DETERMINATION OF RADIONUCLIDES IN TAP WATER OF DHAKA CITY AND THEIR BIOLOGICAL EFFECTS ON HUMAN OF DIFFERENT AGES

M. PHIL. THESIS
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CERTIFICATE

This is to certify that the scientific research work detailed in this thesis entitled "**Determination of Radionuclides in Tap Water of Dhaka city and Their Biological Effects on Human of Different Ages**" has been performed by myself along with my supervisors, and neither this thesis nor any part thereof has been submitted elsewhere for the award of any other degree or diploma.

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ABSTRACT

Twenty tap water samples were collected from different locations in Dhaka city to assess the concentration of natural and artificial radionuclides and to measure the gross alpha and gross beta activity in these samples. Measurements of gamma-emitters ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in tap water samples were done using high-purity (HPGe) co-axial detector (EG & ORTEC) coupled with a Silena Emcaplus Multichannel Analyser system. The activities of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K observed in tap water samples from different locations in Dhaka city are shown in Table A. No ^{137}Cs activity was detected in any sample of tap water. The activities of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K ^{226}Ra in tap water samples were also found comparable with the maximum suggested value.

Table A: Natural radioactivities (Bq L^{-1}) in Tap Water Samples in Dhaka city.

Radionuclides	Minimum	Maximum	Average
^{238}U	0.82 ± 0.26	2.12 ± 0.32	1.40 ± 0.45
^{226}Ra	0.014 ± 0.0054	0.040 ± 0.0055	0.028 ± 0.0071
^{232}Th	0.16 ± 0.003	0.73 ± 0.027	0.39 ± 0.17
^{40}K	2.04 ± 0.009	6.40 ± 0.029	3.99 ± 1.28

From ... data of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K activities, the age dependent associated effective dose and the annual effective dose for human due to ingestion of these isotopes as a consequenc f direct consumption of tap water had been calculated. The average yearly intake of wat was estimated to be 250 litre for the age interval between 0 to 1 y, 328 litre for 1 y to 5 y, litre for 5 y to 10 y, 512 litre for 10 y to 15 y and 731 litre for the adult (18 + y). The effe e dose and annual effective dose calculated on the basis of yearly intake of water by differ age groups agreed well with the range of intakes given for the Reference Man by ICRP (ICRP, Reference Man: Publication 23, 1975). The estimated effective dose and annual effective dose for five age groups are shown in Table B and C.

Table B: Age-Dependent Effective Dose due to Intake of Radionuclides (nSv L^{-1}).

Radionuclides	1 year	5 year	10 year	15 year	Adult (18 + year)
^{238}U					
Minimum	36.08	22.14	12.30	6.89	5.58
Maximum	93.28	57.24	31.80	17.81	14.42
Average	61.64	38.67	21.02	16.39	14.10
^{226}Ra					
Minimum	12.74	8.12	4.90	3.36	3.08
Maximum	36.40	23.20	14.00	9.60	8.80
Average	24.98	20.45	9.63	6.59	6.04
^{232}Th					
Minimum	54.00	42.00	34.80	30.00	27.60
Maximum	229.50	178.50	147.90	127.50	117.30
Average	125.55	94.32	80.91	69.75	66.96
^{40}K					
Minimum	69.36	42.84	22.44	12.85	10.20
Maximum	217.60	134.40	70.40	40.32	32.00
Average	134.81	83.83	43.91	25.15	19.96

Table C: Age-Dependent Annual Effective Dose due to Intake of Radionuclides (μSv y^{-1}).

Radionuclides	**1 year**	**5 year**	**10 year**	**15 year**	**Adult (18+ year)**
^{238}U					
Minimum	9.02	5.54	5.41	3.53	4.08
Maximum	23.32	18.77	13.99	9.12	10.54
Average	14.94	12.15	10.70	6.03	6.96
^{226}Ra					
Minimum	3.19	2.66	2.16	1.72	2.25
Maximum	9.10	7.61	6.16	4.92	6.43
Average	6.23	5.22	4.18	3.38	4.42
^{232}Th					
Minimum	13.75	14.10	15.31	15.87	20.47
Maximum	57.50	58.06	65.08	64.56	84.80
Average	35.50	32.09	33.84	35.78	41.61
^{40}K					
Minimum	17.34	14.05	9.87	6.58	7.41
Maximum	54.40	44.08	30.98	20.64	23.39
Average	47.43	38.44	27.01	18.00	20.39

These values are significantly lower than both the World Health Organization (WHO) and the International Commission on Radiological Protection limits.

The measured gross alpha and gross beta activity in the tap water samples of different locations in Dhaka city are gathered in Table D.

Table D: Gross Alpha and Gross Beta Activity in Tap Water Samples.

	Maximum ($mBqL^{-1}$)	**Minimum ($mBqL^{-1}$)**	**Average ($mBqL^{-1}$)**
Gross alpha activity	8.16 ± 0.034	1.88 ± 0.03	3.76 ± 1.50
Gross beta activity	115.74 ± 0.16	29.305 ± 0.06	60.41 ± 23.57

The instrumentations used to count the gross α and gross β activities were ZnS(Ag) scintillation detector and gas proportional counter respectively. The results showed that the natural activities of α- and β-emitting radionuclides in tap water samples did not exceed WHO recommended levels and were comparable with the data available in other parts of the world. It suggests that the radioactivity in tap water for the people residing in Dhaka city is not yet a problem. To ensure the safe level of radioactivity in drinking water, however, periodic monitoring of water quality for compliance is necessary.

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CHAPTER I

INTRODUCTION

1. General Introduction

Environmental radiation originates from a number of naturally occurring and man-made sources. Natural radionuclides are always present in the earth's crust; where as a large number of radionuclides are produced artificially during processes like fission, fusion and nuclear activation. Release of radioactive elements into the atmosphere may contaminate ground, water, air and the biological organisms. Release of low levels of artificial radionuclides can occur to the environment during normal operations of nuclear installations such as nuclear reactors, particle accelerators, production and application of radioisotopes in the fields of nuclear medicine, research, industry and agriculture (IAEA, 1989).

Water is essential to life as the air breath by humans. Natural water is not completely free of radioactive isotopes due to the presence of beta and alpha emitters from the natural decay series of uranium, thorium and actinium and other isotopes such as ^{40}K. Thus, measurements of natural radioactivity in ground, surface and domestic water have been performed in many parts of the world, mostly for assessment of the doses and risk resulting from consuming water. Efforts to determine levels of such radioactivity will help in the development of guidelines for the protection of the human beings.

In its pure form, water is tasteless and nearly colorless, odorless liquid that is indispensable to all known forms of life. Since it comes from springs, streams, lakes, reservoirs and aquifers, it contains varying levels of naturally occurring radioactivity derived from surrounding rooks and sediments. Therefore, the occurrence and distribution of natural radioactivity in water depends on the local geological characteristics of the sources, soil or rock. Other sources of radioactive substances in water bodies include disposals of radioactive waste from the nuclear and non-nuclear industries, accidental releases and atomic bomb test. In many communities, a lot of people get their drinking water from public water supplies, the purity of which is not regulated by state or federal government. Supply water such as tap water which serves many, is maintained by their

owners and are not monitored. Unsafe drinking water is the causes of many diseases in many undeveloped and developing countries of the third world. The World Health Organization (WHO) has recommended safe values for various drinking water quality permanents in its general guidelines (Geneva: WHO, 1993). These guidelines have been used by different countries to formulate their own national water quality standards. Others are yet to draft theirs.

Humans are exposed naturally to ionizing radiation from a number of sources which include cosmic rays and natural radionuclides in air, food and drinking water. Radionuclides of the uranium and thorium series enter the human body through ingestion and inhalation. Water quality is one of the most important concerns in environmental studies because of its use for human consumption and its ability to transport pollutants in the environment. Among many other relevant parameters, the potential hazard posed to population from its radioactivity content should not be underestimated nor regarded, as is usually the case, as an isolated water quality parameter. The measurement of radioactivity in tap water allows the determination of population exposure to radiation by the habitual consumption of water. The occurrence of radionuclides in tap water causes human internal exposure, due to the decay of radionuclides absorbed into the body through ingestion. Since the dose from these pathways are strongly related to the amount of radionuclides present ,the accurate evaluation of the amounts received in dietary intake is an important parameter for the radiological protection of the population. The United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR. 1988, 2000) has estimated that exposure to natural sources contributes more than 98% of the radiation dose to the population. There is only a very small contribution from nuclear power production and nuclear weapons testing. The global average human exposure from natural sources is 2.4 mSv y^{-1}.

Waters contain a number of both alpha such as ^{238}U, ^{226}Ra and ^{210}Po and beta emitters such as ^{40}K, ^{228}Ra and ^{210}Pb in widely varying concentrations which may be responsible for a fraction, generally small, of the internal exposure by ingestion of natural radionuclides. These daily samples may be counted for alpha-beta radioactivity. The radiological examination of tap water requires a rapid screening technique that permits the determination of the gross alpha and gross beta activities of each sample in order to decide if further radiological analyses are necessary. The maximum contamination level

(MCL) for total radium (^{226}Ra and ^{228}Ra) in drinking water is specified by the US Environmental Protection Agency as 5 pCi L^{-1} (Sidhu *et al.*). The concentration of the radioactive isotopes in water depends on its geo-chemical history. According to the world health organization about of people do not have water and the biological contamination is an important. It is important that the biological Gross alpha activity is defined as the total activity of all alpha emitters once radon has been eliminated. Gross beta activity is defined as the total activity of all beta emitters excluding tritium, though ^{14}C and other soft-beta emitters are also excluded by most of the commonly used screening techniques. In order to guarantee an exposure lower than 0.1 mSv y^{-1} WHO recommends the guideline values for drinking water 0.1 Bq L^{-1} for alpha activity and 1 Bq L^{-1} for gross beta activity (Copenhagen: WHO, 1978).

There are different isotopes of uranium but ^{238}U is the predominant contributor to natural radioactivity. Enhanced levels of uranium and its daughter products might be present in water areas that are rich in natural radioactivity. As groundwater moves through fractures in the bedrock that contain these deposits radioactive minerals can leach out into the ground water system. The analysis of ground water shows that the natural radioactivity in water varies over a wide range, mainly depending on the geological characteristics of the soil. Uranium isotopes (^{238}U, ^{234}U and ^{235}U) have non-negligible radiotoxicity. In addition, several radionuclides in the radioactive decay chain starting from ^{235} U are highly radiotoxic (UNSCEAR, 2000). The water has ^{226}Ra, an alpha emitter with a half-life 1600 years and ^{228} Ra, a beta emitter with half life of 5.8 years (Fujita *et al.*). The annual dietary intake of ^{238}U is ~ 5 Bq in areas of normal natural activity (UNSCEAR, 1993), but it can be considerably higher if drinking water is rich in uranium isotopes. In addition, several radionuclides in the radioactive decay chain starting from ^{238}U are highly radiotoxic. The most radiotoxic and important among them is radium, which is a known carcinogen and exists in several isotopic forms. High radiotoxicity of ^{226}Ra in water requires particular attention for human health. Even a small activity in a radioactive substance which can be ingested or inhaled into the body may produce a damaging biological effect and can create a serious health risk (USEPA). When radium is absorbed into body, its metallic behavior is similar to that of calcium and an appreciable fraction is deposited in the bone, the remaining fraction being distributed almost uniformly in the soft tissues (Wrenn *et al.*). When people are exposed to very high levels of radium for a long time, it may result in cancer of the bone and the nasal cavity in human beings. In

ground water the radium concentrations can reach values up to 38 Bq L^{-1}, depending on factors such as type of aquifer rock and chemical and physical water characteristics.

Cesium is an important radionuclide for public health because of its presence in fallout and its relatively long life. Although, the major source of cesium body burden is from eating foods which may contain radiocesium or natural radiopotassium absorbed daily into different organs, (Fujita *et al.*), the effect of ^{40}K and ^{137}Cs in tap water cannot be neglected. There is a remarkable similarity between the distribution of ^{40}K and ^{137}Cs in the muscles of the human being, since ^{40}K and ^{137}Cs are both 90-100% absorbed from the diet into the tissues of the body (ICRP 60,1991). This is because the two radionuclides have chemical similarity and are similarly metabolized by the same biological system. There are increasingly significant contributions from man-made sources. Two obvious examples are the Windscale accident (1957) and the Chernobyl reactor fire on 26 April 1986. In addition, there is some risk from the medical and industrial uses of radioisotopes. Radiocesium is produced during fission of nuclear fuel as a result of nuclear weapons testing, operation of nuclear reactors, reprocessing of spent fuel and reactor accidents. Sixty percent of the collective effective dose equivalent from external radiation associated with past atmospheric nuclear weapons testing can be attributed to ^{137}Cs (UNSCEAR, 1982). The release of ^{137}Cs is estimated as 9.1×10^5 Bq, 7.0×10^4 Bq and 22 TBq from the testing of nuclear weapons, Chernobyl reactor fire (UNSCEAR, 1993) and Windscale accident (NRPB, 1984), respectively. The worldwide average annual effective dose from natural sources of radiation in areas of normal background is estimated to be 2.4 mSv y^{-1}, while that for all man-made sources including medical exposure is about 0.8 mSv y^{-1} (UNSCEAR, 1993).

For the general public, Nature is the largest source for ionizing radiation in daily life as far as normal background radiation concerned.^{222}Rn and its decay product account for > 50% of the population-weighted annual effective dose arising from all natural sources. In 1991, the US Environmental Protection Agency proposed 11.1 Bq L^{-1} maximum contaminant levels for ^{222}Rn in community water supplies and all non-transient, non-community public water system.

Currently, the ^{222}Rn concentration in drinking water is not regulated, but the EPA has proposed a maximum contaminant level (MCL) of 10.5 Bq L^{-1} (300 pCi L^{-1}). The proposed MCL is based primarily on the inhalation risk from the contribution of water borne ^{222}Rn to the indoor air concentration, previous studies indicate that a waterborne concentration of 370 Bq L^{-1} (10,000 pCi) that contribute approximately 37 mBq L^{-1} (1 pCi L^{-1}) to the indoor air concentration of a typical house. Thus, in water ^{222}Rn concentration of 11 Bq L^{-1} (300 pCi L^{-1}) would contribute approximately 1.1 mBqL^{-1} (0.03 pCi L^{-1}) to the total indoor air concentration of ^{222}Rn.

The tap water ^{222}Rn content depends mainly on the ^{226}Ra and ^{222}Rn concentration of the subsoil, if from ground water. The ^{222}Rn is a short lived radionuclide and degases very easily, the tap water ^{222}Rn content can be very low if the water was agitated previously in some reservoir or cistern.

Although Bangladesh is not a nuclear powered country, nevertheless, it may be vulnerable to atmospheric fallout of ethnogeny radionuclides and waste disposal to the Indian Ocean by neighboring countries or by other developed countries, since no surveillance activity in this regard exists here. Besides this, Bangladesh is subjected to natural radioactivity through the draining of heavily silt-laden water by the Ganges-Brahmaputra-Meghna river system.

In the present study, twenty tap water samples were collected from different locations in Dhaka city in order to assess the concentration of natural and artificial radionuclides and measure the gross alpha and gross beta activity in the water samples. The whole work was undertaken at Heath Physics Division, Atomic Energy Centre, Dhaka.

CHAPTER II

LITERATURE REVIEW

2. Radiation

2.1. Historical Background of Radiation

It is found that a few naturally occurring substances consists of atoms which are unstable – that is they undergo spontaneous transformation into more stable product atoms. Such substances are said to be radioactive and the transformation process is known as radioactive decay. Radioactive decay is usually accompanied by the emission of radiation in the form of charged particles and gamma ray.

The fact that some elements are naturally radioactive was first realized by Becquerel in 1896. He observed blackening of photographic emulsions in the vicinity of a uranium compound. This was subsequently attributed to radiation being emitted by the uranium. In the following ten years the outstanding experimental work of Rutherford and Soddy, M. and Mme Curie and others established the fact that certain nuclei are not completely stable. These unstable nuclei emit radiations (Martin *et al.*).

Radiation and radioactivity occur naturally in the physical world. All living beings require some kinds of radiation just to live. Light and heat, for example, are two basic forms of radiation necessary for all life on earth. All living creatures, from beginning of time, have been, and are still being exposed to radiation. Although, man and animal kingdom, however, made adjustment to this natural radiation, the advent of man-made sources and its widespread application and sometimes accidental uncontrolled release of radioactivity in the environment have altered the balance. The radiation to which human population is exposed comes from diverse source. Radioactivity decay is random in nature and has no threshold value to damage the living cells.

The term "radiation" is very broad, and includes such things as light and radio waves. Radiation is energy transmitted through space in the form of electromagnetic waves or energetic particles. Visible light, the ultra-violet light we receive from the sun and from sun-beds, and transmission signals for TV and radio communications are all forms of radiation that are common in our daily lives. These are all referred to as "non-ionizing" radiation (Cember, H).

Natural radiation in the environment samples (soil, water etc.) constitutes primary cosmic rays, which in turn produce secondary cosmic rays. But the origin of primary cosmic rays is still not yet completely understood. However, it is known that most of the observed radiation originates in our galaxy. Radiation particularly associated with nuclear medicine and the use of nuclear energy, along with x-rays, is "ionizing" radiation, which means that the radiation has sufficient energy to interact with matter and produce ions, i.e. it can eject an electron from an atom. Radioactivity is the spontaneous emission of energy from certain elements, and from other elements under special conditions, in the form of particles or electromagnetic waves.

Radiation materials are also found throughout the natural, in soil, water and vegetation. Besides natural radioactivity, various artificial radioactive elements are also present in the environment and hence in the environmental samples. These are due to diverse human activities of which the most significant radiation is from nuclear medicine therapy. Consumer products such as tobacco, building materials, combustible fuels (gas and coals), road construction materials etc. contribute for the radioactivity in the environment.

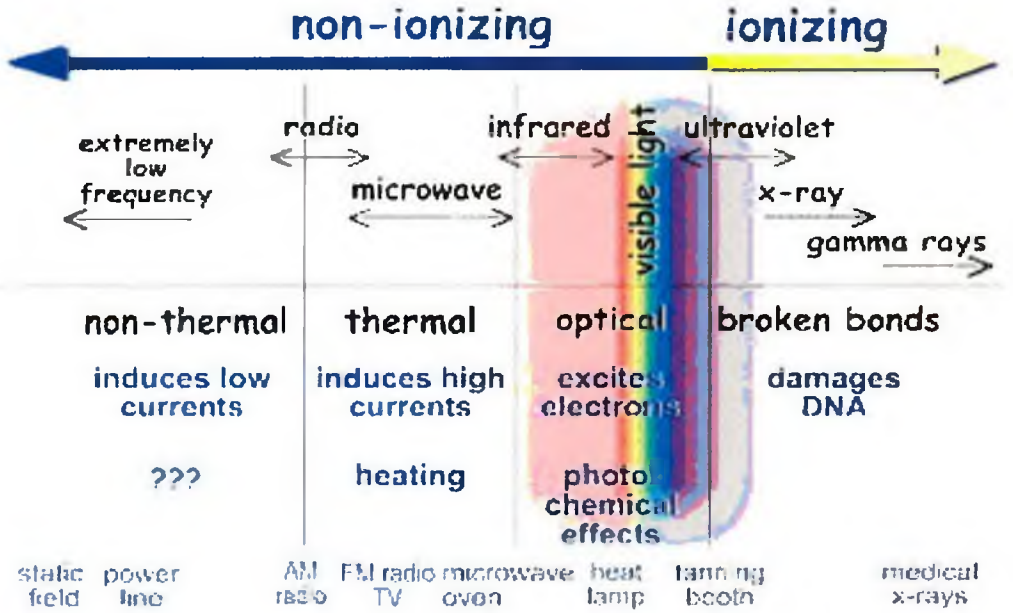

Figure 2.1: Non-ionizing and ionizing radiation.

2.2. Types of Radiation

***Non-Ionizing Radiation*:** Non-ionizing radiation or non-ionizing radiation refers to any type of electromagnetic radiation that does not carry enough energy per quantum to ionize atoms or molecules that is, to completely remove an electron from an atom or molecule. Instead of producing charged ions when passing through matter, the electromagnetic radiation has sufficient energy only for excitation, the movement of an electron to a higher energy state. Nevertheless, different biological effects are observed for different types of non-ionizing radiation.

Near ultraviolet, visible light, infrared, microwave, radio waves, and low frequency RF (long wave) are all examples of non-ionizing radiation. Visible and near ultraviolet may induce photochemical reactions, ionize some molecules or accelerate radical reactions, such as photochemical aging of varnishes or the breakdown of flavoring compounds in beer to produce the 'light struck flavor'. The light from the Sun that reaches the earth is largely composed of non-ionizing radiation, with the notable exception of some ultraviolet rays. However, most ionizing radiation is filtered out by the atmosphere (see Earth's atmosphere). Static fields do not radiate.

Non-ionizing radiation ranges from extremely low frequency radiation, shown on the far left through the audible, microwave, and visible portions of the spectrum into the ultraviolet range.

***Ionizing Radiation*:** Ionizing radiation consists of subatomic particles or electromagnetic waves that are energetic enough to detach electrons from atoms or molecules, ionizing them. The occurrence of ionization depends on the energy of the impinging individual particles or waves, and not on their number. An intense flood of particles or waves will not cause ionization if these particles or waves do not carry enough energy to be ionizing. Roughly speaking, particles or photons with energies above a few electron volts (eV) are ionizing.

Various types of ionizing radiation may be produced by radioactive decay, nuclear fission and nuclear fusion, and by particle accelerators.

In order for a particle to be ionizing, it must both have a high enough energy and interact with the atoms of a target. Photons interact strongly with charged particles, so photons of sufficiently high energy also are ionizing. The energy at which this begins to happen with photons (light) is in the ultraviolet region of the electromagnetic spectrum; sunburn is one of the effects of ionization. Charged particles such as electrons, positrons, and alpha particles also interact strongly with electrons of an atom or molecule. Neutrons, on the other hand, do not interact strongly with electrons, and so they cannot directly cause ionization by this mechanism. However, fast neutrons will interact with the protons in hydrogen (in the manner of a billiard ball hitting another, sending it away with all of the first ball's energy of motion), and this mechanism produces proton radiation (fast protons). These protons are ionizing because of their strong interaction with electrons in matter. A neutron can also interact with an atomic nucleus, depending on the nucleus and the neutron's velocity; these reactions happen with fast neutrons and slow neutrons, depending on the situation. Neutron interactions in this manner often produce radioactive nuclei, which produce ionizing radiation when they decay, and then they can produce chain reactions in the mass that is decaying, sometimes causing a larger effect of ionization.

Depending on the radiation effects on atomic matter, the most common use of the word 'radiation' refers to ionizing radiation. Higher frequency ultraviolet radiation begins to have enough energy to break chemical bonds. x-ray and gamma ray radiation, which are at the upper end of magnetic radiation, have very high frequency - in the range of 100 billion billion Hertz - and very short wavelengths -1 million millionth of a meter. Radiation in this range has extremely high energy. It has enough energy to strip off electrons or, in the case of very high-energy radiation, break up the nucleus of atoms. In the picture, gamma rays are represented by wavy lines, charged particles and neutrons by straight lines. The little circles show where ionization processes occur (Figure 2.2).

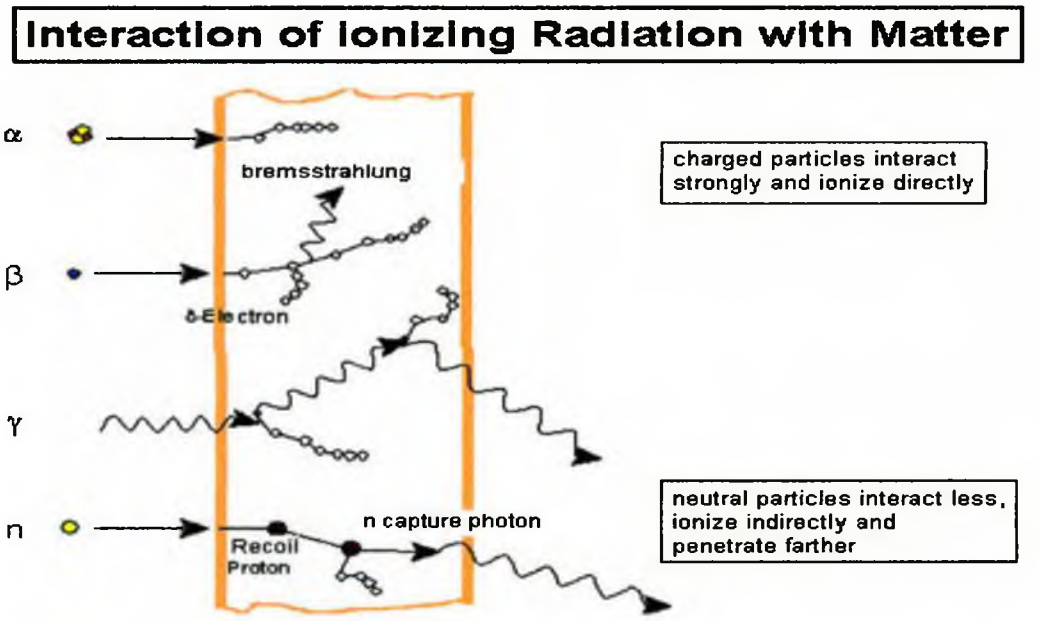

Figure 2.2: Interaction of ionizing radiation with matter.

An ionization event normally produces a positive atomic ion and an electron. High-energy beta particles may produce bremsstrahlung when passing through matter, or secondary electrons (δ-electrons); both can ionize in turn. Each ionization releases approximately 33 eV of energy. Material surrounding the atom absorbs the energy. Compared to other types of radiation that may be absorbed, ionizing radiation deposits a large amount of energy into a small area. In fact, the 33 eV from one ionization is more than enough energy to disrupt the chemical bond between two carbon atoms. All ionizing radiation is capable, directly or indirectly, of removing electrons from most molecules.

Unlike alpha or beta particles, gamma rays do not ionize all along their path, but rather interact with matter in one of three ways: the photoelectric effect, the Compton effect, and pair production. By way of example, the figure shows Compton effect: two Compton scatterings that happen sequentially. In every scattering event, the gamma ray transfers energy to an electron, and it continues on its path in a different direction and with reduced energy.

In the same figure, the neutron collides with a proton of the target material, and then becomes a fast recoil proton that ionizes in turn. At the end of its path, the neutron is captured by a nucleus in an (n, γ) reaction that leads to a neutron capture photon.

Non-ionizing radiation is thought to be essentially harmless below the levels that cause heating. Ionizing radiation is dangerous in direct exposure, although the degree of danger is a subject of debate. Animals (including humans) can also be exposed to ionizing radiation internally: if radioactive isotopes are present in the environment, they may be taken into the body. For example, radioactive iodine is treated as normal iodine by the body and used by the thyroid; its accumulation there often leads to thyroid cancer. Some radioactive elements are also bioaccumulated.

There are three main kinds of ionizing radiation:

- Alpha particles radiation,
- Beta particles radiation, and
- Gamma rays and x-rays.

Alpha Particle Radiation

An alpha particle consists of two neutrons and two protons ejected from the nucleus of an atom. The alpha particle is identical to the nucleus of a helium atom. Examples of alpha emitters are radium, radon, thorium, and uranium.

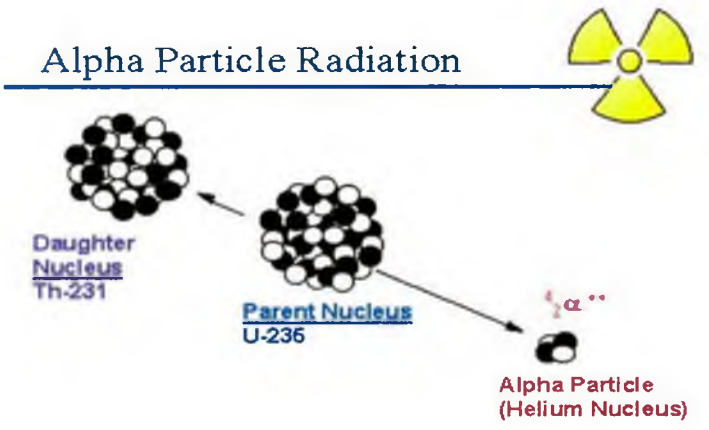

Figure 2.3: Alpha particle radiation

Because alpha particles are charged and relatively heavy, they interact intensely with atoms in materials they encounter, giving up their energy over a very short range. In air, their travel distances are limited to no more than a few centimeters. As shown in the

following illustration, alpha particles are easily shielded against and can be stopped by a single sheet of paper.

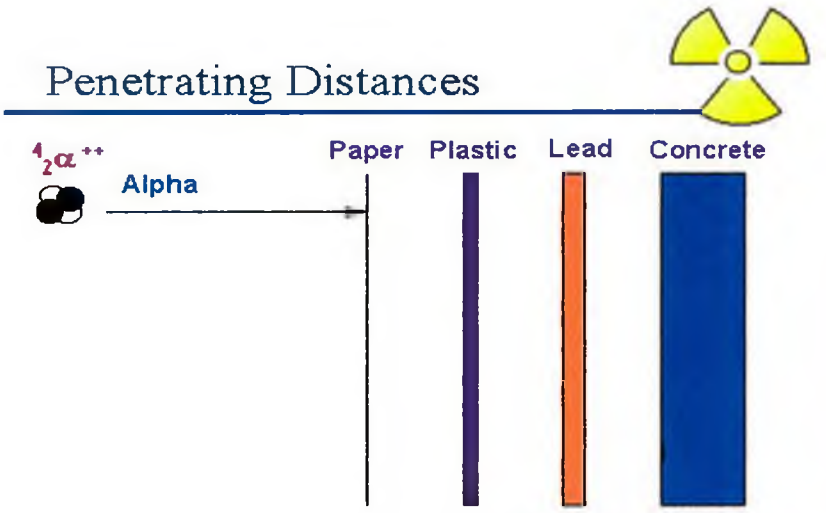

Figure 2.4: Shielding of alpha particles

Since alpha particles cannot penetrate the dead layer of the skin, they do not present a hazard from exposure external to the body. However, due to the very large number of ionizations they produce in a very short distance, alpha emitters can present a serious hazard when they are in close proximity to cells and tissues such as the lung. Special precautions are taken to ensure that alpha emitters are not inhaled, ingested or injected.

