CHAPTER: 1

INTRODUCTION

1.1 DISCOVERY OF RADIATIONS AND RADIOACTIVITY

Radiations are being encountered ever since the formation of earth that is four and half billion years ago. In mid of 15th century, radiations were known as “act or process of emitting light”, to beam shine. From 1560s it was known as rays or beams emitted, in 1650s its meaning changes to (divergence from a centre) and then after this these were known as radiations, where “radi” means radius. These radiations were considered to emitt from various sources like cosmic rays, terrestrial sources, visible light, sun etc.

Scientist truly began to make advances in the study of radiations during the late part of the 19th century. In 1895, Wilhelm Conard Roentgen accidently discovered X-rays, the hitherto unknown “mysterious” rays capable of producing an image on a photographic plate. He "photographed" his wife's hand placed in path of X- rays (Figure 1.1), revealing the unmistakable image of her skeleton along with her wedding ring. This caused scientists' interest in learning more about these undiscovered x-rays. For this remarkable contribution of his discovery in physics, Roentgen received a Noble prize for physics in 1901.

Figure 1.1: W.C. Roentgen photographed his wife’s hand (https://www.dailymail.co.uk/news/article-6491287/Roentgens-human-X-ray-wifes-hand-1895.html)

A French physicist, Henri Becquerel discovered the phenomenon of radioactivity in 1896, when he put wrapped photographic plates away in a darkened

drawer along with some crystals of uranium. Then he found that the plates had been exposed during storage due to uranium emission. These crystals emitted rays their own which led to the discovery of radioactivity. The term “radioactivity” was first used in a publication by Curies in 1899 combining from French “radio-actif” combined form of latin word “ray” which means radius and actif means active. Depicting that radius that is active by its own and capable of spontaneous nucleus decay releasing ionizing emissions.

Marie Curie and her husband, Pierre, continued their study on radioactivity in the Becquerel lab for the rest of their lives. Becquerel had already noticed that uranium rays might turn air into an electrical conductor. In 1898, the curies studied a uranium ore called pitchblende and discovered that it produced radiation 300 times stronger than pure uranium, resulting in the discovery of another radioactive element called polonium, named after Marie's native Poland. Then they chemically isolated another radioactive component from pitchblende that was over a million times more radioactive than uranium which was named as Radium. For their work on radioactivity, Henri Becquerel, Marie Curie and Pierre Curie were jointly awarded the Nobel Prize in Physics in 1903. Ernest Rutherford discovered that the becquerel rays are made up of two distinct components, which he dubbed alpha and beta. By 1907, Rutherford and Soddy had discovered numerous distinct series of naturally occurring radioactive transformations in which each element successfully converted into the next one down the chain until they eventually became non-active lead. Simultaneously, radon is emitted from radium and thoron is emitted from thorium. Rutherford proposed that the proton and neutron exist as two nucleons that make up the atomic nucleus. The process of radioactivity is related to the transition of one nucleus into another by the emission of radiations such as alpha, beta, and gamma.

1.2 RADIATIONS AND ITS TYPES

Radiation is described as energy in the form of a particle or a wave that flows across space or matter. Radiations are normally emitted by radioactive decay of an unstable atom (radionuclide) or by particle-matter interaction. The classification of radiations has been done on the basis of its type and energy. According to the type radiations can either be particulate or electromagnetic. Particulate radiations are made up of particles

with mass and energy, as well as an electric charge e.g., alpha particles, beta particles a0nd neutrons. Electromagnetic radiations are made up of energy-carrying photons with no mass or charge e.g., photons, x-rays and gamma rays.

Further on the basis of energy, radiations are mainly classified as ionizing radiations and non-ionizing radiations (Figure 1.2). The non-ionizing radiation does not have enough energy (10^{-10} to 10^{2} eV) to ionize the material with which they contact and dissipates their energy in the form of heat. Microwave, laser, visible light, radio waves, TV waves are the examples of non-ionizing radiations.

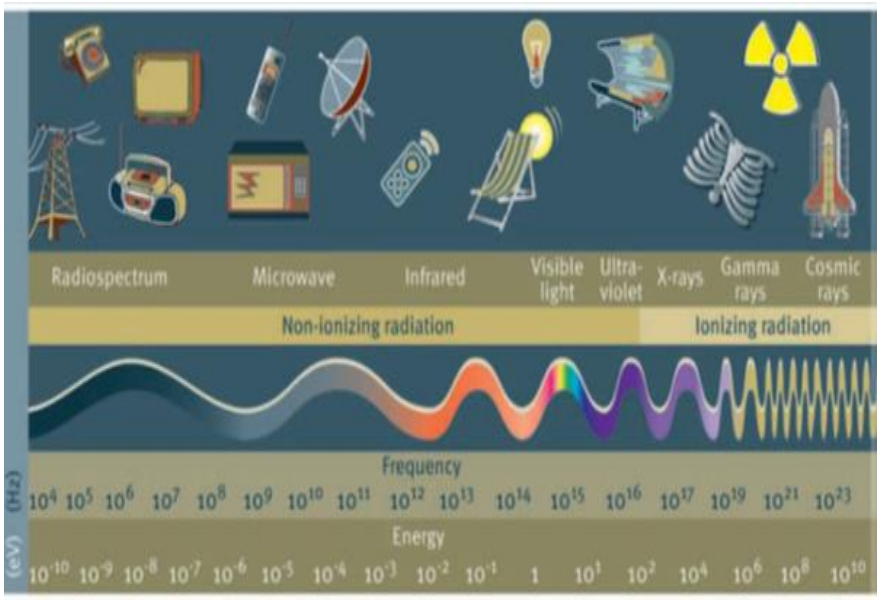

Figure 1.2: Ionizing and non-ionizing radiation sources
(UNEP, Radiations Effects and Sources, 2016)

Ionizing radiations (having energy 10^{2} to 10^{10} eV) has the ability to knock electrons out of molecules/atoms with which it interacts, resulting in the formation of ions. These radiations are invisible but they can be detected and measured with a variety of radiation measuring instruments. There are mainly four types of ionizing radiations such as alpha, beta, gamma and neutrons, which are discussed below.

