THE MEASUREMENT OF THE RADON CONCENTRATIONS IN INDUSTRY AND HOMES IN GAZİANTEP

M. Sc. Thesis

in

Engineering Physics

University of Gaziantep

Supervisor

Prof. Dr. ZİHNİ ÖZTÜRK

BY

Emine Burçin İspir

JULY 2007

ABSTRACT

THE MEASUREMENT OF THE RADON CONCENTRATIONS IN INDUSTRY AND HOMES IN GAZİANTEP

İSPİR Emine Burçin
M. Sc., in P. E. University of Gaziantep
Supervisor: Prof. Dr. Zihni ÖZTÜRK
July 2007, 50 pages

In this study, indoor radon concentrations have been measured in 34 workplaces, 41 homes, and 13 hospitals in Gaziantep. Passive solid state nuclear track detectors (SSNTD type Cr-39) in the diffusion chamber were used to measure indoor radon concentration. Detectors were obtained from the laboratory of Cekmece Nuclear Research and Training Centre. They were etched and evaluated at the same laboratory. The measured radon concentrations had a mean value of 27 Bq/m^3. Values of the concentration ranged from 5 to 117 Bq/m^3.

Keywords: Radon, Radon-222, Radon Risk, Cr-39, RadoSys 2000.

ÖZET

GAZİANTEP'TEKİ İŞ YERLERİNDE VE EVLERDE RADON KONSANTRASYONUNUN ÖLÇÜMÜ

İSPİR Emine Burçin
Yüksek Lisans Tezi, Fizik Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Zihni ÖZTÜRK
Temmuz 2007, 50 sayfa

Bu çalışmada, Gaziantep'te bulunan 34 işyerinde, 41 evde ve 13 hastanede radon gazı konsantrasyonunun ölçümü yapılmıştır. Bu ölçümlerde pasif iz detektörleri SSNDT (Cr-39) kullanılmıştır. Detektörler Çekmece Nükleer Araştırma ve Eğitim Merkezinden elde edilmiş ve aynı merkezde değerlendirilmiştir. Ölçülen radon konsantrasyonunun ortalama değeri 27 Bq/m^3 bulunmuştur. Konsantrasyon değerleri 5 ile 117 Bq/m^3 arasında değişmektedir.

Anahtar Kelimeler: Radon, Radon-222, Radon Riski, Cr-39, RadoSys-2000

ACKNOWLEDGEMENT

During the writing of this thesis, the author received many helps from people to whom she would like to thank. First of all I would like to thank my supervisor Prof. Dr. Zihni ÖZTÜRK for all help and advice given during the preparation of this thesis. I am truly grateful for the encouragement and consideration of him. Secondly, I wish to thank Dr. Nilgün Çelebi and other personnel at the Department of Health Physics for their kind help and friendships at Çekmece Nuclear Research and Training Center. I have benefited from the aid and advice of them during the writing and preparation of this thesis. Finally, I would like to thank my family who support me all time.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

^{222}Rn is an inert radioactive element with a half-life of 3.8 days. It belongs to the radioactive uranium series and occurs in soil gas in varying activities. In recent years, ^{222}Rn has been used as tracer for the origin and trajectory of air masses [1]. Although these elements occur in virtually all types of rocks and soils, their concentrations vary with specific sites and geological materials. As an inert gas, radon can move freely through the soil from its source; the distances are determined by factors such as rate of diffusion, effective permeability of the soil and by its own half-life. The inhalation of short-lived daughter products of naturally occurring radon is a major contributor to the total radiation dose to exposed subjects. Radon progenies might be inhaled and deposited more or less deeply onto the bronchio-pulmonary tree, depending upon the granulometry of the particles on which they become attached. Under specific conditions, such as those prevailing in the uranium mining environment, lung dose due to radon progenies may be sufficiently high to cause an increase in the occurrence of lung cancer [2].

Measurements of indoor radon are of importance because the radiation dose to human population due to inhalation of radon and its daughters contributes more than 50% of the total dose from natural sources [2]. The three radon isotopes (^{219}Rn, ^{220}Rn, ^{222}Rn) are gaseous and they may be released from the ground, rocks and also from building materials and are accumulated with their short-lived daughters in closed spaces, and in particular in tourist karstic caves. ^{220}Rn and ^{219}Rn, mainly because of their short half-lives are not as important as ^{222}Rn, which may reach levels of concentration in the air which are significant in terms of radiological protection.

Worldwide measurements of radon activities in the indoor air of dwellings are continuously presented all over the world [3]. The numerous measurements of the activity concentrations of radon in different countries along with the epidemiologica

studies regarding the indoor radon and the risk of lung cancer have been published in recent years [4].

The International Commission on Radiological Protection (ICRP) has investigated the health effects of inhaled radon and its daughter and has published a report 'Protection against Radon-222 at home and at work'. In this report, radon exposure is limited and an action level related to the annual mean concentration of radon in a building was recommended. The action level for the annual effective dose is limited to the range of 3-10 mSv. The corresponding recommended radon concentrations for these annual exposures are 200-600 Bq/m^3 in home and 500-1500 Bq/m^3 in workplaces [5]. The International Commission on Radiological Protection (ICRP) also pointed out that the increase in lung cancer risk for humans living continuously with a 400 Bq/m^3 concentration is 6 %.

In Turkey, the action level recommended by Turkish Atomic Energy Authority (TAEK) is 400 Bq/m^3 [6].

In the same manner, to discover the radon concentration in Turkey, the first measurements were taken by Cekmece Nuclear Research and Training Centre in İstanbul. Then, these investigations were conducted in other areas of Turkey and the results are given in Table 6.1 in chapter 6.

The solid state nuclear track detectors (SSNTD) have become an important tool in every investigation of the presence of radon gas. The SSNTD have been utilized for studying the radon emanation in Gaziantep as well as for determining radon activity in different states.

In this study, we describe a method based on CR-39 SSNTD provided by Cekmece Nuclear Research and Training Centre in İstanbul, for studing of the indoor radon levels and determining the radon effective dose rates of the dwellings and workplaces in Gaziantep. After two months of waiting period the detectors were collected and then sent to Health Physic Department in ÇANEM for the read out of the samples. At the end of the chemical etching process, the measurement values were obtained in ÇANEM.

CHAPTER 2

RADIATION AND RADIOACTIVITY

2.1. Sources of Ionization Radiation

Radiation with sufficient energy to cause an electron to be removed from an electrically neutral atom or molecule is called ionizing radiation. Ionizing radiation may be a particle or an electromagnetic ray.

Natural background radiation is continuously present and is constantly being absorbed by human beings. Natural background radiation comes from numerous sources in the environment and from within our bodies. Sources of natural background radiation include: cosmic radiation, terrestrial radiation and natural radio nuclides within the body. Figure 2.1 shows sources chart.

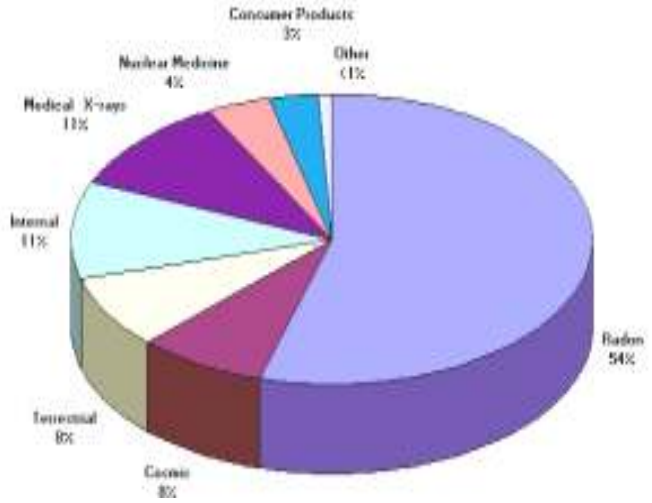

Figure 2.1 Sources chart

Cosmic radiation comes from the sun and outer space. Cosmic radiation exposure increases at higher altitudes, where there is a lower atmospheric density. Individuals flying at high altitudes and into outer space also receive increased amounts of cosmic radiation.

Terrestrial radiation is a natural source of radiation in the ground, rocks, building materials and drinking water supplies. Many areas have elevated levels of terrestrial radiation due to increased concentrations of uranium or thorium in the soil.

Finally, there are natural radionuclides that are within the human body. They include radioisotopes of carbon (^{14}C) and potassium (^{40}K).

In 1895 Wilhelm Roentgen discovered X-rays and in 1896 Henri Becquerel discovered radioactivity. These two discoveries were the beginning of the quest to use radiation and radioactivity for the good of mankind. New, man-made or technically enhanced sources of radiation were now added to the existing natural background sources.

Radiation is used extensively in medicine to diagnose the condition of the human body and to treat diseases, primarily cancer. Other man-made sources of radiation include consumer products such as some luminous dial watches, self-illuminating emergency signs (i.e., where no electrical power is needed), smoke detectors, and static eliminators.

Nuclear reactors, which provide steam to generate electricity in commercial power plants, submarines and ships; and nuclear weapons, are more examples of man-made radiation sources. The dose from man-made radiation sources is relatively small as compared to naturally occurring background sources of radiation.

Radioactive isotopes, by definition, are unstable. Through a process called radioactive decay these materials seek a stable state through transformation. Transformation may or may not result in a stable isotope, so the process may continue in what is called a decay chain in what is called a decay chain. The radiation emitted from radioactive materials comes from these transformations, which release excess energy.

2.2. Radioactivity and Radioactive Decay

Radioactivity may be defined as a spontaneous process in which an atom with an unstable nucleus undergoes transformation to a more stable atom by energy emission in the form of radiation. The released energy can be in the form of a particle with kinetic energy, a photon of electromagnetic energy, or a combination of both.

The original nucleus prior to the transformation is called the "parent" and the resulting nucleus after transformation is called the "progeny". A given transformation, i.e., one parent/progeny transition, is termed a "radioactive decay" or disintegration [7].

Stability of a given nucleus depends on the number and ratio of its neutrons to protons (n:p). The two main forces that act upon the nucleus are electrostatic forces caused by the strong repulsion of the positive charges of the protons and the strong nuclear attraction forces that affect all of the neutrons and protons in a nucleus. In a stable atom the nuclear and electrostatic forces are in balance because the n:p ratio allows the forces to balance. The range of the electrostatic force from a proton is greater than the range of the nuclear force of a neutron or proton. As the number of protons increases in a nucleus more neutrons than a 1:1 ratio are needed to keep the atom stable. As elements increase above an atomic number of 20 the n:p ratio range to remain stable gradually increases until Bismuth, atomic number 83, where the n:p ratio exceeds 1.5:1. Above ^{209}Bi there are no completely stable nuclei [7].