Beta Particle Radiation

A beta particle is an electron emitted from the nucleus of a radioactive atom. Examples of beta emitters commonly used in biological research are: hydrogen-3 (tritium), carbon-14, phosphorus-32, phosphorus-33, and sulfur-35.

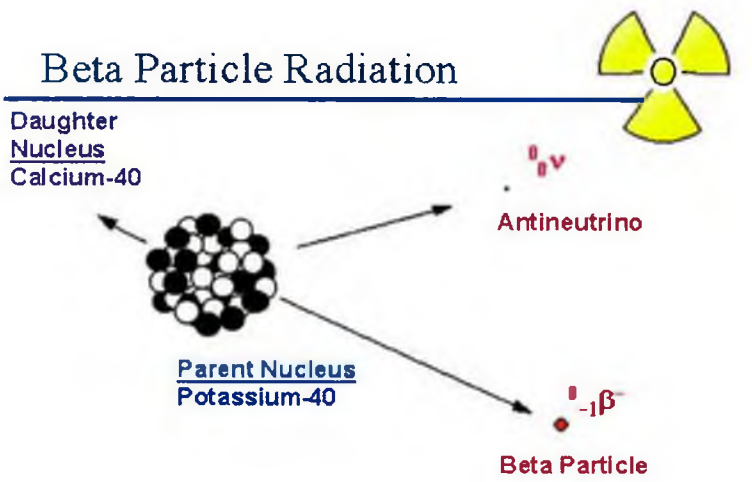

Figure 2.5: Beta particle radiation

Beta particles are much less massive and less charged than alpha particles and interact less intensely with atoms in the materials they pass through, which give them a longer range than alpha particles. Some energetic beta particles, such as those from P-32, will travel up to several meters in air or tens of mm into the skin, while low energy beta particles, such as those from H-3, are not capable of penetrating the dead layer of the skin. Thin layers of metal or plastic stop beta particles.

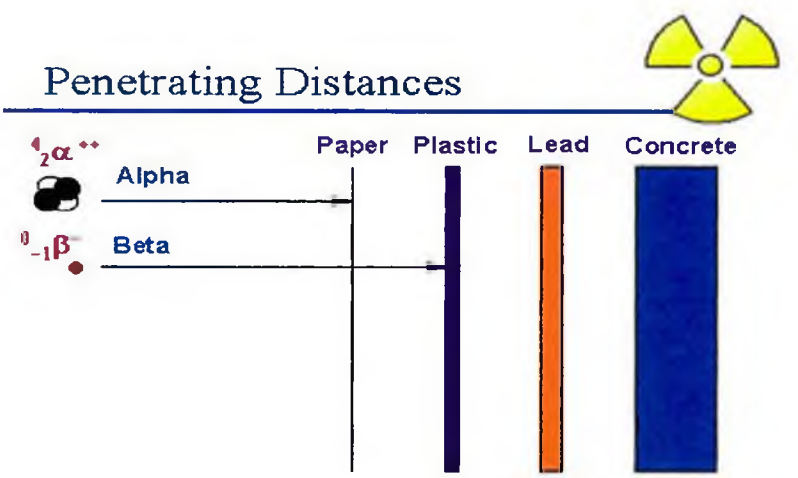

Figure 2.6: Shielding of beta particles.

All beta emitters, depending on the amount present, can pose a hazard if inhaled, ingested or absorbed into the body. In addition, energetic beta emitters are capable of presenting an external radiation hazard, especially to the skin.

Gamma Ray Radiation

A gamma ray is a packet (or photon) of electromagnetic radiation emitted from the nucleus during radioactive decay and occasionally accompanying the emission of an alpha or beta particle. Gamma rays are identical in nature to other electromagnetic radiations such as light or microwaves but are of much higher energy. Examples of gamma emitters are cobalt-60, zinc-65, cesium-137, and radium-226. Like all forms of electromagnetic radiation, gamma rays have no mass or charge and interact less intensively with matter than ionizing particles.

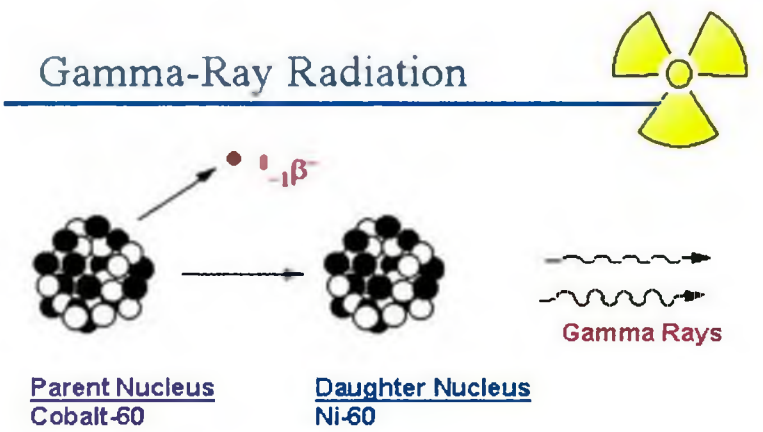

Figure 2.7: Gamma-ray radiation

Because gamma radiation loses energy slowly, gamma rays are able to travel significant distances. Depending upon their initial energy, gamma rays can travel tens or hundreds of meters in air.

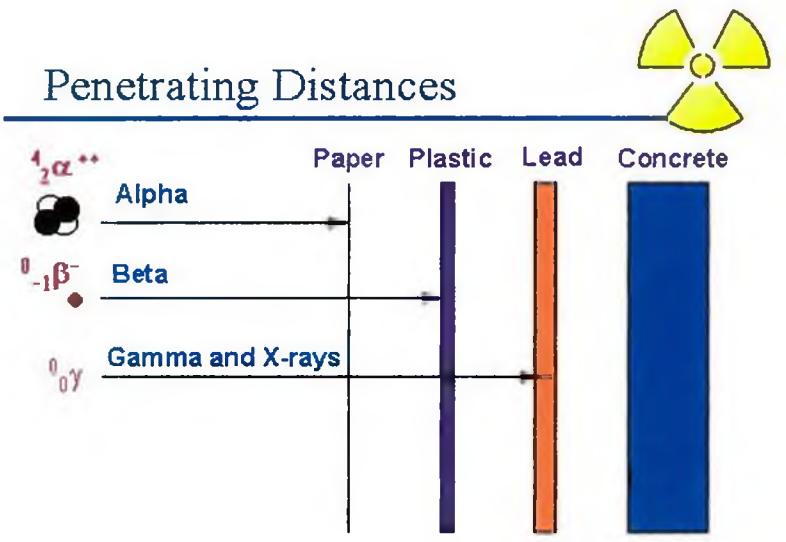

Figure 2.8: Shielding of gamma radiation.

Gamma radiation is typically shielded using very dense materials (the denser the material, the more chance that a gamma ray will interact with atoms in the material) such as lead or other dense metals. Gamma radiation particularly can present a hazard from exposures external to the body.

2.3. Sources

Natural Sources of Radiation: Radiation is all around us. It is naturally present in our environment and has been since the birth of this planet. Consequently, life has evolved in an environment which has significant levels of ionizing radiation. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes. Certain foods such as bananas and Brazil nuts naturally contain higher levels of radiation than other foods. Brick and stone homes have higher natural radiation levels than homes made of other building materials such as wood.

About 15% of background radiation dose to the general public comes from medical x-rays and nuclear medicine applied directly to patients. About 3% background radiation comes from other man made sources.

The features of the environment samples that come from the natural source include:

- Cosmic radiation,
- Solar radiation,
- Terrestrial radiation, and
- Radon

Cosmic Radiation: The Earth, and all living things on it, is constantly bombarded by radiation from outside our solar system. This cosmic radiation consists of positively-charged ions from protons to iron nuclei. The energy of this radiation can far exceed that which humans can create even in the largest particle accelerators. This radiation interacts in the atmosphere to create secondary radiation that rains down, including x-rays, muons, protons, alpha- particles, pions, electrons, and neutrons. The dose from cosmic radiation is largely from muons, neutrons, and electrons, with a dose rate that varies in different parts of the world and based largely on the geomagnetic field, altitude, and solar cycle. The annual dose rate increases about 8% in going from the equator to 50 degree north latitude. Astronauts in low orbits, such as in the ISS or the Space Shuttle are at low risk because the magnetic field of the earth shields out most cosmic rays. The cosmic-radiation dose rate on airplanes is so high that, according to the United Nations UNSCEAR 2000 Report, airline flight crew workers receive more doses on average than any other worker, including those in nuclear power plants.

At the top of the earth's atmosphere, the composition of cosmic rays is 87% protons and 11% alpha particles. The remaining 2% consists of other nuclei. The composition again suggests their origin in the star. Most of the mosses of the stars are hydrogen (protons) helium (alpha particles) which undergo fusion reaction to power the star. At the sea level, cosmic rays consist of 63% mesons, 15% electrons and 21% neutrons. The mesons are released when the high energy primaries collide with the nitrogen and oxygen nuclei making up the atmosphere.

Solar Radiation: While most of the Sun's output consists of light (solar radiation), particle radiation is also produced and varies with the solar cycle. These particles are mostly protons with relatively low energies (10-100 keV). Their average composition is similar to that of the Sun itself. This represents significantly lower energy particles than

come from cosmic rays. Solar particles vary widely in their intensity and spectrum, increasing in strength after some solar events such as solar flares. Further, an increase in the intensity of solar cosmic rays is often followed by a decrease in the galactic cosmic rays, called a Forbush decrease after their discoverer, the physicist Scott Forbush. These decreases are due to the solar wind which carries the Sun's magnetic field out further to shield the earth more thoroughly from cosmic radiation.

Terrestrial Radiation: Radioactive material is found throughout nature. It occurs naturally in the soil, rocks, water, air and vegetables. Most materials on Earth contain some radioactive atoms, even if in small quantities. Most of the terrestrial non-radon-dose one receives from these sources is from gamma-ray emitters in the walls and floors when inside a house, or rocks and soil when outside. The major radionuclides of concern for terrestrial radiation are potassium (K-40), uranium (U-238), and thorium (Th-232). Each of these sources has been decreasing in activity since the birth of the Earth so that our present dose from potassium-40 is about ½ what it would have been at the dawn of life on Earth. It has a natural abundance of 0.01%. The others are all heavy metal nuclides with long-lives. The terrestrial radio nuclide constitute by non-series single stable nuclei such as ^{40}K, ^{50}V, ^{87}Rb, ^{138}In, ^{147}La, ^{147}Sm and four radioactive decay series in nature namely thorium, actinium, neptunium and uranium producing over fifty radio nuclides emitting alpha, beta and gamma radiation of varying intensities and energies.

Radon: Radon-222 is produced by the decay of radium-226 which is present wherever uranium is found. Since radon is a gas, it seeps out of uranium-containing soils found across most of the world and may accumulate in well-sealed homes. It is often the single largest contributor to an individual's background radiation dose and is certainly the most variable from location to location. Radon gas could be the second largest cause of lung cancer in America, after smoking.

Human-Made Radiation Sources: Some of the man-made radiation sources are:

- Nuclear power production,
- Medical irradiation,
- Nuclear explosions, etc.

Nuclear Power Production: A person working in a nuclear power plant would receive approximately 300 additional mrem per year (the Nuclear Regulatory Commission's limit is 5,000 mrem per year for occupational exposures). Natural and artificial radiation sources are similar in their effects on matter. Above the background level of radiation exposure, the U.S. Nuclear Regulatory Commission (NRC) requires that its licensees limit human-made radiation exposure for individual members of the public to 100 mrem (1 mSv) per year, and limit occupational radiation exposure to adults working with radioactive material to 5,000 mrem (50 mSv) per year. The average exposure for Americans is about 360 mrem (3.6 mSv) per year, 81% of which comes from natural sources of radiation. The remaining 19% results from exposure to human-made radiation sources such as medical x-rays, most of which is deposited in people who have CAT scans. This compares with the average dose received by people in the UK of about 2.2 mSv. As already mentioned, an important source of natural radiation is radon gas, which seeps continuously from bedrock but can, because of its high density, accumulate in poorly ventilated houses. The background rate for radiation varies considerably with location, being as low as 1.5 mSv y^{-1} in some areas and over 100 mSv y^{-1} in others. People in some parts of Ramsar, a city in northern Iran, receive an annual absorbed dose from background radiation that is up to 260 mSv y^{-1}. Despite having lived for many generations in these high background areas, inhabitants of Ramsar show no significant cytogenetic differences compared to people in normal background areas. This has led to the suggestion that high but steady levels of radiation are easier for humans to sustain than sudden radiation bursts.

Medical Irradiation: Some human-made radiation sources affect the body through direct radiation, while others take the form of radioactive contamination and irradiate the body from within. Medical procedures, such as diagnostic x-rays, nuclear medicine, and radiation therapy are by far the most significant source of human-made radiation exposure to the general public. Some of the major radionuclides used are ^{131}I, ^{99}Tc, ^{60}Co, ^{192}Ir, and ^{137}Cs. These are rarely released into the environment. The public also is exposed to radiation from consumer products, such as tobacco (polonium-210), building materials, combustible fuels (gas, coal, etc.), ophthalmic glass, televisions, luminous watches and dials (tritium), airport x-ray systems, smoke detectors (americium), road construction materials, electron tubes, fluorescent lamp starters, and lantern mantles (thorium). A typical dose for radiation therapy might be 7 Gy spread daily over two months.

Nuclear Explosions: Of lesser magnitude, members of the public are exposed to radiation from the nuclear fuel cycle, which includes the entire sequence from mining and milling of uranium to the disposal of the spent fuel. The effects of such exposure have not been reliably measured due to the extremely low doses involved. Estimates of exposure are low enough that proponents of nuclear power liken them to the mutagenic power of wearing trousers for two extra minutes per year (because heat causes mutation). Opponents use a cancer per dose model to assert that such activities cause several hundred cases of cancer per year, an application of the controversial Linear no-threshold model (LNT). In a nuclear war, gamma rays from fallout of nuclear weapons would probably cause the largest number of casualties. Immediately downwind of targets, doses would exceed 300 Gy per hour. As a reference, 4.5 Gy (around 15,000 times the average annual background rate) is fatal to half of a normal population, without medical treatment. Occupationally exposed individuals are exposed according to the sources with which they work. The radiation exposure of these individuals is carefully monitored with the use of pocket-pen-sized instruments called dosimeters.

Some of the radionuclides of concern include cobalt-60, cesium-137, americium-241, and iodine-131. Examples of industries where occupational exposure is a concern include:

- Airline crew (the most exposed population),
- Industrial radiography,
- Medical radiology and nuclear medicine,
- Uranium mining, and
- Nuclear power plant and nuclear fuel reprocessing plant workers.

2.4. Pathways of Radionuclides

Naturally occurring radioactive materials are present in our environment and in the human body. People are, therefore, continuously exposed to radiation from radioactive atoms (radionuclides). Radionuclides released to the environment as a result of human activities can add to that exposure. Radionuclides can be hazardous to living tissue when they are inside an organism where radiation released can be immediately absorbed. They may also be hazardous when they are outside of the organism but close enough for some radiation to be absorbed by the tissue.

Radionuclides travel through the environment along the same pathways as other materials. They travel through the air, in water (both groundwater and surface water), and through the food chain. Radionuclides may enter the human body by ingestion (eating or drinking), by inhalation, or through the skin. This fact describes the pathways radioactive materials follow through the environment and into the body.

Pathways through the Environment

Atmospheric Pathway: Radionuclides can be released into the air by human activities. They can also be created in the atmosphere by natural processes such as the interaction of cosmic radiation with nitrogen to produce radioactive Carbon-14. Radionuclides can be removed from the air in several ways. Particles settle out of the atmosphere if air currents cannot keep them suspended. Rain or snow can also remove them. When these particles are removed from the atmosphere, they may land in water, on soil, or on the surfaces of living and non-living things. The particles may return to the atmosphere by resuspension. Resuspension occurs when wind or some other natural or human activity generates clouds of dust containing radionuclides.

Water Pathway: Radionuclides can come into contact with water in several ways. They may be deposited from the air (as described in the previous section). They may also be released to the water from the ground through erosion, seepage, or human activities such as mining. Some radionuclides that reach either groundwater or surface water will move with the water. Others will be deposited on the surrounding soil or rocks. One important factor affecting their movement is how thoroughly they dissolve in water (solubility). Another factor affecting movement is the radionuclide's ability to adhere to the surfaces of rocks or soil through which the water flows.

Food Chain Pathway: Radionuclides in water or air may enter the food chain. For example, plants are capable of absorbing radionuclides from water in the same way as other minerals are absorbed. When animals drink water some of the radionuclides in the water will remain in their bodies. Radionuclides from the air may settle on the surface of plants. When animals eat the plants, they ingest the radionuclides that have settled from the air or have been absorbed from the water. Plants and animals that will eventually become food for people thus provide a pathway for radionuclides to move through the environment to people.

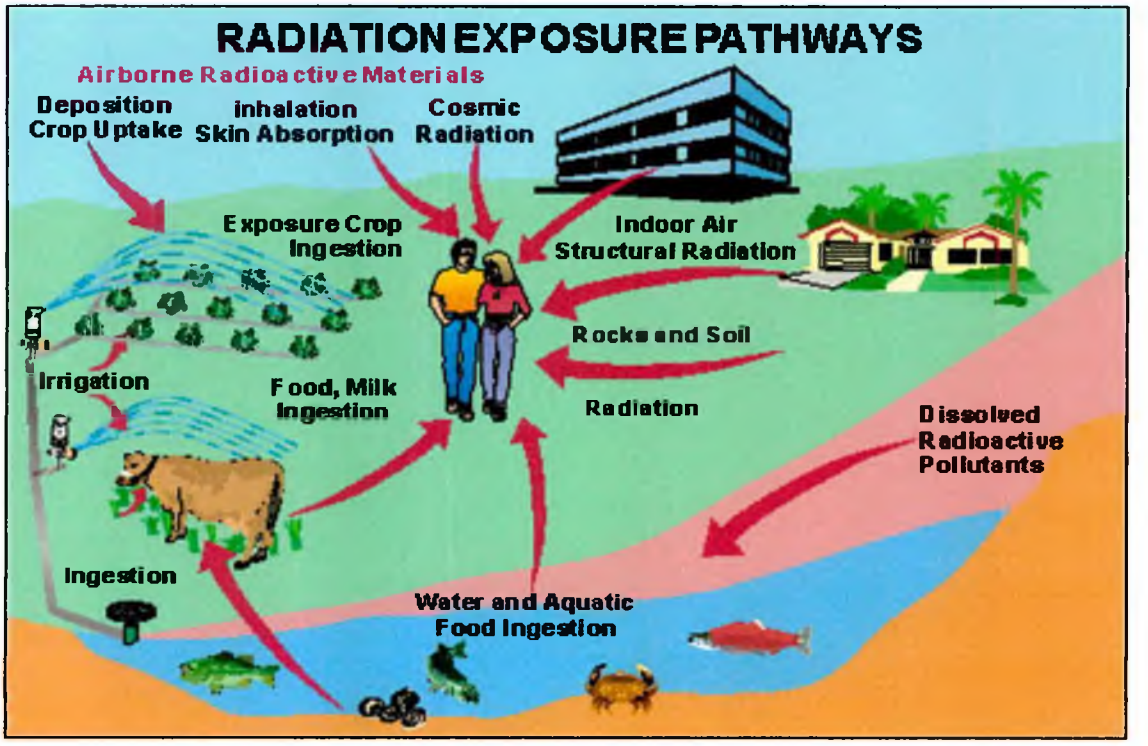

Figure 2.9: Radiation exposure path ways.

Pathways into the Human Body

Ingestion: Anything that people eat can contain radionuclides. The water that people drink may also contain radionuclides. Some radionuclides are intentionally ingested as part of a medical therapy or diagnostic procedure. Some of the radionuclides people ingest can remain in the body for long periods of time while others are quickly eliminated.

Inhalation: Radionuclides suspended in the atmosphere can enter human lungs. Some radioactive particles are exhaled, and some remain in the lungs where the radiation they release immediately strikes the lung tissue.

Through the Skin: Radionuclides may be absorbed through the skin's surface, or may enter the body through a break in the skin. Another pathway is through the injection of radionuclides as part of medical therapy.

Pathways and Low-Level Radioactive Waste

Packaging and disposal facilities for low-level radioactive waste are designed to minimize the amount of radioactive material entering any of the pathways described. Low-level waste is sealed in containers to prevent release of radionuclides to the air during transportation and handling. Low-level radioactive waste disposal facilities must be located away from water. They are also designed to divert water away from the waste and/or to collect and remove radionuclides from water that has come in contact with the waste. This minimizes the amount of radioactive material released into water. Radioactive material from low-level waste that is not released into air or water cannot enter the food chain or reach people.

2.5. Radioactive Decay Chain

In nuclear science, the decay chain refers to the radioactive decay of different discrete radioactive decay products as a chained series of transformations. Most radioactive elements do not decay directly to a stable state, but rather undergo a series of decays until eventually a stable isotope is reached. Decay stages are referred to by their relationship to previous or subsequent stages. A parent isotope is one that undergoes decay to form a daughter isotope. The daughter isotope may be stable or it may decay to form a daughter isotope of its own. The daughter of a daughter isotope is sometimes called a granddaughter isotope.

The time it takes for a single parent atom to decay to an atom of its daughter isotope can vary widely, not only for different parent-daughter chains, but also for identical pairings of parent and daughter isotopes. While the decay of a single atom occurs spontaneously, the decay of an initial population of identical atoms over time, t, follows a decaying

exponential distribution, $e^{-\lambda t}$, where λ is called decay constant. Because of this exponential nature, one of the properties of an isotope is its half-life, the time by which half of an initial number of identical parent radioisotopes have decayed to their daughters. Half-lives have been determined in laboratories for thousands of radioisotopes (or, radionuclides). These can range from nearly instantaneous to as much as 10^{19} years or more.

The intermediate stages often emit more radioactivity than the original radioisotope. When equilibrium is achieved, a granddaughter isotope is present in proportion to its half-life; but since its activity is inversely proportional to its half-life, any nuclide in the decay chain finally contributes as much as the head of the chain. For example, natural uranium is not significantly radioactive, but pitchblende, a uranium ore, is 13 times more radioactive because of the radium and other daughter isotopes it contains. Not only are unstable radium isotopes significant radioactivity emitters, but as the next stage in the decay chain they also generate radon, a heavy, inert, naturally occurring radioactive gas. Rock containing thorium and/or uranium (such as some granites) emits radon gas that can accumulate in enclosed places such as basements or underground mines. Radon exposure is considered the leading cause of lung cancer in non-smokers.

The four most common modes of radioactive decay are: alpha decay, beta minus decay, beta plus decay (considered as both positron emission and electron capture), and isomeric transition. Of these decay processes, alpha decay changes the atomic mass number (A) of the nucleus, and always decreases it by four. Because of this, almost any decay will result in a nucleus whose atomic mass number has the same residue mod 4, dividing all nuclides into four classes. The members of any possible decay chain must be drawn entirely from one of these classes. All four chains also produce helium, from alpha particles.

Uranium Series: The 4n+2 chain of U-238 is commonly called the "radium series" (sometimes "uranium series"). Beginning with naturally occurring uranium-238, this series includes the following elements: astatine, bismuth, lead, polonium, protactinium, radium, radon, thallium, and thorium. All are present, at least transiently, in any uranium-containing sample, whether metal, compound, or mineral.

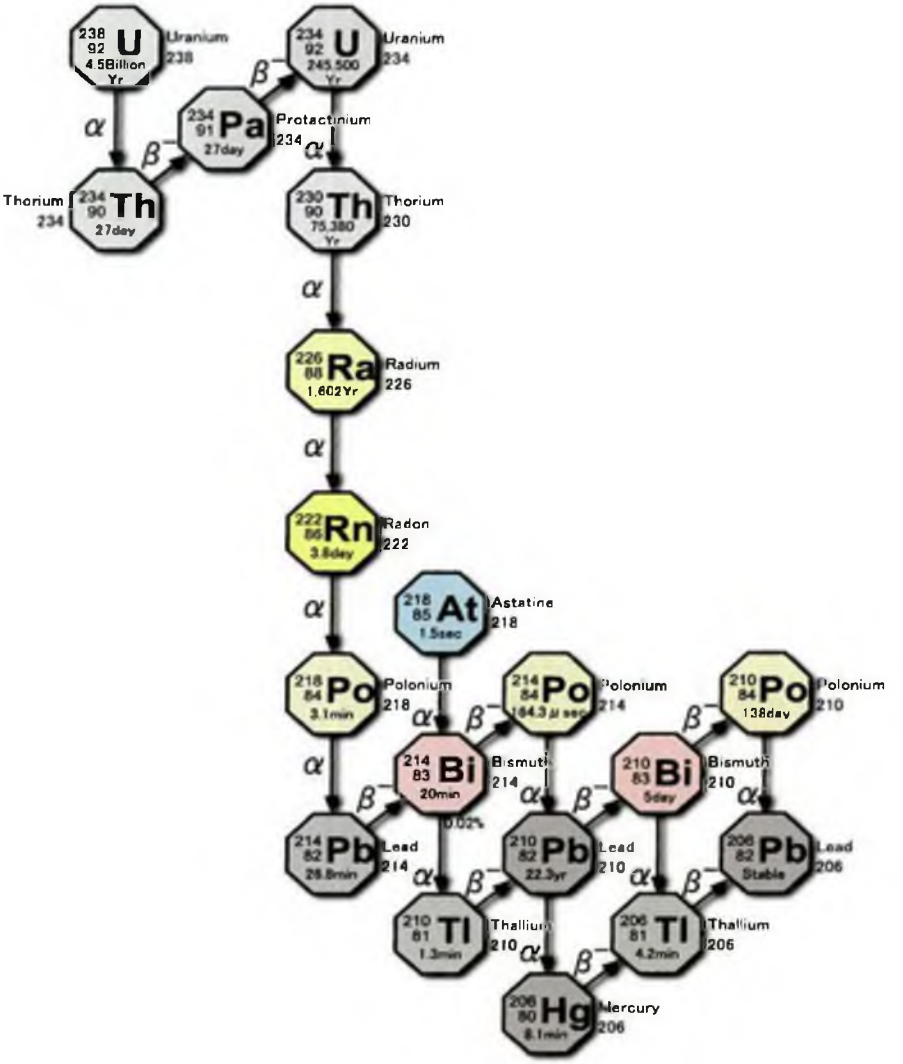

Figure 2.10: Decay scheme of ^{238}U decay series.

Thorium Series: The 4n chain of Th-232 is commonly called the "thorium series." Beginning with naturally occurring thorium-232, this series includes the following elements: Actinium, bismuth, lead, polonium, radium, and radon. All are present, at least transiently, in any natural thorium-containing sample, whether metal, compound, or mineral.

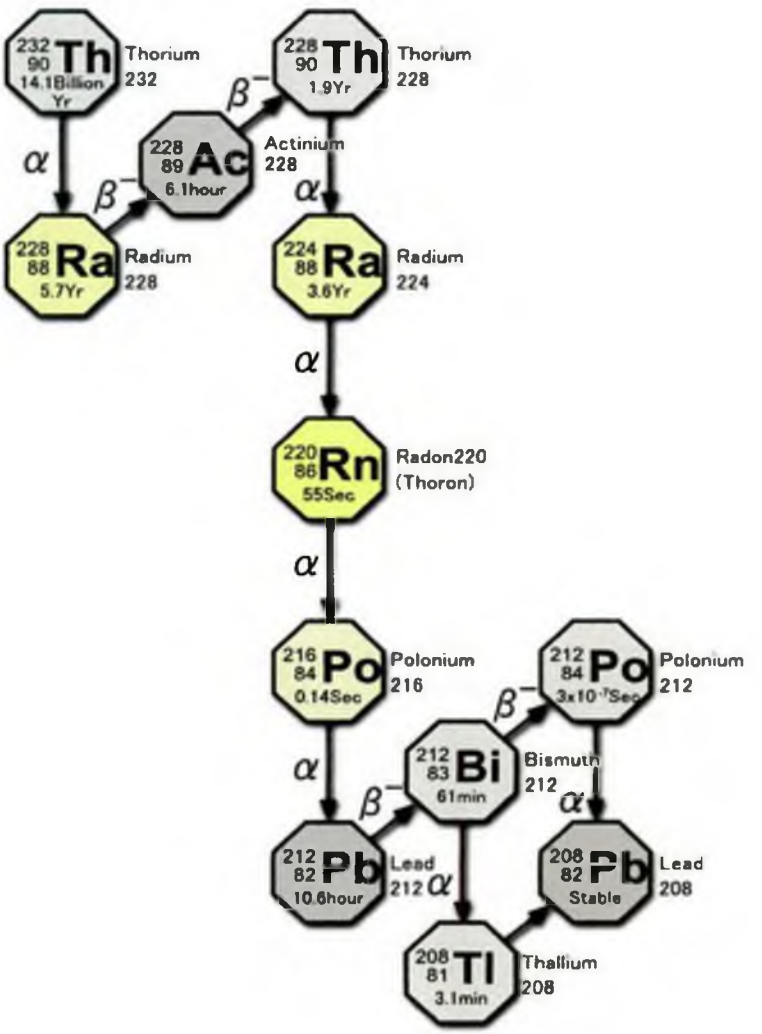

Figure 2.11: Decay scheme of ^{232}Th decay series.

