N, Khan HA : Measurement of radon concentration in some cities of Pakistan, Radiation Protection Dosimeter (in press).

95. Tufail M, Ahmad N, Khan HA : Investigation of natural radioactivity from the building materials used in Islamabad and Rawalpindi. The Science of the Total Environment (in press).

96. Smith D : Ventilation rates and their influence on equilibrium factor, in Second Workshop on Radon and Radon Daughters in Urban Communities Associated with uranium mining and processing, Atomic Energy Control Board, Ottawa, 1979.

97. Mowris RJ and Fisk WJ : Modeling the effects of exhaust ventilation on radon entry rates and indoor radon concentrations, Lawrence Berkeley Laboratory report LBL-22939, Berkeley, CA (submitted to Health Physics), 1987.

98. Henschell DB and Scott AG : The EPA program to demonstrate mitigation measures for indoor radon: Initial results. In Indoor Radon Proc APCA Int Specialty Conf, Philadelphia, Air Pollution Control Association, Pittsburgh, PA, 1986.

Correspondence:
Hameed Ahmed Khan
IA and Training Division,
PAEC Head Office,
P.O. Box 1114,
Islamabad, PAKISTAN.