An atom that is in an unstable range will transform (disintegrate or decay) to move its n:p ratio towards a stable configuration. It does this by transforming a neutron to a proton or vice versa, and then ejecting excess mass or energy from the nucleus in the form of radiation.

2.3. Half-Life

An individual unstable atom in a radioactive material sample decays in a seemingly random fashion; however, projected over a period of time, unstable atoms in a radioactive material sample decay at a fixed rate characteristic of its particular radionuclide. One way to describe this phenomenon for a particular radionuclide is to determine how long it takes for ½ of the radioactive atoms to decay, defined as the half-life (T ½) [8]. The decay continues at an exponential rate, i.e. the fraction of activity remaining after any number of half-lives will be $(½)^n$, where n is the number of half-lives that have elapsed. For example after one half-life there is ½ the original and after two half-lives there is $(½)^2$ or ¼ the original amount.

The decay curve is demonstrated graphically below.

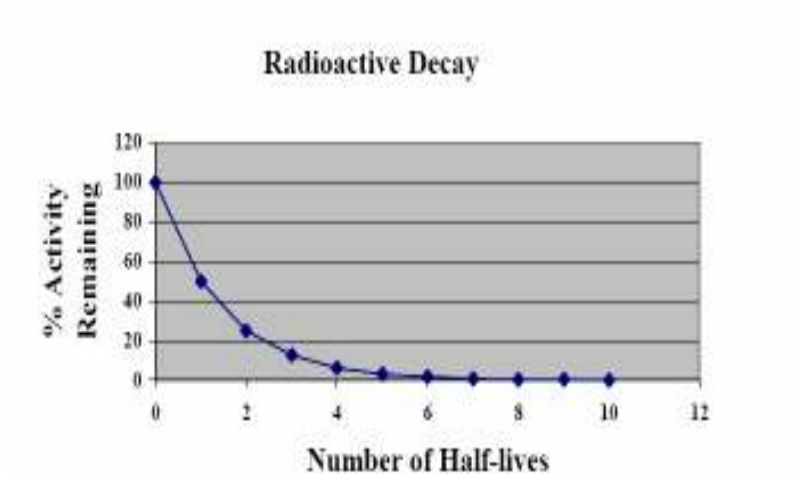

Figure 2.2 Exponential decay of radionuclides

Calculations can be made using the decay law equation to determine activity levels at various times if the activity level is known at some specific time. It is defined as Equation (2.1).

$$A_t = A_o\, e^{-\lambda t} \qquad (2.1)$$

Where A_t = the activity at the time of interest

A_o = the original activity

t = time elapsed since the original activity was known

λ = the decay constant for a particular radionuclide = $(0.693/T_{1/2})$

$T_{1/2}$ = characteristic half-life

Half -lifes of uranium and its decays are given in Table 2.

Table 2.1 Half-lives of uranium and its decay

Radionuclides	Half-life
Uranium-238 ($_{92}$U)	4 510 000 000 years
Uranium-235 ($_{92}$U)	704 000 000 years
Uranium-234 ($_{92}$U)	247 000 years
Radium-226 ($_{88}$Ra)	1 600 years
Radon-222 ($_{86}$Rn)	3,82 days
Polonium-214 ($_{84}$Po)	1.6 X 10^{-4} seconds
Polonium-218 ($_{84}$Po)	3.05 minutes

2.4. Types of Radiation

2.4.1. Alpha particle

Alpha particles are emitted by radioactive nuclei such as uranium or radium in a process known as alpha decay. This sometimes leaves the nucleus in an excited state, with the emission of a gamma ray removing the excess energy. In contrast to beta decay, alpha decay is mediated by the strong nuclear force. Classically, alpha particles do not have enough energy to escape the potential of the nucleus. However, the quantum tunneling effect allows them to escape [8]. Alpha particles are emitted by radioactive nuclei such as uranium or radium in a process known as alpha decay. This sometimes leaves the nucleus in an excited state, with the emission of a gamma ray removing the excess energy. In contrast to beta decay, alpha decay is mediated by the strong nuclear force. Classically, alpha particles do not have enough energy to escape the potential of the nucleus. However, the quantum tunneling effect allows them to escape [8].

When an alpha particle is emitted, the atomic mass of an element goes down by roughly 4 amu, due to the loss of 4 nucleons. The atomic number of the atom goes down by 2, as the atom loses 2 protons, becoming a new element. An example of this is when radium becomes radon gas due to alpha decay (see Eqn.(2.2)).

$$ {}_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + {}_{2}He^{4} \qquad (2.2) $$

Because of their charge and large mass, alpha particles are easily absorbed by materials and can travel only a few centimeters in air. They can be absorbed by tissue paper or the outer layers of human skin (about 40 micrometers, equivalent to a few cells deep) and so are not generally dangerous to life unless the source is ingested or inhaled. Because of this high mass and strong absorption, however, if alpha radiation does enter the body (most often because radioactive material has been inhaled or ingested), it is the most destructive form of ionizing radiation. It is the most strongly ionizing, and with large enough doses can cause any or all of the symptoms of radiation poisoning. It is estimated that chromosome damage from alpha particles is about 100 times greater than that caused by an equivalent amount of other radiation. The alpha emitter polonium-210 is suspected of playing a role in lung and bladder cancer related to tobacco smoking.

Alpha particles are the least penetrating radiation. The major energy loss for alpha particles is due to electrical excitation and ionization. As an alpha particle passes through air or soft tissue, it loses, on the average, 35 eV per ion pair created. Due to its highly charged state, large mass and low velocity, the specific ionization of an alpha particle is very high [7].

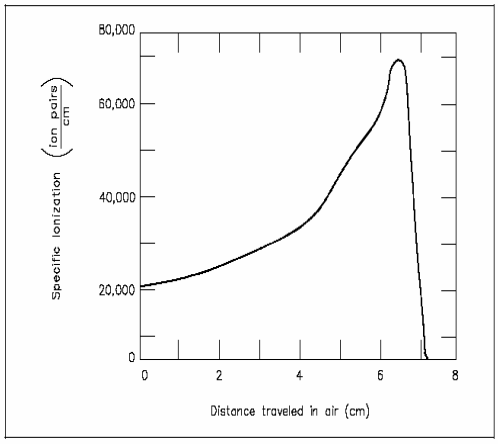

Figure 2.3 Alpha particle specific ionization –vs- distance traveled in air

Figure 2.3 illustrates the specific ionization of an alpha particle, on the order of tens of thousands of ion pairs per centimeter in air. An alpha particle travels a relatively straight path over a short distance.

Alpha particles emitted by radioactive nuclei are among the most hazardous forms of radiation, if these nuclei are incorporated within a human body. As any heavy charged particle, alpha particles lost their energy in very short distance in dense media, causing significant damage to surrounding biomolecules. On the other hand, the external alpha irradiation cannot cause any damages because alphas are completely absorbed by a very thin (micrometers) dead layer of skin as well as by few centimeters of air. However, if a substance radiating alpha particles is injected, ingested or inhaled by an organism it may become a risk, potentially inflicting very serious damage to the organisms' genetic makeup.

2.4.2. Beta particle

Beta particles are high-energy electrons or positrons emitted by certain types of radioactive nuclei such as potassium-40. The beta particles emitted are a form of ionizing radiation also known as beta rays. The production of beta particles is termed

beta decay. They are designated by the Greek letter beta (β). Beta decay is a type of radioactive decay in which a beta particle (an electron or a positron) is emitted.

In the case of electron emission, it is referred to as "beta minus" (β^-), while in the case of a positron emission as "beta plus" (β^+).

Unstable atomic nuclei with an excess of neutrons may undergo β^- decay, where a neutron is converted into a proton, an electron and an electron-type antineutrino as Eqn.(2.3).

$$n^0 \rightarrow p^+ + e^- + \overline{\upsilon}_e \tag{2.3}$$

Unstable nuclei that are ficient in neutrons may undergo β^+ decay, where a proton is converted into a neutron. The proton consists of two up quarks and a down quark, one of the proton up quarks decays to a down quark, doing so, it will emit a W particle, which is unstable and decays further into a positron and an electron neutrino as Eqn.(2.4).

$$p \rightarrow n + e^+ + \upsilon_e \tag{2.4}$$

So, unlike beta minus decay, beta plus decay cannot occur in isolation, because the mass of the neutron alone is greater than the mass of the proton. Beta plus decay can only happen inside nuclei when the absolute value of the binding energy of the daughter nucleus is higher than that of the mother nucleus. The difference between these energies goes into the reaction of converting a proton into a neutron, a positron and a neutrino and into the kinetic energy of these particles [7].

In all the cases where β^+ decay is allowed energetically (and the proton is a part of a nucleus with electron shells), it is accompanied by the electron capture process, when an atomic electron is captured by a nucleus with emission of neutrino as Eqn.(2.5).

$$energy + p^+ \rightarrow n^0 + e^+ + \upsilon_e \tag{2.5}$$

But if the energy difference between initial and final states is low, the electron capture can occur without being accompanied by positron emission. If the proton and neutron are part of an atomic nucleus, these decay processes transmute one chemical element into another. Eqns.(2.6), (2.7), (2.8) are given for example.

$${}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^- + \overline{\upsilon}_e \quad \text{(beta minus)} \tag{2.6}$$

$${}^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + e^+ + \upsilon_e \quad \text{(beta plus)} \tag{2.7}$$

$${}^{22}_{11}Na + e^- \rightarrow {}^{22}_{10}Ne + \upsilon_e \quad \text{(electron capture)} \tag{2.8}$$

2.4.3. Neutrons

Neutrons have no electrical charge and have nearly the same mass as a proton (a hydrogen atom nucleus). A neutron is hundreds of times larger than an electron, but one quarter the size of an alpha particle. The source of neutrons is primarily nuclear reactions, such as fission, but they are also produced from the decay of radioactive elements. Because of its size and lack of charge, the neutron is fairly difficult to stop, and has a relatively high penetrating power.

Neutrons may collide with nuclei causing one of the following reactions:

1. Inelastic scattering,
2. Elastic scattering,
3. Radioactive capture,
4. Fission.

1. Inelastic scattering causes some of the neutron's kinetic energy to be transferred to the target nucleus in the form of kinetic energy and some internal energy. This transfer of energy slows the neutron, but leaves the nucleus in an described by the compound nucleus mode; the neutron is captured, then re-emitted from the nucleus along with a gamma ray photon [8].

2. Elastic scattering is the most likely interaction between fast neutrons and low atomic mass number absorbers. The interaction is sometimes referred to as the "billiard ball effect." The neutron shares its kinetic energy with the target nucleus without exciting the nucleus.

3. Radiative capture (n, γ) takes place when a neutron is absorbed to produce an excited nucleus. The excited nucleus regains stability by emitting a gamma ray.