Actinium Series: The 4n+3 chain of U-235 is commonly called the "actinium series." Beginning with naturally occurring uranium-235, this series includes the following elements: Actinium, astatine, bismuth, francium, lead, polonium, protactinium, radium, radon, thallium, and thorium. All are present, at least transiently, in any uranium-containing sample, whether metal, compound, ore, or mineral.

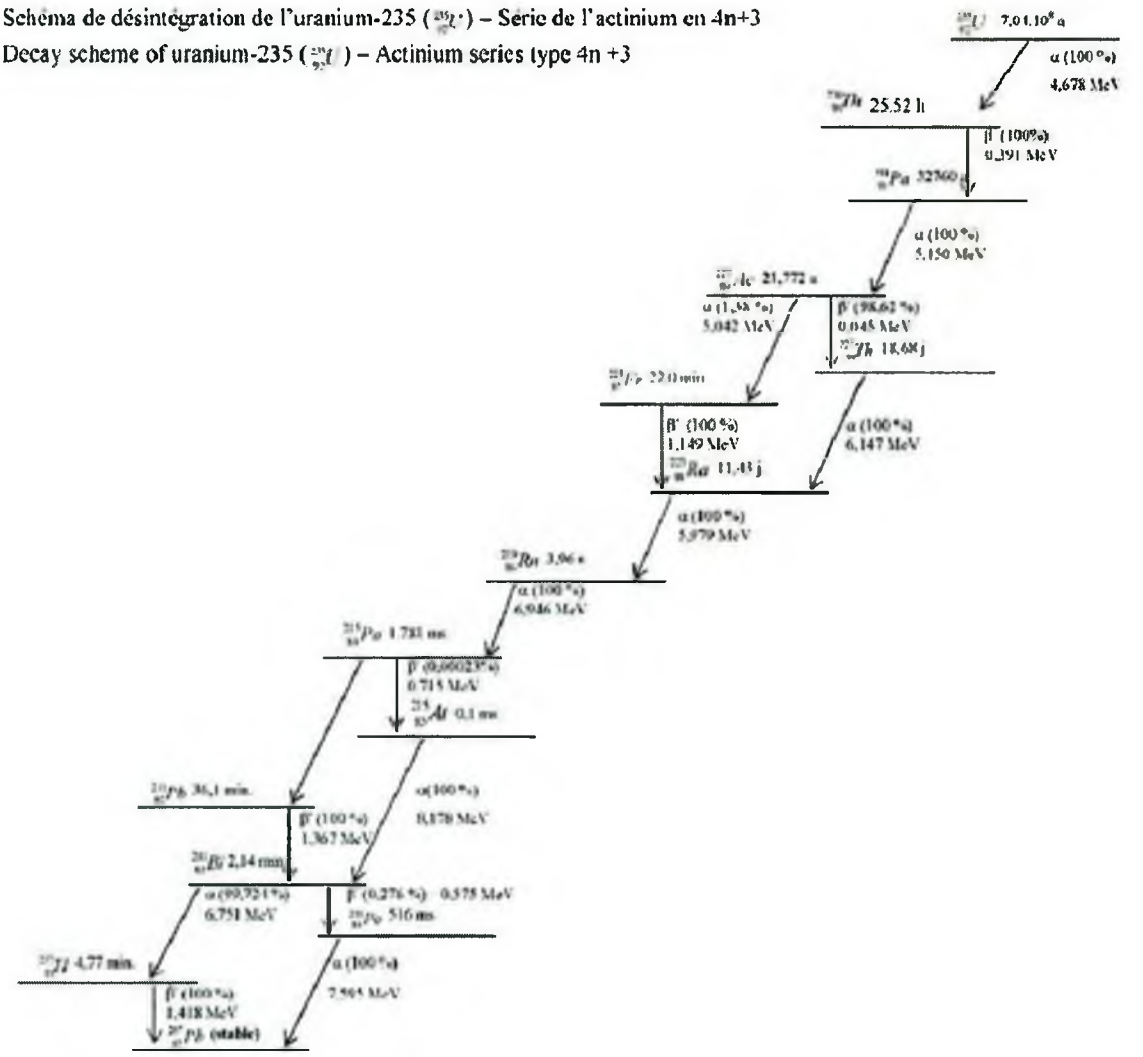

Figure 2.12: Decay scheme of ^{235}U decay series.

Neptunium Series: The 4n + 1 chain of Np-237 is commonly called the "neptunium series." In this series, only two of the elements are found naturally, bismuth and thallium. A smoke detector containing an americium-241 ionization chamber accumulates a significant amount of neptunium-237 as its americium decays; the following elements are also present in it, at least transiently, as decay products of the neptunium: Actinium, astatine, bismuth, francium, lead, protactinium, radium, thallium, thorium, and uranium. Since this series was only studied more recently, its nuclides do not have historic names.

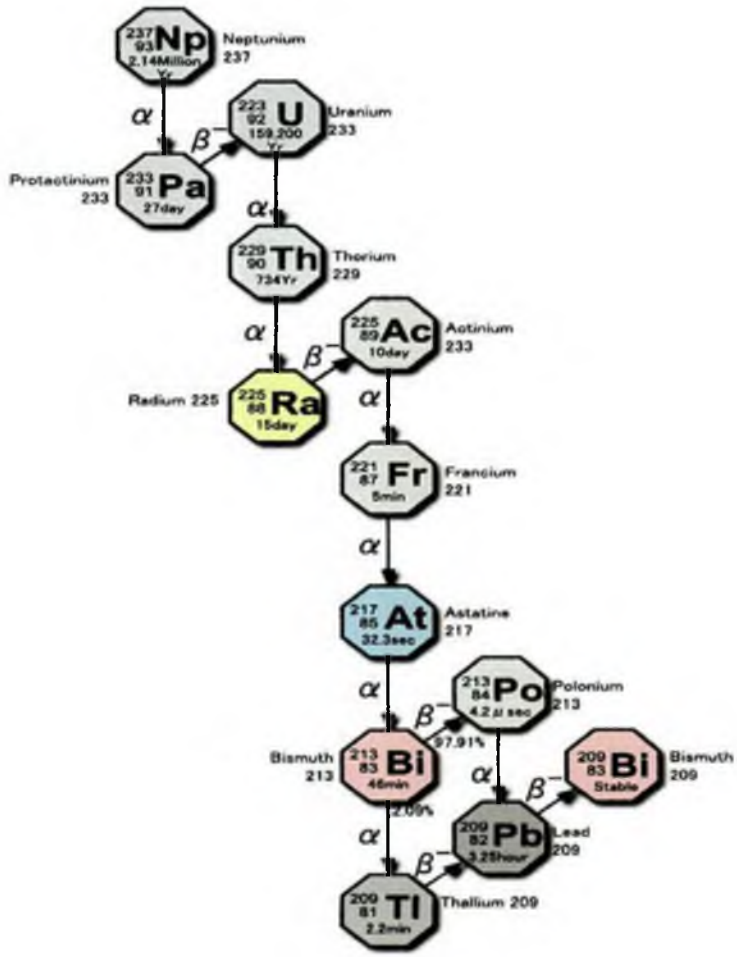

Figure 2.13: Decay scheme of ^{237}Np decay series.

2.6. Exposure from Natural and Man-Made Radiation

Everything on the earth's surface has always been exposed to the action of ionizing radiation from natural sources. Natural radiation, which accounts for 85.5% of total radioactivity (natural plus artificial), is made up of 71% telluric radiation and about 14.5% cosmic radiation. The radionuclides formed by the interaction of cosmic rays arriving from stars, and especially the sun, with the nuclei of elements present in the atmosphere (oxygen and nitrogen) are, in decreasing order of dose received by the population, carbon-14, beryllium-7, sodium-22 and tritium (hydrogen-3). The last two are responsible for only very low doses.Carbon-14, with a half life of 5,730 years, is found in the human body. Its activity per unit mass of carbon has varied over time: it has diminished as carbon dioxide emissions from the combustion of fossil fuels have raised, then was increased by atmospheric nuclear weapon tests. Beryllium-7, with a half life of 53.6 days, falls onto the leaf surfaces of plants and enters the body by ingestion. About 50 Bq per person per year of beryllium-7 are ingested. The main or primordial radionuclides are potassium-40, uranium-238 and thorium-232. Along with their radioactive decay products, these elements are present in rocks and soil and are therefore found in many building materials. Their concentrations are generally very low, but vary according to the nature of the mineral. The gamma radiation emitted by these radionuclides forms the telluric radiation, which is responsible for the external exposure of the body (Bertell, R., 1981).

The primordial radionuclides and many of their long-lived descendants are also found in trace amounts in drinking water and plants: these results in an internal exposure by ingestion, plus an additional low exposure by inhalation of airborne suspended dust particles. Potassium-40 is a beta and gamma emitter with a half life of 1.2 thousand million years, and has no radioactive descendants. This radioactive isotope makes up 0.0118% of all natural potassium, and enters the body by ingestion. The mass of natural potassium in the human body is independent of the quantity ingested. Uranium-238 is an alpha emitter with a half life of 4.47 thousand million years. It has thirteen main alpha- beta- and gamma-emitting radioactive descendants, including radon-222 (3.82 days) and uranium-234 (0.246 million years). Uranium-238 and its two descendant's thorium-234 (24.1 days) and protactinium-234m (1.18 min), and uranium-234 are essentially incorporated by ingestion and are mainly concentrated in the bones and kidneys. Thorium-230, derived from uranium-234, is an alpha emitter with a period of 80,000

years. It is an osteotrope, but enters the body mainly by the pulmonary route (inhalation). Radium-226, a descendant of thorium-230, is an alpha emitter with a half life of 1,600 years. It is also an osteotrope and enters the body mainly via food. Another osteotrope, lead-210 (22.3 years), is incorporated by inhalation though mostly by ingestion. Thorium-232 is an alpha emitter with a half life of 14.1 thousand million years. It possesses ten main alpha-, beta- and gamma-emitting radioactive descendants including radon-220 (55s). Thorium-232 enters the body mainly by inhalation. Radium-228, a direct descendant of thorium-232, is a beta-emitter with a half life of 5.75 years. It enters the body mainly in food. Radon, a gaseous radioactive descendant of uranium-238 and thorium-232, emanates from the soil and building materials, and along with its short-lived alpha-emitting descendants constitutes a source of internal exposure through inhalation. Radon is the most abundant source of natural radiation (about 40% of total radioactivity). The human body contains nearly 4,500 Bq of potassium-40, 3,700 Bq of carbon-14 and 13 Bq of radium-226 essentially imported in food.

Natural radiation is supplemented by an anthropic component, resulting from the medical applications of ionizing radiation and to a lesser extent from the nuclear industry. It accounts for about 14.5% of the total radioactivity world-wide, but much more in the developed countries. In the medical field, irradiation by external sources predominates: radiodiagnosis (x-rays) and radiotherapy, long based on cesium-137 and cobalt-60 sources, but now more and more often using linear accelerators. Irradiation by internal routes (curie-therapy with iridium-192) has more specialized indications (cervical cancer, for example). The metabolic and physico-chemical properties of some twenty radionuclides are put to use for medical activities and in biological research. The medical applications comprise radiodiagnostics (scintigraphy and radioimmunology), and treatment, including thyroid disorders using iodine-131, radioimmunotherapy in certain blood diseases (phosphorus-32) and the treatment of bone metastasis with strontium-89 or radiolabelled phosphonates alongside other uses of radiopharmaceuticals. Among the most widely used radionuclides are: technetium-99m (half life 6.02 hours) and thallium 201 (half life 3.04 days), iodine-131 (half life 8.04 days) (treatment of hyperthyroidism), iodine-125 (half life 60.14 days) (radioimmunology), cobalt-60 9half life 5.27 years) (radiotherapy), and iridium-192 (half life 73.82 days) (curietherapy). The average contribution of radiological examinations to total radioactivity amounts to 14.2%.

The early atmospheric nuclear weapon tests scattered fallout over the whole of the earth's surface and caused the exposure of populations and the contamination of the food chain by a certain number of radionuclides, most of which, given their short radioactive half lives, have now vanished. There remain cesium-137 (30 years), strontium-90 (29.12 years), some krypton-85 (10.4 years) and tritium (12.35 years), and the isotopes of plutonium (half lives 87.7 years to 24,100 years). Currently, the doses corresponding to the fallout from these tests are essentially attributable to fission products (cesium-137) and to carbon-14, rather than activation products and plutonium. In the Chernobyl accident (Ukraine), which occurred in 1986, the total radioactivity dispersed into the atmosphere was of the order of 12 milliard milliard (10^{18}) becquerels over a period of 10 days. Three categories of radionuclides were disseminated. The first consisted of volatile fission products such as iodine-131, iodine-133 920.8 hours), cesium-134 (2.06 years), cesium-137, tellurium-132 (3.26 days). The second was composed of solid fission products and actinides released in much smaller amounts, in particular the strontium isotopes ^{89}Sr (half life 50.5 days) and ^{90}Sr, the ruthenium isotopes ^{103}Ru (half life 39.3 days) and ^{106}Ru (half life 368.2 days), and plutonium-239 (24,100 years). The third category was rare gases which although they represented most of the activity released, were rapidly diluted in the atmosphere. They were mainly xenon-133 (5.24 days) and krypton-85. The contributions of the early atmospheric nuclear weapon tests and the Chernobyl accident to the total radioactivity are roughly 0.2% (0.005 mSv) and 0.07% (0.002 mSv) respectively.

The whole of the nuclear-powered electricity production cycle represents only about 0.007% of total radioactivity. Almost all the radionuclides remain confined inside the nuclear reactors and the fuel cycle plants. In a nuclear reactor, there actions that take place inside the fuel yield transuranics. Uranium-238, which is non-fissile, can capture neutrons to give in particular plutonium isotopes ^{239}Pu, ^{240} Pu (half life 6.560 years), and americium-241 (432.7 years). The main fission products generated by the fission of uranium-235 (704 million years) and plutonium-239 are iodine-131, cesium-134, cesium-137, strontium-90 and selenium-79 (1.1 million years).

The main radionuclides present in releases, which are performed in a very strict regulatory framework are in liquid release, tritium, cobalt-58 (70.8 days), cobalt-60, iodine-131, cesium-134, cesium-137 and silver-110m (249.9 days). In gaseous releases carbon-14 is the most abundant radionuclide, emitted most often as carbon dioxide. In all the reactors in the world, the total production of radiocarbon dioxide amounts to one tenth of the annual production formed naturally by cosmic radiation. In addition, certain radionuclides related to the nuclear industry exhibit chemical toxicity.

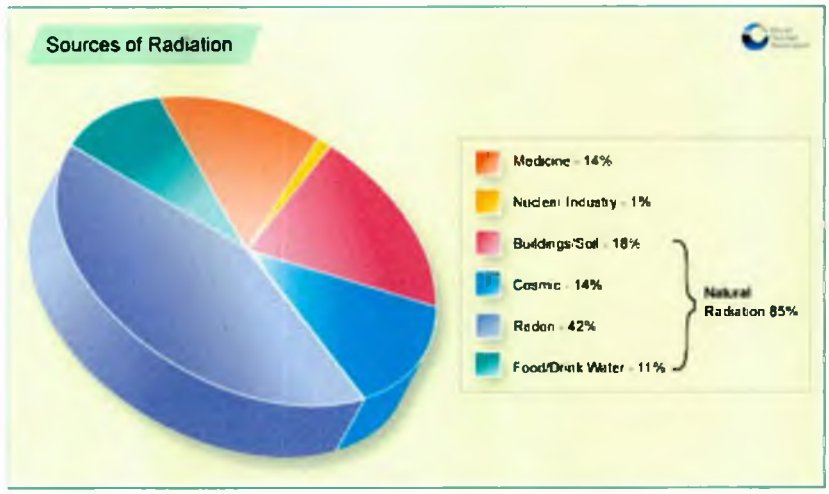

Figure 2.14: Sources and distribution of average radiation exposure to the world population.

2.7. High Background Radiation Areas

Through history man has been exposed to radiation from the environment. It is impossible to decide whether the natural background radiation has been harmful or beneficial to the development of human species. A very small, but finite, fraction of the natural mutations in cells must be beneficial since it contributes to the evolution of higher forms of life. On the other hand a major proportion of all genetic mutations lead to hereditary defects and genetic death. It is clear that these two effects have achieved some sort of balance and that man has evolved to his present state in spite of background radiation, or perhaps even because of it. Background radiation levels arise from a combination of terrestrial (from the ^{40}K, ^{232}Th, ^{226}Ra etc.) and cosmic radiation (photons, muons etc.).

Around the world through, there are some areas with sizable populations that have high background radiation levels. This background radiation of the earth varies from place to place, subject to human alternation and their interferences with the natural environment such as mining, milling, nuclear fuel fabrication and various industrial setups. According to the latest report of the United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR, 2000) the greatest contribution to mankind's exposure comes from natural background radiation. However, much higher values are usual for the inhabitants of high level natural radiation areas (HLNRAs). The most well known HLNRAs are Kerala in India; coastal region of Espirito Santo and Mineas Gerais in Brazil and many other areas such as Yangjiang in China, the Nile Delta in Egypt (Bennett, 1997) and Ramsar (Sohrabi, 1997) in Iran. The higher radiation levels are due to high concentrations of radioactive minerals in soil. One such mineral, Monazite, is a highly insoluble rare earth mineral that occurs in beach sand together with the mineral ilmenite, which gives the sands a characteristic color. The principal radionuclides in monazite are from the series, but there is also some uranium its progeny, ^{226}Ra. Some of these areas have been under study for many years in order to determine the risks and effects of long-term low-level natural exposure.

In Brazil, the monazite sand deposits are found along certain beaches. The external radiation levels on these black sands range up to 5 mrad h^{-1} (50 μGy h^{-1}), which is almost 400 times normal background in the U.S. Some of the major streets of the surrounding cites have radiation levels as high as 0.13 mrad h^{-1} (1.3 μGy h^{-1}), which is more than 10 times the normal background. Another high background area in Brazil is the result of large rare earth ore deposits that form a hill that rises about 250 meters above the surrounding area. An ore body near the top of the hill is very near the surface and contains an estimated 30,000 tons of thorium and 100,000 tons of rare earth elements. The radiation levels near the top of the hill are 1 to 2 mrad h^{-1} (0.01 to 0.02 mGy h^{-1}) over an area of about 30,000 m^2. The plants found there have absorbed so much ^{228}Ra, that they can be produce a self "x-ray" if placed on a sheet of photographic paper (an auto-radiographed).

On the Southwest coast of India, the monazite deposits are larger than those in Brazil. The dose from external radiation is, on average, similar to the doses reported in Brazil, 500-600 mrad y^{-1} (5-6 mGy y^{-1}), but individual doses up to 3260 mrad y^{-1} (32.6 mGy y^{-1}) have been reported. An area in china, has dose rates that is about 300-400 mrad y^{-1} (3-4 mGy y^{-1}). This is also from monazite that contains thorium, uranium and radium.

The Cox's Bazar area in Bangladesh is the high natural background radiation which has been found to be above global average. The high level in background radiation at Cox's bazaar sea beach is due to presence of Monazite sand, which contains ^{232}Th and its series. The dose rates varied from 2621 to 35391 μGy y^{-1} with a mean of 11968 μGy y^{-1}. The average dose rate is found to be significantly higher than the world average value.

In areas of high natural background radiation, an increased frequency of chromosome aberrations has been noted repeatedly. The increases are consistent with those seen in radiation workers and in persons exposed at high dose levels, although the magnitudes of the increases are somewhat higher than predicted. No increase in the frequency of cancer documented in populations residing in areas of high natural background radiation.

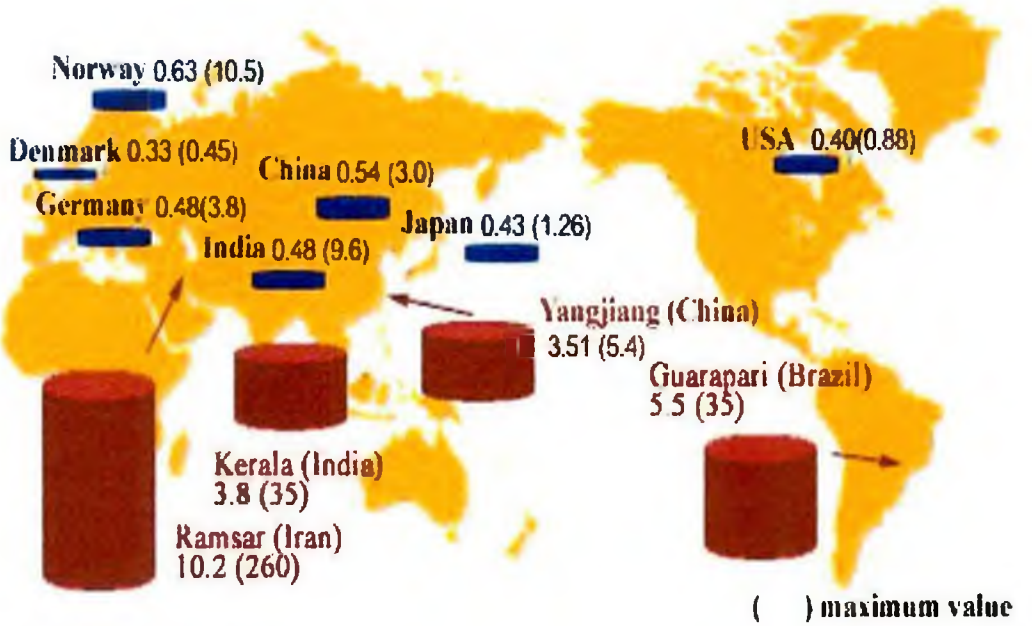

Figure 2.15: High background radiation areas around the world. Numbers given are in mSv y^{-1}.

2.8. Basic Requirements of Radiation Protection

Radiation protection, sometimes known as radiological protection, is the science of protecting people and the environment from the harmful effects of ionizing radiation, which includes both particle radiation and high energy electromagnetic radiation (USNCRP).

The aim of a Radiation protection is to reduce the radiation doses and the risks of receiving a significant radiation dose to the lowest possible levels that are reasonably achievable for radiation workers and members of the public. The reduction in dose is achieved by limiting the exposure of people to ionizing radiation. The reduction in the risk of receiving a dose is achieved by monitoring radiation doses and by planning so as to reduce the effects of unexpected events.

Radiation Protection is based on

Justification - the use of radiation should produce a benefit to the exposed individual or to society to offset the harmful effect it causes.

Optimisation - exposures to ionizing radiation should be kept as low as reasonably achievable (ALARA), taking into account economic and social factors.

Dose limits and constraints - exposures of individuals to radiation should be subjected to dose limits and dose constraints. The use of x-ray equipment or sealed radioactive sources may result in radiation exposure from Radiation sources external to the body. The handling of unsealed radioactive materials may result in radiation exposure from radioactivity both external and internal to the body (through ingestion).

External radiation exposure can be managed by a combination of these factors:

(i) ***Time:*** Reducing the time of an exposure reduces the effective dose proportionally. An example of reducing radiation doses by reducing the time of exposures might be improving operator training to reduce the time they take to handle a source.

(ii) ***Distance:*** Increasing the distance from the source is the most effective and economical means of reducing radiation exposure. For point sources the intensity of the radiation varies inversely with the square of the distance from the source. By doubling the distance from the source the radiation intensity

falls to a quarter of the original value. The variation of the radiation intensity with distance is more complex if the source is large compared with the distances involved (non-point source). The intensity decreases with distance but does not follow a simple law. As a rough guide the inverse square law can be applied if the distance from the source is greater than about 5 times the dimensions of the source. Distance should be used whenever possible to minimize radiation exposure. Use tongs or other long handled tools rather than fingers for handling radioactive materials. Even short forceps provide a large reduction in the radiation dose from that given to the skin by direct contact.

(iii) ***Shielding:*** Adding shielding can also reduce radiation doses. The radiation getting through falls exponentially with the thickness of the shield. Shielding placed between the source and the worker absorbs the ionizing radiation and therefore reduces the dose rate outside the shielding. It should be used whenever maximum distance and minimum time are not sufficient to reduce exposure to an acceptable level.

All three concepts (time, distance and shielding) must be taken together. It is useless to add shielding, or use 2 m tongs, if these increase the difficulties of working, and increase the time. The dose may be greater than it would be without the Shielding.

Internal radiation exposure is controlled by:

- limiting the dispersal of the material so that it cannot be breathed or ingested,
- limiting contact with the material.

Control is achieved by:

- using the radionuclides in properly designed laboratories,
- confining the handling of the radionuclide preparations in well-defined and separate areas of the laboratory,
- wearing appropriate protective clothing,
- following clearly defined procedures and working rules and good housekeeping,
- careful monitoring of workplaces, gloves and protective clothing after use.

2.9. Biological Effects of Radiation

The human body is made up of many organs, and each organ of the body is made up of specialized cells. Ionizing radiation can potentially affect the normal operation of these cells. In this unit, we will discuss the potential for biological effects and risks due to ionizing radiation and put these potential risks into perspective when compared to other occupations and daily activities.

Effects of Radiation on Cells

Biological effect begins with the ionization of atoms. The mechanism by which radiation causes damage to human tissue, or any other material, is by ionization of atoms in the material. Ionizing radiation absorbed by human tissue has enough energy to remove electrons from the atoms that make up molecules of the tissue. When the electron that was shared by the two atoms to form a molecular bond is dislodged by ionizing radiation, the bond is broken and thus, the molecule falls apart. This is a basic model for understanding radiation damage. When ionizing radiation interacts with cells, it may or may not strike a critical part of the cell. We consider the chromosomes to be the most critical part of the cell since they contain the genetic information and instructions required for the cell to perform its function and to make copies of it for reproduction purposes. Also, there are very effective repair mechanisms at work constantly, which repair cellular damage - including chromosome damage (BEIR, 111).

The following are possible effects of radiation on cells:

Cells are undamaged by the dose Ionization may form chemically active substances which in some cases alter the structure of the cells. These alterations may be the same as those changes that occur naturally in the cell and may have no negative effect.

Cells are damaged, repair the damage and operate normally Some ionizing events produce substances not normally found in the cell. These can lead to a breakdown of the cell structure and its components. Cells can repair the damage if it is limited. Even damage to the chromosomes is usually repaired. Many thousands of chromosome aberrations (changes) occur constantly in our bodies. We have effective mechanisms to repair these changes.

Cells are damaged, repair the damage and operate abnormally If a damaged cell needs to perform a function before it has had time to repair itself, it will either be unable to perform the repair function or perform the function incorrectly or incompletely. The result may be cells that cannot perform their normal functions or that now are damaging to other cells. These altered cells may be unable to reproduce themselves or may reproduce at an uncontrolled rate. Such cells can be the underlying causes of cancers.

Cells die as a result of the damage If a cell is extensively damaged by radiation, or damaged in such a way that reproduction is affected, the cell may die. Radiation damage to cells may depend on how sensitive the cells are to radiation.

All cells are not equally sensitive to radiation damage. In general, cells which divide rapidly and/or are relatively non-specialized tend to show effects at lower doses of radiation then those which are less rapidly dividing and more specialized. Examples of the more sensitive cells are those which produce blood. This system (called the hemopoietic system) is the most sensitive biological indicator of radiation exposure.

Acute and Chronic Radiation Dose

Potential biological effects depend on how much and how fast a radiation dose is received. Radiation doses can be grouped into two categories, *acute* and *chronic* dose.

Acute Dose: An acute radiation dose is defined as a large dose (10 rad or greater, to the whole body) delivered during a short period of time (on the order of a few days at the most). If large enough, it may result in effects which are observable within a period of hours to weeks. Acute doses can cause a pattern of clearly identifiable symptoms (syndromes). These conditions are referred to in general as *Acute Radiation Syndrome.* Radiation sickness symptoms are apparent following acute doses $\geq$ 100 rad. Acute whole body doses of $\geq$ 450 rad may result in a statistical expectation that 50% of the population exposed will die within 60 days without medical attention. As in most illnesses, the specific symptoms, the therapy that a doctor might prescribe, and the prospects for recovery vary from one person to another and are generally dependent on the age and general health of the individual.

Blood-forming organ (Bone marrow) syndrome (>100 rad) is characterized by damage to cells that divide at the most rapid pace (such as bone marrow, the spleen and lymphatic tissue). Symptoms include internal bleeding, fatigue, bacterial infections, and fever.

Gastrointestinal tract syndrome (>1000 rad) is characterized by damage to cells that divide less rapidly (such as the linings of the stomach and intestines). Symptoms include nausea, vomiting, diarrhea, dehydration, electrolytic imbalance, loss of digestion ability, bleeding ulcers, and the symptoms of blood-forming organ syndrome.

Central nervous system syndrome (>5000 rad) is characterized by damage to cells that do not reproduce such as nerve cells. Symptoms include loss of coordination, confusion, coma, convulsions, shock, and the symptoms of the blood forming organ and gastrointestinal tract syndromes. Scientists now have evidence that death under these conditions is not caused by actual radiation damage to the nervous system, but rather from complications caused by internal bleeding, and fluid and pressure build-up on the brain.

Other effects from an acute dose include:

- 200 to 300 rad to the skin can result in the reddening of the skin (erythema), similar to a mild sunburn and may result in hair loss due to damage to hair follicles.
- 125 to 200 rad to the ovaries can result in prolonged or permanent suppression of menstruation in about fifty percent (50%) of women.
- 600 rad to the ovaries or testicles can result in permanent sterilization.
- 50 rad to the thyroid gland can result in benign (non cancerous) tumors.