1.2.1 Alpha Particles

The nucleus of an alpha particle is made up of two protons and two neutrons, just like the nucleus of a helium atom. It is emitted with a velocity of about 1/20 that of light

and energy ranging from 4 to 9 MeV from a radioactive atom. Due to relatively mass and charge, an alpha particle produces ions in a very localized area. It has a short range in air and cannot penetrate the skin's outer layer (Figure 1.3). However, if alpha-emitting materials are ingested, breathed in or consumed, they can directly expose inside tissues and potentially causing biological damage.

1.2.2 Beta Particles

Beta particles can have a positive or negative charge. Negatrons are electrons that originate in the nucleus of an atom and undergo radioactive decay when a neutron is converted to a proton. When an atom decays by turning a proton into a neutron, it emits a positron. Like alpha particles, beta particles lose their energy through ionisation and excitation, although interactions are less frequent due to their smaller mass (1/7300 of an alpha) and lower charge (1/2 that of an alpha). Although beta particles are smaller and penetrate deeper than alpha particles, their tissue range is still somewhat limited. The range of the beta particle in matter is determined by its energy and the material's composition. They can pass through 1-2 centimetres of water. A sheet of aluminium a few millimetres thick will stop beta radiation in most cases.

1.2.3 Gamma Rays

Gamma rays are electromagnetic radiations emitted by an atom to dissipate surplus energy. They are energy bundles with no charge or mass that can travel over great distances through air, body tissue and other materials, but can be stopped by strong concrete or lead walls.

1.2.4 Neutrons

Neutrons are uncharged particles that do not immediately cause ionisation, making them more penetrating. Thick amounts of concrete, water or paraffin are the only things that can stop them. The interaction of neutrons with matter atoms can produce alpha, beta, gamma, or X-rays, which can lead to ionisation.

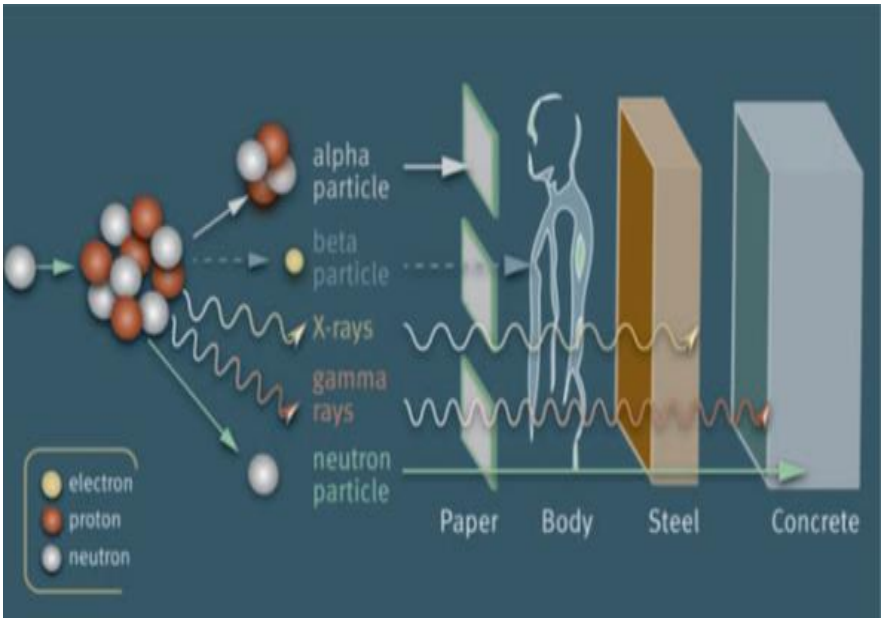

Figure 1.3: Penetrating power of radiations
(UNEP, Radiations Effects and Sources, 2016)

1.3 SOURCES OF RADIATIONS

There are mainly two types of sources of radiations that is natural and artificial. According to the NCRP's most recent study (2009), natural background radiation accounts for 50% of radiation exposure, while man-made sources account for the remaining 50%.

1.3.1 Natural Radiations

Natural radiations originate from extra-terrestrial and terrestrial sources. Extra-terrestrial radiation begins as primary cosmic rays in outer space and travels through the atmosphere at almost the speed of light. They come from the Sun, outside the Solar System in our own galaxy, and from faraway galaxies. These rays interact with the incoming energy and particles, resulting in secondary cosmic rays that are harmful to living creatures on the planet's surface. The average annual effective exposure from cosmic rays is 0.39 mSv over the world (UNSCEAR, 1993 & 2000) (Figure 1.4). Terrestrial radiation is emitted by the earth's primordial radioactive atoms, which have been present since its genesis. These radioactive atoms, known as radionuclides, such as uranium, thorium, and potassium, are found in different proportions in soils and

rocks, as well as in the atmosphere and water (IARC, 2001). Outdoor sources like rocks, soil, outside air, natural gases and indoor sources like soil, construction materials are all examples of terrestrial radiation sources.

1.3.2 Artificial Radiations

Following the discovery of x-rays and radioactivity, several applications of ionising radiation were developed, as well as the advent of man-made radiation. Several hundred radionuclides have been "artificially" generated by man over the previous few decades. Man harnessed the power of the atom for a wide range of applications, from medicine to weapons, from energy production to fire detection, and from illuminating timepieces and markers to mineral prospecting. Nuclear weapons are made with ionising radiation, as are nuclear exposures, radioactive fallout, and nuclear reactor waste. Medical diagnosis or treatment requiring ionising radiation, such as medical and dental x-rays, Magnet resonance tomography, ultrasound, Computer tomography Scan, exposes people to radiation (Figure 1.4).