4. The fission process for uranium (^{235}U or ^{238}U) is a nuclear reaction whereby a neutron is absorbed by the uranium nucleus to form the intermediate (compound) uranium nucleus (^{236}U or ^{239}U).The compound nucleus fissions into two nuclei (fission fragments) with the simultaneous emission of one to several neutrons. The fission fragments produced have a combined kinetic energy of about 168 MeV for ^{235}U and 200 MeV for ^{238}U, which is dissipated, causing ionization. The fission reaction can occur with either fast or thermal neutrons.

The distance that a fast neutron will travel, between its introduction into the slowing-down medium (moderator) and thermalization, is dependent on the number of collisions and the distance between collisions. Though the actual path of the

neutron slowing down is tortuous because of collisions, the average straight-line distance can be determined; this distance is called the fast diffusion length or slowing-down length. The distance traveled, once thermalized, until the neutron is absorbed, is called the thermal diffusion length.

Fast neutrons rapidly degrade in energy by elastic collisions when they interact with low atomic number materials. As neutrons reach thermal energy, or near thermal energies, the likelihood of capture increases. In present day reactor facilities the thermalized neutron continues to scatter elastically with the moderator until it is absorbed by fuel or non-fuel material, or until it leaks from the core.

Secondary ionization caused by the capture of neutrons is important in the detection of neutrons. Neutrons will interact with ^{10}B to produce ^{7}Liand ^{4}He as in that Eqn.(2.9).

$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li^{+++} + ^{4}_{2}He^{++} + 5e^{-} \qquad (2.9)$$

The lithium and alpha particles share the energy and produce "secondary ionizations" which are easily detectable.

2.4.4. Gamma ray

Gamma rays (often denoted by the Greek letter gamma, γ) are an energetic form of electromagnetic radiation produced by radioactive decay or other nuclear or subatomic processes such as electron-positron annihilation.

Gamma rays can be emitted when a nucleus undergoes a transition from one such configuration to another. For example, this can occur when the shape of the nucleus undergoes a change. Neither the mass number nor the atomic number is changed when a nucleus emits a γ ray in the reaction (see Eqn.(2.10)).

$$^{152}Dy^{*} \rightarrow ^{152}Dy + \gamma \qquad (2.10)$$

Gamma rays form the highest-energy end of the electromagnetic spectrum. They are often defined to begin at an energy of 10 keV, a frequency of 2.42 EHz, or a wavelength of 124 pm, although electromagnetic radiation from around 10 keV to several hundred keV is also referred to as hard X rays. It is important to note that there is no physical difference between gamma rays and X rays of the same energy — they are two names for the same electromagnetic radiation, just as sunlight and moonlight are two names for visible light. Rather, gamma rays are distinguished

from X rays by their origin. Gamma ray is a term for high-energy electromagnetic radiation produced by nuclear transitions, while X ray is a term for high-energy electromagnetic radiation produced by electron transitions due to accelerating electrons. Because it is possible for some electron transitions to be of higher energy than some nuclear transitions, there is an overlap between what we call low energy gamma rays and high energy X-rays.

Gamma rays are a form of ionizing radiation; they are more penetrating than either alpha or beta radiation (neither of which is electromagnetic radiation), but less ionizing. There are three methods of attenuating (reducing the energy level of) gamma-rays: photoelectric effect, compton scattering, and pair production.

2.4.4.1. Photoelectric effect

Concentrating on photon energies that are associated with nuclear energy levels, those in the region from 10 keV to 10 MeV, we find that only three types of interactions play a role in attenuating a photon beam. Each photon that interacts with an atom via any one of the mechanisms will be lost from beam. The type of interaction is random but their relative probabilities depend on the photon energy.

Photoelectric absorption dominates at low energies, $E\gamma < 0.1$MeV in the heaviest elements, while Compton scattering is most important at intermediate energies, whereas pair-production has an absolute threshold at 1.022 MeV and only is important for the highest energy photons.

The photoelectric effect occurs when a low energy gamma strikes an orbital electron, as shown in Figure 4.

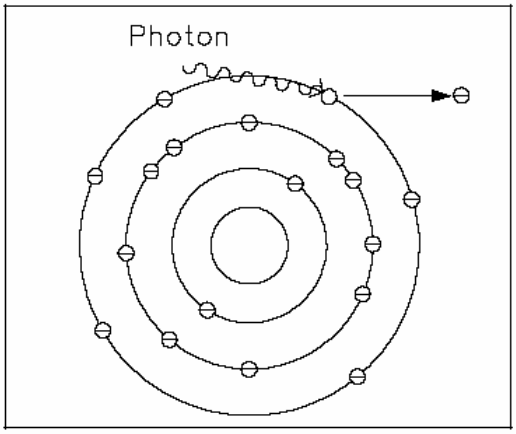

Figure 2.4 Photoelectric effect

The total energy of the gamma is expended in ejecting the electron from its orbit. The result is ionization of the atom and expulsion of a high energy electron. The photoelectric effect is most predominant with low energy gammas and rarely occurs with gammas having energy above 1 MeV (million electron volts).

2.4.4.2. Compton effect

Compton scattering is an elastic collision between an electron and a photon, as shown in Figure 5.

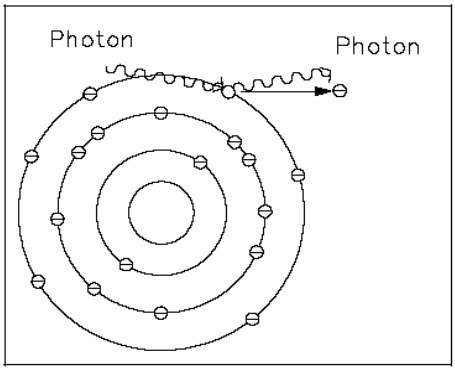

Figure 2.5 Compton effect

In this case, the photon has more energy than is required to eject the electron from orbit, or it cannot give up all of its energy in a collision with a free electron. Since all of the energy from the photon cannot be transferred, the photon must be scattered; the scattered photon must have less energy, or a longer wavelength. The result is ionization of the atom, a high energy beta, and a gamma at a lower energy level than the original. Compton scattering is most predominant with gammas at an energy level in the 1.0 to 2.0 MeV range.

2.4.4.3. Pair production

At higher energy levels, pair production is predominate. When a high energy gamma passes close enough to a heavy nucleus, the gamma disappears, and its energy reappears in the form of an electron and a positron (same mass as an electron, but has a positive charge), as shown in Figure 6. This transformation of energy into mass must take place near a particle, such as a nucleus, to conserve momentum. The

kinetic energy of the recoiling nucleus is very small; therefore, all of the photon's energy that is in excess of that needed to supply the mass of the pair appears as kinetic energy of the pair. For this reaction to take place, the original gamma must have at least 1.02 MeV energy.

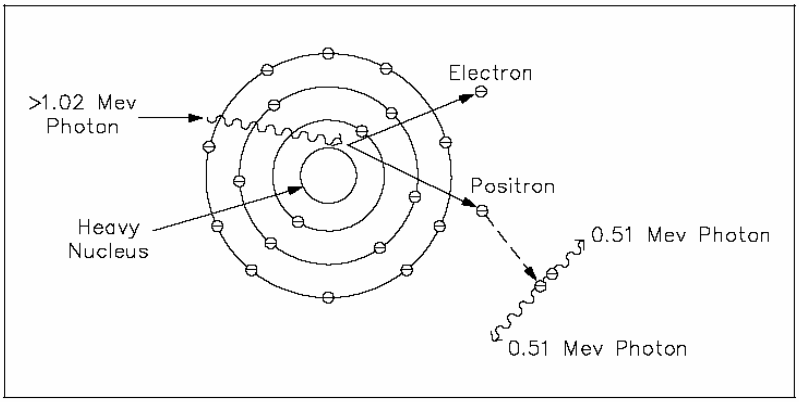

Figure 2.6 Pair production

The electron loses energy by ionization. The positron interacts with other electrons and loses energy by ionizing them. If the energy of the positron is low enough, it will combine with an electron (mutual annihilation occurs), and the energy is released as a gamma. The probability of pair production increases significantly for higher energy gammas.

Gamma radiation has a very high penetrating power. A small fraction of the original stream will pass through several feet of concrete or several meters of air. The specific ionization of a gamma is low compared to that of an alpha particle, but is higher than that of a beta particle.

2.4.5. X-rays

X-ray was the name given to the highly penetrating rays which emanated when high energy electrons struck a metal target. Within a short time of their discovery, they were being used in medical facilities to image broken bones. We now know that they are high frequency electromagnetic rays which are produced when the electrons are suddenly decelerated - these rays are called bremsstrahlung radiation, or "braking radiation". X-rays are also produced when electrons make transitions between lower atomic energy levels in heavy elements. X-rays produced

in this way have have definite energies just like other line spectra from atomic electrons. They are called characteristic x-rays since they have energies determined by the atomic energy levels.

In interactions with matter, x-rays are ionizing radiation and produce physiological effects which are not observed with any exposure of non-ionizing radiation, such as the risk of mutations or cancer in tissue.

2.5. Rate of Radioactive Decay

The rate of radioactive decay of a substance is its activity, defined as the number of transformations or disintegrations per unit time. The standard international (SI) unit of activity is the Becquerel (Bq), equal to 1 disintegration per second. The historical unit of activity is the curie (Ci), equal to 3.7 $X10^{10}$ disintegrations per second.

Originally, the curie unit applied only to radium and was based on the disintegrations per second (dps) occurring in the radon gas being produced in equilibrium from one gram of radium. If permitted to attain equilibrium, the atoms in this quantity of radon gas undergo about 3.7 x 10^{10} disintegrations per second. In 1950, the International Joint Commission on Standards, Units, and Constants of Radioactivity defined the curie unit by accepting 3.7 x 10^{10} dps as a curie of radioactivity regardless of its source or characteristics.

Because the becquerel is very small and the curie is very large it is common practice to express activity using measurement prefixes discussed earlier. Also, activity is often converted to disintegrations per minute (dpm) by multiplying by 60.

Table 2.2 shows a summary. Increasingly, throughout the world the becquerel is becoming the industry standard. Currently, however, both activity units are still used and the radiation worker must be able to convert between them.

Table 2.2 Summary of activity units

Units	dps	dpm
Curie	3.7×10^{10}	2.22×10^{12}
Millicurie	3.7×10^{7}	2.22×10^{9}
Microcurie	3.7×10^{4}	2.22×10^{6}
Nanocurie	3.7×10^{1}	2.22×10^{3}
Picocurie	3.7×10^{-2}	2.22
Becquerel	1	60
Kilobecquerel	1×10^{3}	6×10^{4}
Megabecquerel	1×10^{6}	6×10^{7}
Gigabecquerel	1×10^{9}	6×10^{10}
Terabecquerel	1×10^{12}	6×10^{13}

CHAPTER 3

RADON AND ITS PROGENY

3.1. The History of Radon

The existence of a high mortality rate among miners in central Europe was recognized before 1600, and the main cause of death was identified as lung cancer in the late nineteenth century [5]. It was suggested that the cancers could be attributed to radon exposure in 1924 [5].