As a group, the effects caused by acute doses are called *deterministic*. Broadly speaking, this means that severity of the effect is determined by the amount of dose received. Deterministic effects usually have some threshold level - below which, the effect will probably not occur, but above which the effect is expected. When the dose is above the threshold, *the severity of the effect increases as the dose increases.*

Chronic Dose: A chronic dose is a relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate a chronic dose than an acute dose. The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body also has time to replace dead or non-functioning cells with new, healthy cells. This is the type of dose received as occupational exposure.

The biological effects of high levels of radiation exposure are fairly well known, but the effects of low levels of radiation are more difficult to determine because the deterministic effects described above do not occur at these levels. Since deterministic effects do not generally occur with chronic dose, in order to assess the risk of this exposure, we must look to other types of effects. Studies of people who have received high doses have shown a link between radiation dose and some delayed, or latent effects. These effects include some forms of cancer and genetic effects. The risks for these effects are not directly measurable in populations of exposed workers, therefore the risk values at occupational levels are estimates based on risk factors measured at high doses.

To make these estimates, we must use a relationship between the occurrence of cancer at high doses and the potential for cancer at low doses. Since the probability for cancer at high doses increases with increasing dose, this relationship is assumed to hold true with low doses. This type of risk model is called *stochastic.*

Somatic vs. Genetic Effects

Somatic effects appear in the exposed person. Somatic effects may be divided into two classes based on the rate at which the dose was received.

Prompt somatic effects are those that occur soon after an acute dose (typically 10 rad or greater to the whole body in a short period of time). One example of a prompt effect is the temporary hair loss which occurs about three weeks after a dose of 400 rad to the scalp. New hair is expected to grow within two months after the dose, although the color and texture may be different.

Delayed somatic effects are those that may occur years after radiation doses are received. Among the delayed effects thus far observed have been an increased potential for the development of cancer and cataracts. Since some forms of cancer are

among the most probable delayed effects, the established dose limits were formulated with this risk in mind. These limits are set such that the calculated risk of cancer in radiation workers is an increase of a very small fraction of the normal cancer risk. (More on risk in a moment)

Genetic, or heritable effects appear in the future generations of the exposed person as a result of radiation damage to the reproductive cells. Genetic effects are abnormalities that may occur in the future generations of exposed individuals. They have been extensively studied in plants and animals, but risks for genetic effects in humans are seen to be considerably smaller than the risks for somatic effects. Therefore, the limits used to protect the exposed person from harm are equally effective to protect future generations from harm.

Prenatal Radiation Exposure

Since an embryo/fetus is especially sensitive to radiation, (embryo/fetus cells are rapidly dividing) special considerations are given to pregnant workers. Protection of the embryo/fetus is important because the embryo/fetus is considered to be at the most radiosensitive stage of human development, particularly in the first 20 weeks of pregnancy.

Limits are established to protect the embryo/fetus from any potential effects which may occur from a significant amount of radiation. This radiation exposure may be the result of exposure to external sources of radiation or internal sources of radioactive material. Potential effects associated with prenatal radiation doses include:

- Growth retardation
- Small head/brain size
- Mental retardation
- Childhood cancer

At present occupation dose limits, the actual probability of any of these effects occurring in the embryo/fetus from occupational exposure of the mother is small.

2.10. Radiation Dose from Natural and Man Made Sources

The average individual radiation exposures from natural and artificial sources are shown in Table 2.1 and Table 2.2 respectively.

Local gamma radiation comes from mainly the ^{238}U and ^{232}Th decay series and also from 40 K. In certain parts of the world it is much higher than the monazite sand region of Kerala state of India, Some parts of Brazil, and Cox's bazaar beach and offshore islands of Bangladesh, the average annual whole-body dose can be as high as 0.12 Sv y^{-1}.

Table 2.1: Doses from Natural Radiation Sources (UNSCEAR, 1988, 2000).

Sources of radiation	Annual effective dose equivalent (mSv)		
	External	Internal	Total
Cosmic rays:			
Directly Ionizing Component	0.30	-	0.30
Neutron Component	0.055	-	0.055
Cosmogenic radionuclides	-	0.015	0.015
Primordial radionuclides:			
Potassium-40	0.15	0.18	0.33
Rubidium-87	-	0.006	0.006
Uranium- 238 series:	0.1	-	1.34
Uranium-238 to Uranium-234	0.005	-	-
Thorium-230	0.007	-	-
Radium-226	0.007	1.24	-
Radon-222 to Polonium-214	1.1	-	-
Lead-210 to Polonium-210	0.12	-	
Thorium series:	0.16	-	0.34
Thorium-232	0.003	-	-
Radium-228 to Radium-224	0.013	0.18	-
Radon to Thallium-208	0.16	-	-
Total	0.8	1.6	2.4

The dose figures given in the Table 2.1 and 2.2 are due to both internal radiation and external exposure. The internal radiation is mostly caused by radionuclides entering in the body through ingestion and inhalation.

Table 2.2: Average Annual Dose Equivalent from Artificial Radiation Sources.

Source of Radiation	Effective dose equivalent per year
Annual doses from medical uses of radiation: (corresponds to about 20% of the annual exposure from natural background)	0.40 mSv
Annual doses from nuclear explosives testing: (corresponds to about 1 % of the annual exposure from natural Background)	0.02 mSv
Annual doses from nuclear power production: (corresponds to about than 0.5% of the annual exposure from natural background)	0.001 mSv

These radionuclides enter the human body mainly through ingestion and inhalation and may cause irradiation. Man is exposed to these radiations both externally and internally. A country wide radiation survey in Bangladesh has shown that the external background radiation levels lie between 1 - 3.9 mSv y^{-1} with an average of 2 mSv y^{-1} excluding Cox's Bazar beach sand area where an average value of 13 mSv y^{-1} with a range of 2.6 - 44.0 mSv y^{-1} was observed In this context, it may be mentioned that no study has yet been made to assess internal dose resulting from ingested radionuclides to the population of Bangladesh. Radiation survey studies made at different times subsequently in the Cox's Bazar beach sand areas have demonstrated similar high radiation levels as mentioned and discussed above. The total radiation exposure (both external and internal) reported in other countries shown in the Table 2.3 of has a range between 1.88 - 2.22 mSv y^{-1}. From Table 2.3 it is observed that the average ratio of external to internal exposure is about 1.8. Since we have not yet been able to assess the internal exposure to the population of Bangladesh is not possible to assess the total exposure. However if the same ratio 1.8 as obtained in other countries Table 2.3 is maintained in the dose pattern of public in Bangladesh, the internal dose equivalent component would be around 3.6 mSv y^{-1} giving

a total public dose equivalent of 5.6 mSv y^{-1} from both external and internal sources of background radiation. This is nevertheless a high radiation exposure to the population and can not be readily accepted without verification if at all referred, it should be done with caution.

Table 2.3: Background Radiation Levels in Some Countries of Europe and Bangladesh.

Effective dose equivalent (mSv y^{-1})	Source	Country			
		U.K.	France	Germany	Bangladesh
External irradiation	Cosmic rays	0.30	0.30	0.33	2.0
	Local gamma radiation	0.40	0.35	0.47	
	Subtotal	0.70	0.65	0.80	2.0
Internal irradiation	Potassium-40	0.20	0.18		
	Radon, Thoron and decay products	0.80	0.95	1.42	3.6
	Carbon-14	0.01	0.02		
	U and Th nuclides in body	0.17	0.19		
	Subtotal	1.18	1.33	1.42	5.6
Total		1.88	1.98	2.22	5.6

2.11. Radioactivity in Drinking Water

Radionuclides in Water

Everyone is exposed to some natural radiation that comes from both cosmic rays and terrestrial sources. Minute traces of radioactivity are normally found in all drinking water. The concentration and composition of these radioactive constituents vary from place to place, depending principally on the radiochemical composition of the soil and rock strata through which the raw water may have passed.

Many natural and artificial radionuclides have been found in water, but most of the radioactivity is due to a relatively small number of nuclides and their decay products. Among these are the following emitters of radiation of low linear energy transfer (LET): potassium-40 (^{40}K), tritium (^{3}H), carbon-14 (^{14}C) and rubidium-87 (^{87}Rb). In addition, high LET, alpha-emitting radionuclides, such as radium-226 (^{226}Ra), the daughters of radium-228 (^{228}Ra), polonium-210 (^{210}Po), uranium (U), thorium (Th), radon-220 (^{220}Rn), may also be present in varying amounts.

Natural Radionuclides

Source of Low LET Radiation: Some of the radionuclides that are responsible for the natural radioactivity in drinking water come from radioactive elements and their decay products that were incorporated in the earth at its formation and others are produced by cosmic ray interactions with atmospheric oxygen and nitrogen. It is then oxidized to tritiatrd water, which mixes into the hydrosphere. Tritium concentrations in water supplies vary from about 10 to 25 pCi L^{-1} (Jacobs, 1968).

In similar fashion, carbon-14, produced by cosmic ray [$^{14}N(n, p)^{14}C$] interactions with atmospheric nitrogen (UNSCEAR, 1972), is oxidized to $^{14}CO_2$, which is generally found at a concentration corresponding to about 6 pCi ^{14}C per gram of carbon. In water containing about 1 mg of carbon per litre, a concentration of 0.006 pCi L^{-1} might be expected. In ocean water, the concentration might be about 0.1 pCi L^{-1} (NCRP, 1975). Of all the natural radionuclides that occur in water and emit low LET radiation, potassium-40 is likely to be the most significant. This primordial radionuclide occurs as a constant percentage (0.011%) of total potassium. Adults in the United States ingest about 2,300 pCi of potassium-40 per day, but almost all of it is derived from foodstuffs. Since potassium concentrations in man seem to be under homeostatic control, wide fluctuations in drinking water potassium would have negligible effects on internal concentrations. Assuming that there is 0.2% potassium in soft tissue, a dose rate of 19 mrad y^{-1} has been estimated; of this, 17 mrad are due to beta radiation (UNSCEAR, 1972).

Sources of High-LET Radiation: Radionuclides that are produced by the decay of uranium-238 and thorium-232 are widely distributed throughout the earth's crust. The majorities of them is alpha-emitters and include isotopes of polonium, radon and radium (UNSCEAR, 1972). Concentrations of uranium in drinking water are extremely variable,

apparently ranging from 0.02 to 200 μg L^{-1} in fresh waters. The thorium content of drinking water has not been extensively measured but its concentration in the human skeleton is about 1 pCi g^{-1} of ash; the corresponding abundance of uranium in the skeleton is about 10 times greater.

The natural alpha-emitters that occur in drinking water appear to be brine seekers. Of these, radium-226 and its daughters and the daughters of radium-228 probably have the greatest potential for producing radiation surface water is variable, ranging from 0.01 to about 0.1 pCi L^{-1}. Some groundwater may contain up to 100 pCi L^{-1}. Drinking water obtained from surface supplies generally does not contain significant amounts of radium and treatment processes, such as flocculation and water-softening can remove the bulk of radium from water. The major additional contribution to the alpha-emissions in drinking water is due to the decay of radium-228; although other alpha-emitting natural radionuclides have been found in drinking water, they occur in exceedingly small concentrations. For example, one analysis of water containing 5 pCi of radium-228 per litre was found to contain less than 0.02 pCi L^{-1} of thorium isotopes and only 0.03 pCi L^{-1} of uranium (Stehney, 1960).

Two other radium isotopes may be present in drinking water, but although both radium-223 and radium-224 may contribute to the gross alpha activity of water measured soon after drawing from the tap, their contributions to the long-term dose deposited in the skeleton are negligible because they have short half-lives. However, radium-228, which decays by beta emission and therefore does not contribute to gross alpha activity in drinking water, will as a result of its subsequent decay scheme, give rise to a series of alpha-emitting daughter products. It is these radium-228 daughter products and radium-226 and its daughters that produce the major alpha-particle dose to the tissues of the body, particularly to the skeleton. Thus radium in drinking water, it is essential to distinguish between the isotopic mixture measured in freshly drawn drinking water and the long-term alpha dose that might be accumulated in tissue. Because of the different decay schemes for radium-226 and radium-228, different alpha doses are received under equilibrium conditions from each of these two radium isotopes. In waters of low alpha-particle radioactivity, the activity concentration of radium-228 is generally equal to that of radium-226, whereas at high radioactivity concentrations it is only half that of radium-226 (Lucas and Krause, 1960).

The abundance of the radioactive gas radon-222, which is formed by the decay of radium-226, is not highly correlated with the radium concentration in fresh water. Radon concentration is generally 1 pCi L^{-1} in surface water, but activity concentrations in groundwater are typically a few thousand times greater. Some mineral or spa waters, however, may contain 500,000 pCi L^{-1}. Consumption of water containing 1 μCi of radon-222 will result in a stomach dose of about 20 mrads, but the doses to other organs will be lower by at least a factor of 10 (UNSCEAR, 1975). Furthermore, consumption of 2 litres per day of water containing 1 nCi L^{-1} of radon-222 would deliver an annual stomach dose of about 12 mrad.

In three large American cities, the total daily intake of uranium, radium-226, radium-228 and lead-210 in water have all been quoted to range approximately between 0.01 and 0.05 pCi d^{-1} (NCRP, 1975). When compared with other compared with other components of the diet, drinking water usually contributes less than about 2% of these alpha-emitting radionuclides to the daily dietary intake (NAS-NRC, 1973). The greatest dose potential from alpha-radiation from naturally occurring radionuclides in drinking water will be related to the ingestion of radium-226 in areas where its concentration is high.

Artificial Radionuclides

To some extent, all drinking water obtained from surface sources will reflect contamination from atmospheric testing of nuclear weapons. Extensive measurements have been made of the contribution of airborne fission products to drinking water contamination and in particular to the levels that were produced by testing weapons before the Nuclear Test Ban Treaty of 1963. The sharp decrease in radioactive fallout since that date has been followed by a corresponding decrease in the radioactivity of surface water. Although the analyses are not very extensive, the temporal characteristics provide some information that is useful in predicting the transport and fate of radionuclides in water. Some of the longer-lived radionuclides still persist from early tests, together with smaller quantities of fission products injected irregularly into the atmosphere from the testing of weapons by nontreaty nations.

Many of the states conduct periodic surveys of the radioactivity of drinking water. Unfortunately, these consist, for the most part, in counting only the gross beta and gross alpha activity in the water. In addition, there is a considerable body of data on the temporal patterns and regional concentrations of the fission products strontium-90 and cesium-137, the physical half-lives of which are about 30 year. For a major part of the potential dose from nuclear fission and activation products, and because of their biological significance, considerable attention has been devoted to strontium-90, cesium-137, iodine-131, tritium and carbon-14 as potential water contaminants. Sources of man-made radionuclides, in addition to atmospheric weapons tests, include local discharge of radiopharmaceuticals and the possible entry of radioactivity into watersheds from the use and processing of nuclear fuel to produce electric power.

Risks from Radioactive Drinking Water

Minute traces of radioactivity are normally found in all drinking water. The radiation associated with most water supplies is such a small proportion of the normal background radiation to which all human beings are exposed, that it is difficult, if not impossible, to measure any adverse health effects with certainty. In a few water supplies, however, radium can reach concentrations that pose a higher risk of bone cancer for the people exposed. Risk estimates were made of three kinds of adverse health effects that radiation could produce: developmental and teratogenic effects, genetic effects and somatic effects.

Developmental and Teratogenic Effects: On the basis of the effects of external radiation, it has become generally accepted that developing mammals are more radiosensitive than adults (BEIR Committee, 1972; Sikov and Mahlum, 1969). Although the developing fetus is sensitive to radiation, the total low-dose rate doses that would be delivered during the sensitive periods of gestation are so small that no measurable effects of the radiation from drinking water will be found. The lowest dose level at which any effect has been reported is 3 mrem day^{-1} or 1,100 mrem y^{-1}. Since the basis interactions of radiation do not differ with age, it appears that the increased sensitivity follows from the high rates of cell proliferation and the complex interactions associated with development. Also, the variety of integrated developmental stages, through which the immature organism must progress to attain maturity, increases the chance that derangements will occur. In general, these deleterious effects may be divided into three categories: increased tumor incidence, death and developmental abnormalities. In the broad sense, the last category includes

physiological and biochemical deficits and deviations, as well as malformations. The doses required for embryo lethality change during development and vary by more than a factor of 10. There are also short "critical periods" for most, if not all, malformative events. Most of the available data suggest an apparent threshold at about 10 rad of acute exposure and a sigmoid dose-response relation for production of lethality and developmental abnormalities (BEIR Committee, 1972; Brent and Gorson, 1972).

In general, protracting the dose from low LET radiation results in a decreased biological effect. For developmental effects, the influence of protraction of exposure is even greater because only a small fraction of the life span is spent in the susceptible prenatal and neonatal a stages. Only radiation that is absorbed during the critical period of hours or days would be effective in altering the particular processes occurring at that time.
The water intake of the neonate is initially minimal, increasing with time. Even in the juvenile period, milk is often the major source of fluid, and it reflects, to some extent, the radionuclide content of the water supplies and food.

The exposure of the fetus to radionuclides depends on the maternal body burden and particularly on the concentrations of radionuclides in the material circulation; the fraction available to cross the placenta depends on the rate of removal from the circulation. The amount of activity to which the concepts may be exposed is also a function of the facility with which the nuclide crosses the placenta. Radioisotopes of normal dietary constituents generally behave as do the stable isotopic species. Availability is influenced also by the chemical and physiochemical form of the nuclide and changes with the stage of gestation. Most elements, in their usual forms, fall into three broad categories relative to cross-placental transfer. The first category includes materials such as phosphorus and iodine that freely cross the placenta, either by rapid diffusion or by active transport, and reach fetal blood concentrations approximating those of the mother. Tissue concentrations depend on metabolic considerations and may influence the rate of removal from the blood. These processes are age-dependent, in that it is not until thyroid function or skeletal calcification begins that significant quantities of iodine or strontium are removed from the circulation. At these times, the fetal concentrations in the target organs may slightly exceed those in the mother, although they are often smaller. The second category encompasses the many elements that diffuse relatively slowly and may include those for which there appear to be placental barriers to them or in their usual chemical form are

poorly transferred to the conceptus. The average concentration of such a material in the fetus is only a small fraction of that in the mother, although specific tissue concentrations occasionally approach maternal values (Wrenn, 1975). For some of these elements (e.g. ^{239}Pu) it appears from rodent studies that most of the embryotoxicity early in gestation is attributable to material localized in the villus yolk sac (Sikov and Mahlum, 1972). Because this structure is vestigial in man, it is uncertain whether this finding has significance for exposure of humans.

Genetic Effects: Mutations, changes in the genetic information, can occur at any time in any cell of the body. Geneticists, however, are concerned primarily with mutations that occur in the genes and chromosomes of germ cells, sperm and eggs, or the cells from which they are derived. Sperm and egg cells, after fertilization, give rise to the individuals of the next and later generations. Thus, a mutation originating in germ cells could, in time, spread through the population. Mutations fall into three major categories of genetic alteration: gene mutations, chromosome aberrations, and changes in chromosome number. Gene mutations, in which the genetic change is restricted to a submicroscopic region of a chromosome, affect only a rather restricted amount of the cell's information content. For example, mutations in the gene controlling the production of hemoglobin in red blood cells may be manifested as altered or missing hemoglobin. Such a mutation may have no bearing on the manner in which the hemoglobin functions or it may be the cause of severe anemia, as in sickle cell anemia. In the fertilized egg, chromosomes and genes are inherited in pairs, one member of the pair coming from each parent. Mutant genes are usually described by the manner in which their activity is manifested. A dominant mutation or gene is one that gives an altered effect in the presence of a normal partner gene. A recessive mutant gene is one whose effect is apparent in the individual only if both members of the pair of genes are mutant; when the recessive and normal are both present, the mutant trait does not appear. Sex-linked recessive genes-those on the X-chromosome-govern traits more commonly observed in males than in females. Males have only one X-chromosome, whereas, in females, unless both X-chromosomes contain the recessive, it cannot. Some gene mutations are caused by the deletion of a single base pair within the gene. In practice, it is usually difficult or impossible to discriminate between gene mutations and deletions that extend beyond the borders of a single gene to neighboring genes. If the deletions are microscopically invisible, they will usually be classified as simple gene mutations.

Deletions may vary in scale from the loss of a single base pair to larger losses that extend into the second major category of genetic change: chromosome aberrations. This category encompasses alterations in chromosomal structure that are visible under the microscope. Recognizable aberrations include deletions of chromosomal segments, additions of segments, and changes in the position of segments, either within a single chromosome or between two or more chromosomes. These changes can have considerable biological consequences in that the health, survival, and reproduction of individuals with such altered chromosomes may be impaired. Although these individuals may appear to be normal, their offspring could be severely afflicted as a result of the reshuffling of the genetic information that routinely occurs in the formation of new germ cells.

The third category of mutation consists of changes in the number of whole chromosomes in the genetic set carried in the germinal cells. In man, each germ cell contains 23 chromosomes; the fertilized egg and the individual produced there from have 23 distinctly recognizable pairs of chromosomes in each somatic cell. With the exception of the X- and Y- chromosomes of the male, the members of each pair are morphologically alike. During meiosis, the process of germ-cell formation, the chromosomes are redistributed, so that each germ cell will contain only one member of each pair. During this redistribution, mistakes sometimes occur, and some cells receive two members of a pair. Correspondingly other cells receive neither member when severe congenital abnormality occurs. Examples of this are Down's syndrome, Edwards' and Patau's syndromes and various sex-chromosome anomalies.

Although there is no definitive proof that any single mutant human individual resulted from exposure of the parents to a known mutagen (radiation or chemical) and thus no direct proof that these agents are indeed mutagenic in man, radiation has been demonstrated to be mutagenic in so many organisms that it seems very unlikely that it is not mutagenic in man.

Basic for Estimating Genetic Risk in Man

The estimates of genetic effects of low levels of radiation on human are due to ingestion of radioactive isotopes in drinking. Three major principles of particular relevance to human risk estimates have emerged from studies of induced mutation.

(i) Radiation or other mutagens appear to produce genetic changes that are qualitatively the same as those that occur naturally.

(ii) At low doses and low dose rates of low LET radiation, mutations are induced in direct proportion to the dose.

(iii) In the low dose range of irradiation to which human populations are normally exposed from natural background or man-mad sources, the manner in which the dose is received will not affect the yield of induced mutations. The same number of mutations will result if 100 mrem are received all at once or spread out over weeks, months, or even years.

For the general population, the maximum permissible dose of man-made radiation is 170 mrem y^{-1}, excluding medical uses of radiation. This amounts to a 5 rem genetic dose in each 30 year generation. This dose would increase the current incidence of genetic diseases, which is about 94,400 per million live births, by about 200 per million in the first generation. The estimate of 200, however, is so uncertain that there are very large limits about the value. The gonadal dose of 0.244 mrem y^{-1} calculated for the hypothetical drinking water is expected to increase the genetic diseases from the $94{,}000/10^6$ live births by 200×0.244 mrem / 30×170 mrem = 0.0098 additional genetic diseases per million live births per year. Since there are approximately 3.6 million live births in the United States each year, this is an increase of 0.035 total genetic diseases in the United States per year. If one takes the unlikely extreme limits of the estimated genetic hazards of radiation (about 4,000) instead of the value 200, the increase is 0.7 cases per year.

Somatic Effects: The natural background of radiation can be estimated to cause 4.5 to 45 fatal cases of cancer per year per million people. Less than 1% of this will be contributed by the radionuclides in drinking water.

Variations in the radium content of drinking water, however, may cause appreciable differences in the radiation dose to the skeleton and, in turn, in the risks of associated

carcinogenic effects. Under average conditions, the annual dose to bone from radium amounts to approximately 6.4 mrem y^{-1}, which represents about 6% of the total dose to the skeleton from all sources of natural background radiation. The highest radium levels in drinking water (25 pCi L^{-1} of ^{226}Ra and an additional 12.5 pCi L^{-1} of ^{228}Ra), however, may be expected to deliver a dose to the skeleton of about 600 mrem y^{-1}, which would represent a sixfold increase in the total dose to bone from all natural sources combined. If the carcinogenic risks associated with skeletal irradiation are assumed to be 0.2 fatal cases of bone cancer per million persons per year per rem, then for a period up to 30 year, in a population with a typical distribution of ages, the risks attributable to natural background radiation can be estimated to range up to about 0.6 per million persons per year under average conditions, and to 4.2 per million persons per year under conditions of maximal intake of radium in the drinking water (about 600 mrem y^{-1} from the radium).

In addition to these risks, the possibility of carcinogenic effects from radium on cells adjacent to bone, such as those in epithelia lining cranial sinuses and those in the bone marrow, should also be mentioned. However, the risks of such effects are likely to be appreciably smaller and con not be estimated precisely from existing data. In comparison with the overall risks of cancers of all sites combined, of which 4.5 to 45 fatal cases per million per year can be attributed to natural background radiation at average levels, the additional 3.6 fatal bone malignancies per million per year ascribable to maximal intakes of radium in drinking water constitute a significant increment. It should be noted that only about 120,000 people drink water estimated to contain between 9 and 25 pCi L^{-1}. Thus the excess bone cancers in this group would be between 0.16 and 0.43 per year; that is to say, one excess bone cancer every 2 to 6 year. Since about 113,000 of the 120,000 people drink water containing less than 20 pCi L^{-1}, the true number of excess bone cancers will lie somewhere towards the lower end of the range.

When interpreting the above estimates, it must be remembered that they depend on dose-response models that remain highly uncertain. For example, the value given for the combined frequency of deaths from all types of cancer attributable to natural background radiation namely, 45 deaths per million per year is higher by a factor of three or more than estimates derived with any of the other risk models cited. Likewise, the corresponding risk estimates for skeletal cancer could vary widely, depending on the postulated dose-response relationship.

2.12. Review of the Past Work

Water is vital for our life. It is contaminated fast after the nuclear explosion or other events such as atmospheric pollutions and radioactive fallout. Underground water is contaminated by U, Th, Ra, K and Rn from soil and mines. Lots of works on the radioactivity of water including drinking water were carried out over the whole world.

Godoy. observed that over twenty samples of bottled mineral waters from different states of Brazil were analyzed for ^{226}Ra, ^{228}Ra and ^{210}Pb content. Mean values of 27 mBq L^{-1} for ^{226}Ra and 77 mBq L^{-1} for ^{210}Pb were found. ^{228}Ra was found in only two samples and the highest value was 300 m Bq L^{-1}. Based upon the production rate and the measured concentrations, collective committed effective dose per year of 1.5 manSv for ^{226}Ra, 1.4 manSv for ^{228}Ra and 17 manSv for ^{210}Pb were obtained.

Sanchez-Cabeza J.A. and Pujol Li. presented a rapid method for the simultaneous determination of gross alpha and beta activities in water samples using a low background liquid scintillation counter. The detection limits achieved were 0.012 Bq L^{-1} and 0.14 Bq L^{-1} for gross alpha and beta activity respectively according to the world Health Organization (WHO) guideline values.

Lo'pez-Gona'lez H. observed gross alpha and gross beta activity of water samples from (Instituto Nacional Investigaciones Nucleares) ININ and Maquixco in the state of Mexico. The gross alpha and gross beta radioactivity in the samples were determined by a gas- flow proportional counter. The results indicated that the gross alpha and gross beta radioactive contamination in water samples were below the maximum contaminant level (MCL).

Fatima et al., observed the natural radionuclides (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) and also ^{137}Cs in drinking water of Pakistan. The concentrations of ^{226}Ra, ^{232}Th and ^{40}K were 11.3 ± 2.3, 5.2 ± 0.4 and 140.9 ± 30.6 mBq L^{-1} respectively. The annual cumulative effective dose due to intake all the natural radionuclides for different age groups of 1-5 year, 5-10 year, 10-15 year and adults (≥ 18 year) were estimated to be 4.0, 3.4, 3.1 and 4.1 μSv y^{-1}, respectively.

Cevik et al., examined the activity concentrations in tap water of Turkey. The concentrations of ^{214}Pb, ^{214}Bi, ^{226}Ra, ^{40}K and ^{222}Rn were 6.73, 6.19, 16.16, 8.57 mBq L^{-1} and 10.82 Bq L^{-1} respectively. The effective doses were determined due to intake of these radionuclides as a consequence of direct consumption of tap water sample. The estimated effective doses were 6.878×10^{-4} μSv y^{-1} for ^{214}Pb, 4.800×10^{-4} μSv y^{-1} for ^{214}Bi, 3.916 μSv y^{-1} for ^{226}Ra, 6.763 μSv y^{-1} for ^{40}K, 0.052 μSv y^{-1} for ^{137}Cs and 5.848 μSv y^{-1} for ^{222}Rn.

Ajayi O.S. and Owolabi T.P. presented the activity concentration of radionuclides in drinking water in private due wells in Akure, Southwestern Nigeria. Activity concentration ranged from 0.57 to 26.86 Bq L^{-1} for ^{226}Ra, 0.20 to 60.06 Bq L^{-1} for ^{228}Ra and 0.35 to 29.01 Bq L^{-1} for ^{40}K. Total annual effective doses from the intake of these radionuclides in the water ranged from 0.02 to 76.84; 0.02 to 38.80 and 0.05 to 481.60 mSv y^{-1} for age group (1, 2-7, and ≥ 17) respectively.

Ahmed N.K. observed in ground and drinking water in upper Egypt. In drinking water in Qena, the Red sea region, the activity concentration of ^{226}Ra was 1.32 ± 0.7 pCi L^{-1} and in ground water in Safaga and Quseir, the Red Sea region, the concentration of ^{226}Ra and ^{232}Th were 3.05 ± 0.9 and 1.39 ± 0.6 npCi L^{-1}. A man annual effective dose taken into the body by the population drinking this tap water may account for 0.008 mSv which is lower than the limit recommended by WHO.