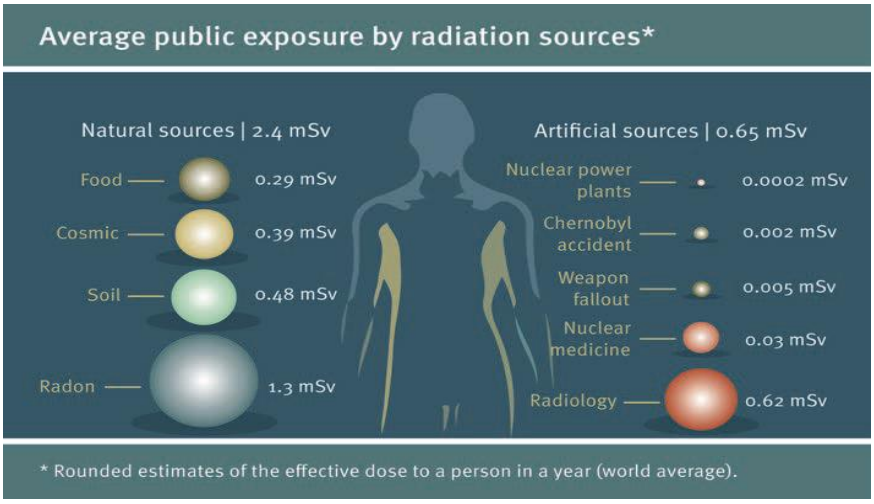

Figure 1.4: Exposure of radiations from different sources
(UNEP, Radiations Effects and Sources, 2016)

1.4 RADIATION ACTIVITY AND EXPOSURE

Knowledge of a few radioactive quantities, such as activity, units, energy, exposure, is required for assessing the carcinogenicity of ionising radiation, and is discussed below:

1.4.1 Activity

The number of nuclear transformations of energy per unit of time is known as activity concentration. It is measured as decays per seconds and expressed in Becquerel. Becquerel was chosen as the unit of radioactivity during a meeting of the General Conference of Weights and Measures (GCPM) in 1975. It is defined as the rate at which one nucleus of an atom disintegrates every second. Curie and Becquerel have a strong relationship, with one curie equalling 3.7×10^{10} Becquerel.

The traditional unit of activity is count rate. It is the number of radiation interactions that occur in a detector over a certain period of time, is the simplest fundamental measurement. This measurement is expressed in cps (counts per second) or cpm (counts per minute). Although the count rate is commonly expressed in dps (disintegrations per second) or dpm (disintegrations per minute), this is not a genuine count rate. The efficiency of the detectors has been taken into consideration in measurements reported in dps or dpm in order to estimate the genuine disintegration rate.

1.4.2 Exposure

All exposures to ionizing radiation carry a risk to human beings, although this risk decreases as the exposure decreases. Natural background radiation poses a very low risk. The risk is slightly higher for workers in some occupations, such as miners and medical radiographers. Depending on the nature of the incident, the type of radiation involved, and even weather patterns, exposure levels as a result of a nuclear or radiological catastrophe can vary dramatically.

There are a number of factors that must be taken into consideration in calculating the quantity, or dose, of radiation a person has received, including

- The nature of the ionizing radiation,
- The strength of the source,
- The biological sensitivity of the area exposed, and
- Exposure factors such as time, distance, and shielding from the source.

The amount of electric charge produced by photons in a mass of air is measured as exposure. The electric charge is generated by ion pairs, which are collected by the detector and quantified as a current. For sources that generate radiation continuously, it can be assessed as a rate (exposure per unit time), or as a total integrated exposure for sources that emit radiation in a single pulse, such as x-ray tubes.

The roentgen is the typical exposure unit (R). At standard temperature and pressure, 1 R is the quantity of radiation necessary to liberate one electrostatic unit of charge (of either sign) in 1 cm^3 of air (STP). This translates to 2.08 x 10^9 ion pairs. 1 R = 2.58 x 10^{-4} C/kg in SI units.

1.5 RADIATION DOSE AND ITS UNITS

Radiation has the potential to cause damage to living tissue, and the amount of energy deposited in living tissue is measured in dose. Dose quantities are stated in a variety of ways depending on how much of the body and its components are irradiated, whether one or many people are exposed, and how long the exposure lasts (e.g., acute exposure).

1.5.1 Absorbed Dose

The energy deposited in a substance by all sources of radiation is measured by the absorbed dose. The rad (radiation absorbed dosage), which is equal to 100 ergs/gram, is the customary unit. The gray (Gy) is the SI unit for absorbed dosage, equal to 1 joule/kg. 100 rads = 1 Gy.

1.5.2 Equivalent Dose

The "equivalent dose," which considers the nature of radiations, is a refinement of the absorbed dose, which was initially used in the history of radioprotection and nuclear medicine to measure the energy deposited in the human body by radioactive or X-ray sources. In 1920, the first absorbed dosage unit was established. The 'rad,' a unit worth 100 rads, has subsequently been replaced by the gray. Doctors care about the quantity of grays or milligrays absorbed by an organ or tissues in radiotherapies and nuclear treatments.

However, in the field of radioprotection, the idea of absorbed dose quickly proven to be insufficient. In the 1950s, it was discovered that a 'gray' of neutrons was 10 times more carcinogenic than a 'gray' of photons after exposure to both. As a result, the absorbed neutron dose had to be multiplied by ten to produce a new, more useful quantity known as the 'equivalent dose.'

The equivalent dose is calculated by multiplying the absorbed dose for an organ or body part by a weighting factor, which considers the nature of the radiations (such as whether they are made up of photons, electrons, neutrons, or alpha particles) as well as the severity of the biological damage they cause. The rem, which is comparable to the rad, was the first equivalent dose unit. The former measure for equivalent dose, the 'rem,' has been replaced by the sievert, which has a value of 100 rems.

The weighting factors are based on empirical values that reflect current radioprotection knowledge and may be improved in the future. For example, they overlook an important factor: the dose rate, or the number of grays absorbed per second. Photons and electrons, which are less ionising, are the least harmful particles.

1.5.3 Effective Dose

The "effective dose" is a biological dose that is often used in radioprotection to estimate how damaging a person's radiation exposure can be. It considers not only the nature of the incoming radiation, but also the sensitivity of the afflicted bodily parts. The sievert is the same unit that is used to measure the equivalent dose absorbed locally by an organ, a gland, or any other area of the body. This effective dose is what we're interested in in the subject of radioprotection, even though the equivalent dose is what matters in medicine. The radioprotectionists' unwise decision to utilise the same unit for both dosages makes it difficult for non-experts to understand these tissues.