Early environmental measurements were largely confined to outdoor air for the study of diverse phenomena such as atmospheric electricity, atmospheric transport and exhalation of gases from soil. The first indoor measurements were made in the 1950s [9], but attracted little attention. In recent years, there has been an upsurge in the interest in radon in dwellings and workplaces [5].

3.2. Radon and Its Progeny

Radon is a radioactive noble gas. Of all radon isotopes only two, radon-222 (radon) and radon-220 (thoron) occur in significant amounts indoors. Radon-222 is one of the decay products of uranium-238 (half-life 4.5×10^9 years) and radon-220, a nuclide thorium-232 decay (half-life 1.4×10^{10} years). The mother nuclides are radium-226 and radium-224, respectively. Thoron has a half-life of only 55 seconds, which mostly results in low levels indoors [2].

Recent measurements in some countries have shown, however, that in certain situations the doses from thoron and its progeny are significant and comparable to those from radon [10, 11].

Radon decays into radioactive metal ions by alpha radiation. The most important of the radon decay products in the present context are the alpha emitters polonium-218 (half-life 3.05 min) and polonium-214 (half-life 1.5×10^{-4} seconds).

Immediately after the decay, the progeny are unattached, but a large portion is soon attached to particles in the air or to surfaces. The short-lived progeny collectively have a half-life of about half an hour. The first long-lived progeny, lead-210, has a half-life of 22.3 years.

Figure 3.1 and figure 3.2 show decay scheme for Radon-222 and Radon-226. Also, Table 3.1 gives decay properties of radon-222 and short lived progeny with main radiation energies and yield.

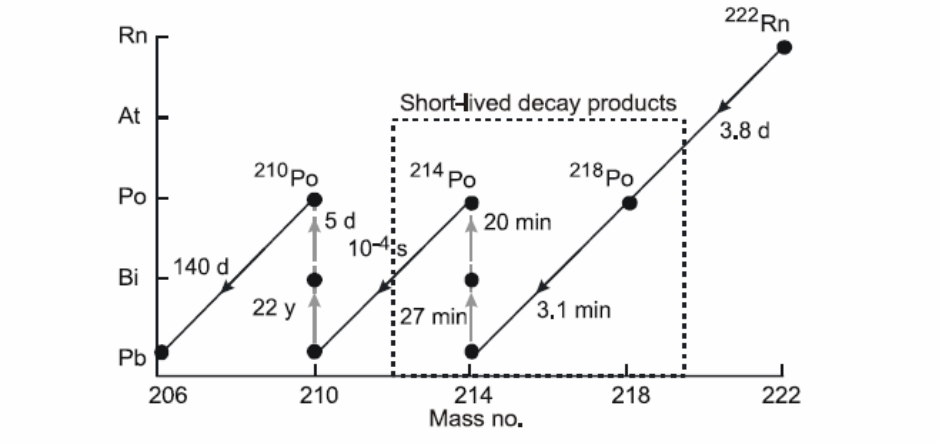

Figure 3.1 Decay scheme for ^{222}Rn showing the short-lived decay products to ^{210}Pb and the subsequent transformations to ^{206}Pb

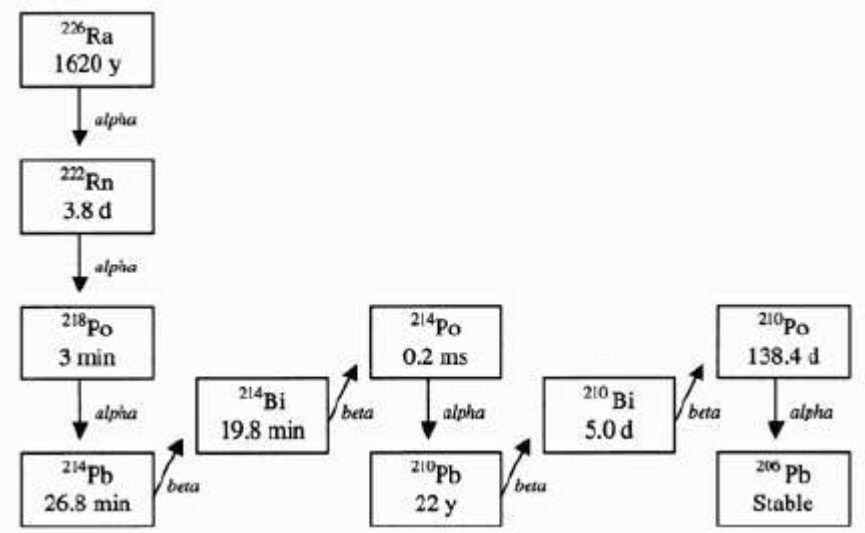

Figure 3.2 Decay scheme for ^{226}Ra

Table 3.1 Decay properties of radon-222 and short lived progeny

Radionuclide	Half-life	Main radiation energies and yields(y)					
		ALPHA		BETA		GAMMA	
		Energy MeV	y (%)	Energy (max) MeV	y (%)	Energy MeV	y (%)
^{222}Rn	3.824 days	5.49	100	-	-	-	-
^{218}Po	3.05 min	6.00	100	-	-	-	-
^{214}Pb	26.8 min	-	-	1.02	6	0.35	37
				0.70	42	0.30	19
				0.65	48	0.24	8
^{214}Bi	19.9 min	-	-	3.27	18	0.61	46
				1.54	18	1.77	16
				1.51	18	1.12	15
^{214}P o	164 µs	7.69	100	-	-	-	-

3.3. Sources

Uranium is present in the earth's crust and radon occurs in building materials, groundwater and natural gas. Nevertheless, the ground is the major radon source. The lower air pressure indoors gives rise to a pressure-driven flow of radon-rich soil air into the indoor environment through cracks in the bottom slab and cellar walls. Certain rocks and soil, such as some granites and shales, contain more uranium than others. However, ground with moderate contents of uranium and/or radium can also give high indoor radon concentrations [12, 13]. The inflow depends largely on the building construction and the permeability of the ground materials.

Building materials made from soil (e.g. clay bricks) or rock always contains uranium and radium. The content is usually low, but some materials may have high

concentrations of radium-226, for example alum shale concrete and building materials made of volcanic tuff, gypsum waste, etc. The radon concentration can reach several thousand bequerels per litre (Bq/l) in water from drilled wells in regions with granite rock.

3.4. Occurrence in Air

The radon concentration in outdoor air is higher over large continents than over sea. During temperature inversions (a reversal of the normal atmospheric temperature gradient), levels may reach hundreds of Bq/m^3 over regions with enhanced concentrations of uranium and radium in the ground [14, 15]. The radon concentration outdoors is usually about 10 Bq/m^3 as an annual average [2].

Indoor radon concentrations depend on the house construction and the underlying soil. Together with climatic factors and human habits, this leads to variations in radon levels by hour, day, season and year [13]. Furthermore, the concentration varies between buildings and rooms, and within rooms. When the major radon source is the ground, rooms in basements or in contact with the ground have higher radon concentrations than rooms on higher floors.

Within rooms the radon concentrations may vary, for example near inlet or outlet ducts, and near points of high inflow of radon from the ground, building materials or radon-rich water.

The distribution of radon concentrations in dwellings is approximately log-normal, with a tendency for high concentrations to lie above those predicted by this distribution [16]. The geometric mean and geometric standard deviation describe the distribution, while the arithmetic mean is often used to estimate the average probability of detrimental health effects.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has estimated the worldwide, population-weighted values of these parameters for dwellings to be 25 Bq/m^3, 2.5 Bq/m^3 and 40 Bq/m^3, respectively [2].

Radon concentrations in dwellings differ between countries because of differences in geology and climate, in construction materials and techniques, and in domestic customs. The arithmetic means for countries vary from 12 to 140 Bq/m^3 [2]. Determined limits are given in Table 3.2. for some countries. More than 10% of

the dwellings in certain countries such as Finland and Sweden have levels exceeding 200 Bq/m^3.

Table 3.2. Radon concentration for some countries

Country	Concentration at old buildings (Bq/m^3)	Concentration at new buildings (Bq/m^3)	Year
Germany	250	250	1988
United States	150	150	1988
Austria	400	200	1992
Australia	200	-	-
Finland	800	-	-
England	200	200	1990
Ireland	200	200	1988
Sweden	400	140	1990
Switzerland	1000	-	
Canada	800	-	1988
Luxemburg	250	250	
Norway	>800	-	1986

3.5. Conversion Factors

Large-scale measurements of radon are made by determining the activity of radon gas. The equilibrium factor between the radon progeny and the radon gas depends on several factors, principally the aerosol concentration and air exchange rate. Measurements in several countries have shown equilibrium factors in dwellings of between 0.2 and 0.8 [2]. UNSCEAR and the International Commission on Radiological Protection [5] have adopted a typical worldwide equilibrium factor of 0.4.

The SI unit for activity concentration is the bequerel (Bq), which is one radioactive decay per second. (The old unit is the curie (Ci), with one pCi/l equivalent to 37 Bq/m^3.) There are several measures for radon progeny.

The equilibrium equivalent concentration of radon is the activity concentration of radon, in equilibrium with its short-lived progeny, that would have the same potential alpha energy concentration as the existing non-equilibrium mixture given in Bq/m^3. The SI measure for radon progeny is the concentration of short-lived radon progeny in air in terms of the alpha energy released during complete decay through polonium-214 given in joule-hours per cubic metre ($J \cdot h/m^3$).

The cumulative exposure is given as $Bq \cdot h/m^3$, $Bq \cdot y/m^3$ (the average radon concentration at 100% occupancy), $J \cdot h/m^3$ or $J \cdot y/m^3$. The potential alpha energy exposure of workers is often expressed in terms of the working level month (WLM). 1 WL was originally defined as the concentration of potential alpha energy associated with the radon progeny in equilibrium with 100 pCi/l (3700 Bq/m^3). Since the quantity was introduced for specifying occupational exposure, one month was taken to be 170 hours.