Welcha et al. observed gross beta activity in ground water. Analyses of about 800 samples from 5 ground-water regions of the United States provide a basis for evaluating the utility of this measurement. Although ^{40}K and ^{228}Ra appear to be the primary sources of beta activity in ground water, the sum of ^{40}K plus ^{228}Ra appears to be less than the measured gross-beta activity in most ground-water samples. The difference between the contribution from these radionuclides and gross-beta activity is most pronounced in ground water with gross-beta activities > 10 pCi L^{-1}, where these radionuclides account for less than one-half the measured gross-beta activity. One exception is ground water from the Coastal Plain of New Jersey, where ^{40}K plus ^{228}Ra generally contribute most of the gross-beta activity. In contrast, ^{40}K and ^{228}Ra generally contribute most of beta

activity in ground water with gross-beta activities < 1 pCi L^{-1}. The gross-beta technique does not measure all beta activity in ground water. Although H contributes beta activity to some ground water, it is driven from the sample before counting and therefore is not detected by gross-beta measurements. Beta-emitting radionuclides with half-lives shorter than a few days can decay to low values between sampling and counting. Although little is known about concentrations of most short-lived beta-emitting radionuclides in environmental ground water (water unaffected by direct releases from nuclear facilities and weapons tests), their activities are expected to be low. In growth of beta-emitting radionuclides during sample holding times can contribute to gross-beta activity, particularly in ground water with gross-beta activities > 10 pCi L^{-1}. In growth of beta-emitting progeny of ^{238}U, specifically ^{234}Pa and ^{234}Th, contributes much of the measured gross-beta activity in ground water from 4 of the 5 areas studied. Consequently, gross-beta activity measurements commonly overestimate the abundance of beta-emitting radionuclides actually present in ground water. Differing sample holding times before analysis lead to differing amounts of in growth of the two progeny. Therefore, holding times can affect observed gross-beta measurements, particularly in ground water with ^{238}U activities that are moderate to high compared with the activity of ^{40}K plus ^{228}Ra. Uncertainties associated with counting efficiencies for beta particles with different energies further complicate the interpretation of gross-beta measurements.

Bombén, A.M. and Palacios, M.A presented as part of the national survey to evaluate natural radioactivity in the environment, concentration levels of natural uranium and ^{226}Ra have been analyzed in over 300 drinking water samples taken from different locations in Argentina. ^{226}Ra was determined by ^{222}Rn emanation and liquid scintillation counting, and natural uranium by a fluorimetric procedure. Values ranging from 0.03 to 24 μg $L^{-1}$of natural uranium and from 0.06 to 50 μg L^{-1}, were measured on drinking water samples taken from tap water systems and private wells, respectively. Concentrations up to 15 mBq L^{-1} and to 22 mBq $L^{-1}$of ^{226}Ra were found in drinking water samples taken from tap water systems and private wells, respectively. These values are compared with the reference values accepted for drinking water. Based on the water intake rate, the age distribution and the measured concentrations, an annual collective effective dose of 1.9 manSv and an individual committed effective dose of 0.49 μSv y^{-1}were calculated for the city of Buenos Aires adult inhabitants, for the ingestion of both natural radionuclides analyzed in drinking water.

Kiefer. et al. measured ^{226}Ra and ^{222}Rn concentrations in drinking water in parts of the Federal Republic of Germany. 254 samples were analyzed for ^{226}Ra, 57 for ^{222}Rn. The average contents were found to be 4.4 x 10^{-3} Bq L^{-1}(0.2 pCi L^{-1}) for ^{226}Ra and 7.4 Bq L^{-1} (0.2 nCi L^{-1}) for ^{222}Rn with maximum values of 0.11 Bq L^{-1} (3 pCi L^{-1}) and 43 Bq L^{-1} (1.2 nCi L^{-1}) respectively. The average yearly doses to the critical organs are estimated to be about 0.003 mSv y^{-1} for ^{226} R (bone lining) and about 70 μSv y^{-1} for ^{222}Rn (stomach).

Cothern C.R. and Lappenbusch W.L. tabulated and examined the range of concentration existing uranium in drinking water supplies in the U.S. Projections from the available date lead to estimates that of the 59.812 community drinking water supplies in the U.S., 22-650 would exceed a uranium concentration of 20 pCi L^{-1}, 100-200 would exceed 10 pCi L^{-1} and 2500-5000 would exceed 5 pCi L^{-1}.

Waston. et al. performed the measurement of ^{222}Rn in ground water supplies in 400 North Carolina homes. The arithmetic measurement of ^{222}Rn concentration measured in ground water supplies state wide was 67 Bq L^{-1} (1,800 pCi L^{-1}) and the geometric mean was 24 Bq L^{-1} (660 pCi L^{-1}). 67% of the state's homes with wells had ^{222}Rn water concentration in excess supplies of 11 Bq L^{-1} (300 pCi L^{-1}).

Yu K.N. and Mao S.Y. observed the natural radionuclides (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) and also ^{137}Cs in drinking water of Hong Kong. The ^{238}U concentration was 79 mBq L^{-1}, ^{226}Ra concentration 4.4 mBq L^{-1}, ^{232}U concentration was 79 mBq L^{-1}, ^{226}Ra concentration 4.4 mBq L^{-1}, ^{232}Th concentration 71 mBq L^{-1}, ^{137}Cs concentration 1.1 mBq L^{-1}, ^{40}K concentration 0.11 mBq L^{-1}.

Sasser K. and Waston J.E. Jr. analyzed to determine the presence of ^{222}Rn in water samples from 225 North Carolina ground water supplies. The results were reported in pCi L^{-1} and range up to maximum of 46.600. Approximately 33% of the water supplies were found to have concentrations greater that 2000 pCi L^{-1}, the old standard listed by the NCRP in NBS Hand Book 52. These studies indicated that ^{222}Rn concentration in water in the range of 3000-7000 pCi L^{-1} delivers to the stomach the 0.5 rem y^{-1} dose limit recommended by the ICRP for the general population.

Countess R.J. measured the concentration of radon in samples of water from about 30 houses within a 50 mile radius of New York City. In some samples, the concentration of radon was undetectable, in others he found up to 2000 pCi L^{-1}.

Buchli R. and Burkart W. measured concentration of ^{222}Rn in tap water Switzerland. A mean tap water ^{222}Rn content of 38.3 Bq L^{-1} and 10.4 Bq L^{-1} was measured in 31 villages with a crystalline subsoil (upper Rhine valley) and 73 villages with a sedimentary subsoil (Helvetic nappes), respectively. Radon -222 degassing from the tap water into the indoor air leads to an additional exposure of about 0.11 mSv y^{-1} and 0.03 mSv y^{-1} in homes with a crystalline subsoil and homes with sedimentary subsoil respectively.

Muth et al. reported the experimental results concerning the normal radium (^{226}Ra) content on food, drinking water, the distribution of normal radium in the human body and the $^{226}Ra/Ca$ ratio. The daily uptake of radium by a "standard man" amounts to about 3 x 10^{-12}c and under normal environmental conditions, 90 per cent on this amount enters the body with food and only 10 per cent with water.

Watson et al. measured the ^{226}Ra and ^{222}Rn concentrations in North Carolina wells located in the vicinity of the phosphate mining sites were relatively low when compared to concentrations found elsewhere in the state. The mean ^{226}Ra concentration for all wells sampled was 0.016 Bq L^{-1} (0.43 pCi L^{-1}) and the mean ^{222}Rn concentration for all wells sampled was 7.3 Bq L^{-1} (198 pCi L^{-1}).

Fisenne et al. estimated the daily intake of long-lived α-emitting members of the U, Th and Ac series by New York City residents from measurement of diet, water and air samples. The total daily intakes from inhalation, food and water consumption in mBq are 18 (^{234}U), 0.7 (^{235}U), 16(^{238}U), 6(^{230}Th), 4(^{232}Th) and 52(^{226}Ra). From this, we infer that the total daily intakes of ^{228}Th and ^{228}Ra are 4 and 35 mBq respectively.

Cothern C.R. and Lappenbusch W.L. showed resulting contribution from drinking water sources to the annual effective does equivalent is in the range of 0.002 to 0.05 mSv y^{-1} (0.2-5 mrem y^{-1}) for those using community drinking water supplies (approx. 216 million people in the United States). The contribution to the annual effective does equivalent

CHAPTER III

OBJECTIVE

3.1. Objective of Present Study

There are certain amounts of ionizing radiations around us and everything in the environment is continuously exposed to the ionizing radiations. Man was exposed to natural radiation only until recent times when the growth of atomic energy created other sources of radiation exposure like radioactive fallout from nuclear tests, releases from nuclear reactor operations accidents, exposures due to radioactive waste disposal and industrial, medical and agriculture uses of radioisotopes. However, the major contribution to the average annual dose received by mankind still comes from natural radiation sources. Also the distinctive features of natural radiation are that it involves the whole population of the world and that it has been radiated for a long period of time. For these reasons it may be used as a reference level for comparison with man-made sources of ionizing radiation (UNSCAER, 1993).

The most probable radioactive materials present in the samples of natural water are tritium, carbon. iodine, potassium, strontium, radium, uranium, thorium etc., which emit nuclear radiations. Living beings are exposed to these radiations through water. Although, in general radiation is hazardous to living beings, there is a certain level of radiation dose which a living being can withstand called the "tolerance level". If the radiation dose exceeds this tolerance level, it does harm to living beings, causing long term effect. Since the internal radiation doses received by a living being through food-stuff and drinking liquids are more dangerous than external ones and since water is a drinking liquid, the Knowledge of the level of natural radioactivity in water is of prime importance.

In water and the environment, the content of radioactive elements increases due to continuous generation of radioactive isotopes by:

(i) the reaction of cosmic radiation with the atoms of the atmospheric elements

(ii) the operation of nuclear reactions and their fuel reprocessing plants

(iii) nuclear test's fallouts, and

(iv) the other world-wide nuclear activities.

Recently in addition to the developed countries, some developing countries in Asia have started nuclear programmers to achieve nuclear power. By this time some successful explosions have already been made by our neighboring countries-India and china. Also Pakistan and South Korea have been reported to be on the way to have nuclear power. Although Bangladesh is not a nuclear powered country, nevertheless, it may be vulnerable to atmospheric fallout of technogenic radionuclides and waste disposal to the Indian Ocean by neighboring countries or by other developed countries, since no surveillance activity in this regard exists here. Besides this, Bangladesh is subjected to natural radioactivity through the draining of heavily silt-laden water by the Ganges-Brahmaputra-Meghna river system. Therefore, the probability of contaminating the environment of Bangladesh including water may further be increased and if so their radioactivity level will change with time due to nuclear wastes. The assessment of the radiation doses in human from natural sources of special importance because natural radiation is by far the largest contribution to the collective dose received by the population.

The radiation dose may be imparted to body both internally (when the source is inside the body) and externally (when the radioactive source is outside the body). Radionuclides enter the human body mainly through ingestion, inhalation and contamination and also through food, drink and air. Different radionuclides present different health hazards depending on

(i) the nature of radionuclides
(ii) the nature of emitted radiation
(iii) its half life
(iv) decay scheme
(v) the chemical form in which the radionuclides is encountered
(vi) the fraction that is assimilated
(vii) the organ in which it may accumulate and
(viii) the concentration that may be reached

Dhaka is a densely populated city and its major growth in population mainly due to migration from the city-side and townships. One of the main challenges for Dhaka Water and Sewerage Authority (DWASW) is to provide adequate and safe water for drinking, domestic and other uses in its jurisdiction in Dhaka city. Of the total water supply, 82% is from ground water. About 77% of the drinking and households are provided with tap water and about 20% use tube well water in Dhaka city. The remaining three percent households are depend on well, pond, canal and rivers for drinking water. So a minimum of environmental pollution like radiation hazard, industrial pollution or waste disposal has a tremendous impact on us. The distribution of radionuclides in nature and xenobiotic exposure of radiation due to mishandling of radioactive materials or installation, their concentration and movements can seriously affect human lives. Assessment of any release of radioactivity to the environment is important for the protection of public health, especially if the released radioactivity can enter the food chain. Assessment demands rapid, reliable and practical techniques for analysis radionuclides. Therefore, the present study for the measurement of natural and artificial radioactivity level in supply water has been undertaken in Bangladesh, choosing different locations in Dhaka city as sampling.

Under this research the following studies were carried out:

(i) Determination of the natural radionuclides of ^{232}Th, ^{228}Ra, ^{238}U, ^{226}Ra and ^{40}K in supply water,

(ii) Measurement of artificial radioactivity ^{137}Cs in supply water,

(iii) Measurement of gross alpha activity of tap water sample,

(iv) Measurement of gross beta activity of tap water sample, and

(v) Assessment of the committed effective doses and annual effective doses from the radionuclides.

The present work would help create a public awareness about tap water i.e. supply water. This work is a part of radiological assessment in Bangladesh which is establishing a baseline map and developing a database on background radioactivity levels in the environment. Also the results presented in the study may prove helpful in establishing a regulatory limit on radiation in public drinking water as well as tap water in Bangladesh and shall as a bench mark for further changes in this regard. The whole work was undertaken at Heath Physics Division, Atomic Energy Centre, Dhaka.

3.2. Basic Requirements of the Study

In the present study, a series of experiment have been designed and carried out:

- Sample preparation,
- Energy calibration of high purity germanium (HPGe) detector,
- Energy resolution of HPGe detector,
- Efficiency calculation of HPGe detector,
- Efficiency calculation of ZnS(Ag) scintillation detector,
- Efficiency calculation of gas proportional counter.

CHAPTER IV

EXPERIMENTAL SET-UP AND MEASUREMENT

4.1. Introduction

Ionizing radiation cannot be seen or even sensed by human sensors. To detect the presence and measure the rate of radiation, physical and chemical effects of ionizing radiation on materials are used. These effects include ionization of gases, which requires about 34 eV of energy to produce an ion pair, production of ionization and excitation in various solid materials, production of change in biochemical and chemical system and raising of temperature of an absorbed by radiant energy.

The most common radiation monitors rely on the ionization of gas. When this process occurs the resulting electrons and positively charged ions are separated by an electric field. These separated ions are then collected by electrodes and their numbers are determined, thus giving a measure of the amount of ionization and therefore the amount of radiation. The use of different instruments in detecting radiation is based on the type and intensity of radiation. In present work two types of radiation detectors namely: a complete HPGe detector lab facility, Scintillation Detector and Gas proportional Counter were used to detect the radiation level of water samples.

Laboratory Set-up

The present experiment was carried out by employing a highly sophisticated and expensive HPGe detector- Intrinsic Germanium p-type Coaxial (supplied ORTEC Detector System, USA) and Dual Phosphor ZnS(Ag) Detector and Gas proportional Counter for measuring the radioactivity levels in water samples of Dhaka city.

4.2. High Purity Germanium (HPGe) Detector

Introduction: HPGe detector is a high quality precision instrument used in gamma-ray spectrometry above 100 keV for its high efficiency and good resolution. It is a solid analogue of a gaseous ionization chamber where high-purity Germanium is used instead of usual gas. The performance of the detector depends on its depletion depth. The depletion depth at a given voltage increases in proportion to the square root of the

material resistivity and inversely proportional to the net impurity concentration in the available with the impurity concentrations in the range of 10^9 to 10^{11} atoms cm^{-3} and thus making it possible to fabricate large volume germanium detectors.

When a photon interacts with the HPGe detector in the depletion region, electron hole pairs are produced, which are proportional to the absorbed energy of the incident photon. These electron-hole pairs are then swept by the electric field to their respective collecting electrodes. The resulting induced charge is integrated by the charge sensitive preamplifier to produce an output voltage pulse whose magnitude is proportional to the energy deposited in the detector.

The HPGe detectors are available in two geometries: the planar detector, in which the electric field is fairly uniform, and the coaxial configuration, in which the electric field varies inversely with the radial distance from the detector axis. The characteristics of the HPGe are high atomic number of Ge impurity concentration, i.e. large depletion depth, lowest ionizing energy (3 eV/pair) required to produce an electron hole pair, higher conductivity, compact size, fast time response, high resolution and most importantly it can be preserved at room temperature. Important physical characteristics of intrinsic Germanium are summarized in Table 4.1.

Since Germanium has relatively low band gap and high temperature sensitivity, these detectors must be cooled in order to reduce the thermal generation of charge carriers (thus reduce leakage current) to acceptable level; otherwise, leakage current induced noise destroys the energy resolution of the detector.

Liquid nitrogen, which has a temperature of 77 K is the common cooling medium for such detector. The detector is mounted in a vacuum chamber which is attached to or inserted into a liquid nitrogen dewar. The sensitive detector surfaces are thus protected from moisture and contaminants.

Table 4.1: Properties of Intrinsic Germanium.

Atomic number	32
Atomic weight	72.60
Density	5.33 g cm^{-3} (300 K)
Atomic density	4.41x 10^{12} atoms cm^{-3}
Dielectric constant	16
Forbidden energy gap	0.665 eV (300 K), 0.746 eV (0 K)
Intrinsic carrier density	2.4 $\times 10^{3}$ cm^{-3} (300 K)
Intrinsic resistivity	47 Ωcm (300 K)
Electron drift mobility	3900 cm^2 V^{-1} s^{-1} (300 K), 3.6 $\times 10^{4}$ cm^2 V^{-1} s^{-1} (77 K)
Hole drift mobility	1900 cm^2 V^{-1} s^{-1} (300 K), 4.2 $\times 10^{4}$ cm^2 V^{-1} s^{-1} (77 K)
Energy per hole-electron pair	2.96 eV/ (77 K)
Fano-factor	From 0.057 to 0.129 (77 K)

The performance of an HPGe is usually specified in terms of energy resolution, relative efficiency, lower limit of detection (LLD), and peak-to-Compton ratio etc. The detector manufacture commonly specify the energy resolutions of their germanium detectors in term of full width at half maximum (FWHM) at the 1332 keV ^{60}Co peak.

Detector 'ORTEC' Set-up: The High Purity Germanium "closed-end-coaxial p-type dipstick" radiation detector 'ORTEC" was employed in the present research for measurement of radioactivity level in tap water samples of Dhaka city. The high resolution of the detector and its reliability along width a charge sensitive preamplifier, an amplifier and a pulse height analyzer made it possible to use exclusively in the analysis of complex gamma-ray spectra. The main electric components associated with the counting system and HPGe detector coupled with the personal computer analyzer (PCA) consists of the following units:

(i) Liquid nitrogen dewar with cryostat, (ii) Preamplifier, (iii) Spectroscopy amplifier, (iv) High voltage detector power supply, (v) PC based multichannel analyzer (MCA), (vi) Shielding arrangement of the detector, and (vii) Printer.

Shielding Arrangement of the Detector

The shielding reduces the background resulting from cosmic radiation and from natural radionuclides in the lab building materials. Because of high density (11.4 g L^{-1}) and large atomic number (Z = 82) and comparatively low cost, lead is the most widely used material for construction of radiation shields. Further, for avoiding the effect of scattered radiation, the distance between the detector and shielding arrangement is made sufficiently large. In the present experiment, the shielding arrangement was made using 5 concentric MS rings around the detector whose outer and inner diameter were 0.54 m (21.3 inch) and 0.30 m (12 inch) respectively. In addition to these an aluminum and a copper rings were also used for further increasing the inner shielding. For the top shielding a 5 cm thick Pb in a MS support was used for protecting cosmic ray as well as background radiation.

HPGe Detector 'ORTEC' Specification

The basic configuration of HPGe detector 'ORTEC' are given in Table below:

Table 4.2: 'ORTEC' HPGe Detector Specification.

Detector		High Purity Germanium (HPGe)
Characteristics		Intrinsic p-type coaxial Ge crystal geometry
Crystal	Diameter	5.41 cm
	Length	4.13
	Volume	94.89 cm^3
Detector- window distance		0.3 cm
Face dead-layer thickness		0.07 cm
Liquid nitrogen dewar volume		30 litre, ORTEC
Preamplifier		Resistive feedback RFP11
Operating ranges	Operating bias	+3200 Volts DC
	Polarity	Positive
	Shaping time	6 μ sec
	Leakage current	< 50 pA
	Test point	- 0.70 Volts at operating bias
	Cool down time	6 hours
Resolution FWHM for ^{60}Co		2.3
Relative efficiency		20%

Energy Calibration of HPGe Detector

For identifying the radionuclides and their activity in the samples, it is necessary to calibrate the observed gamma energy spectrum against the channel number of MCA. In case of an HPGe detector, the relation between gamma–ray energy and channel number is approximately linear.

The energy calibration of the HPGe detector was made by using the known gamma point sources placed close to the detector inside the shield and the results were recorded in the Table 4.3. The straight energy calibration curve in the Figure 4.3 shows the linear response of the detector. In this way the MCA were adjusted to suitable channel numbers by entering the energies of the calibration sources in keV into the MCA to convert all 4096 channels to respective energies.

Table 4.3: Energy Calibration of the HPGe Detector.

Known Gamma Source	Gamma ray Energy (keV)	Channel No. appearing the full energy peak
^{137}Cs	661.66	417
^{60}Co	1173	751
	1332	855
^{40}K	1460	939

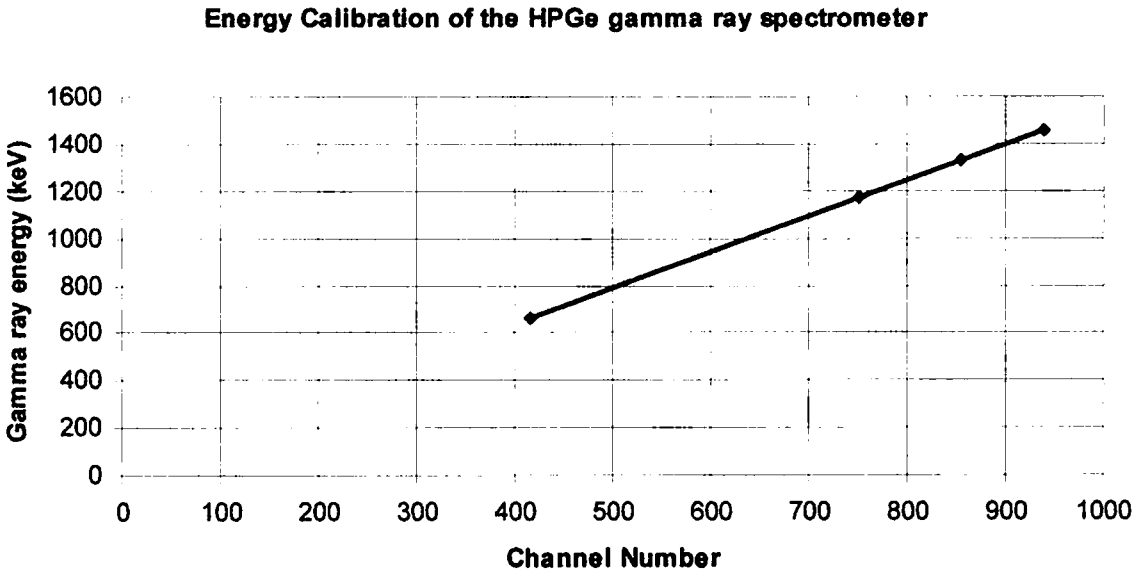

Figure 4.3: Energy calibration of the HPGe gamma spectrometry.

Energy Resolution of HPGe Detector

The resolving power of a detector is called the energy resolution of the detector to separate two adjacent peaks in a gamma-ray spectrum. In general, the resolution is a measure of the detector's ability to distinguish between two closely spaced gamma energy peaks in a gamma-ray spectrum. The resolution of a coaxial detector is given for 1332 keV ^{60}Co line and is defined as the Full width at Half Maximum (FWHM) of the full energy peak and expressed in keV. Resolution, R is calculated as

$$R = \frac{E_2 - E_1}{S_2 - S_1} \times \partial S$$

Where,

E_2 = highest energy peak of ^{60}Co, 1332 keV

E_1 = lowest energy peak of ^{60}Co, 1173 keV

S_2 = channel number of 1332 keV peak

S_1 = channel number of 1173 keV peak

∂S = the number of channel under FWHM in the 1332 peak

For this detector, E_2 = 1332 keV, E_1 = 1173 keV, S_2 = 855, S_1 = 751, and ∂S = 1.5

Therefore, R = [(1332-1173) / (855-751)]* 1.5 = 2.29 keV

Thus the detector resolution resolution at full width at half maximum (FWHM) obtained in this measurement was found to be 2.29 keV at FWHM of the 1332 keV peak of ^{60}Co source which is in excellent agreement. The resulting spectrum is shown in Figure 4.4.

$t_{1/2}$ = half life of the radioactive source,

cps = recorded counts per sec,

f = photon emission probability at a given energy.

The efficiency of the detector was determined by mixing standard Eu-152 source with 250 mL 1 M HCl at different energy such as 121.78 keV, 244.69 keV, 344.27 keV, 411.11 keV, 443.91 keV, 778.89 keV, 963.38 keV, 1085.78 keV, 1112.01 keV and 1407.67 keV following the standard method.

Efficiency = (Net count per sec/p_γ A) ×100%

Where p_γ = the fraction of a particular gamma-ray energy, and A = activity of the radionuclide present in the samples.

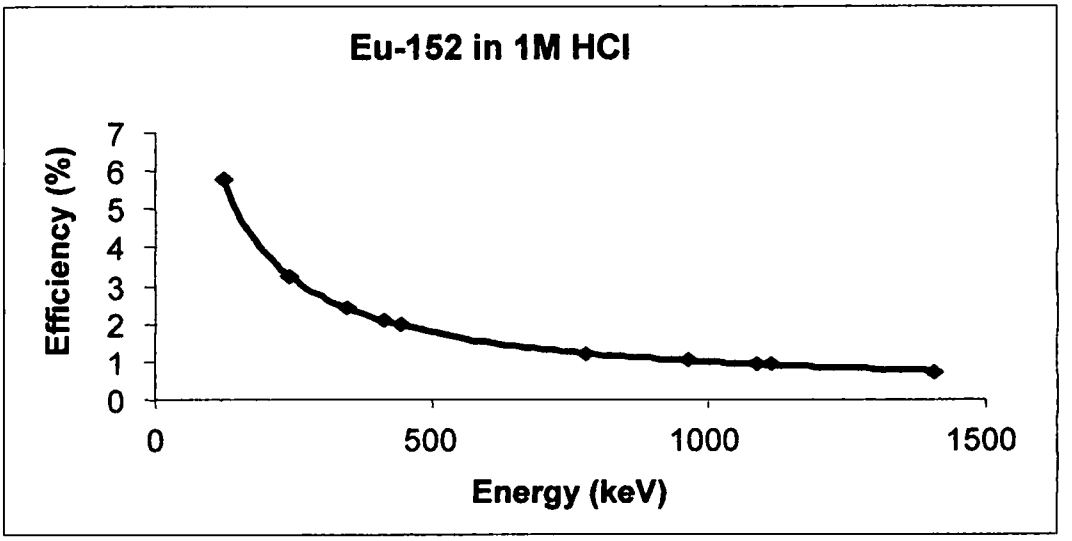

Figure 4.5: Efficiency of the HPGe detector.

The calculation of the concentration of different radionuclides was based on the measured detector efficiency as a function of energy curve as in figure for same counting geometry and time.

Low Limit Detection of HPGe Detector

Detection limits is a term used to express the detection capability of a measurement system under certain conditions. To obtain low detection limits the efficiency of the detector should be high, the sample quantity should be as reasonably large as practicable, the counting time should be as long as possible and the background should be as low as achievable. However, an optimization between the sample quality and the counting time may be necessary to obtain a reasonable counting statistics.

A generally accepted expression for lower limits of detection (LLD) is given by the following equation

$$LLD = (4.66/Ef) \times S_b$$

Where, S_b is the standard error of the net count rate, E is the counting efficiency of the detector for the particular gamma ray energy emitted from the particular radionuclides, and f is the fraction of gamma ray intensity at particular energy.

Table 4.4: LLD of HPGe Detector.

Radionuclide (Energy in keV)	Fraction of gamma ray intensity f at particular energy	Standard error of the background S_b (cps)	Efficiency of the HPGe detector (E)	LLD in Bq 5000 sec
^{214}Pb (352 keV)	0.389	0.0052	0.0238	2.62
^{214}Bi (609 keV)	0.433	0.0024	0.015	1.72
^{228}Ac	0.166	0.0023	0.0102	6.33
^{40}K	0.1067	0.0051	0.0072	30.94

4.3. Dual Phosphor Detector

Introduction

Dual phosphor or dual scintillator detectors are made by coupling two scintillating materials to a photomultiplier tube. These detectors are sometimes referred to as a "phoswich" (for phosphor sandwich). This type of detector is used primarily because it does not need a supply of counting gas. Without a high pressure gas supply the detector and counting system can be moved and located more easily. There is also no safety hazard from the P-10 gas bottle. The MPC-2000-B-DP contains a custom designed detector with a zinc sulfide layer bonded to a plastic scintillator. The combination is optically coupled to a PMT. The outermost layer detects alpha particles, and the inner layer detects beta particles.

In general, and compared to a gas flow detector, the DP (phoswich) detector offers equivalent alpha efficiency, and slightly lower beta efficiency. Background performance is somewhat similar, but is very much dependent on the environment.

Count Time Requirements

The counting time required to meet a specific measurement sensitivity is dependent upon the absolute counting efficiency, the inherent background of the instrument, and the representative volume or mass of the sample. Measurement sensitivities are often referred to as Lower Limits of Detection (LLD) or Minimum Detectable Activity (MDA) and their respective equations were developed using statistical decision theory techniques. The counting time is required 100 minute for the water samples and detector during this experiment.