The effective dose's goal is to offer a dose that is appropriate for the entire body. This entails considering how each area of the body has been exposed and how sensitive it is to radiations: a gray absorbed in the thyroid would contribute significantly more than one absorbed in a muscle. As a result, each organ's 'equivalent dose' is multiplied by a sensitivity factor - a weight - that reflects its relevance. The effective dose is then determined by combining all of the weighted equivalent doses together.

The sum of the sensitivity or weight factors is 1. These parameters are standardised so that the effective dose (in sieverts) obtained by an individual receiving a uniform gamma exposure is equal to the absorbed dose (in grays). The equivalent doses used to compute effective doses describe the quantity of energy deposited per unit of volume in an organ or tissue and are unaffected by the organ or tissue's size. Valid comparisons between dosages received by people of different sizes or ages, such as a baby and an adult, can be made if the weighting parameters are accurately defined. Global exposures of various natures or origins can also be compared using effective dosages.

Doses range from a few sieverts to a fraction of a millisievert (mSv). Strong doses of the order of a sievert are considered effective. They have major "deterministic" consequences, which can be fatal. The effects may or may not show at lesser doses. It is the possibility of their occurrence, not their severity, that is affected by the dose. Probabilistic effects are what they're termed. In some aspects, the effective dose is a weighted average of an individual's local equivalent doses.

1.6 PATHWAYS OF RADIATION EXPOSURE

The various ways by which a person can be exposed to radioactive material are known as radiation exposure pathways. The effective dosage of one Sievert causes a 5.5 percent chance of acquiring cancer (ICRP, 2009) and this amount includes both internal and exterior radiation doses. Hence it is important to estimate the dose from radiation exposure and to calculate health risk. Depending upon the intensity of radiation exposure, it is classified into mainly as occupational and public exposure.

Occupational exposure to ionizing radiation can occur in a range of industries, in mining and milling, in medical institutions, in educational and research establishments and in nuclear fuel cycle facilities. The term ‘occupational exposure’ refers to the radiation exposure incurred by a worker which is attributable to the worker’s occupation and received or committed during a period of work. According to the latest report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000), an estimated 11 million workers worldwide are monitored for exposure to ionizing radiation. They incur radiation doses which range from a small fraction of the global average background exposure to natural radiation up to several times that value.

Public that is being exposed to radiations in normal environment is also a matter of concern. There are mainly two types of pathways of exposure in which human beings are exposed that is internal and external exposure.

1.6.1 Internal Exposure

When radioactive nuclides are inhaled and absorbed by our bodies, this is known as an inhalation exposure. Radioactive contaminated dust particles and some gaseous radionuclides, such as radon, are the most common sources of inhalation. Radionuclides and their progeny can easily bind to dust particles in the air and enter the lungs by inhalation. These contaminated dust particles are alpha emitters, which collect mostly in the tracheobronchial and pulmonary regions of the lungs. When these radionuclides or their offspring produce alpha particles, a huge quantity of energy is delivered to the tissues, damaging DNA and raising the risk of lung cancer. As long as these radionuclides are present in the lungs, this type of exposure persists. Chronic exposure comes from the accumulation of small amounts of radionuclides present in the human body over a lengthy period and is referred to as long term exposure. According to a UNSCEAR report from (2000), the global average annual radiation exposure from radon inhalation is 1.2 mSv.

When radioactive nuclides are consumed by our bodies, we are exposed to them through ingestion. These radioactive nuclides are all alpha, beta and gamma emitters, which means they release a lot of energy into tissues, causing stomach cancer and kidney damage. The following are the main sources of dietary exposure by which radionuclides enter human bodies:

- Consumption of radioactively contaminated groundwater.
- Food plants that have been grown on radioactive soil.
- Use of contaminated water to irrigate crops.
- As a result of the widespread use of nuclear therapies.

The worldwide average annual radiation dosage owing to the intake of food and drinking water is 0.3 mSv, according to UNSCEAR assessment from (2000).

1.6.2 External Exposure

External exposure occurs when radiation emitted from an external source and penetrates our bodies. The effect of exposure to different kind of radiations depends upon ionizing and penetration power. Alpha particles rarely penetrate the outer dead skin of the body due to their low penetrating power. Beta particles have a far lower penetrating power than gamma radiation. As a result, the beta particles do not pass through the skin. Some beta particles with high energy might cause injury to the skin or eyes. Because of their tremendous penetration power, X-rays, gamma rays, neutrons and cosmic radiations are the key concerns for external exposure. The gamma rays emitted by terrestrial radionuclides can infiltrate our bodies and raise the risk of cancer. X-rays are commonly used to expose the abdomen region, which can raise the risk of genetic harm, which may be hereditary. X-ray radiation is also connected to high blood pressure and heart disorders.

Exposure to external radiation may be controlled by limiting the working time in the radiation field, working at a distance from the source of radiation, inserting shielding between the worker and the source, and by using no more radioactive material than necessary.

1.7 EFFECTS OF IONIZING RADIATIONS

Ionizing radiations has sufficient energy to affect the atoms in living cells and thereby damage their genetic material (DNA). If the damage is not repaired correctly, a cell may die or eventually become cancerous. Various studies have been conducted including pooled studies that shows the hazardous effects of ionizing radiations on human body or tissue. These radiations may affect lungs, kidney, liver, GI Track, bones by damaging the cells or genetic material, which eventually leads to lung, stomach, prostate cancer or may cause cardiovascular diseases. Depending upon the energy, type, duration these effects have been broadly classified into stochastic and deterministic effects which are explained below.

1.7.1 Stochastic Effect

When a modest dose is given over a lengthy period, a stochastic health effect occurs. As a result, it's also known as the low-level long-term exposure effect. There is no lower critical value for the stochastic health effect. The probability of a stochastic health effect depends on the dose consumed. The damage caused by this impact is depending on the kind of tissue, i.e. whether the tissue is more or less sensitive, and is independent of the absorbed dose. According to the statistics, the risk of cancer in the United States is predicted to be 20% for non-radiation workers and 21% for those who are routinely exposed to radiation. There have been few genetic impacts reported in Japanese atomic bomb survivors who were exposed to far higher levels of radiation than their average exposure. As a result, if humans are directly exposed to radiation, genetic impacts are unlikely to rise. Cancer, leukaemia, and other cacogenic health effects fall within the area of stochastic health effects.