3.6. Radon Gets in Through House

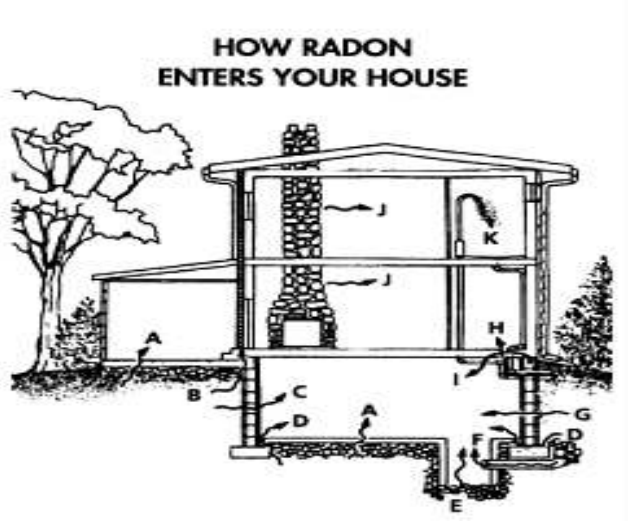

Figure 3.3 How radon enters your house

A. Cracks in concrete slabs.
B. Spaces behind brick veneer walls that rest on uncapped hollow-brick foundation.
C. Pores and cracks in concrete blocks.
D. Floor-wall joints.
E. Exposed soil, as in a sump.
F. Weeping (drain) tile, if drained to open sump.
G. Mortar joints.
H. Loose fitting pipe penetrations.

İ. Open tops of block walls.

J. Building materials such as some rocks.

K. Water (from some wells).

3.7. The Health Effects of Exposure to Indoor Radon

Radon is a naturally occurring gas that seeps out of rocks and soil. Radon comes from uranium that has been in the ground since the time the earth was formed, and the rate of radon seepage is very variable, partly because the amounts of uranium in the soil vary considerably. Radon flows from the soil into outdoor air and also into the air in homes from the movement of gases in the soil beneath homes. Outside air typically contains very low levels of radon, but it builds up to higher concentrations indoors when it is unable to disperse. Some underground mines, especially uranium mines, contain much higher levels of radon.

Although radon is chemically inert and electrically uncharged, it is radioactive, which means that radon atoms in the air can spontaneously decay, or change to other atoms. When the resulting atoms, called radon progeny, are formed, they are electrically charged and can attach themselves to tiny dust particles in indoor air. These dust particles can easily be inhaled into the lung and can adhere to the lining of the lung. The deposited atoms decay, or change, by emitting a type of radiation called alpha radiation, which has the potential to damage cells in the lung. Alpha radiations can disrupt DNA of these lung cells. This DNA damage has the potential to be one step in a chain of events that can lead to cancer. Alpha radiations travel only extremely short distances in the body. Thus, alpha radiations from decay of radon progeny in the lungs cannot reach cells in any other organs, so it is likely that lung cancer is the only potentially important cancer hazard posed by radon.

For centuries, it has been known that some underground miners suffered from higher rates of lung cancer than the general population. In recent decades, a growing body of evidence has causally linked their lung cancers to exposure to high levels of radon and also to cigarette smoking. The connection between radon and lung cancer in miners has raised concern that radon in homes might be causing lung cancer in the general population, although the radon levels in most homes are much lower than in most mines. The National Research Council study, which has been carried out by the sixth Committee on Biological Effects of Ionizing Radiation (BEIR) VI, has used the

most recent information available to estimate the risks posed by exposure to radon in homes.

The most direct way to assess the risks posed by radon in homes is to measure radon exposures among people who have lung cancer and compare them with exposures among people who have not developed lung cancer. Several such studies have been completed, and several are under way. The studies have not produced a definitive answer, primarily because the risk is likely to be very small at the low exposure encountered from most homes and because it is difficult to estimate radon exposures that people have received over their lifetimes. In addition, it is clear that far more lung cancers are caused by smoking than are caused by radon.

Since a valid risk estimate could not be derived only from the results of studies in homes, the BEIR VI committee chose to use the lung-cancer information from studies of miners, who are more heavily exposed to radon, to estimate the risks posed by radon exposures in homes. In particular, the committee has drawn on 11 major studies of underground miners, which together involved about 68,000 men, of whom 2,700 have died from lung cancer. The committee statistically analyzed the data to describe how risk of death from lung cancer depended on exposure. In this way, the committee derived two models for lung cancer risk from radon exposure. In converting radon risks from mines to homes, the committee was faced with several problems.

First, most miners received radon exposures that were, on the average, many times larger than those of people in most homes; people in a few homes actually receive radon exposures similar to those of some miners. It was necessary for the committee to estimate the risks posed by exposures to radon in homes on the basis of observed lung cancer deaths caused by higher exposures in mines. The committee agreed with several earlier groups of experts that the risk of developing lung cancer increases linearly as the exposure increases; for example, doubling the exposure doubles the risk, and halving the exposure halves the risk. Furthermore, the existing biologic evidence suggests that any exposure, even very low, to radon might pose some risk. However, from the evidence now available, a threshold exposure, that is, a level of exposure below which there is no effect of radon, cannot be excluded. The second problem is that the majority of miners in the studies are smokers and all inhale dust and other pollutants in mines. Because radon and cigarette smoke both

cause lung cancer, it is complicated to disentangle the effects of the 2 kinds of exposure. That makes it especially difficult to estimate radon risks for nonsmokers in homes using the evidence from miners. A final problem is that the miners were almost all men, whereas the population exposed to radon in homes also includes men, women, and children.

The committee used the information from miners and supplemented it with information from laboratory studies of how radon causes lung cancer. Then, with facts about the US population, including measurements of radon levels in homes, it estimated the number of lung-cancer deaths due to radon in homes. In 1995, about 157,400 people died of lung cancer (from all causes including smoking and radon exposure) in the United States. Of the 95,400 men who died of lung cancer, about 95% were probably ever-smokers; of the 62,000 women, about 90% were probably ever-smokers. Approximately 11,000 lung cancer deaths are estimated to have occurred in never-smokers in 1995.

The BEIR VI committee's preferred central estimates, depending on which one of the two models are used, are that about 1 in 10 or 1 in 7 of all lung-cancer deaths—amounting to centralestimates of about 15,400 or 21,800 per year in the United States—can be attributed to radon among ever-smokers and never-smokers together. Although 15,400 or 21,800 total radon-related lung-cancer deaths per year are the committee's central estimates, uncertainties are involved in these estimates. The committee's preferred estimate of the uncertainties was obtained by using a simplified analysis of a constant relative risk model based on observations closest to residential exposure levels. The number of radon-related lung-cancer deaths resulting from that analysis could be as low as 3,000 or as high as 32,000 each year. Most of the radon-related lung cancers occur among ever-smokers, and because of synergism between smoking and radon, many of the cancers in ever-smokers could be prevented by either tobacco control or reduction of radon exposure. The committee's best estimate is that among the 11,000 lung-cancer deaths each year in never-smokers, 2,100 or 2,900, depending on the model used, are radon-related lung cancers.

Radon, being naturally occurring, cannot be entirely eliminated from our homes. Of the deaths that the committee attributes to radon (both independently and through joint action with smoking), perhaps one-third could be avoided by reducing radon in homes where it is above the "action guideline level" of 148 Bqm^{-3} to below

the action levels recommended by the Environmental Protection Agency. The risk of lung cancer caused by smoking is much higher than the risk of lung cancer caused by indoor radon. Most of the radon-related deaths among smokers would not have occurred if the victims had not smoked. Furthermore, there is evidence for a synergistic interaction between smoking and radon. In other words, the number of cancers induced in ever-smokers by radon is greater than one would expect from the additive effects of smoking alone and radon alone. Nevertheless, the estimated 15,400 or 21,800 deaths attributed to radon in combination with cigarette-smoking and radon alone in never-smokers constitute an important public-health problem.

3.8. Radon Signals for Earthquake Prediction

In recent years, there have been many studies of radon variations in water and soil gas as a precursor of possible earthquake events [17]. The use of radon for monitoring of volcanic activities [18], environmental research, mapping of fault zones, prediction of earthquakes, geological traces has been developed mainly with uranium [19]. There have been various researches dealing with the measurements of radon concentration in soil, gas emanating from the ground along active faults, which may provide useful signals before seismic events [20, 21]. Radon tends to migrate from its source mainly upwards. This rate of migration is affected by many factors, such as distribution of uranium (especially ^{226}Ra in the same series) in the soil and bedrock, soil porosity and humidity, micro-cracks of bedrock, rainfall, air temperature, barometric pressure, surface winds and so on [22]. A research group discussed the subject of the radon emanation from fracture and fault zones in bedrock [21]. They have also discussed the radon concentration changes with earthquakes in fault zones and the radon transportation by diffusion or groundwater movement in fracture zones.

Radon activities are clearly high in some areas such as geological fault systems, geothermal sources, uranium deposit and volcano areas [23]. The radon emanation measurement in fault zones, soil and rocks, in Turkey, according to our best knowledge, is not encountered in the literature except those works by Baykara et al [24].

CHAPTER 4

RADON DETECTION SYSTEM

4.1. Radon Detection System

Thousands of radon tests are conducted all over the world in a single week. The radon is the most significant naturally occuring radioactive source in the living environment. Its existence is quite independent from the industrial activity as well as from the application of the nuclear power. The potential health risk of the radon existed even at the ancient time of the history, just this had been unknown until its discovery at the middle of the ‘80s.

Nowadays hundreds of health care organizations and home inspection companies conduct radon tests in dwellings, workplaces and schools regularly in order to locate the living sites with high radon risk. In many countries every new house is required to in incorporate some degree of radon preventive measures at the time of construction in accordance with the governmental regulation.

RadoSys system concept is that the RadoSys offers the user a system which includes all of the components that is needed for conducting a radon survey.

The usage of the system does not need any additional research. Unwrapping the units it is applicable for radon test instantly. The routine usage of the system does not need skilled person, it is easy to use and step by step instruction manual helps the training. The consumed components, that are the CR-39 detector, exposure pot and detector holder, are supplied by the manufacturer at an in-stock basis.

4.2. The Advantage of the Cr-39

The CR-39 technology provides the opportunity of conducting Radon Activity Concentration (RAC) test at many thousands of sites at the same time.

This also provides time integral RAC value, therefore any short-term variation of the local RAC value can not provide misleading result.At the radon test of a site, the study of the integral RAC value is relevant, since this provides information about the irradiation load of the personals living at the site to be tested. The detector itself that is placed to the site to be tested for two-three months is inexpensive; therefore the management of the detectors does not need any particular security consideration.

4.3. Radon Detection System in ÇANEM:

4.3.1. The Radosys concept

The RadoSys is a radon detection system based on Cr-39 etched-track technology which is utilized in ÇANEM. It is fundamental concept of the RadoSys, that the product comprises all of the components and tools that is necessary to conduct series of radon activity concentration measurement regularly. Nevertheless the system offers the feature of the large-scale radon survey. The user can run many thousands of measurement at the same time, and after taking the test detectors back to the user's laboratory, the evaluation and the RAC data is provided quickly, thanks to the large capacity etching unit and to the full automated track evaluation image analyzer microscope. The user can carry out the whole process without any assistance either of other laboratories or of the manufacturer. As a result of the measure process, the user gets a calibrated RAC data.