Low Background Material Selection

Construction material used in the MPC 2000 is carefully selected for low inherent activity. The sample media used should also be selected carefully, if the lowest background performance is desired. Stainless steel planchets are preferable to aluminum for this reason. Plastics are suitable for instruments with entrance windows on the sample detector as long as static charge buildup can be prevented. Plastics should be avoided for windowless operation since the insulating properties changes the detector internal field strength, reducing the multiplication process.

Background Stability

Construction material used in the MPC 2000 is carefully selected for low inherent activity. The sample media used should also be selected carefully, if the lowest background performance is desired. Stainless steel planchets are preferable to aluminum for this reason. Backgrounds are due to random decay and therefore are subject to statistical fluctuations. When background values are determined, they are mean values gathered from several tests. The lower the background becomes, the more difficult (time consuming) it is to determine the true mean of the background value. Often the background fluctuations due to random decay are confused as instrument instability.

Counting Geometry and Efficiency

Since geometry places such a vital role in counting efficiency, it is important to match the geometries of the calibration source to that of the unknown samples. One aspect of the counting geometry is the distance between the sample and the active volume of the detector. Alpha and beta particles emitted at small angles from thin samples placed in deep planchets will lose energy in interaction with the planchet walls. This loss of energy decreases the likelihood of detection since the lower ionization trail produced can recombine before multiplication occurs. The MPC-200-B-DP detector was calibrated using electrodeposited sources of Th-230 (1020 dpm) and Pu-239 (1397 dpm) which efficiencies 28.97% and 31.59% respectively. The average efficiency of Th-230 and Pu-239 is 30%.

Absolute Counting Efficiency

The absolute counting efficiency, usually expressed as a percentage, represents the ratio of the measured count rate and the actual count rate (total disintegration's per minute) emitted by the sample. The absolute counting efficiency is influenced by the intrinsic detector efficiency, counting geometry effects, and sample self absorption. Absolute counting efficiency is very much energy dependent. This dependence is due primarily to the absorption characteristics of the radiation and the design of the detector.

Figure 4.6: ZnS(Ag) Scintillation detector.

Low Limits Detection

LLD values provide a basis for predicting the least amount of radiation which can be detected by the instrument in the given counting time with the given set of calibration factors and sample variables. The equation is shown below,

$$LLD = 1.92 + (3.69 + 7.68\ R_bT)^{1/2} / TE$$

Where, R_b = Background count rate, T = Sample and background count time, and E = Counting efficiency.

Table 4.5: LLD of ZnS Scintillation Detector

Date	Background Count (CPM)	Counting Time (min)	Counting Efficiency	LLD in Bq
02.10.2009	0.03	100	30	0.0028
07.10.2009	0.05	100	30	0.0033
12.10.2009	0.07	100	30	0.0038
16.10.2009	0.04	100	30	0.0031
20.10.2009	0.03	100	30	0.0028
24.10.2009	0.02	100	30	0.0023

4.4. Gas Proportional Counter

Introduction

The Gamma Products G5000 gas flow proportional counting systems use the traditional Guard-Sample detector arrangement for the detection and analysis of incoming radiation to the detectors.

The sample and guard detectors are P10 or Methane gas filled proportional counters. The sample detector incorporates a thin mylar window for particle entry into the detector. Lead and copper shielding surround the detectors to reduce the affects of environmental radiation on the counting statistics. The gas flows through the detectors while a voltage is applied to the detectors in order to create a detecting medium. When a charged particle enters the proportional detector, it collides with gas molecules and gas ionization occurs. This ionization creates positive ions and free electrons which travel in opposite directions at a velocity that is directly dependent upon the electric field strength (bias applied to the detector) and inversely dependent upon the gas pressure. A charged pulse proportional in size to the amount of energy released within the detector by the incident nuclear particle results from the collection of free electrons at the electrode. This charge is converted to an electronic pulse by a charge sensitive preamplifier, amplified and shaped for analysis by a main amplified and then analyzed as to radiation type. This analyzed data is then stored in the PC system memory for later display, Calculation or printout requirements.

Figure 4.7: Gas proportional counter

Counting System

Setting up the G5000 for initial system operations requires five main operator functions.

(i) Setting the detector gas flow rate,

(ii) Initializing the system,

(iii) Sample loading,

(iv) Entering the count routines,

(v) Starting the count operation.

Activating and setting the proper gas flow rate requires that all gas pressure valves and regulators are correctly set and that the detectors have been purged for at least 30 minutes.

Initializing the system requires that all system AC power and signal cords are properly connected and that the G5000 system Diskette has been installed in the A disk drive or the default drive before system power has been switched on.

Loading samples for counting involves the placing of the samples into the sample cartridge and placing the cartridge in the sample changer mechanism.

Initiating the counting operation involves entering user defined operating routines into the G5000 processor control menus and starting the count operation.

Detector Efficiency

The probability that radioactivity penetrating a proportional detector window will create enough ion parts to produce a count is the intrinsic efficiency of that detector. Gas flow counters can achieve intrinsic efficiencies approaching 100% when plateaus slopes are better than 3% per 100 volts. Gas flow proportional counters typically have detectors plateau slopes of 1.5% to 2.0% 100 volts. The detector is calibrated using standard source Sr-90 which efficiency is 36%. The efficiency, ε(E) of the proportional counter can be found from the following equation.

$$A = A_o e^{-\lambda t} = A_o e^{-[0.693/t_{1/2}]t}$$

$$\varepsilon(E) = \frac{Cps}{A} \times 100$$

Where, A_o = the initial activity of the reference source

A = activity of that reference source on the measurement date

λ = the decay constant of the source

t = the elapsed time

$t_{1/2}$ = half life of the radioactive source

cps = recorded counts per sec

Background Counts

All proportional counters exhibit background counts. These are counts which occur when no sample is present under the sample detector. For proportional counters these background counts usually come from alpha, beta, gamma and cosmic radiation. This background radiation may come from contamination of system materials, environmental radiation and cosmic radiation.

The G5000 low background counting system uses four inches of lead shielding to reduce the effects of environmental gamma radiation. The lead itself is contaminated to a certain extent by natural radioactivity from heavy elements such as Uranium and Thorium. To counteract this radiation, the detector cavity is lined with oxygen free high conductivity copper (OFHC). This copper lining shields the detector from the natural radiation occurring in the lead.

Detection Limit

Detection limits is a term used to express the detection capability of a measurement system under certain conditions. An estimate for the lowest amount of activity of radionuclide that can be detected at the time of measurement can be calculated from several different expressions.

$$LLD = 1.92 + (3.69 + 7.68\ R_bT)^{1/2} / TE$$

Where, R_b = Background count rate, T = Sample and background count time, and E = Counting efficiency.

Table 4.6: LLD of Gas Proportional Counter.

Date	Background Count (CPM)	Counting Time (min)	Counting Efficiency	LLD in Bq
01.10.2009	2.533	30	36	0.517
05.10.2009	2.700	30	36	0.525
10.10.2009	2.20	30	36	0.501
16.10.2009	2.600	30	36	0.510
20.10.2009	2.467	30	36	0.356
25.10.2009		30	36	0.488

Factors Affecting the Count Rate

Various factors can affect counting results. Spurious counts from background activity can affect counting results, cosmic events and electrical noise can alter system counting results. A brief description of some of the factors which can affect counting results follows:

Background Counts: All proportional counters exhibit background counts. These are counts which occur when no sample is present under the sample detector. This background radiation may come from contamination of system materials, environmental radiation and cosmic radiation.

Cosmic Radiation: The earth is continually bombarded with cosmic radiation. This radiation produces a large spectrum of secondary particles consisting of electrons, protons, mesons, etc. at the earth's surface.

Noise: Another source of background counts is electrical noise. Electronic noise is present in every environmental laboratory. Power line noise, noise from electrical motors, fluorescent lighting, and changing electrical loads; such as communications, elevators and motor controllers, can create system background noise.

Count Rate Loss: In addition to background counts other can enter into sample count rate determination. These factors include detector window energy absorption, sample to detector distance, detector efficiency, detector active area and sample preparation. Absorption can be of several types; sample self absorption, absorption in the medium between the sample and counter, and window absorption.

Sample Distance: The solid angle effect and the absorption in the air between the sample and detector window can become significant for low energy beta and alpha emitters. For Carbon-14, air absorption affects become significant above 2.5 millimeters sample to window spacing. For beta emitters above 0.3 MeV, the air absorption does not become significant until 10 millimeters or above.

Window Absorption: Window absorption is very critical for low energy beta emitters. The gas proportional counting system standard window thickness is 500 $\mu g\ cm^{-2}$ of mylar with gold film. This window thickness is recommended for counting 0.3 MeV or greater beta emitters. For softer beta emitters such as Carbon-14 at 0.1 MeV, a thin 80 $\mu g\ cm^{-2}$ thick mylar with gold film is recommended.

Detector Efficiency: The probability that radioactivity penetrating a proportional detector window will create enough ion parts to produce a count is the intrinsic efficiency of that detector. Gas flow counters can achieve intrinsic efficiencies approaching 100% when plateaus slopes are better than 3% per 100 volts. Gas flow proportional counters typically have detectors plateau slopes of 1.5% to 2.0% 100 volts.

Detector Area: The sensitive area of a detector varies directly as the square of the detector diameter and is the most important factor affecting sample count rate. The sample count rate for a given sample thickness varies as the sample are; therefore the sample rate is proportional to the square of the detector diameter. It is important to match the detector diameter to the size of the sample for best counting results.

Sample Preparation: Another factor affecting sample counting is sample preparation. Samples whose thickness approach or exceed self absorption limits of the material will produce low counting yields and erroneous data. Sample should be prepared in a manner consistent with reasonable self absorption effects.

Measurement Procedure

4.5. Sampling

Sample Collection

Dhaka is the capital of Bangladesh and the principal city of Dhaka District. Dhaka is a megacity and one of the major cities of South Asia. Dhaka, along with its metropolitan area, has a population of over 12 million, making it the largest city in Bangladesh. Dhaka is located in central Bangladesh at latitude 23.42° N and longitude 90.375° E, on the eastern banks of the Buriganga River. The city lies on the lower reaches of the Ganges Delta and covers a total area of 153.84 square kilometers (59.40 sq mi). Dhaka district has an area of 1463.60 square kilometers (565 sq mi) and is bounded by the districts of gazipur, Tangail, Munshigonj, Rajbari, Narayanganj, Manikgonj. Tropical vegetation and moist soils characterize the land, which is flat and close to sea level. This leaves Dhaka susceptible to flooding during the monsoon seasons owing to heavy rainfall and cyclones. Increasing air and water pollution emanating from traffic congestion and industrial waste are serious problems affecting public health and the quality of life in the city. Coupled with pollution, such erosion of natural habitats threatens to destroy much of the regional biodiversity.

The water demand is supplied by water and sewerage Authority (WASW) in the Dhaka city. In order to measure the natural and artificial radioactivity in tap waters, twenty tap water samples of different locations were collected randomly from public utility stores commonly used in the study. The choice of sampling locations was based on population density and accessibility. The samples were kept into previously cleaned 2 L capacity plastic bottle using manual procedure. The samples were appropriately coded from 1 to 20, from which the samples were collected and transferred to laboratory for analysis.

Figure 4.8: Map showing the study area of Dhaka city.

Sample Preparation

Twenty 1-L capacity Pyrex beakers were washed with distilled water and left to dry so that the sample will not be contaminated. About 1 L of each sample was poured into a Pyrex beaker. One millilitre concentrated HNO_3 was added to each water sample to avoid the collection of organic materials and changes in the sate of the ions present in the samples. Subsequently, the tap water samples were slowly evaporated by water bath treatment at 105°C in order to reduce its volume from 200 mL to 250 mL. The water samples were transferred in plastic container (diameter 7.5 cm × height 6.5 cm) for measurement of gamma emitting radionuclides. Those were then sealed tightly with caps, wrapped with thick vinyl tape around their screw necks and then stored for a period of ~ 4 weeks. This was done in order to enable an approach to secular equilibrium of ^{226}Ra with its decay products in the Uranium series and ^{228}Ra with its daughters in the Thorium

series. This is necessary to ensure that radon gas confined within the volume and the progeny will also remain in the sample. After the gamma counting, all the samples of tap water were again evaporated by water bath treatment in order to reduce its volume from 30 mL to 40 mL. Then each of the samples were dried under IR lamp on steeliness steel planchette for gross alpha and gross beta analysis.

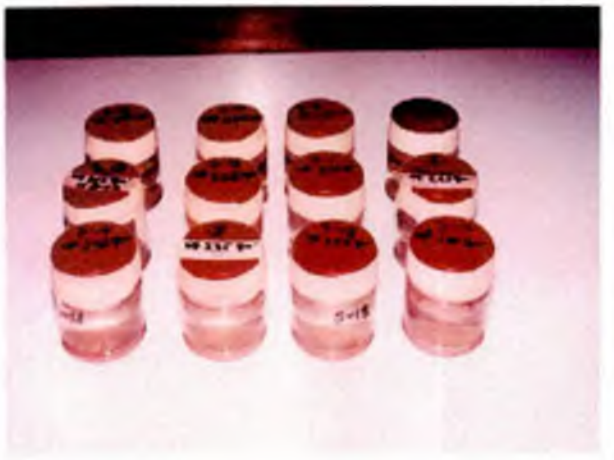

Figure 4.9: Sample for gamma counting.

Figure 4.10: Sample for gross alpha and gross beta analysis.

4.6. Measurement of Natural and Artificial Radioactivity by Gamma Spectrometry

Gamma-ray spectrometry is a fast and simple tool for measuring natural and man-made radionuclides. Gamma ray spectrometry allows both qualitative identification and quantitative determination of the radionuclides in the sample. The radioactivities of tap water samples were measured using a low-level gamma counting system, a high resolution HPGe coaxial detector (EG & G ORTEC) coupled with a silena Emcaplus multichannel analyzer (MCA) and associate microprocessors. The effective volume of the detector was 83.469 mL and energy resolution of the 1.33 Mev energy peak for ^{60}Co was found as 1.69 keV at full width half maximum (FWHM) with a relative efficiency of 20%. The detector was shielded by using requisite thickness of mild steel ring at the side and lead at the top for optimization of the background radiation level. The γ-ray energies of ^{228}Ac (969 keV) were used to determine the concentration of ^{232}Th, the γ-transition of and ^{214}Pb (351.9 keV) were used to determine the activity of ^{238}U and the γ-ray energy of ^{214}Bi (609.3 keV) was used to determine the activity of ^{226}Ra. The ^{40}K and ^{137}Cs

radionuclides were measured from their respective γ-ray energies 1460 and 661.66 keV respectively.

The geometry of the counting samples was the same as that of the standard samples and the counting time for all the sample was 5000 sec. In order to determine the background distribution in the environment around the detector, an empty sealed plastic container was counted in the same manner and in the same geometry as the samples. The background spectra were used to correct the net peak area of gamma rays of measured isotopes.

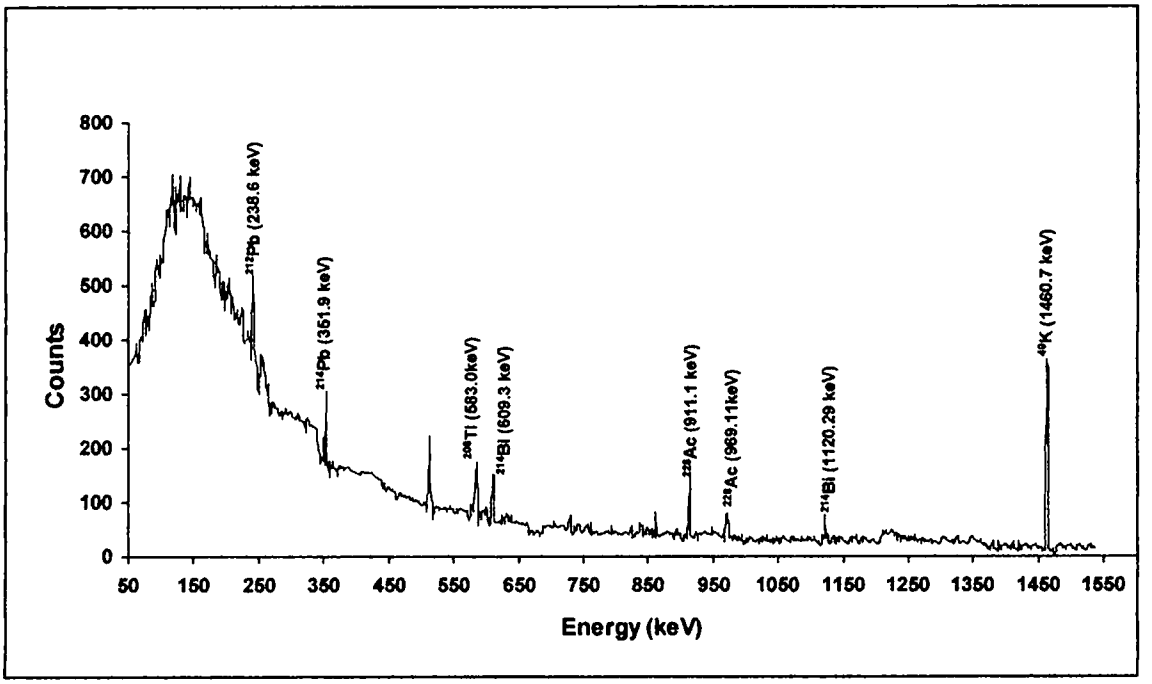

Figure 4.11: Gamma spectrum of tap water.

Measurement of Gross Alpha Activity by ZnS Scintillation Counter

ZnS Scintillation counter is a dual phosphor detector coupling two scintillating materials to a photomultiplier tube. The MPC-2000-B-DP contains a custom designed detector with a zinc sulfide layer bonded to a plastic scintillator. The combination is optically coupled to a PMT and the inner layer detects beta particles. The dual phosphor detector was calibrated using electrodeposited standard sources of Th-230 (1020 dpm) and Pu-239 (1397 dpm) of which efficiencies are 28.97% and 31.59% respectively. The average efficiency of Th-230 and Pu-230 is 30%. The diameter of the detector is 2 inch. The counting time was required 100 minutes per sample.

Measurement of Gross Beta Activity by Gas Proportional Counter

Gas flow proportional counter is used for the gross beta activity of tap water. The Gas proportional counter was calibrated by planchette deposited standard source Sr-90. The efficiency of the detector is 36%. The counting time is required 30 min. for each sample and Background counts.

After the gamma counting, all the samples of tap water were again evaporated by water bath treatment in order to reduce its volume from 30 mL to 40 mL. Then each of the samples was dried under IR lamp on Steeliness steel planchette for gross alpha and gross beta analysis by ZnS scintillation and Gas Proportional Counter. A blank planchette was used for background count. Subtraction of the background count from the sample count gives the net count of the water sample.

4.7. Analysis of the Data

Calculation of Activity

The activities of the radionuclides were calculated using the following equation,

Activity (A) = Net cps/ p_γ. e. w

Where A = activity of the radionuclide in Bq L^{-1} present in the samples, cps = counts per sec, p_γ = the fraction of a particular gamma-ray energy, e = efficiency of the detector for a particular gamma-ray energy (emitted from the specific radionuclide of interest), w = Quantity of the sample in Liter.

Error Analysis

Experimental observations may be inaccurate due to systematic and random errors. The systematic errors can be minimized by implying sophisticated equipment and techniques and by improving personal skill. Random errors can also be reduced but cannot be completely eliminated. Hence, in order to compute and interpret experimental data and results, it is necessary to find the extent of the error associated with the analysis of samples. However, with the knowledge of the statistical behavior of error in observation i.e. deviation from normal value, it is possible to reduce the effect of errors of the final result.

The error calculation was done by the following formula

$$\sigma = \sqrt{\left\{\frac{(S+B)}{T^2} + \frac{B}{T^2}\right\}}$$

Where, (S+B) = Sample count, B = Background count and T = Counting time.

Calculation of Gross Alpha/Beta Activity

The activity of gross alpha/beta was calculated using the following equation:

$$DPM = NET\_CPM \times 100 / EFF$$

Where, DPM = Alpha/Beta disintegration per minute, NET_CPM = Net alpha/beta count per minute, and EFF = Alpha/Beta efficiency percent.

Calculation of Annual Effective Dose

The annual effective dose due to the intake of natural radionuclides from drinking water was calculated using the following equation given by Alam *et al.*

$$D_{ing} = C_R \,.\, I_F \,.\, E_D$$

Where D_{ing} is the annul effective dose (Sv y^{-1}) to an individual due to the ingestion of radionuclides from drinking water, C_R the activity concentration of radionuclides in the ingested drinking water (Bq L^{-1}), I_F the annual intake of drinking water (l y^{-1}) and E_D the ingested dose conversion factor for radionuclides (Sv Bq^{-1}).

CHAPTER V

RESULTS AND DISCUSSION

5.1. Radioactivity of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in Tap Water

Activity concentrations of radionuclides like ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were determined in tap water samples using gamma spectroscopy. Measured activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in tap water samples of different locations in Dhaka city are shown in Table 5.1.

The observed activity concentrations of ^{238}U found in tap water samples varied from 0.82 ± 0.26 Bq L^{-1} to 2.12 ± 0.32 Bq L^{-1} with mean concentration 1.401 ± 0.45 Bq L^{-1}. The highest activity of ^{238}U was found in a sample of Kawran Bazar and the lowest in the sample of Moulovi Bazar.

The activity of ^{226}Ra found in the water samples varied from 0.014 ± 0.0054 Bq L^{-1} to 0.040 ± 0.0055 Bq L^{-1} with mean concentration 0.0275 ± 0.0071 Bq L^{-1}. The highest activity of ^{226}Ra was found in a sample of Kamlapur and the lowest in the sample of Shatroja.

The activity of ^{232}Th found in the water samples varied from 0.16 ± 0.003 Bq L^{-1} to 0.73 ± 0.027 Bq L^{-1} with mean concentration 0.393 ± 0.17 Bq L^{-1}. The highest activity of ^{232}Th was found in a sample of Agargao and the lowest in the sample of Chankher Pool.

The ^{40}K activity in these tap water samples ranged from 2.04 ± 0.0094 Bq L^{-1} to 6.40 ± 0.027 Bq L^{-1} with average 3.992 ± 1.28 Bq L^{-1}. The highest activity was found in the sample of Moulovi Bazar and lowest in the sample of Shatroja. No ^{137}Cs activity was detected at any of the sample in the whole study area. A bar diagram of activity concentration for natural radionuclides in tap water samples of different locations is shown in Figure 5.1.

Table 5.1: Activity Concentration of Radionuclides in Tap Water Samples.

Sl. No.	Name of Locations	Radioactivity in Tap Water (Bq L^{-1})				
		^{238}U	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
1	Chankher Pool	1.44±0.92	0.039±0.004	0.16 ± 0.003	2.57±0.012	ND
2	Nazimuddin Road	0.83±0.09	0.026±0.009	0.41±0.11	2.95±0.012	ND
3	Moulovi' Bazar	0.82±0.26	0.021±0.0054	0.19±0.092	2.04±0.009	ND
4	Midford	0.83±0.25	0.022±0.0035	0.16±0.067	4.31±0.018	ND
5	Shatroja	1.68±0.85	0.014±0.0054	0.47±0.11	6.40±0.027	ND
6	Polash Bazar	1.24±0.92	0.033±0.0034	0.46±0.069	5.12±0.022	ND
7	Azimpur	1.99±0.96	0.025±0.0031	0.46±0.070	4.22±0.018	ND
8	BDR	2.03±0.99	0.031±0.0057	0.51±0.033	5.07±0.021	ND
9	Dhaka College	1.44±0.31	0.023±0.0054	0.57±0.031	3.10±0.013	ND
10	Rayer Bazar	0.91±0.04	0.021±0.0057	0.45±0.027	3.82±0.016	ND
11	Hatirpool	1.17±0.76	0.027±0.0028	0.20±0.034	5.28±0.022	ND
12	Kwran Bazar	2.12±0.32	0.031±0.0055	0.62±0.034	2.86±0.012	ND
13	Farmgate	1.57±0.99	0.039±0.0030	0.32± 0.028	5.58±0.024	ND
14	Agargao	2.07±0.99	0.028±0.0054	0.73±0.027	3.50±0.015	ND
15	Mohakhali	1.38±0.65	0.037±0.0017	0.24±0.033	3.59±0.015	ND
16	Komlapur	1.58±0.73	0.040±0.0055	0.18±0.035	2.20±0.009	ND
17	Motijheel	1.96±0.47	0.028±0.0075	0.71±0.057	3.22±0.014	ND
18	Narinda	1.18±0.88	0.019±0.0075	0.38±0.018	6.30±0.026	ND
19	Koratitolla	0.87±0.49	0.022±0.0026	0.37±0.059	3.01±0.012	ND
20	Jurain	0.91±0.88	0.023±0.007	0.28±0.082	4.70±0.020	ND
	Mean	1.401	0.0275	0.393	3.992	
	S.D.	0.45	0.0071	0.17	1.28	

ND = Not Detectable.

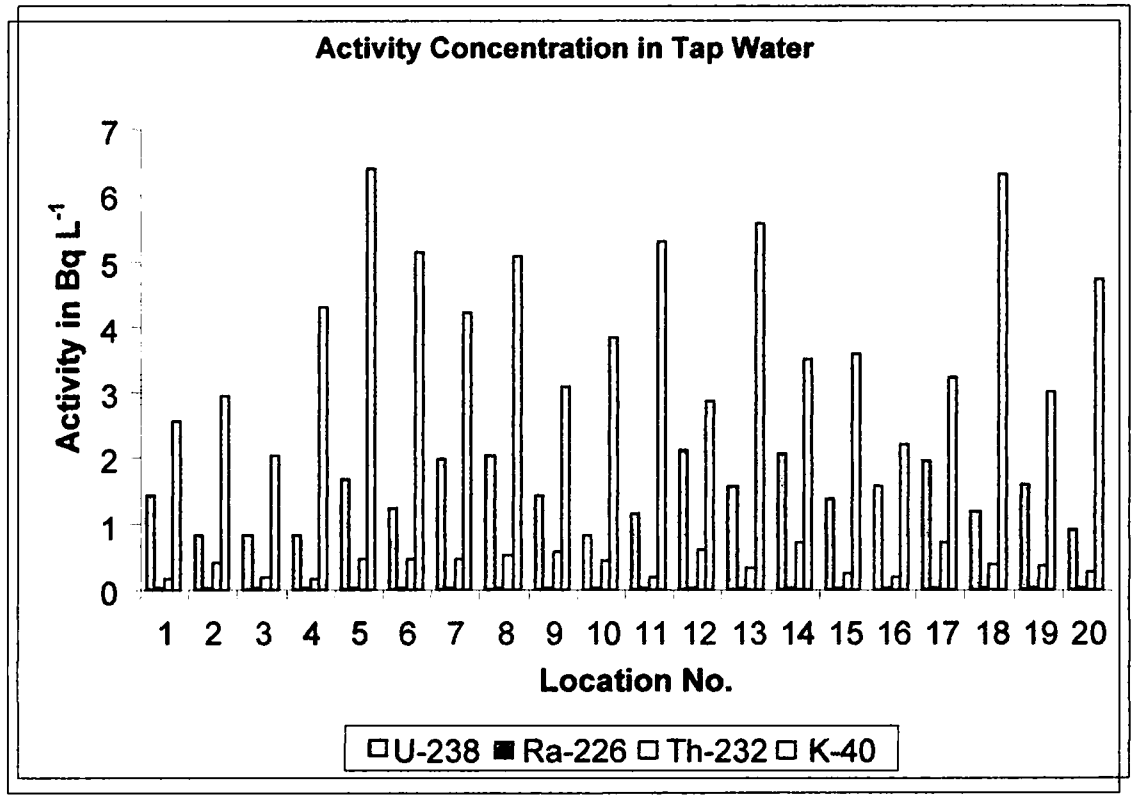

Figure 5.1: Activity concentrations in tap water samples of different locations.

The concentrations of ^{226}Ra in the underground water and well water in Saudi Arabia, Asia and Far East including India and Japan, are found to occur over a wide range, 0.11 to 7.84 Bq L^{-1}(Iyengar,1990). The various geological characteristics of these areas are the main cause for such a wide range of ^{226}Ra contents found in the under ground water. The ^{226}Ra contents of all the samples are less than the regulation limits of the ^{226}Ra activity concentrations in drinking water, i.e. no greater than 1.00 Bq L^{-1} (IAEA,1989) and 0.185 BqL^{-1} based on the US drinking Water Regulation (US EPA,1986).

Tap water supplies serve 80% of the community drinking water users. In present study, ^{226}Ra contents of all tap water samples of the Dhaka region of Bangladesh was estimated to range from 0.014 ± 0.0054 Bq L^{-1} to 0.040 ± 0.0055 Bq L^{-1} with mean concentration 0.0275 ± 0.0071 Bq L^{-1} which is lower than the US National committee on Radiation Protection (NCRP,1954) maximum permissible concentration of ^{226}Ra activity concentrations in drinking water, i.e. no greater than 100 mBq L^{-1}. The mean ^{226}Ra concentration value obtained in tap water samples of Dhaka city of Bangladesh is compared with those obtained by other workers which are shown in table 5.2.