1.7.2 Deterministic Effect

When a significant dose is given for a short period, a non-stochastic health effect arises. The acute or deterministic effect is another name for it. Lower critical values exist for non-stochastic health effects, below which the effect does not occur. The amount of the absorbed dose is directly related to the extent of the non-stochastic health effect. For the lens of the eyes, the ICRP (1990) established a threshold dose of 150 mSv (one single absorption). The lens of the eyes is safe below the threshold value, but when the dose exceeds the threshold value of 150 mSv, lens contraction occurs. When a radiographer comes into touch with a high-intensity radiation emitter, skin burning can occur. Non-stochastic health effects are non-cancerous and can be noticed in an hour or days. Non-stochastic health effects include hair loss, skin burns, central nervous system damage, and bone marrow illness.

The biological effects of low amounts of radiation exposure are so minor that they may go undetected. The body contains systems to heal the damage caused by both radiation and chemical carcinogens. As a result, the biological effects of radiation on living cells may result in one of three outcomes:

(1) injured or damaged cells repair themselves, leaving no residual damage.

(2) cells die, much like millions of body cells die every day due to normal biological processes.
(3) cells repair themselves incorrectly, resulting in a biophysical change.

The majority of studies on the link between ionising radiation and cancer formation are based on populations exposed to high levels of ionising radiation. Leukaemia, breast, bladder, colon, liver, lung, oesophageal, ovarian, multiple myeloma, and stomach cancers are all linked to high-dose exposure. Ionizing radiation may also be linked to prostate, nasal cavity/sinuses, pharyngeal and laryngeal cancers, and pancreatic cancer, according to the literature.

The latent period is the time between exposure to radiation and the discovery of cancer, and it can last many years. Cancers that develop as a result of exposure to radiation are indistinguishable from cancers that arise spontaneously or as a result of exposure to other carcinogens. Other chemical and physical risks, as well as lifestyle variables (such as smoking, alcohol consumption, and food), have been shown to have a substantial role in many of these disorders.

1.8 RADIATION PROTECTION AND MONITORING

Large doses of ionising radiation have long been known to cause tissue damage in humans. Scientists became increasingly concerned about the possible harmful effects of exposure to huge quantities of radiation as more was learnt over time. The need to limit radiation exposure led to the development of several expert organisations to evaluate what should be done. The International X-ray and Radium Protection Committee, an independent non-governmental organisation of professionals in the subject, was founded in 1928. The International Commission on Radiological Protection was later renamed (ICRP). Its goal is to define basic principles for radiation protection and make suggestions.

National regulations governing the exposure of radiation workers and members of the public are based on these concepts and guidelines. Atomic Energy Regulatory Board (AERB), Radiation Protection and Advisory Division (RPAD) and Board of Research in Nuclear Sciences (BRNS) in India are regulating the guidelines and safety limit for protection from radiations.

The International Atomic Energy Agency (IAEA) has also incorporated them into its Basic Safety Standards for Radiation Protection, which was issued in collaboration with the World Health Organization (WHO), the International Labour Organization (ILO) and the OECD Nuclear Energy Agency (NEA). These guidelines are used all around the world to assure the safety of radiation workers and the general public.

In 1955, the United Nations General Assembly established the UN Scientific Committee on the Effects of Atomic Radiation (UN Scientific Committee on the Effects of Atomic Radiation or UN Scientific Committee on the Effects of Atomic Radiation or UN Scientific Committee on the Effects of Atomic Radiation or UN Scientific Committee on the (UNSCEAR). The fundamentals of radiation protection are the same all across the world. Any exposure above natural background radiation, according to the ICRP, should be maintained as low as reasonably possible, yet within individual dose limits. Individual exposure limits for radiation workers are 100 mSv per year averaged over 5 years, and 1 mSv per year for the general population. These dosage limits were calculated using a conservative method, assuming that there is no level below which there is no effect. It means that any additional dose will raise the likelihood of a health consequence proportionally. In the low dose range, where the dose limits have been defined, this association has yet to be established.

The annual radiation dosage received by members of the general population in many high natural background radiation places across the world is several times higher than the ICRP dose limit for radiation workers. The number of people exposed is too little to expect epidemiologically detectable increases in health impacts. However, just because there has been no indication of an increase thus far does not imply the risk is being completely ignored.

Individual doses should be kept as low as reasonably practicable, according to the ICRP and the IAEA, and consideration should be given to the presence of additional sources that may cause simultaneous radiation exposure to the same group of people. Allowance must also be made for future sources or behaviours so that the total dose received by a single member of the public does not exceed the dose limit.

1.9 NATURAL RADIOACTIVE ELEMENTS: RADON/THORON AND THEIR PROGENY

The goal of this investigation is to determine the concentrations of radon, thoron and their progeny in the environs of Northern Rajasthan. These radionuclides have been found in the earth's crust since the planet's formation. People are exposed to terrestrial radiations which are present as a result of radioactive decay of these radionuclides in the form of alpha, beta and gamma radiations and exposure to these radiations is matter of concern due to hazardous health effects in the humans. Both uranium and thorium start a chain of radioactive progeny and eventually disintegrate into a stable lead. The concentrations of radionuclides is influenced by the geological and geographical conditions of the place and thus causes variation in the radiation doses (Radhkrishna et al., 1993; Quindos et al., 1994; UNSCEAR, 2000). The basic details of these radionuclides has been discussed below.