During the development of the RadoSys, the engineers paid a big attention to the safety of the user. Concerning the safety, the only critical step is the etching of the detectors. Since at this step the user have to treat dense sodium-hydroxide, this step of the process needs some particular consideration. The process of the etching step and the structure of the RadoBath etching unit was designed to prevent the user from any direct contact with this dangerous material. Following the instruction of the user manual makes this etching step extremely safe.

The only component that are needed for the test process and are not provided by the manufacturer of the RadoSys, these are a few sort of fine chemicals for the detector etching step. However these chemicals are widely available at fine chemical material suppliers, no any particularity with this material.

4.4. The RadoSys Components

4.4.1. Radoset detectors

Various types of detector housings are available. The main group of types is the Radopot housing. The items of this group differ at the type of the external label. The Radomon is a quite different type, offering the feature of smaller size and the opportunity for portable applications, e.g. personal radon dosimetry. The Radoset Extra type is a unique option offering the most convenient way for radon survey of dwellings.

We used Radoset Detectors for radon concentration measurement in Gaziantep.

Figure 4.1 RadoSet detector

4.5. The Radon Measurement Process

4.5.1. Preparation of detectors for measurement

The RadoSet detectors are available in two different forms of complexity. Each form needs its own way of preparation. The basic group of Radoset Minor/Eco + Radopot needs more care before usage. The advanced group of Radoset Extra needs no any preparation. We used the group of Radoset Minor/Eco + Radopot detectors.

4.5.1.1. Preparation of Radoset Minor/Eco + Radopot for measurement

Before the exposure that is before placing the detector to the site to be tested, the test detector should be assembled from components. The components to be used in this step can be found in the Radoset package and in the Radopot package. The alpha particle sensitive plastic piece should be fixed into the upper part of the exposure pot by means of a removable adhesive piece. After closing the exposure pot again, the test detector assembly is ready to use. The removable fixing adhesive is included in the Radoset package. It is also included a set of self-adhesive identification label, should be placed on the pot, with an ID number indicating the ID number of the plastic detector inside the pot. At the detector fixing by adhesive an additional assembly tool helps the user; this tool is delivered with the RadoBath package.

4.5.2. Exposure

The assembled test detector can be placed to the site to be tested. It should stay there for duration of 2-3 months. The Radosys default calibration requires 60 days exposure time. After this time the test detector should be taken back to the laboratory for evaluation.

4.5.3. Preparation of detectors for evaluation

In order to prepare the detector plastic pieces for etching, these should be dismounted out of the Radopot and should be mounted to the Radoslide accessory tool. The Radoslide is a plastic holder, with 12 nests for 12 detectors pieces providing perfect matching and fixing. The Radoslide accessory is delivered with the Radoset package.

To finish the preparation for etching, the slides with detectors should be placed onto the etching drum. 36 slides can be placed on etching drum maximum. The etching drum is a part of the RadoBath unit. The Radoslide accessory is useful also as a long term storage tool after the evaluation helping any repeated evaluation later.

4.5.4. Etching process

As a first step of the etching, the user should prepare the etching bath. After the insertion of the stirrer accessory and closing the door of the RadoBath the user fills the components of the etching bath into the RadoBath through a filler hole on the top of the enclosure unit. The components of the bath are distillated water and solid sodium-hydroxide (NaOH). The process of solution is exothermal generating harmful vapors, however the compact structure of the RadoBath prevents the user against this vaporization. As soon as the solution process finished, the user can exchange the stirrer accessory to the etching drum by a caliper accessory. The etching drum fed by slides and detectors should be inserted into the etching chamber of the RadoBath unit. The etching process takes 4 hours.

Figure 4.2 RadoBath

4.5.5. Analysis

Removing the slides with detectors from the etching drum, these should be inserted to the RadoMeter automated microscope. The RadoMeter evaluates the detectors and provides the RAC data either by printing or in data file format.

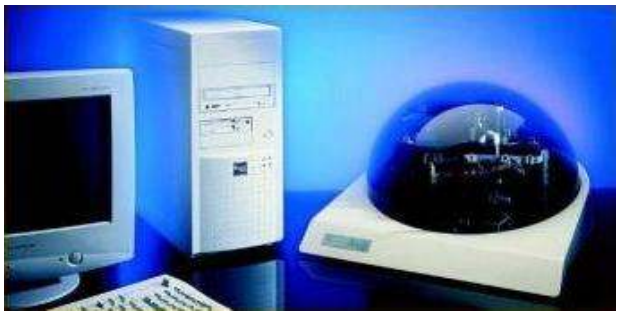

Figure 4.3 Radometer

4.5.6. System calibration check

For the safety of the accuracy of the long-term operation, the calibration check of the measure system should be done from time to time. It can be carried out by means of the RadoCal calibration package. Processing the detectors with known RAC value of the RadoCal, the calibration check can be done efficiently.

CHAPTER 5

EXPERIMENTS

In this study, indoor radon concentrations have been measured in 34 workplaces, 41 homes and 13 some hospitals in Gaziantep. Passive solid state nuclear track detectors (SSNTD type Cr-39) in the diffusion chamber were used to measure indoor radon concentration. The Cr-39 detectors are made up of allyl-diglycol carbonate plastic. The thickness of these detectors was 0.50 mm. These detectors were selected because of their high sensitivity to alpha particle radiation, ruggedness, availability, ease of handling and low cost.

The Cr-39 plastic sheets:

- are colorless and completely transparent to the visible light and almost completely opaque in infrared and ultraviolet region of the spectrum. For these reasons, it is largely used for the production of sun glass lenses. They can be colored by surface dyeing or bulk tinting;
- have high abrasion resistance and high-quality optical properties;
- weigh about half as much as glass;
- keep their excellent optical properties despite long-term exposure to chemicals like solvents, highly oxidizing acids, and strong basis;
- resist to heat distortion up to 100 °C and are resistant to small hot flying particles such as welding sparks.

The Cr-39 foil pieces were placed in the bottom of plastic cups' cap in the horizontal position. Air holes on the cups were closed by cloth pieces to avoid dust particles or aerosols other than radon gas. Thus, only radon gas could pass into the cups by diffusion.

These detectors were located;

1. Forty-one pairs of detectors were given to each selected home and they were located at bedrooms. Seventeen pairs of them were placed in the ground bedroom and the rest of them in the third floor bedroom.

2. In addition, thirty-five pairs of detectors were distributed to factories in the industrial region.

3. In the similar way, thirteen pairs of detectors were placed in hospitals.

The distributed detectors were placed from 24.07.2005 to 24.09.2005. After sixty days, the distributed detectors were collected and their air holes were covered by nylon band. So that the detectors could not be influenced by radon and its progeny during transport to the radon laboratory at Çekmece Nuclear Research and Training Center. Evaluations of radon detectors have been carried out in the laboratory under defined etching condition. The detector foils of Cr-39 were subjected to a chemical etching process in 25 % of a sodium hydroxide (NaOH) solution at 60 ^{0}C for 4 hours.

Thus, after the etching process, region on each foils were counted by Radometer. The Radometer 2000 unit is an advanced automatic microscope with a dedicated software to analyze Cr-39 detectors. It consists of a microscope and a controller computer. Each counted region had 47 mm^2 surface areas.

The detector foils were read three times by RadoMeter. And the averages of activities of the counted radon detectors were found by this way. Their units were Bq/m^3. After taking these activities, the graphics of the radon concentration distribution according to houses, workplaces and hospitals were drawn in chapter 6. Also, the graphics of the radon concentration distribution according to district were drawn in chapter 6.

CHAPTER 6

RESULTS AND DISCUSSIONS

The measured radon concentrations had a mean value of 27 Bq/m^3. Values of the concentration change in a range of between 5 and 117 Bq/m^3.

The International Commission on Radiological Protection (ICRP) has investigated the health effects of inhaled radon and its progeny and has published a report "Protection against Radon-222 at Home and Work". In this report radon exposure is limited and action level related to the annual mean concentration of radon in a building was recommended. The action level for the annual effective dose is limited to the range of 3-10 mSw. The corresponding recommended radon concentrations for these annual exposures are 200-600 Bq/m^3 in dwellings and 500-1500 Bq/m^3 in work places.

It was observed that the values of the radon concentration at Gaziantep were under the annual effective doses, which were defined by the ICRP.

The lower concentration of radon is caused by less ventilation in respect of hotter countries but it is not a certain result. The effect of radon inhalation on public health depends on various factor: population density, conditions of the environment, types of materials using building construction, ventilation, residence times in enclosed rooms, and habits and customs.

According to the ICRP, the risk of cancer is 6% at the limit of 400 Bq/m^3. The greater ratio of smoking, the more risks of cancer because some radioactive materials like Po present in tobacco and this materials are transported easily from one place to any other.

Also, indoor radon concentrations were measured from 1414 homes in different cities by ÇANEM. Table 6.1 shows indoor radon concentration in some cities/towns in Turkey. The mean value of summer and winter measurements is considered as the arithmetic mean value of the dwelling.

The measured distribution of radon levels varied between 10 and 380 Bq/m^3. The arithmetic mean value of the radon concentration was found to be 35 Bq/m^3 with a standard deviation of 12 Bq/m^3.

Table 6.1 Indoor radon concentration of Turkish dwelling

Towns and cities under study	Number of surveyed houses	Number of houses of different radon concentrations				
		1-50 Bqm^{-3}	51-100 Bqm^{-3}	101-200 Bqm^{-3}	201-300 Bqm^{-3}	301-400 Bqm^{-3}
İstanbul	524	267	234	23	-	-
Bursa	50	34	15	1	-	-
Eskişehir	50	12	37	1	-	-
Adana	25	3	22	-	-	-
Mersin	97	87	10	-	-	-
Kahramanmaraş	45	45	-	-	-	-
Adıyaman	43	42	1	-	-	-
Şanlıurfa	24	2	19	3	-	-
Elazığ	19	5	12	2	-	-
Erzurum	23	8	11	4	-	-
Kocaeli	81	78	-	3	-	-
Köprübaşı	15	8	7	-	-	-
Tosya	26	14	10	2	-	-
Afyon	25	4	19	2	-	-
Balıkesir	30	24	6	-	-	-
Sındırgı	19	10	8	1	-	-
Gaziantep	27	18	8	1	-	-
KestanboluÇanakkale	47	-	7	30	7	3
Zeytinburnu İstanbul	77	53	22	2	-	-
Yatağan thermic central	13	-	9	4	-	-
Antalya	23	19	4	-	-	-
Sakarya	27	13	9	2	1	2
Gölcük	27	16	5	5	-	1
Bolu	18	9	4	2	2	1
Düzce	18	12	-	5	1	-
Kırklareli	14	-	2	12	-	-
Malatya	27	18	9	-	-	-

Radon concentrations of Malatya, Gölcük, and Sakarya are measured 27 Bq/m^3 by ÇANEM [25]. Similar values of radon concentration are obtained in the region of Gaziantep

It may be just a coincidence that the mean value of radon concentration measured for Gaziantep about ten years ago is in excellent agreement with the results obtained in this study.