Table.5.2: Comparative study of the present work with others Countries

Country	Type of Water	Ra-226 (mBq/l)	Reference
Australia	Mineral water Bottled water	3.7-211 <0.020-0.225	walher et.al., 2008 Fralik et.al., 2003
Poland	Bottled Mineral water	<10-335	Kozlowska et.al., 2007
Italy	Tap water Mineral Bottled water Tap water Tap water	0.50-60.8 <10.00-52.50 <1.70-15.31 <3.00-5.00	Jia &Torri, 2007 Desideri et. al.,2007 Desideri et.al., 2007 Forte et. al., 2007
Iran	Well water Spring water River water	<2-3.1 <2 5	2007, Hosseinj
Finland	Well water	3-50	2007, Vesterbacka
Brazil	Ground water	34-58	Reyes & Marques, 2008
Egypt	Drinking water Ground water	48.8 79.2	Ahmed, 2004
Jordan Aqaba	Tap water	70±3	Sajedah M. Al-Amir et.al., 2009
Bangladesh Dhaka	Tap water	27.5±7.1	Present work

Yu et.al. observed ^{232}Th in drinking water of Hong Kong. The concentrations was 0.0071 Bq L^{-1}. In present findings, ^{232}Th activity in tap water samples of different locations in Dhaka city is comparatively higher than the results from the above work.

^{40}K is a naturally abundant radionuclide in the soil with a long half-life of 1.28×10^9 y, originating from weathering and recycling of terrestrial minerals and rocks. The mean measured activity of 3.99 ± 1.28 for ^{40}K in the water samples is well above the reported concentrations of 0.11 Bq L^{-1} from Hong Kong (Yu and Mao), 0.140 ± 0.031 Bq L^{-1} from Pakistan (Fatima et al.) and 0.169 ± 0.08 from Turkey (Cevik,U.).

5.2. Concentration of Gross Alpha Activity

Concentration of gross alpha activity was determined in tap water samples using ZnS scintillation detector. The measured activity concentrations of gross alpha in tap water samples of different locations in Dhaka city are gathered in Table 5.2. The observed gross alpha activity found in tap water samples vary from 1.88 ± 0.030 to 8.16 ± 0.0344 mBq L^{-1} with average 3.76 ± 1.50 mBq L^{-1}. The highest gross alpha activity in the water was found in Rayer Bazar and the lowest gross beta activity in tap water samples was found in Chankherpool.

Table 5.3: Gross Alpha Activity in Tap Water Samples.

Sl. No.	Name of Location	Gross Alpha activity in mBq L^{-1}
1	Chankher Pool	1.88 ± 0.030
2	Nazimuddin Road	5.02 ± 0.0304
3	Moulovi Bazar	1.91 ± 0.019
4	Midford	4.39 ± 0.0295
5	Shatroja	3.77 ± 0.032
6	Polash Bazar	5.65 ± 0.0277
7	Azimpur	3.14 ± 0.0215
8	BDR	4.32 ± 0.0304
9	Dhaka College	2.51 ± 0.023
10	Rayer Bazar	8.16 ± 0.0344
11	Hatirpool	4.42 ± 0.0296
12	Kawran Bazar	1.88 ± 0.0296
13	Farmgate	3.14 ± 0.031
14	Agargaon	3.14 ± 0.028
15	Mohakhali	5.02 ± 0.0304
16	Kamlapur	3.77 ± 0.032
17	Motijheel	3.13 ± 0.0313
18	Narinda	3.09 ± 0.024
19	Koratitolla	2.51 ± 0.0237
20	Jurain	4.39 ± 0.0312
	Mean	3.76 ± 1.50

The gross alpha activity in water sample is primarily comprised uranium decay products such as ^{226}Ra and ^{40}K. In order to lower exposure WHO recommends the parameters of gross alpha activity concentration is 0.1 Bq L^{-1}. If the gross alpha activity doses not exceed 0.1 Bq L^{-1}, it can assume that the annual total indicative dose is less than 0.1 mSv per year. The results obtained show that the measured activity concentrations of gross alpha in all tap water samples are found to be less than 0.1 Bq L^{-1} which is recommended by WHO. It is evident from these results that total indicative doses due to natural radioactivity in all tap water samples calculated for adults are below the reference value of 0.1 mSv y^{-1} recommended by WHO which is shown in Table 5.3.

5.3. Concentration of Gross Beta Activity

The gross beta activity was determined in tap water samples using gas proportional counter. The measured activity concentrations of gross beta in tap water samples of different locations in Dhaka city are shown in Table 5.3. The observed gross beta activity found in tap water samples vary from 29.305 ± 0.062 to 115.740 ± 0.165 mBq L^{-1} with average 60.408 ± 23.57 mBq L^{-1}. The highest gross beta activity in the water was found in Azimpur and the lowest gross beta activity in tap water samples was found in Narinda.

The gross beta activity in water sample is primarily comprised uranium decay products such as ^{228}Ra and ^{40}K. In order to lower exposure WHO recommends the parameters of gross beta activity concentration is 1.0 Bq L^{-1}. If the gross beta activity doses not exceed 1.0 Bq L^{-1}, it can assume that the annual total indicative dose of adults is less than 0.1 mSv y^{-1}. The results obtained show that the measured activity concentrations of gross beta in all tap water samples are found to be less than 1.0 Bq L^{-1} which is recommended by WHO. It is evident from these results that total doses due to natural radioactivity in all tap water samples calculated for adults are below the reference value of 0.1 mSv y^{-1} recommended by WHO (Table 5.4).

Table 5.4: Gross Beta Activity in Tap Water Samples.

Sl. No.	Name of Location	Gross beta activity in mBq L^{-1}
1	Chankher Pool	60.185 ± 0.079
2	Nazimuddin Road	63.287 ± 0.172
3	Moulovi Bazar	74.347 ± 0.172
4	Midford	33.981 ± 0.062
5	Shatroja	77.22 ± 0.062
6	PolashiBazar	43.194 ± 0.172
7	Azimpur	115.740 ± 0.165
8	BDR	35.509 ± 0.062
9	Dhaka College	95.694 ± 0.079
10	Rayer Bazar	106.481 ± 0.078
11	Hatirpool	52.453 ± 0.165
12	Kawran Bazar	75.602 ± 0.172
13	Farmgate	52.222 ± 0.172
14	Agargaon	43.241 ± 0.173
15	Mohakhali	60.185 ± 0.062
16	Komlapur	55.556 ± 0.167
17	Motijheel	55.56 ± 0.162
18	Narinda	29.305 ± 0.062
19	Koratitolla	37.037 ± 0.062
20	Jurain	41.372 ± 0.079
	Mean	60.408 ± 23.57

In Table 5.5., the observed concentrations of gross alpha and gross beta in tap water of Dhaka city of Bangladesh were compared with others countries of the world.

Table 5.5: Comparison with other countries

Country	Type of Water	Gross Alpha (Bq/l)	Gross Beta (Bq/l)	Reference
Greece	Bottle water	0.008-0.094	0.071-0.350	Karamanis et.al.,2007
Australia	Drinking water	0.7-1.40	0.98-1.15	Kelinschmidt, 2004
Mexico	Mineral water	<0.011-0.415	<0.026-0.695	Davila Rangel et.al., 2002
Turkey	Tap water	0.0002-0.015	0.0252-0.2644	Damla et. al., 2007
Brazil	Ground water	0.001-0.4	0.12-0.86	Bonotto et.al., 2008
Italy	Tap water Tap water Tap water	<0.0077-0.349 <0.008-0.186 <0.01812-0.1282	<0.025-0.273 <0.048-0.150 <0.04157-0.25859	Rusconi et. al.,2004 Forte et.al.,2007 Desideri et.al.,2007
Jordan Amman	Tap water	<0.05-0.2495±0.0232	<0.1879-0.3270±0.0286	Sajedah M. Al-Amir et. al., 2009
Jordan Aqaba	Tap water	0.04±0.02	0.71±0.03	Sajedah M. Al-Amir et. al., 2009
Bangladesh Dhaka	Tap water	0.0037±0.0015	0.0604± 0.023	Present work

Dose Due to ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in Tap Water

The ingested dose conversion factor E_D varies with both radioisotopes and the age of the individual. The total dose is obtained by summing contributions for the radioisotopes in the samples. The E_D values are taken from the annuals of the ICRP publication 72 and are listed in Table 5.6.

Table 5.6: Age-Dependent the Ingested Dose Conversion Factor for Radionuclides (Sv Bq^{-1}).

Radionuclide	1 year	5 year	10 year	15 year	≥18
U-238	4.4×10^{-8}	2.7×10^{-8}	1.5×10^{-8}	8.4×10^{-9}	6.8×10^{-9}
Ra-226	9.1×10^{-7}	5.8×10^{-7}	3.5×10^{-7}	2.4×10^{-7}	2.2×10^{-7}
Th-232	4.50×10^{-7}	3.50×10^{-7}	2.90×10^{-7}	2.50×10^{-7}	2.30×10^{-7}
K-40	3.4×10^{-8}	2.1×10^{-8}	1.1×10^{-8}	6.3×10^{-9}	$5.0 \times 1\ 0^{-9}$

The effective doses and annual effective doses from the drinking water due to the intake of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K radionuclides were calculated and the results are shown in Table 5.7 to 5.14. The average yearly intake of water is estimated to be 250 litre for the age interval between 0 and 1 y, 328 litre for the age interval 1 y to 5 y, 440 litre for the age interval 5 y to 10 y, 512 litre for the age interval 10 y to 15 y and 731 litre for the adult (18+ y). These values are in good agreement with the range of intakes given for the Reference Man by ICRP.

Table 5.7: Age-Dependent Effective Dose (nSv L^{-1}) due to Intake of ^{238}U from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	63.36	38.88	21.6	12.10	9.79
2	36.52	22.41	12.45	6.97	5.64
3	36.08	22.14	12.3	6.89	5.58
4	36.52	22.41	12.45	6.97	5.64
5	73.92	45.36	25.2	14.11	11.42
6	54.56	33.48	18.6	10.42	8.43
7	87.56	53.73	29.85	16.72	13.53
8	89.32	54.81	30.45	17.05	13.80
9	63.36	38.88	21.60	12.10	9.79
10	40.04	24.57	13.65	7.64	6.19
11	51.48	31.59	17.55	9.81	7.96
12	93.28	57.24	31.80	17.81	14.42
13	69.08	42.39	23.55	13.19	10.68
14	91.08	55.89	31.05	17.39	14.08
15	60.72	37.26	20.7	11.59	9.38
16	69.52	42.66	23.7	13.27	10.74
17	86.24	52.92	29.4	16.46	13.33
18	51.92	31.86	17.7	9.91	8.02
19	38.28	23.49	13.05	7.31	5.92
20	40.04	24.57	13.65	7.64	6.19
Mean	61.64	38.67	21.02	16.39	14.10

Table 5.8: Age-Dependent Annual Effective Dose (μSv y^{-1}) due to Intake of ^{238}U from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	15.84	12.75	9.50	6.19	7.16
2	9.13	7.38	5.48	3.57	4.13
3	9.02	5.54	5.41	3.53	4.08
4	9.13	7.38	5.48	3.57	4.13
5	18.50	11.34	11.09	7.23	8.35
6	13.64	10.98	8.18	5.33	6.16
7	21.89	17.62	13.13	8.56	9.89
8	22.33	17.98	13.40	8.73	10.09
9	15.84	12.75	9.50	6.19	7.16
10	10.01	8.06	6.01	3.91	4.52
11	12.87	10.36	7.72	5.03	5.82
12	23.32	18.77	13.99	9.12	10.54
13	17.27	13.90	10.36	6.75	7.80
14	22.77	18.33	13.66	8.90	10.29
15	15.18	12.22	9.11	5.94	6.86
16	17.38	13.99	10.43	6.80	7.85
17	21.56	17.35	12.94	8.43	9.74
18	12.98	10.45	7.79	5.07	5.87
19	9.57	7.70	5.74	3.74	4.32
20	10.01	8.06	6.01	3.91	4.52
Mean	14.94	12.15	10.70	6.03	6.96

Table 5.9: Age-Dependent Effective Dose (nSv L^{-1}) due to Intake of ^{226}Ra from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	35.49	22.62	13.65	9.36	8.58
2	23.66	15.08	9.10	6.24	5.72
3	19.11	12.18	7.35	5.04	4.62
4	20.02	12.76	7.70	5.28	4.84
5	12.74	8.12	4.90	3.36	3.08
6	30.03	19.14	11.55	7.92	7.26
7	22.75	14.50	8.75	6.00	5.50
8	28.21	17.98	10.85	7.44	6.82
9	20.93	13.34	8.05	5.52	5.06
10	19.11	12.18	7.35	5.04	4.62
11	24.57	15.66	9.45	6.48	5.94
12	28.21	17.98	10.85	7.44	6.82
13	35.49	22.62	13.65	9.36	8.58
14	25.48	16.24	9.80	6.72	6.16
15	33.67	21.46	12.95	8.88	8.14
16	36.4	23.20	14.00	9.60	8.80
17	25.48	16.24	9.80	6.72	6.16
18	17.29	11.02	6.65	4.56	4.18
19	20.02	12.76	7.70	5.28	4.84
20	20.93	13.34	8.05	5.52	5.06
Mean	24.98	20.45	9.63	6.59	6.04

Table 5.10: Age-Dependent Annual Effective Dose (μSv y^{-1}) due to Intake of ^{226}Ra from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	8.87	7.42	6.01	4.79	6.27
2	5.92	4.95	4.00	3.19	4.18
3	4.47	4.00	3.23	2.58	3.38
4	5.01	4.19	3.39	2.70	3.54
5	3.19	2.66	2.16	1.72	2.25
6	7.51	6.28	5.08	4.06	5.31
7	5.69	4.76	3.85	3.07	4.02
8	7.05	5.90	4.77	3.81	4.99
9	5.23	4.38	3.54	2.83	3.70
10	4.77	4.00	3.23	2.58	3.38
11	6.14	5.14	4.16	3.32	4.34
12	7.05	5.90	4.77	3.27	4.99
13	8.87	7.42	6.01	4.79	6.27
14	6.37	5.33	4.31	3.44	4.50
15	8.42	7.04	5.70	4.55	5.95
16	9.10	7.61	6.16	4.92	6.43
17	6.37	5.33	4.31	3.44	4.50
18	4.32	3.61	2.93	2.33	3.06
19	5.01	4.19	3.39	2.70	3.54
20	5.23	4.38	3.54	2.83	3.70
Mean	6.23	5.22	4.18	3.38	4.42

Table 5.11: Age-Dependent Effective Dose (nSv L^{-1}) due to Intake of ^{232}Th from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	72.00	56.00	46.40	40.00	36.80
2	184.50	143.50	118.90	102.50	94.30
3	85.50	66.50	55.10	47.50	43.70
4	72.00	56.00	46.40	40.00	36.80
5	211.50	164.50	136.30	117.50	108.10
6	207.00	161.00	133.40	115.00	105.80
7	207.00	161.00	133.40	115.00	105.80
8	229.50	178.50	147.90	127.50	117.3
9	198.00	154.00	127.60	110.00	101.20
10	76.50	59.50	49.30	42.50	39.10
11	90.00	70.00	58.00	50.00	46.00
12	67.50	52.50	43.50	37.50	34.50
13	144.00	112.00	92.80	80.00	73.6
14	54.00	42.00	34.80	30.00	27.60
15	108.00	84.00	69.60	60.00	55.20
16	67.50	52.50	43.50	37.50	34.50
17	54.00	42.00	34.80	30.00	27.60
18	193.50	150.50	124.70	107.50	98.90
19	72.00	56.00	46.40	40.00	36.80
20	117.00	91.00	75.40	65.00	59.80
Mean	125.55	94.32	80.91	69.75	66.96

Table 5.12: Age-Dependent Annual Effective Dose (μSv y^{-1}) due to Intake of ^{232}Th from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	18.00	18.37	20.42	20.48	27.01
2	46.00	46.90	52.32	52.22	67.98
3	21.25	21.65	24.24	24.06	31.43
4	17.75	18.04	20.42	19.97	26.06
5	52.50	53.46	59.97	59.90	78.22
6	51.75	52.81	58.70	58.88	77.49
7	51.75	52.81	58.70	59.00	77.49
8	57.50	58.06	65.08	64.51	84.80
9	49.50	50.51	56.14	56.32	73.83
10	18.50	19.02	21.69	20.99	27.78
11	22.00	22.30	25.52	25.09	32.89
12	17.75	18.04	19.14	20.00	26.32
13	35.75	36.74	40.83	40.45	53.36
14	14.00	14.10	15.31	15.87	21.20
15	26.50	26.90	30.62	30.21	49.47
16	17.00	17.38	19.14	19.46	25.59
17	13.75	14.10	15.31	16.00	20.47
18	51.75	52.81	54.87	58.90	77.48
19	17.75	18.04	20.42	19.96	26.28
20	29.25	29.85	33.18	33.28	43.86
Mean	31.50	32.09	33.84	35.78	41.61

Table 5.13: Age-Dependent Effective Dose (nSv L^{-1}) due to Intake of ^{40}K from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	87.38	53.97	28.27	16.19	12.85
2	100.3	61.95	32.45	18.59	14.75
3	69.36	42.84	22.44	12.85	10.20
4	146.54	90.51	47.41	27.15	21.55
5	217.60	134.40	70.40	40.32	32.00
6	174.08	107.52	56.32	32.26	25.60
7	143.48	88.62	46.42	26.59	21.10
8	172.38	106.47	55.77	31.94	25.35
9	105.40	65.10	34.10	19.53	15.50
10	111.52	80.22	42.02	24.07	19.10
11	179.52	110.88	58.08	33.26	26.40
12	97.24	60.01	31.46	18.02	14.30
13	189.72	117.18	61.38	35.15	27.90
14	119.00	73.50	38.50	22.05	17.50
15	122.06	75.39	39.49	22.62	17.95
16	74.80	46.20	24.20	13.86	11.00
17	109.48	67.62	35.42	20.29	16.10
18	214.20	132.30	69.30	39.69	31.5
19	102.34	63.21	33.11	18.96	15.05
20	159.80	98.70	51.70	29.61	23.50
Mean	134.81	83.83	43.91	25.15	19.96

Table 5.12: Age-Dependent Annual Effective Dose (μSv y^{-1}) due to Intake of ^{40}K from Tap Water.

Sl. No.	1 year	5 year	10 year	15 year	Adult (18+ year)
1	21.85	17.70	12.44	8.66	9.39
2	25.08	20.32	14.28	9.52	10.77
3	17.34	14.05	9.87	6.58	7.46
4	36.64	29.69	20.86	13.90	15.75
5	54.40	44.08	30.98	20.64	23.39
6	43.52	35.27	24.78	16.52	18.71
7	35.87	29.07	20.42	13.61	15.42
8	43.10	34.92	24.54	16.35	18.53
9	26.35	21.35	15.00	10.00	11.33
10	27.88	26.31	18.49	12.32	13.96
11	44.88	36.37	25.56	17.03	19.30
12	24.31	19.70	13.84	9.23	10.45
13	47.43	38.44	27.01	18.00	20.39
14	29.80	24.11	16.94	11.29	12.79
15	30.52	24.73	17.38	11.58	13.12
16	18.70	15.15	10.65	7.10	8.04
17	27.37	22.18	15.58	10.39	11.77
18	53.55	43.39	30.49	20.32	23.03
19	25.59	20.73	14.57	9.71	11.00
20	39.95	32.37	22.75	15.16	17.18
Mean	33.71	30.59	19.05	15.89	14.59

Table 5.15: The Age-Dependent Effective Dose due to Intake of Different Radionuclides (nSv L^{-1}).

Radionuclides	1 year	5 year	10 year	15 year	Adult (18+ year)
^{238}U					
Minimum	36.08	22.14	12.30	6.89	5.58
Maximum	93.28	57.24	31.80	17.81	14.42
Average	61.64	38.67	21.02	16.39	14.10
^{226}Ra					
Minimum	12.74	8.12	4.90	3.36	3.08
Maximum	36.40	23.20	14.00	9.60	8.80
Average	24.98	20.45	9.63	6.59	6.04
^{232}Th					
Minimum	54.00	42.00	34.80	30.00	27.60
Maximum	229.50	178.50	147.90	127.50	117.30
Average	125.55	94.32	80.91	69.75	66.96
^{40}K					
Minimum	69.36	42.84	22.44	12.85	10.20
Maximum	217.60	134.40	70.40	40.32	32.00
Average	134.81	83.83	43.91	25.15	19.96

Table 5.16: The Age-Dependent Annual Effective Dose due to Intake of Different Radionuclides (μSv y^{-1}).

Radionuclides	1 year	5 year	10 year	15 year	Adult (18+ year)
^{238}U					
Minimum	9.02	5.54	5.41	3.53	4.08
Maximum	23.32	18.77	13.99	9.12	10.54
Average	14.94	12.15	10.70	6.03	6.96
^{226}Ra					
Minimum	3.19	2.66	2.16	1.72	2.25
Maximum	9.10	7.61	6.16	4.92	6.43
Average	6.23	5.22	4.18	3.38	4.42
^{232}Th					
Minimum	13.75	14.10	15.31	15.87	20.47
Maximum	57.50	58.06	65.08	64.56	84.80
Average	35.50	32.09	33.84	35.78	41.61
^{40}K					
Minimum	17.34	14.05	9.87	6.58	7.41
Maximum	54.40	44.08	30.98	20.64	23.39
Average	47.43	38.44	27.01	18.00	20.39

The effective doses from the drinking water due to the intake of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K radionuclides were calculated and the average results are shown in Table 5.15

The effective dose due to the intake of ^{238}U by ingestion to humans varied from 36.08 to 93.28 nSv L^{-1} with an average 61.64 nSv L^{-1}; 22.14 to 57.24 nSv L^{-1} with an average 38.67 nSv L^{-1}; 12.30 to 31.80 nSv L^{-1} with an average 21.02 nSv L^{-1}; 6.89 to 17.81 nSv L^{-1} with an average 16.39 nSv L^{-1}; and 5.58 to 14.42 nSv L^{-1} with an average 14.10 nSv L^{-1} for age groups of 1 y, 5 y, 10 y, 15 y and adults (18+ y) respectively. The effective dose due to the intake of ^{226}Ra by ingestion to humans of age groups 1 y, 5 y, 10 y, 15 y and adults (18+ y) varied from 12.74 to 36.40 nSv L^{-1}, 8.12 to 23.20 nSv L^{-1}, 4.90 to 14.00 nSv L^{-1}, 3.36 to 9.60 nSv L^{-1} and 3.08 to 8.80 nSv L^{-1} respectively; with averages of 24.98 nSv L^{-1}, 20.45 nSv L^{-1}, 9.63 nSv L^{-1}, 6.59 nSv $L^{-1}$and 6.04 nSv L^{-1} respectively. The average highest effective dose is for 1 year children 24.98 nSv L^{-1} and lowest for adults of 6.04 nSv L^{-1}. The effective dose due to the intake of ^{232}Th by ingestion to humans of age groups 1 y, 5 y, 10 y, 15 y and adults (18+ y) varied from 54.00 to 229.50 nSv L^{-1}, 42.00 to 178.50 nSv L^{-1}, 34.80 to 147.90 nSv L^{-1}, 30.00 to 127.50 nSv L^{-1} and 27.60 to 117.30 nSv L^{-1} respectively; with averages of 125.55 nSv L^{-1}, 94.32 nSv L^{-1}, 80.91 nSv L^{-1}, 69.75 nSv $L^{-1}$and 66.96 nSv L^{-1} respectively. The average highest effective dose is for 1year children 125.55 nSv L^{-1} and lowest for adults of 66.96 nSv L^{-1}. The effective dose for different age groups due to the intake of ^{40}K from drinking water was calculated. For the 1 y age group the dose varied from 69.36 to 217.60 nSv L^{-1} with an average 134.81 nSv L^{-1}, for the 5 y age group 42.84 to 134.40 nSv L^{-1} with an average 83.83 nSv L^{-1}, for the 10 y age group 22.44 to 70.40 nSv L^{-1} with an average 43.91 nSv L^{-1}; for the 15 y age group 12.85 to 40.32 nSv L^{-1} with an average 25.15 nSv L^{-1}; and for the adult (18+ y) group 10.20 to 32.00 nSv L^{-1} with an average 19.96 nSv L^{-1}. From these results, the average highest effective dose is found for 1 year children and lowest for adults.

From the annual intake values an estimation of the associated effective doses due to the ingestion of these radionuclides has been done by using the age dependent effective doses per unit activity ingestion to members of the public for ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K. All the average results are shown in Table 5.16.

Owing to intake of ^{238}U, the annual effective dose vary from 9.02 to 23.32 μSv y^{-1}, 5.54 to 18.77 μSv y^{-1}, 5.41 to 13.99 μSv y^{-1}, 3.53 to 9.12 μSv y^{-1} and 4.08 to 10.54 μSv y^{-1} respectively; with averages of 14.94 μSv y^{-1}, 12.15 μSv y^{-1}, 10.70 μSv y^{-1}, 6.03 μSv $y^{-1}$and 6.96 μSv y^{-1} respectively. The annual effective dose due to the intake of ^{226}Ra vary from 3.19 to 9.10 μSv y^{-1} with an average 6.23 μSv y^{-1}; 2.66 to 7.61 μSv y^{-1} with an average 5.22 μSv y^{-1}; 2.16 to 6.16 μSv y^{-1} with an average 4.18 μSv y^{-1}; 1.72 to 4.92 μSv y^{-1} with an average 3.38 μSv y^{-1}; and 2.25 to 6.43 μSv y^{-1} with an average 4.42 μSv y^{-1} for age groups of 1 y, 5 y, 10 y, 15 y and adults (18+ y) respectively. The annual effective dose due to the intake of ^{232}Th vary from 13.75 to 57.50 μSv y^{-1} with an average 35.50 μSv y^{-1}; 14.10 to 58.06 μSv y^{-1} with an average 32.09 μSv y^{-1}; 15.31 to 65.08 μSv y^{-1} with an average 35.84 μSv y^{-1}; 15.87 to 64.56 μSv y^{-1} with an average 35.78 μSv y^{-1}; and 20.47 to 84.80 μSv y^{-1} with an average 41.61 μSv y^{-1} for age groups of 1 y, 5 y, 10 y, 15 y and adults (18+ y) respectively. The annual effective dose due to the intake of ^{40}K vary from 17.34 to 54.40 μSv y^{-1} with an average 47.43 μSv y^{-1}; 14.05 to 44.08 μSv y^{-1} with an average 38.44 μSv y^{-1}; 9.87 to 30.98 μSv y^{-1} with an average 27.01 μSv y^{-1}; 6.58 to 20.64 μSv y^{-1} with an average 18.00 μSv y^{-1}; and 7.41 to 23.39 μSv y^{-1} with an average 20.39 μSv y^{-1} for age groups of 1 y, 5 y, 10 y, 15 y and adults (18+ y) respectively. The cumulative average effective dose and annual effective dose due to contributions from all natural radionuclides are 346.98 nSv L^{-1} and 104.10 μSv y^{-1}; 237.27 nSv L^{-1} and 87.9 μSv y^{-1}; 155.47 nSv L^{-1} and 75.73 μSv y^{-1}; 117.88 nSv L^{-1} and 63.19 μSv y^{-1}; 107.06 nSv L^{-1} and 73.38 μSv y^{-1} for all the above age groups, respectively. A bar diagram comparison of cumulative effective dose (nSv L^{-1}) and annual effective dose (μSv y^{-1}) for all age groups are shown in Figure 5.2.

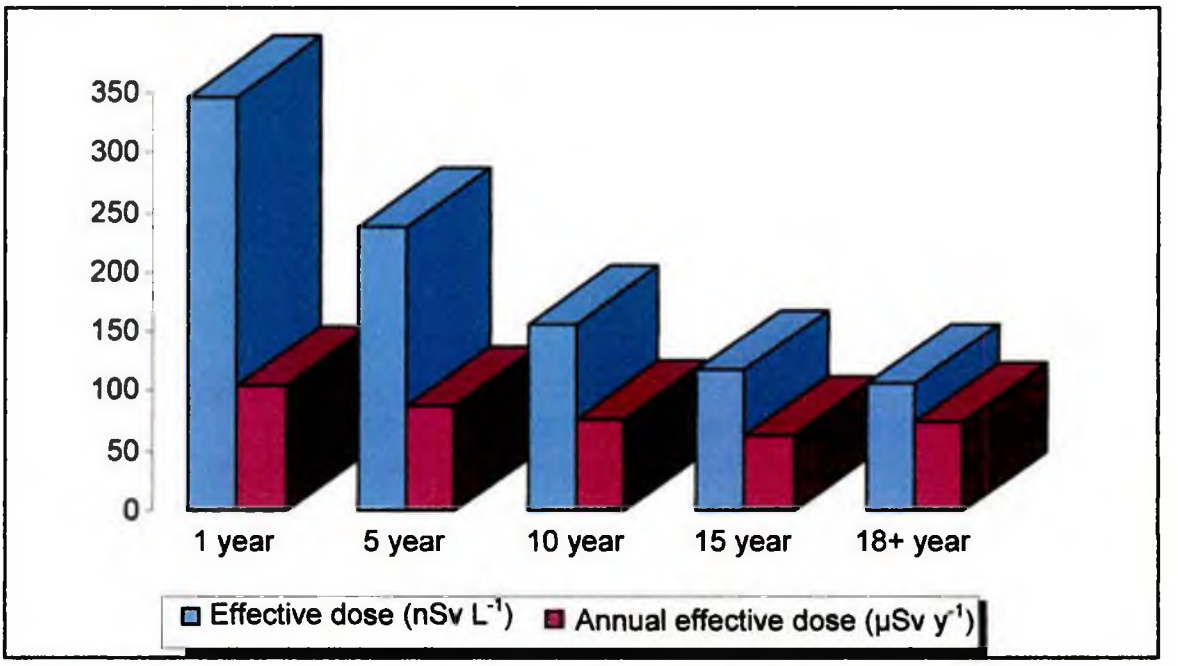

Figure 5.2: A bar diagram comparison of cumulative effective dose (nSv L^{-1}) and annual effective dose (μSv y^{-1}) for all age groups.