1.9.1 General Information

The discovery of radon came soon after the Curies discovered radium in 1898 (Kolthoff et al., 1966). The Curies discovered that when air comes into contact with radium compounds, it forms an electrical conductor. In 1900, Dorn demonstrated that this phenomenon was caused by radium emanation and Rutherford verified that thorium compounds emitted a comparable emanation as well. This element was given the name "Radon" by the International Committee on Chemical Elements in 1923. Ramsay and Rutherford investigated the chemical properties of radium as well as the spectrum that it emits. Soddy and other scientists discovered that radon is chemically similar to inert gases and belongs to the argon group. Elster and Geitael, (1901) were the first to notice radon in the free atmosphere, followed by Gish, (1951). Radon is a harmless gas that can be found in its basic form as a gas or dissolved in water. The three natural isotopes of radon i.e. 222Rn from 238U, 220Rn from 232Th, and 219Rn from 235U are available as radioactive decay products are produced by radium alpha emission in the each decay chain. Their half lifetimes are 3.82 days, 55.6 seconds and 3.96 seconds, with an average or mean life of 5.51 d, 80.2 s, and 5.71 s. respectively.

In thoron (Rn-220) decay chain, the first daughter, Po-216, decays so quickly (mean life 0.22 s) that it takes the place of 220Rn. Then comes the Bi-212 with mean life of 15.2 h, which is long enough to be transported primarily from the bronchial sections of the lungs and get deposited at sites of stagnation found at bronchial bifurcations. Its principal health effect occurs because of emitted alpha particles.

Despite the fact that both radon and thoron are prevalent in the atmosphere, most studies disregard the latter due to its short half-life. Thoron, on the other hand, may not be negligible in all conditions, particularly in areas with thorium-bearing sediments, often known as High Background Radiation Areas (HBRAs). Monazite-bearing sands in Kerala, India, and parts of Yangjiang, China, are examples of such places, where thoron concerns may not be minor. Hence, these make a natural study group for investigating the effects of thoron exposure for the general public residing in these areas. As a result, various large-scale research projects have been launched in these areas to address the thoron problem in a systematic manner (Mayya et al., 2012; Ramola et al., 2012). Furthermore, India's future nuclear power programme based upon the use of thorium waste fuel, the thoron problem will be of particular importance. This emphasises the growing concern about thoron exposure, which may not be inconsequential in the global perspective, particularly in countries like India.

The large disparity in half-lives between Rn-222 (3.8 days) and Rn-220 (55 sec) plays a vital role in their emanation, their distribution in the free atmosphere above the ground, and indoor air dwellings. Polonium, Bismuth, Lead, and Thallium are the decay products of radon/thoron produced by the emission of alpha, beta and gamma rays. Radon decay products are categorized into two groups: "short-lived" radon daughters with half lives less than 30 mins. such as Po-218 (3.05 min), Pb-214 (26.8 min), Bi-214 (19.7 min) and Po-214 (164 s) and "long-lived" Radon daughters with half lives greater than 30 mins., such as Po-210 (138.4 days), Bi-210 (5.01 days), Pb-210 (22.3 years). There is no long-lived Rn-220 daughter group. However, as compared to the short-lived radon decay products, the thoron decay products have a longer half-life. The lead isotope Pb-212, of thoron with half life of 10.6 hours, is the most important radionuclide in this chain. Figure 1.5 shows the decay series of uranium and thorium with half-lives and various emitted radiations during decay, as well as the energy of the emitted particle, for both 222Rn and 220Rn decay products.

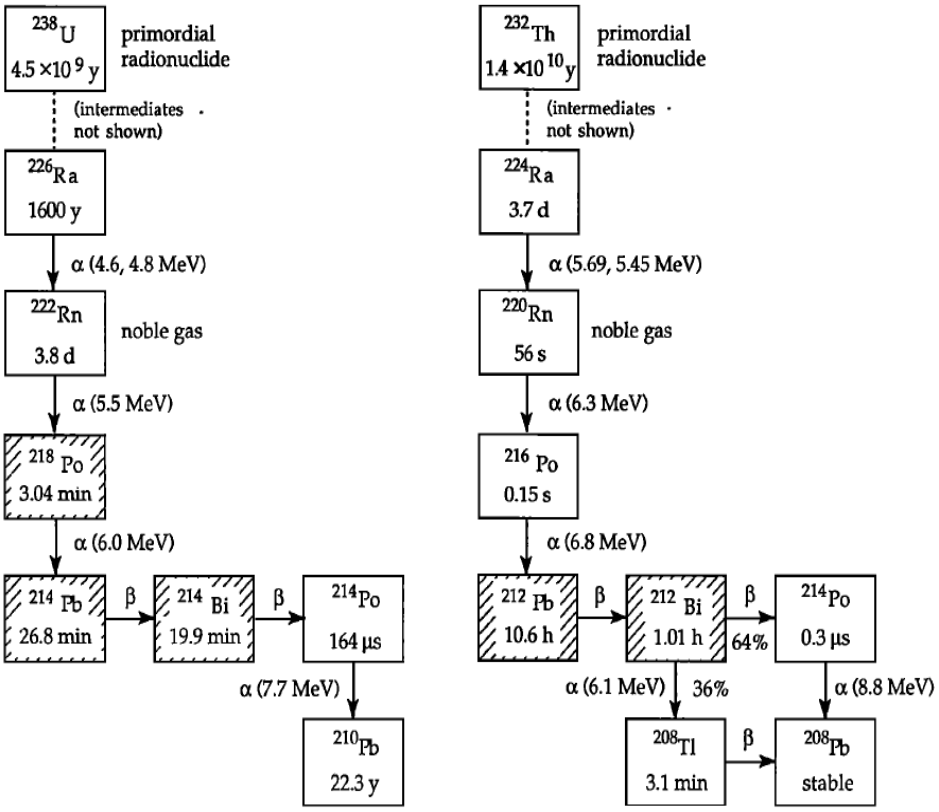

Figure 1.5: Uranium and thorium decay series

1.9.2 Occurrence

Radionuclides such as radon (Rn-222) and thoron (Rn-220) from the uranium and thorium decay series are produced by the decay of their immediate respective parent nuclides Ra-226 and Ra-224. Radon, as a gas, flows freely in the environment. Radon is produced by minerals and certain rocks and gets accumulated into the soil and air around these sources. There are different ways by which the radon enters the air from the soil like emanation from the mineral grains, diffusion from the pore space within the soil or with the flow of air or with air ambient gases for e.g. CO_2 and CH_4 or water moving in the soil horizons. 90% of radon emanated from radon source is transported by diffusion with normal moisture content (UNSCEAR, 1982). The transport distance for thoron is insignificant because of its short half life i.e. 55.6 seconds. Occurrence of these radionuclides in the indoor air, outdoor air, soil and water has been discussed below.