The highest value of the radon concentrations was measured as 53.37 Bq/m^3 in third organize sanayi for workplaces as given in Table 6.2, while it was found to

be 117 Bq/m^3 in houses as presented in Table 6.3. And the maximum radon concentration for hospitals was found to be 95.67 Bq/m^3 (see Table 6.4). Table A.2, Table A.3 and Table A.4 in Appendix A provide the location of detectors in industry region, hospitals and houses, separately.

The average values of the radon concentration in different regions and districts are presented in Table A.1 in Appendix A. The highest radon activity was measured to be 44.83 Bq/m^3 in Konak district.

Table 6.2 Radon concentration in workplaces

The detector numbers		Radon activity values (Bq/m^3)		Average radon activity values (Bq/m^3)
1	6	11	12	9,67
2	11	28	23	20,67
3	15	12	25	17,33
4	9	8	9	8,67
5	11	14	10	11,67
6	14	6	11	10,33
7	14	6	13	11,00
8	14	9	16	13,00
9	6	6	7	6,33
10	64	72	25	53,67
11	11	6	6	8,33
12	7	6	6	6,33
13	4	8	7	6,33
14	7	15	13	11,67
15	14	16	14	14,67
16	16	12	12	13,33
17	23	13	6	14,00
18	4	11	15	10,00
19	5	3	2	3,33
20	28	28	29	28,33
21	9	10	9	9,33
22	4	7	4	5,00
23	5	7	4	5,33
24	43	44	39	42,00
25	40	53	57	50,00
26	36	39	44	39,67
27	30	15	23	22,67
28	15	5	11	10,33
29	4	6	11	7,00
30	28	13	22	21,00
31	18	22	33	24,00
32	11	19	14	14,67
33	13	10	16	13,00
34	9	5	8	8,67

Table 6.3 Radon concentration in houses

The detector numbers	Radon activity values (Bq/m^3)			Average radon activity values (Bq/m^3)
48	5	7	14	8,67
49	46	54	56	52,00
50	11	16	17	14,67
51	20	21	14	18,33
52	11	16	11	12,67
53	18	12	16	15,33
54	15	24	26	21,67
55	79	99	103	93,67
56	28	25	20	24,33
57	32	31	32	31,67
58	39	28	35	34,00
59	3	3	5	3,67
60	42	47	45	44,67
61	11	5	8	8,00
62	22	23	16	20,33
63	8	20	15	14,33
64	15	30	29	24,67
65	18	13	35	22,00
66	124	106	122	117,33
67	25	21	26	24,00
68	54	45	46	48,33
69	19	14	6	13,00
70	7	13	10	10,00
71	12	13	7	10,67
72	70	83	92	81,67
73	37	41	44	40,67
74	34	33	18	28,33
75	10	13	12	11,67
76	28	37	42	35,67
77	12	27	30	23,00
78	10	12	2	8,00
79	6	8	12	8,67
80	10	6	11	9,00
81	24	19	14	19,00
82	50	49	60	53,00
83	13	26	34	24,33
84	16	14	15	15,00
85	30	22	31	27,67
86	10	11	12	11,00
87	5	3	4	4,00
88	9	8	9	8,67

Table 6.4 Radon concentration in hospitals

The detector numbers	Radon activity values (Bq/m^3)			Average radon activity values (Bq/m^3)
35	16	18	11	15,00
36	15	20	22	19,00
37	32	33	35	33,33
38	21	19	23	21,00
39	7	6	16	9,67
40	64	55	59	59,33
41	5	10	3	6,00
42	21	19	20	20,00
43	12	7	12	10,33
44	82	100	105	95,67
45	22	37	34	31,00
46	82	93	87	87,33
47	42	47	45	44,67

Tables 6.5 and Table 6.6 provide the radon concentrations in different floor of homes. It is expected that the radon concentrations in the ground floor of houses are usually higher than that of the upper floor. This trend is also seen in our results. The highest value of the radon concentration in the ground floor of houses is measured by the detector 66 placed in Konak district (see Table A.4 in Appendix). The average value is found to be 45.67 Bq/m^3 in the ground floor of homes.

Table 6.5 Radon concentration in the ground floor of houses

The detector numbers	The average radon activity values (Bq/m^3)
49	52.00
51	18.33
54	21.67
55	93.67
57	31.67
58	34.00
60	44.67
64	24.67
66	117.33
68	48.33
72	81.67
73	40.67
74	28.33
76	35.67
77	23.00
82	53.00
85	27.67

As seen in the Table 6.6, the highest radon activities in the upper floor of homes are found by the detectors 56 located in University district, 67 located in Konak district, and 83 located in Gazi Muhtar district. The average value of radon concentration in the upper floor of homes is measured to be 13.3 Bq/m^3, which is lower than the value of ground floor.

Table 6.6 Radon concentration in the upper floor of houses.

The detector numbers	The average radon activity values (Bq/m^3)
48	8.67
50	14.67
52	12.67
53	15.33
56	24.33
59	3.67
61	8.00
62	20.33
63	14.33
65	22.00
67	24.00
69	13.00
70	10.00
71	10.67
75	11.67
78	8.00
79	8.67
80	9.00
81	19.00
83	24.33
84	15.00
86	11.00
87	4.00
88	8.67

Also, Figure 6.1, Figure 6.2 and Figure 6.3 show the distribution of radon concentrations in houses, ground and upper floor of houses.

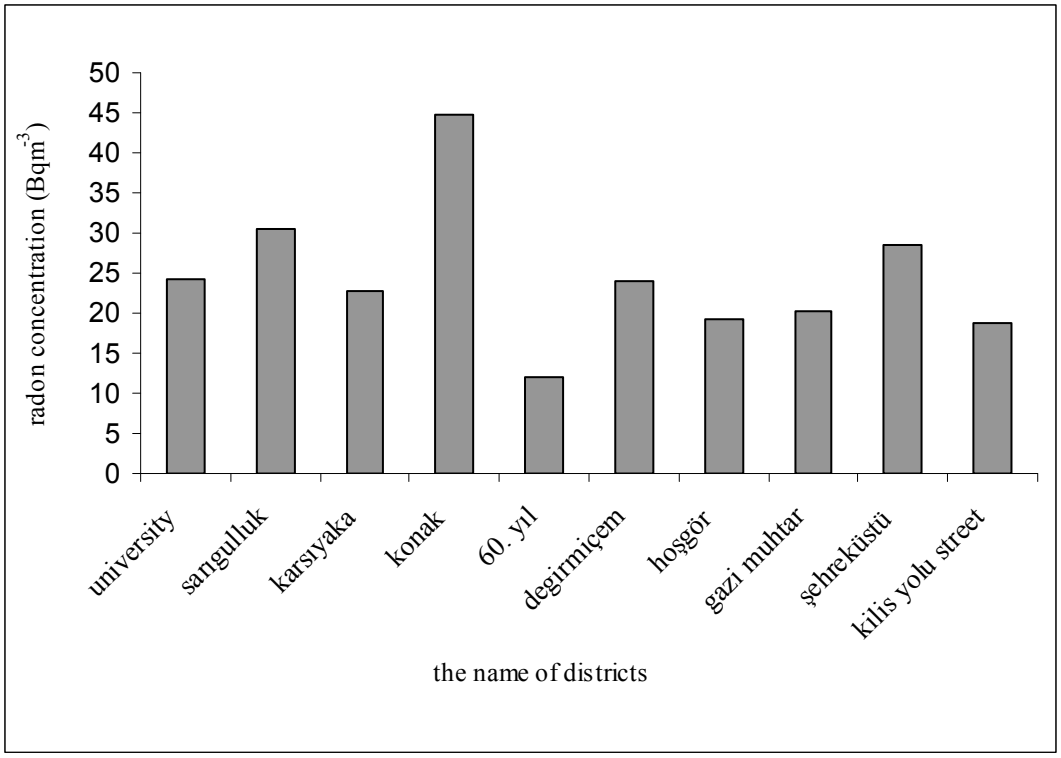

Figure 6.1 The distribution of radon concentration in Gaziantep houses

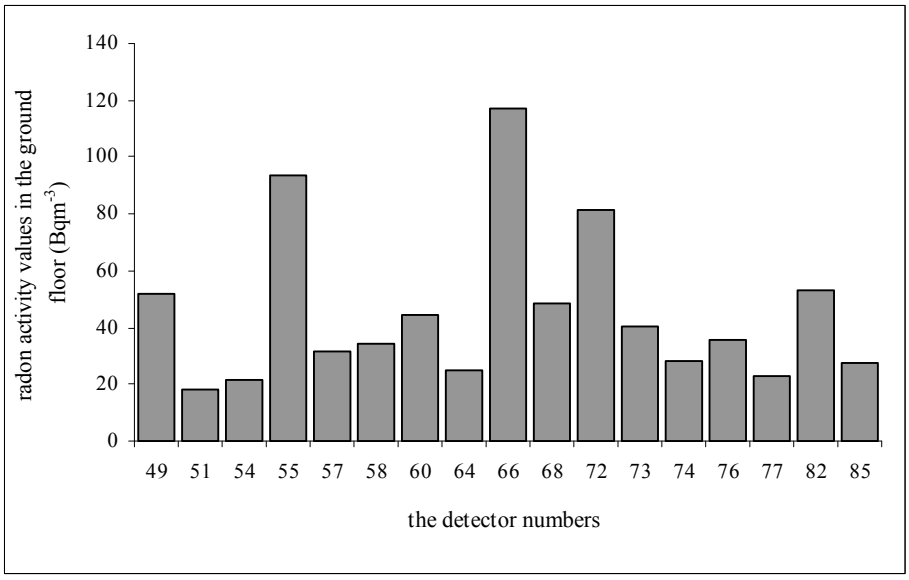

Figure 6.2 The distribution of radon concentration in the ground floor of houses in Gaziantep.