^{226}Ra is a highly radiotoxic radionuclide. When humans ingest radium, ~ 20% is absorbed into the blood stream. The absorbed radium is initially distributed to soft tissues and bones, but its retention is mainly in growing bones. The intake of ^{226}Ra in drinking water as well as tap water assessed in this work represents a contribution of 6% of the total dose, intake of ^{232}Th of 44% of the total dose, intake of ^{238}U of 13% of the total dose and from ^{40}K, a contribution of 37% of the total dose.

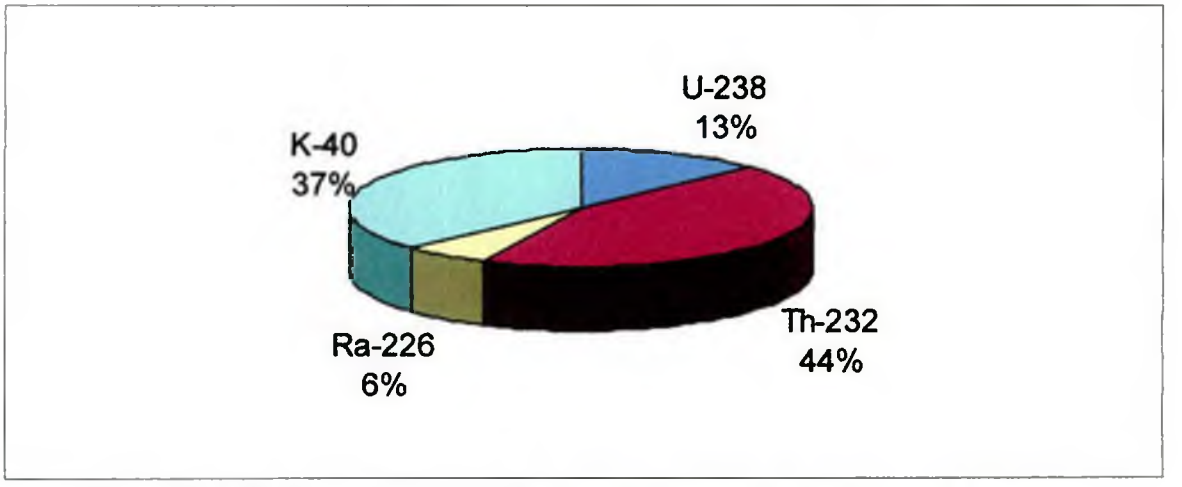

Figure 5.3: The fractional distribution of the population in age intervals.

The fractional distribution of the population in age intervals is shown in Figure 5.3. From the effective doses to different age interval groups, the mean annual effective dose due to intake of these radionuclides can be assessed and the obtained values are 10.16 μSv for ^{238}U, 4.69 μSv for ^{226}Ra, 35.76 μSv for ^{232}Th and 30.25 μSv for ^{40}K. Considering now that the worldwide average committed dose due to ingestion and inhalation of terrestrial radionuclides is 0.23 mSv, the contribution to the total dose of radionuclides considered in this work is 0.081% of the total.

CHAPTER VI

CONCLUSIONS

In conclusion, the tap water samples from Dhaka city do not contain any anthropogenic radionuclide (^{137}Cs), but the natural radionuclides such as ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K are identified. Measured activities of these radionuclides in tap water samples of Dhaka city are shown in Table 6.1. As ^{226}Ra is a highly radiotoxic radionuclide, our great concern is on the activities of ^{226}Ra in tap water. However, our findings reveal that the activity of ^{226}Ra in all the studied samples are below the recommended limits of 1.00 (IAEA,1989) and 0.185 Bq L^{-1} (USEPA), respectively.

Concentrations ranging from 1.88 ± 0.030 to 8.16 ± 0.0344 mBq L^{-1} with an average 3.762 ± 1.50 mBq L^{-1} and from 29.305 ± 0.062 to 115.740 ± 0.165 mBq L^{-1} with an average 60.408 ± 23.57 mBq L^{-1} were observed for the gross α and gross β activities, respectively, (Table 6.2). For all tap water samples the gross β activities are higher than the corresponding gross α activities. Both gross alpha and gross beta activities are respectively lower than 0.1 Bq L^{-1} and 1.0 Bq L^{-1} recommended by WHO (World Health Organization). Since the gross alpha activity in drinking water is lower than 0.1 Bq L^{-1} and the gross beta activity does not exceed 1.0 Bq L^{-1}, it can be assumed that the annual effective dose is less than 0.1 mSv y^{-1}. Bangladesh has no public drinking water standards for radioactivity yet. So, the above results are comparable with the guideline values of WHO for drinking water. It is found that the radionuclides concentration in tap water samples of Dhaka city is still below the maximum suggested values.

The effective dose and annual effective dose due to the natural radionuclides are also determined and given in Table 6.3 and 6.4. To the total dose of radioactivity arising from the consumption of drinking water, the contribution of ^{226}Ra is 6%; ^{232}Th is 44%; ^{238}U of 13% and ^{40}K is 37%. The effective dose is also lower than the worldwide average value suggested to be 0.23 mSv. Annual estimated effective doses for all five age groups from the intake of natural radionuclides in tap water are far below the WHO recommended limit of 0.1 mSv y^{-1}, as well as the average radiation dose of 0.29 mSv y^{-1} received per

head world wide due to ingestion of natural radionuclides assessed by UNSCEAR, 2000 for radiologically safe drinking water.

From the present work, it seems that the dwellers are not supposed to acquire any serious radiological complication from our drinking water system at least in the Dhaka city. The data gathered in this study will provide base–line radiometric values of drinking water in this region that can be used to evaluate the possible changes in future. This work could help to create a public awareness about the amount of radioactivity in drinking water and the radiological impact on the dweller's health. Finally, this work will help in establishing a regulatory limit on radiation in public drinking water as well as in tap water in Bangladesh.

Table 6.1: Natural radioactivities (Bq L^{-1}) in Tap Water Samples from Dhaka city

Radionuclides	Minimum	Maximum	Average
^{238}U	0.82 ± 0.26	2.12 ± 0.32	1.40 ± 0.45
^{226}Ra	0.014 ± 0.0054	0.040 ± 0.0055	0.028 ± 0.0071
^{232}Th	0.16 ± 0.003	0.73 ± 0.027	0.39 ± 0.17
^{40}K	2.04 ± 0.009	6.40 ± 0.029	3.99 ± 1.28

Table 6.2: Gross Alpha and Gross Beta Activity in Tap Water Samples.

	Maximum ($mBqL^{-1}$)	Minimum ($mBqL^{-1}$)	Average ($mBqL^{-1}$)
Gross Alpha activity	8.16 ± 0.034	1.88 ± 0.03	3.76 ± 1.50
Gross beta activity	115.74 ± 0.16	29.305 ± 0.06	60.41 ± 23.57

Table 6.3: Age-Dependent Effective Dose due to Intake of Radionuclides (nSv L^{-1}).

Radionuclides	1 year	5 year	10 year	15 year	Adult (18+ year)
^{238}U					
Minimum	36.08	22.14	12.30	6.89	5.58
Maximum	93.28	57.24	31.80	17.81	14.42
Average	61.64	38.67	21.02	16.39	14.10
^{226}Ra					
Minimum	12.74	8.12	4.90	3.36	3.08
Maximum	36.40	23.20	14.00	9.60	8.80
Average	24.98	20.45	9.63	6.59	6.04
^{232}Th					
Minimum	54.00	42.00	34.80	30.00	27.60
Maximum	229.50	178.50	147.90	127.50	117.30
Average	125.55	94.32	80.91	69.75	66.96
^{40}K					
Minimum	69.36	42.84	22.44	12.85	10.20
Maximum	217.60	134.40	70.40	40.32	32.00
Average	134.81	83.83	43.91	25.15	19.96

Table 6.4: Age-Dependent Annual Effective Dose due to Intake of Radionuclides (μSv y^{-1}).

Radionuclides	**1 year**	**5 year**	**10 year**	**15 year**	**Adult (18+ year)**
^{238}U					
Minimum	9.02	5.54	5.41	3.53	4.08
Maximum	23.32	18.77	13.99	9.12	10.54
Average	14.94	12.15	10.70	6.03	6.96
^{226}Ra					
Minimum	3.19	2.66	2.16	1.72	2.25
Maximum	9.10	7.61	6.16	4.92	6.43
Average	6.23	5.22	4.18	3.38	4.42
^{232}Th					
Minimum	13.75	14.10	15.31	15.87	20.47
Maximum	57.50	58.06	65.08	64.56	84.80
Average	35.50	32.09	33.84	35.78	41.61
^{40}K					
Minimum	17.34	14.05	9.87	6.58	7.41
Maximum	54.40	44.08	30.98	20.64	23.39
Average	47.43	38.44	27.01	18.00	20.39

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Appendices

Appendix-A

Data for Radioactivity in Tap Water Samples by HPGe Detector

Sample No. 01

Sample Name: Tap Water

Collection Place: Chankher Pool

Radionuclides	Energy (keV)	Sample cps	Bkg Cps	Net Cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0311	0.0178	0.0133	0.389	2.38	1.437
^{214}Bi	609.31	0.02835	0.0281	0.00025	0.433	1.5	0.039
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.02737	0.0269	0.00047	0.166	1.02	0.16
^{40}K	1460.8	0.1330	0.131	0.0020	0.1067	0.72	2.57

Sample No. 02

Sample Name: Tap Water

Collection Place: Nazimuddin Road

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0255	0.0178	0.0077	0.389	2.38	0.832
^{214}Bi	609.31	0.00298	0.00281	0.00017	0.433	1.5	0.0262
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01749	0.0168	0.00069	0.166	1.02	0.41
^{40}K	1460.8	0.1333	0.131	0.0023	0.1067	0.72	2.95

Sample No. 03

Sample Name: Tap Water

Collection Place: Moulovi Bazar

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0254	0.0178	0.0076	0.389	2.38	0.82
^{214}Bi	609.31	0.00295	0.00281	0.00014	0.433	1.5	0.021
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01712	0.0168	0.00032	0.166	1.02	0.19
^{40}K	1460.8	0.1326	0.131	0.0016	0.1067	0.72	2.04

Sample No. 04

Sample Name: Tap Water

Collection Place: Midford

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0255	0.0178	0.0077	0.389	2.38	0.83
^{214}Bi	609.31	0.00295	0.00281	0.00014	0.433	1.5	0.022
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01707	0.0168	0.00027	0.166	1.02	0.16
^{40}K	1460.8	0.1343	0.131	0.0033	0.1067	0.72	4.31

Sample No. 05

Sample Name: Tap Water

Collection Place: Shatroja

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0333	0.0178	0.0155	0.389	2.38	1.68
^{214}Bi	609.31	0.00290	0.00281	0.00009	0.433	1.5	0.014
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01759	0.0168	0.00079	0.166	1.02	0.47
^{40}K	1460.8	0.1359	0.131	0.0049	0.1067	0.72	6.40

Sample No. 06

Sample Name: Tap Water

Collection Place: Polash Bazar

Radionuclides	Energy (keV)	Sample Cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0293	0.0178	0.0115	0.389	2.38	1.24
^{214}Bi	609.31	0.00302	0.00281	0.00021	0.433	1.5	0.033
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01758	0.0168	0.00079	0.166	1.02	0.46
^{40}K	1460.8	0.1349	0.131	0.0039	0.1067	0.72	5.12

Sample No. 07

Sample Name: Tap Water

Collection Place: Azimpur

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0362	0.0178	0.0184	0.389	2.38	1.99
^{214}Bi	609.31	0.00297	0.00281	0.00016	0.433	1.5	0.025
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01759	0.0168	0.00079	0.166	1.02	0.46
^{40}K	1460.8	0.1342	0.131	0.0032	0.1067	0.72	4.22

Sample No. 08

Sample Name: Tap Water

Collection Place: BDR

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0366	0.0178	0.0188	0.389	2.38	2.03
^{214}Bi	609.31	0.00301	0.00281	0.00020	0.433	1.5	0.031
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01766	0.0168	0.00086	0.166	1.02	0.51
^{40}K	1460.8	0.1349	0.131	0.0039	0.1067	0.72	5.07

Sample No. 12

Sample Name: Tap Water

Collection Place: Kwran Bazar

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0374	0.0178	0.0196	0.389	2.38	2.12
^{214}Bi	609.31	0.00283	0.00281	0.00020	0.433	1.5	0.031
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.0178	0.0168	0.00104	0.166	1.02	0.62
^{40}K	1460.8	0.1332	0.131	0.0022	0.1067	0.72	2.86

Sample No.13

Sample Name: Tap Water

Collection Place: Farmgate

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0323	0.0178	0.0145	0.389	2.38	1.57
^{214}Bi	609.31	0.0031	0.00281	0.00025	0.433	1.5	0.039
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.0173	0.0168	0.00054	0.166	1.02	0.32
^{40}K	1460.8	0.1353	0.131	0.0043	0.1067	0.72	5.58

Sample No. 14

Sample Name: Tap Water

Collection Place: Agargao

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0369	0.0178	0.0192	0.389	2.38	2.07
^{214}Bi	609.31	0.00299	0.00281	0.00018	0.433	1.5	0.028
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.0180	0.0168	0.00123	0.166	1.02	0.73
^{40}K	1460.8	0.1337	0.131	0.0027	0.1067	0.72	3.50

Sample No. 09

Sample Name: Tap Water

Collection Place: Dhaka College

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0311	0.0178	0.01333	0.389	2.38	1.44
^{214}Bi	609.31	0.00296	0.00281	0.00015	0.433	1.5	0.023
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.0178	0.0168	0.00096	0.166	1.02	0.57
^{40}K	1460.8	0.1334	0.131	0.0024	0.1067	0.72	3.10

Sample No. 10

Sample Name: Tap Water

Collection Place: Rayer Bazar

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0262	0.0178	0.0084	0.389	2.38	0.91
^{214}Bi	609.31	0.00295	0.00281	0.00014	0.433	1.5	0.021
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01756	0.0168	0.00076	0.166	1.02	0.45
^{40}K	1460.8	0.1339	0.131	0.0029	0.1067	0.72	3.82

Sample No. 11

Sample Name: Tap Water

Collection Place: Hatirpool

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0286	0.0178	0.0108	0.389	2.38	1.17
^{214}Bi	609.31	0.00299	0.00281	0.00018	0.433	1.5	0.027
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01713	0.0168	0.00034	0.166	1.02	0.20
^{40}K	1460.8	0.1350	0.131	0.0041	0.1067	0.72	5.28

Sample No. 15

Sample Name: Tap Water

Collection Place: Mohakhali

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0306	0.0178	0.0128	0.389	2.38	1.38
^{214}Bi	609.31	0.00305	0.00281	0.00024	0.433	1.5	0.037
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01721	0.0168	0.00041	0.166	1.02	0.24
^{40}K	1460.8	0.1338	0.131	0.0028	0.1067	0.72	3.59

Sample No. 16

Sample Name: Tap Water

Collection Place: Kamlapur

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0324	0.0178	0.0146	0.389	2.38	1.58
^{214}Bi	609.31	0.00307	0.00281	0.00026	0.433	1.5	0.040
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01710	0.0168	0.00030	0.166	1.02	0.18
^{40}K	1460.8	0.1323	0.131	0.0017	0.1067	0.72	2.20

Sample No. 17

Sample Name: Tap Water

Collection Place: Motojheel

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0359	0.0178	0.018	0.389	2.38	1.96
^{214}Bi	609.31	0.00299	0.00281	0.00018	0.433	1.5	0.028
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.0180	0.0168	0.0012	0.166	1.02	0.71
^{40}K	1460.8	0.1335	0.131	0.00247	0.1067	0.72	3.22

Sample No. 18

Sample Name: Tap Water

Collection Place: Narinda

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0287	0.0178	0.011	0.389	2.38	1.18
^{214}Bi	609.31	0.00293	0.00281	0.00012	0.433	1.5	0.019
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01749	0.0168	0.00069	0.166	1.02	0.38
^{40}K	1460.8	0.1358	0.131	0.0048	0.1067	0.72	6.30

Sample No. 19

Sample Name: Tap Water

Collection Place: Koratitolla

Radionuclides	Energy (keV)	Sample cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.02585	0.0178	0.0081	0.389	2.38	0.87
^{214}Bi	609.31	0.00298	0.00295	0.00014	0.433	1.5	0.022
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.01743	0.0168	0.00063	0.166	1.02	0.37
^{40}K	1460.8	0.1333	0.131	0.0023	0.1067	0.72	3.01

Sample No. 20

Sample Name: Tap Water

Collection Place: Jurain

Radionuclides	Energy (keV)	Sample Cps	Bkg cps	Net cps	Pγ	Effi.	Activity in Bq
^{214}Pb	351.92	0.0262	0.0178	0.0084	0.389	2.38	0.91
^{214}Bi	609.31	0.00296	0.00281	0.00015	0.433	1.5	0.023
^{137}Cs	661.66				0.89	1.4	
^{228}Ac	969.11	0.0173	0.0168	0.00047	0.166	1.02	0.28
^{40}K	1460.8	0.1346	0.131	0.0036	0.1067	0.72	4.70

Data for Gross Alpha Activity in Tap Water Samples by Dual Phosphor Detector

Sl. No.	Name of Locations	Back ground Count (CPM)	Samples Counts(CPM)	Efficiency (%)	Activity (mBq L^{-1})
1.	Chankher Pool	0.04	0.10	30	1.88±0.030
2.	Nazimuddin Road	0.05	0.13	30	5.02±0.0304
3.	Moulovi Bazar	0.02	0.05	30	1.91±0.019
4.	Midford	0.05	0.12	30	4.39±0.0295
5.	Shatroja	0.07	0.13	30	3.77±0.032
6.	Polash Bazar	0.03	0.12	30	5.65±0.0277
7.	Azimpur	0.02	0.07	30	3.14±0.0215
8.	BDR	0.03	0.10	30	4.32±0.0304
9.	Dhaka College	0.03	0.07	30	2.51±0.023
10.	Rayer Bazar	0.05	0.18	30	8.16±0.0344
11.	Hatirpool	0.05	0.12	30	4.42±0.0296
12.	Kwran Bazar	0.07	0.10	30	1.88±0.0296
13.	Farmgate	0.07	0.12	30	3.14±0.031
14.	Agargao	0.05	0.10	30	3.14±0.028
15.	Mohakhali	0.05	0.13	30	5.02±0.0304
16.	Kamlapur	0.07	0.13	30	3.77±0.032
17.	Motijheel	0.07	0.12	30	3.13±0.0313
18.	Narinda	0.03	0.08	30	3.09±0.024
19.	Koratitolla	0.07	0.11	30	2.51±0.0237
20.	Jurain	0.03	0.11	30	4.39±0.0312

Data for Gross Beta Activity in Tap Water Samples by Gas Proportional Counter.

Sl. No.	Name of Locations	Back ground Count (CPM)	Samples Counts (CPM)	Efficiency (%)	Activity (mBq L^{-1})
1.	Chankher Pool	4.200	2.700	36	60.185±0.079
2.	Nazimuddin Road	3.567	2.200	36	63.287±0.172
3.	Moulovi Bazar	3.800	2.200	36	74.347±0.172
4.	Midford	3.267	2.533	36	33.981±0.062
5.	Shatroja	4.200	2.533	36	77.22±0.062
6.	Polash Bazar	3.133	2.200	36	43.194±0.172
7.	Azimpur	4.700	2.200	36	115.740±0.165
8.	BDR	3.267	2.500	36	35.509±0.062
9.	Dhaka College	4.767	2.700	36	95.694±0.079
10.	Rayer Bazar	5.000	2.700	36	106.481±0.078
11.	Hatirpool	3.333	2.200	36	52.453±0.165
12.	Kwran Bazar	3.833	2.200	36	75.602±0.172
13.	Farmgate	2.200	3.333	36	52.222±0.172
14.	Agargao	3.467	2.533	36	43.241±0.173
15.	Mohakhali	4.00	2.500	36	60.185±0.062
16.	Kamlapur	3.400	2.200	36	55.556±0.167
17.	Motijheel	3.400	2.200	36	55.56±0.162
18.	Narinda	3.333	2.500	36	29.305±0.062
19.	Koratitolla	3.333	2.500	36	37.037±0.062
20.	Jurain	2.900	2.100	36	41.372±0.079

Appendix-B

Units and Conversion

Term	Old Unit	SI Unit	Relation
Activity	Curie, Ci	Becquerel, Bq 1 dps = 1 Bq	1 Ci = 3.7 x 10^{10} Bq 1 μCi = 37 kBq 1 mCi = 37 MBq 1 Bq = 27.027 pCi
Absorbed Dose	rad	Gray, Gy 1 Gy = 1 J/kg	1 Gy = 100 rad
Equivalent Dose (absorbed dose × radiation weighting factor, x, γ = 1, α = 20)	rem For x, β, γ, 1 rem = 1 rad	Sievert, Sv For x, β, γ, 1 Sv = 1 Gy	1 Sv = 100 rem 1 mrem = 10 μSv 1 rem = 10 mSv
Effective Dose (equivalent dose × tissue weighting factor)		Sievert, Sv	
Exposure	Röntgen, R = the production of ions (of one sign) carrying a charge of 1 R = 2.58 x 10^{-4} C kg^{-1}	Sievert, Sv 1 mSv y^{-1} 0.5 μSv h^{-1} [50 weeks, 40 working hours/ week] [300 μSv for 3 months TLD reading]	1 R = 8.73 mSv (air) 1 mR = 8.73 1 mR ~ 10 μGy = 10 μSv 1 μR = 0.01 μSv 1 Sv = 100 R 1 μSv =100 μR

Appendix-C

GLOSSARY OF TERMS

ALARA: As low as reasonably achievable.

Abundance: The percentage of one isotope to the total occurring in nature.

Atom: The building blocks that makes up all matter.

Atomic Mass (A): The total number of protons and neutrons in the nucleus of an atom.

Atomic Mass Unit: This is defined as one twelfth of the mass of a carbon-12 (^{12}C) atom and is equal to 1.66×10^{-24}g.

Atomic Number (Z): The number of protons in the nucleus of an atom.

Activity: The number of disintegrations of a nucleus occurring per second.

Alpha Particle: A particle consisting of two protons and two neutrons tightly bound together, and which is ejected from the nucleus during radioactive decay.

Absorbed Dose: The mean energy deposited by ionizing radiation per unit mass of the body or organ or tissue of the body.

Acute Exposure: Exposure to radiation over a short time period (a few hours or less).

Background Radiation: The radiation to which an individual is exposed arising from natural radiation sources such as terrestrial radiation from radionuclides in the soil, cosmic radiation from space, and naturally occurring radionuclides deposited in the body from foods, etc.

BSS: Basic Safety Standards. The practical guide for the design and implementation of an effective radiation protection system.

Beta Particle: Radiation consists of lighter charged particles than alpha particles that travel faster and are thus more penetrating than alpha radiation.

Bequrel (Bq): An SI unit of radioactivity, equivalent to 1 nuclear transformation per second. Used as a measurement of the quantity of a radionuclide since the number of radioactive transformations (disintegrations) is directly proportional to the number of atoms of the radionuclide present.

Boiling Point: The temperature at which a liquid changes to a vapour.

Contamination: Radioactive material present in excess of natural background quantities in a place it is not wanted.

Curie (Ci): A unit of activity equivalent to 3.7×10^{10} disintegrations per second.

Chemical Bond: The way in which atoms are joined together.

Chemical Symbol: The letter(s) used to denote a particular element

Covalent Bond: A type of chemical bond where electrons are shared between atoms.

Cosmic Radiation: Radiation which comes from outside the planet Earth.

Constraint: Restriction on the exposure to ionizing radiation.

Cosmogenic: Cosmogenic radionuclides are produced by interaction of cosmic rays with stable nuclides in the Earth's atmosphere.

Curies (Ci) and **Becquerel** (Bq) measure the activity as number of disintegrations per second. Activity is a property of the source of radiation; it indicates nothing about the effect of the radiation on the target material.

Chronic Exposure: Exposure to radiation over a long time period (months or years).

Cell Membrane: The boundary of the cell.

Chromosomes: Fine fibrous strands of genes.

Density: The mass of material divided by its volume.

Decay: A process followed by an unstable nucleus to gain stability by the release of energy in the form of particles and/or electromagnetic radiation.

Daughter: The more stable nuclide which results from radioactive decay. (See **progeny**).

Decay Constant: The fraction of atoms which undergo decay in a unit of time.

Decay Series: The paths in which radionuclides decay in order to obtain stability.

Deterministic Effect: An effect of radiation (e.g. skin reddening) which is characterized by having a threshold dose.

Dose: The amount of ionizing radiation absorbed by a human being.

Dose Constraint: Restriction on the dose received as a result of ionizing radiation.

Dose Limit: The value of dose that may not be exceeded under normal operational conditions.

Exposure: The process of a human being exposed to radiation or radioactive materials.

Electron: A negatively charged particle orbiting the nucleus of an atom.

Element: A substance in which all the atoms have the same number of protons.

Electromagnetic Radiation: Energy which travels in the form photons at the speed of light.

Electron Capture: A process whereby an electron in the innermost electron shell is captured by a proton in the nucleus to form a neutron. As a result, characteristic x-rays are produced.

Electron Volt: The amount of energy gained by an electron accelerating across a potential difference of one volt and is mathematically equivalent to 1.6×10^{-19} joules.

Early Effect: A radiation effect which occurs within a few days or weeks of exposure.

Effective Dose: Radiation dose for primary radiation dose limits. It represents the sum of the equivalent doses received by different tissues of the human body, each multiplied by a "tissue weighting factor".

Equivalent Dose: The absorbed dose multiplied by a "radiation weighting factor", which accounts for the different potential for adverse effects of the different types of radiation.

Fetus: An unborn child.

Free Radical: A chemically reactive atom group which may be formed by the ionization of water in the cell.

Fission: The process whereby a heavy nucleus is split into smaller nuclei.

Gamma Ray: Electromagnetic radiation which comes from the nucleus of an atom as a result of radioactive decay.

Gene: The part of a chromosome consisting of proteins and DNA molecules.

Half-Life: The time taken for half of the atoms of a radionuclide to undergo radioactive decay.

Hereditary Effect: An effect of radiation which could be passed on to future generations.

Isotopes: Atoms of a particular element with different numbers of neutrons.

Internal Conversion: The process whereby excess energy from the nucleus is transferred to an orbital electron. The electron is then ejected from the atom. The electron vacancy is filled by an electron from an outer shell and results in the release of a characteristic x-ray.

ICRP: International Commission on Radiological Protection. The organization which makes recommendations and provides guidance on the fundamental principles of radiation protection.

Intervention: A human activity which decreases the overall exposure to ionizing radiation.

Ion Bombardment: The process whereby high energy, charged particles are fired at a target. The particles are absorbed and the target becomes radioactive.

Ionizing Radiation: Any particle or ray which has sufficient energy to remove electrons from atoms.

Isomeric Transition: The process whereby a metastable radionuclide emits a gamma ray thereby removing excess energy from the nucleus.

Justification: The benefits of a practice are greater than the risks of that practice.

Late Effect: A radiation effect which occurs years after exposure.

Metal: An element which needs to lose electrons to become chemically stable.

Molecule: A group of atoms which are joined by chemical bonds.

Neutron Number (N): The number of neutrons found in the nucleus of an atom.

Nucleus: The positively charged centre of an atom, consisting of protons and neutrons.

Nuclide: A general term referring to any isotope of any element.

Neutron: An uncharged particle in the nucleus of an atom composed of a proton and an electron.

Occupational Exposure: The exposure of a person to ionizing radiation in the workplace as a result of their work.

Optimization: Individual doses, the number of people exposed and the likelihood and magnitude of potential exposures should all be kept as low as reasonably achievable, economic and social factors being taken into account.

Orbit: The path of an electron around an atomic nucleus.

Periodic Table: The grouping of elements according to how the electron shells are filled.

Proton: A positively charged particle found in the nucleus of an atom.

Parent: The original radionuclide before undergoing radioactive decay.

Positron: A particle which is similar to a beta particle with the same mass but opposite charge.

Primordial: Primordial radionuclides are naturally occurring in the Earth's crust.

Progeny: The more stable nuclide which results from radioactive decay (See **daughter**).

Potential Exposure: Radiation exposure that is not expected to occur but which could arise from events such as equipment failures or operator errors.

Practice: A human activity which increases the overall exposure to ionizing radiation.

Public Exposure: Public exposure applies to the exposure of a person to ionizing radiation other than from occupational or medical exposure.

Radiation Protection: The science and practice of limiting harm to human beings from radiation.

Risk: The combination of the probability that a harmful consequence may occur and the size of that consequence.

Radioactive Decay: The change that takes place in the nucleus of an atom to make it more stable.

Radioisotope: An isotope which emits radiation.

Radionuclide: A nuclide which emits radiation.

Secular Equilibrium: The situation reached when the activity of a long lived parent is the same as the activity of the much shorter lived progeny.

Specific Activity: The amount of activity per unit of mass or per unit volume.

Stochastic Effect: An effect of radiation (e.g. cancer) where the probability of the effect is proportional to the dose received. The severity of the effect is, however, independent of the dose.

Sieverts (Sv) or ram measure dose equivalents, a quantity used in radiological protection. The units of sieverts are also joules per kilogram. The sievert and gray both measure the effect of radiation on the target, but the sievert takes into account the effects of different types of radiation on human tissue.

Threshold Dose: The dose of radiation below which there is no observable radiation injury.

Terrestrial Radiation: Radiation which comes from the rocks of the planet Earth.

Transient Equilibrium: The situation reached when the progeny radionuclide is decaying at the same rate as it is being produced.

Tissue Weighting Factor: A factor which considers the differences in probability of fatal cancer for different organs and tissues.