1.9.2.1 In Indoor Air. The typical emanation of radium from the earth's surface, which is further dependent on the uranium/thorium concentration in the material, is one of the principal sources of radon/thoron in the atmosphere. The immediate parent radium in the site's ground and the construction, components are the primary source of indoor radon/thoron (Nero, 1988 & 1989). Through the ventilation, the outdoor air contributes to the indoor radon concentration. With a few exceptions, tap water and household gas supplies are mainly modest radon sources. Some of the radon can also escape from water and add to the inhalation dose due to radon already present in the environment. Radon is emitted from the water and mixes with the interior air in numerous settings, including showering, washing clothing, and flushing toilets (Figure 1.6). The increasing concern about the quality of drinking water across the world has led to setting up of different standards and regulations for the control of various pollutants in it. Considering the potential health risk of radon in water, regulations have been set for it too.

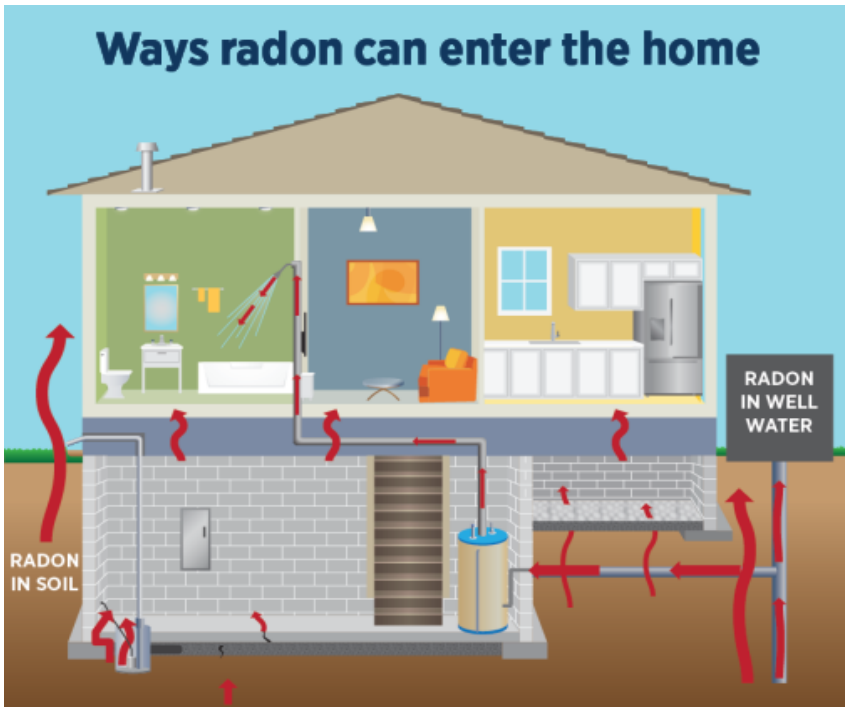

Figure 1.6: Migration of radon into indoor environment
(Reducing the Risk from Radon: Information and Interventions A Guide for Health Care Providers. Publication No. E-18-2.)

Natural sources include emissions from the earth's crust's soil, rocks, and ore bodies, as well as, to a lesser extent, emissions from various building materials such as

bricks, cement, tiles, and so on (UNSCEAR, 2000). Radon exhalation is influenced by parameters such as the fraction of radon produced that is released from the material, its porosity, and the surface preparation and polish of the walls, in addition to the radium concentration. Radium levels may be substantially higher in building materials containing by-product gypsum (UNSCEAR, 1982) and concrete containing alum shale. Clay bricks contains typically 1.4 ppm of radium whereas granite bricks has an elevated concentration of 2.4 ppm (Hamilton, 1971). If the raw materials were taken from areas with high levels of natural radioactivity, the activity concentrations in brick and concrete could be significant as well. The principal sources of thoron in indoor air are building materials. Thoron produced in the soil is effectively prevented from entering buildings due to its short half-life (55 s) and so has a low contribution to indoor thoron levels.

1.9.2.2 In Outdoor Air. The concentration of radon in outdoor air is primarily influenced by atmospheric pressure and follows a normal fluctuating temporal pattern, with greater levels at night. Soil and water are two main sources by which radon concentration is influenced in outdoor. Radon reaches environment from matrix of soil and building materials through emanation and exhalation processes (Sapra et al., 2016; Pyngrope et al., 2021). The first stage is emanation from building materials, in which radon escapes from solid mineral grains to air-filled pores and in second stage it is exhaled from the matrix, in which radon gas transports from air-filled pores to atmosphere. The amount of radium activity in the subsoil and its permeability to airflow determine the possibility for radon entrance from the earth. Alum shales, some granites, and volcanic rocks, have a high radon potential due to high radium concentrations and the existence of eskers, all of which are characterised by high permeability. The primary mode of radon entrance from the soil is pressure-driven flow, with diffusion playing a minor part (Meijer et al., 1992). The air pressure difference between soil and outdoor air, the tightness of the surfaces in contact with the soil on the site, and the radon exhalation rate of the underlying soil are all factors that influence the amount of the influx in outdoor air.

The second most important contributor to outer radon is emanation from ground water sources. Ground water in contact with crustal rock penetrates into the pores and voids present in the rocks and soils and dissolves radon that emanates into these spaces following ^{226}Ra decay. Radon is very soluble in water (Misdaq et al.,

2000). The level of radon in drinking water is primarily determined by two variables. i.e. the geologic characteristics of the area and the type of water supply. Radon is released from water when: (i) pressure is reduced; (ii) temperature is raised; (iii) water is aerated; and (iv) plants draw up groundwater (NCRP, 1984). In case of country like India the presence of radon in water assumes a greater significance as most of the daily water requirement of the body is met by direct consumption of drinking water. This water frequently passes through rock containing natural uranium, releasing radon into the water. Radon concentrations in groundwater are typically substantially higher than in surface water such as lakes and streams. Radon is produced by natural radioactive decay of radium, present in the lithosphere. It enters into water as a result of diffusion and dissolution from the rocks and other materials in its contact or by decay of radium dissolved in water from surrounding earthen material and to a lesser extent from dissolution of radon present in air in its contact (Andrews and Woods, 1972; Tanner, 1980; Bonotto and Caprioglio, 2002).