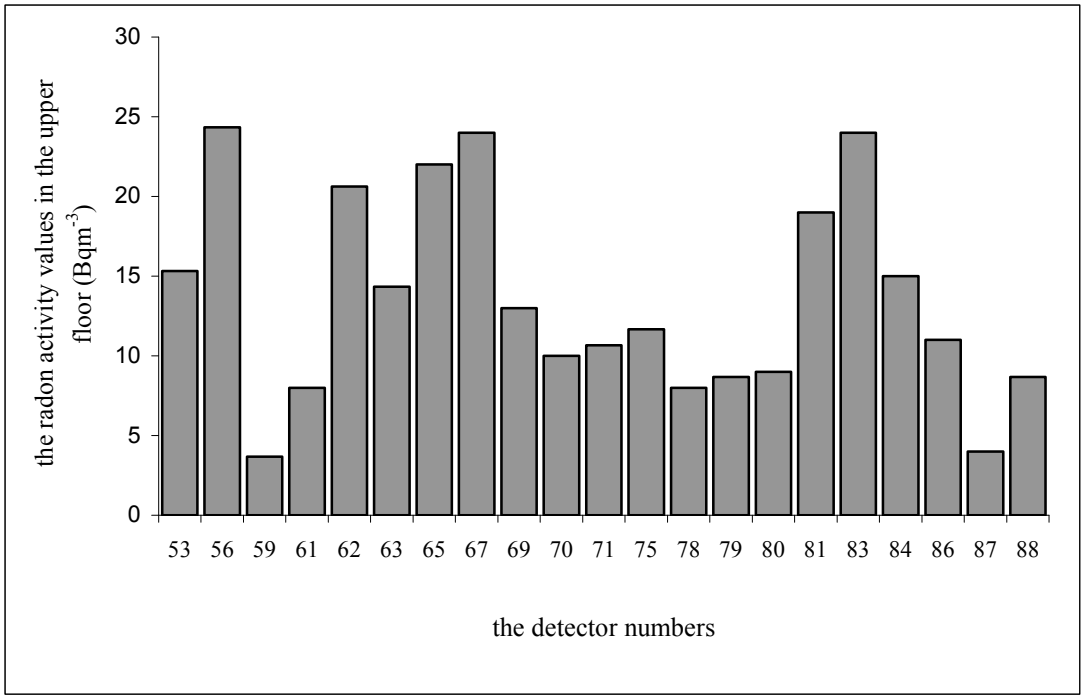

Figure 6.3 The distribution of radon concentration in the upper floor of houses in Gaziantep.

According to the ICRP, the risk of cancer is 6% at the limit of 400 Bq/m^3. Our resutls show that the cancer risk in 27 Bq/m^3 is 0.4% for houses in Gaziantep.

Some handicaps were seen in the measurement made with passive detectors. One of the most important handicaps was delivering the radon detectors to house which little children live, because the cover of radon detectors looked like a kind of toys for them. So, these detectors should be given to conscious people and prepared stable enough against probable accidents as much as possible.

In the measurements made with passive detectors the time range should be widen. The advantage of the wider measurement time is that; the value of average concentration becomes more acceptable and reliable.

It would be much better to make the radon measurements in day time and night time, separately. However, in this study radon concentration measurement was made during the whole day and the results could not be separated from each other. Hence the results are the average of the day and night.

Radon measurements should be done widespread in our country and people should be informed how they can protect themselves from the radiation.

CHAPTER 7

CONCLUSIONS

In this study, the radon-222 activities were measured in 41 homes, 35 workplaces and 13 hospitals in Gaziantep during July 2005 and September 2005 using the radon dosimeters (Cr-39).

According to the results of this study, the radon activity and radon effective dose rate depend upon many factors inside the homes, the workplace, and hospitals.

1. Ventilation plays an important role. The results indicated that ventilation of the buildings has a very important effect in decreasing the radon concentration.
2. Since the radon levels were measured only in summer, the ventilation system of the measured places was very effective. Hence this is the one reason why the rate of the radon concentration in Gaziantep is low.
3. Radon gas concentration of the ground floor is higher than that of the upper floors.

This result arises from the exhalation of radon gas through the building materials. Basement flats are in direct contact with the soil, so that penetration of radon gas to the basement flat is much more than to upper floors. If the comparison is made with ICRP limitations, it can be seen that the results for Gaziantep are less than these values. It was found that only one measurement was above 117 Bq/m^3.

REFERENCES

[1] Larson, R., Bressan, P., (1980). Radon-222 as an indicator of continental air masses and air mass boundaries over ocean areas. *The Natural Radiation Environment,* **3**, National Technical Information Service, Springfield.

[2] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR),. (1993). Sources and Effects of Ionizing Radiation. United Nations, New York.

[3] Singh, S. Kumar, A. Singh, B., (2002). Radon level in dwellings and its correlation with uranium and radium content in some areas of Himachal Pradesh. *Environ. Int.*, **28**, 97–101.

[4] Papastefanou, C. Stoulos, S. Monolopoulou, M. Ioannidou, A. Charalambous,S., (1994). Indoor radon concentrations in Greek apartment dwellings, *Health Phys*., **66**, 270–273.

[5] International Commission on Radiological Protection (ICRP)., (1993). Protection against radon at home and work. ICRP Publication 65. Annals of the ICRP, **23**(4).

[6] TAEK,. (2000) Regulations for the Radiation Safety, No.2399

[7] Lehmann R., (1975). Introduction to Nuclear Engineering. Addison-Wesley Publishing Company, Massachusetts.

[8] Knoll G. F., (1979). Radiation Protection and Measurement. John Wiley &Sons, New York.

[9] Hultqvist, B., (1956). Studies on naturally occuring ionising radiations (Thesis). K.Svenska Vetenskakad. Handl. **6** (3). Almqvistu. Wiksells Boktryckeri, Stockholm.

[10] Sciocchetti, G., (1992). Indoor radon and thoron survey in high radioactivity areas of Italy. *Radiation Protection Dosimetry*, **45**, 509–513.

[11] Steinhausler, F., (1994). Thoron exposure of man: a neglible issue. *Radiation Protection Dosimetry*, **56**, 127–131.

[12] Castren, O., (1988). Varovaisus paikallaan [radon update]. *Tiede*, **7**, 28–31.

[13] Hubbard, L. (1991). Radon dynamics in Swedish dwellings: a status report. In Proceedings of the 1991 International Symposium on Radon and Radon Reduction Technology, Philadelphia.

[14] Robe, M.C., (1992). Radon measurement in the environment in France. *Radiation Protection Dosimetry*, **45**, 455–457.

[15] Tyson, J.L., (1993). Elevated radon levels in ambient air. *Proceedings of Indoor Air'93*, **4**, 443–448.

[16] Swedjemark, G.A., (1993). Radon levels in the 1988 Swedish housing stock. *Proceedings of Indoor Air '93*, **4**, 491–496.

[17] Erees, F.S., Yener, G., Salk, M., Özbal, Ö., (2006). Measurements of Radon Content in Soil Gas and in the Thermal Waters in Western Turkey. *Radiation Measurement.,* **41**, 354-361.

[18] Sato, J., (2003). Natural radioactivity in volcanic activity. *Appl. Radiat. Isot*., **58**, 393–399.

[19] Ioannides, K., Papachristodoulou, C., Stamoulis, K., Karamanis, D., Pavlides, S., Chatzipetros, A., Karakala, D., (2003). Soil gas radon: a tool for explorinactive fault zones. *Appl. Radiat. Isot*., **59**, 205–213.

[20] Papastefanou, C., Manolopoulou, M., Stoulos, S., Ioannidou, Gerasopoulos, E., (2001). Radon measurements along active faults in the Langadas basin, *Natural Hazards Earth System Sci*., **1**, 159–164.

[21] Durrani, S.A., Ili´c, R., (1997). Radon Measurements by Etched Track Detectors. World Scientific Publishing Co. Pte. Ltd, Singapore.

[22] Planini´c, J., Radoli´c, V., Lazanin, Ž., (2001). Temporal variations of radon in soil related to earthquakes. *Appl. Radiat. Isot*, **55**, 267–272.

[23] Al-Tamimi, M.H., Abumurad, K.M., (2001). Radon anomalies along faults in North of Jordan. *Radiat. Meas*., **34**, 397–400.

[24] Baykara, O., Dogru, M., Inceöz, M., Aksoy, E., (2005). Measurements of radon emanation from soil samples in triplejunction of the North and East Anatolian active fault systems in Turkey. *Radiat. Meas.*, **39**, 209–212.

[25] Köksal E. M., Çelebi N., Özçınar B., (1993). Indoor Rn-222 Concentrations in İstanbul Houses. *Healt Physics* **, 65,** 87-88.

APPENDIX A

Table A.1 The average radon activities for different locations

Regions	Average Activities (Bq/m^3)
Second Industry Region	11.83
Third Industry Region	22.07
Fourth Industry Region	12.42
Small Indusrty Region	17.78
Hospitals	34.79
Üniversity District	24.20
Sarıgüllük District	30.51
Karşıyaka District	22.73
Konak District	44.83
60. Yıl District	12.00
Değirmiçem District	24.00
Hoşgör District	19.17
Gazi Muhtar District	23.17
Şehreküstü District	28.44
Kilis Yolu Street	18.84

Table A.2 The location of detectors in industry region

The detector numbers	The location of detectors in workplaces
1	Second industry region
2	Second industry region
3	Second industry region
4	Second industry region
5	Second industry region
6	Second industry region
7	Second industry region
8	Third industry region
9	Third industry region
10	Third industry region
11	Third industry region
12	Third industry region
13	Second industry region
14	Fourth industry region
15	Fourth industry region
16	Fourth industry region
17	Third industry region
18	Fourth industry region
19	Second industry region
20	Second industry region
21	Second industry region
22	Third industry region
23	Second industry region
24	Third industry region
25	Third industry region
26	Small industry region
27	Small industry region
28	Small industry region
29	Small industry region
30	Small industry region
31	Small industry region
32	Small industry region
33	Small industry region
34	Small industry region

Table A.3 The location of detectors in hospitals

The detector numbers	The location of detectors in hospitals
35	University district
36	Ali Fuat Cebesoy district
37	Ali Fuat Cebesoy district
38	Ali Fuat Cebesoy district
39	Değirmiçem district
40	Değirmiçem district
41	Değirmiçem district
42	Konak district
43	60. yıl district
44	Karşıyaka district
45	Hoşgör district
46	Hoşgör district
47	Hoşgör district

Table A.4 The location of detectors in houses

The detector numbers	The location of detectors in houses
48	University district
49	University district
50	University district
51	University district
52	University district
53	University district
54	Sarıgüllük district
55	University district
56	Karşıyaka district
57	Karşıyaka district
58	Kilis street
59	Kilis street
60	Konak district
61	Değirmiçem district
62	Sarıgüllük district
63	Karşıyaka district
64	Konak district
65	Konak district
66	Konak district
67	Şehreküstü district
68	Şehreküstü district
69	Şehreküstü district
70	Sarıgüllük district
71	Hoşgör district
72	Sarıgüllük district
73	Sarıgüllük district
74	Değirmiçem district
75	University district
76	Değirmiçem district
77	Gazi Muhtar district
78	Gazi Muhtar district
79	Gazi Muhtar district
80	60. yıl district
81	Karşıyaka district
82	Gazi Muhtar district
83	Karşıyaka district
84	60. yıl district
85	Hoşgör district
86	University district
87	University district
88	Sarıgüllük district