1.9.3 Radiological Significance

Radon, thoron, and their progeny in natural environment supply more than half of the doses to the human population. The International Agency for Research on Cancer has classified radon as a human carcinogen (IARC, 1988). The health risks of radon and thoron are mostly related to the short-lived daughters that can be ingested, rather than the isotopes themselves. Radon gas decays into various radium-series solid particulate radioactive nuclides. These radioactive particles are breathed and become trapped in the lungs, exposing the person to further radiation.

There are shreds of evidence of adverse effects due to radon even before its discovery. In the sixteenth century a large number of workers' deaths in mines of Eastern Europe attracted the attention towards the existence of some gases (Agricola, 1556). Lung cancer has been associated with inhaling high cumulative amounts of 222Rn and in particular, its α-particle-emitting decay products (ICRP, 1987; BEIR IV 1999). Harting and Hesse (1879) discovered a considerably increased lung cancer risk among miners around 125 years ago, which became known as "Schneeberger Berkrankheit" (Schneeberger mountain sickness). Ludewing and Lorenzer (1924) hypothesised 45 years later that the high lung cancer incidence in the Schneeberg mines may be due to radon concentrations ranging from 10^3 Bqm^{-3} to $5x10^4$ Bqm^{-3}. In certain

investigations of 222Rn in households, exposure to lower levels of 222Rn has been linked to lung cancer (Lubin' 1997). A recent study of European case-control studies (Darby et al., 2005) suggests an increased risk of lung cancer of about 8% (3–16%) per 100 Bqm^{-3} of 222Rn concentration, which is consistent with an estimate of 11 percent (0–28%) obtained in a combined review of North American studies (Krewski et al., 2005).

The United States Environmental Protection Agency (USEPA) estimates that radon in drinking water causes about 168 cancer deaths per year, with 89 percent of these deaths due to lung cancer caused by breathing radon released into the indoor air from water and 11 percent due to stomach cancer caused by consuming radon-containing water, according to a National Academy of Science report (USEPA, 1999). In United States alone, radon is responsible for about 21,000 lung cancer deaths annually. About 2,900 of these deaths occur among people who have never smoked (Poulopoulo, 2016). According to an approximation, Radon is estimated to cause 1100 deaths per year in the United Kingdom (Milner et al., 2014) and 300 cases of lung cancer in Ireland every year can be linked to radon (Dowdall et al., 2017). If the concentration of radon and physicochemical parameters in drinking water are higher than permissible limit, leads to water borne diseases such as fluorosis, typhoid, jaundice, cholera etc. (WHO, 1991; Reddy et al., 2017) and also lead to a significant risk of stomach and gastrointestinal cancer (Kendal et al., 2002; Srinivasa et al., 2019). The ingestion of radon bearing water results in radiation exposure to tissues and organs of digestive system, leading to an enhanced risk of stomach and gastrointestinal cancer (Ye et al., 1998; Auvinen et al., 2005).

Based on these findings, it is now widely assumed that inhalation exposure to these radioactive species is the second most major cause of lung cancer after smoking (WHO, 2009). These results, as well as the WHO's observation, have reignited interest in radon research in a number of countries, and have cast doubt on the need to develop various control mechanisms to reduce radon concentrations in the environment, and therefore exposure. This can be accomplished by identifying various sources of these gases, researching their emission mechanisms, and creating tools to measure and minimise their emissions into the environment.

Considering the importance of these radiations, investigations have been carried out in different parts of India and abroad to measure the radionuclides level and hence to determine the radiological hazards associated with them. In India Atomic Energy

Regulatory Board (AERB) is looking into the regulation of radiation protection in the country. Bhabha Atomic Research Centre (BARC), Mumbai, India has undertaken various research projects to monitor Radon, Thoron, and their decay products in the environment. Many research groups are working for many years to study radiation levels throughout the country for radon mapping, associated health risk affects and to find high background radiation areas.

Although good amount of data related to these studies is available for some of the regions in India but the data is still scarcely available for the studied area of Rajasthan. Hence to get the accurate authenticated data, the present investigation has been conducted under a three years research project sanctioned by BARC, Mumbai, India with indigenously developed instruments. The study has been carried out for one year in each of the three districts for the measurement of natural radioactivity in air, water and soil in Hanumangarh, Sri Ganganagar and Churu district respectively.

1.10 STUDY AREA

In the present investigation to find natural radiation levels, three northern districts Hanumangarh, Sri Ganganagar and Churu of Rajasthan have been selected as shown in Figure 1.7. The study area has longitude and latitude are 72.2’ to 75.5’ and 28.17’ to 32.24’ respectively. The region is irrigated by Gang canal and Bhakra canal tributaries. There are mainly three types of soil structures found in the studied area, namely yellow - brown soil, black soil, red loam soil. Due to rainfall less than 400 mm, texture is sandy loam, is contains a high percentage of soluble salt and have high pH value. It experiences low, erratic and spotty rainfall, high temperature with large variations. Soils vary widely with respect to morphology, lime and silica content. The area is covered by windblown isolated sand and alluvium except for a few patches of recent calcareous and sandy sediments associated with gypsite. The oldest rocks of the area belong to Aravali Supergroups, which includes phyllite, shale and quartz vein. These are overlaid by the rocks of upper Vindhyan which are entirely made up of bright to pale red, fine and medium grained compact sand stone and siltstone. The only major mineral occurrence of the district is gypsite. The higher thorium rich contents in rocks in the Northern portion of India (Ramchandran et al., 2009; Prajith et al., 2019; Gusain et al., 2009).

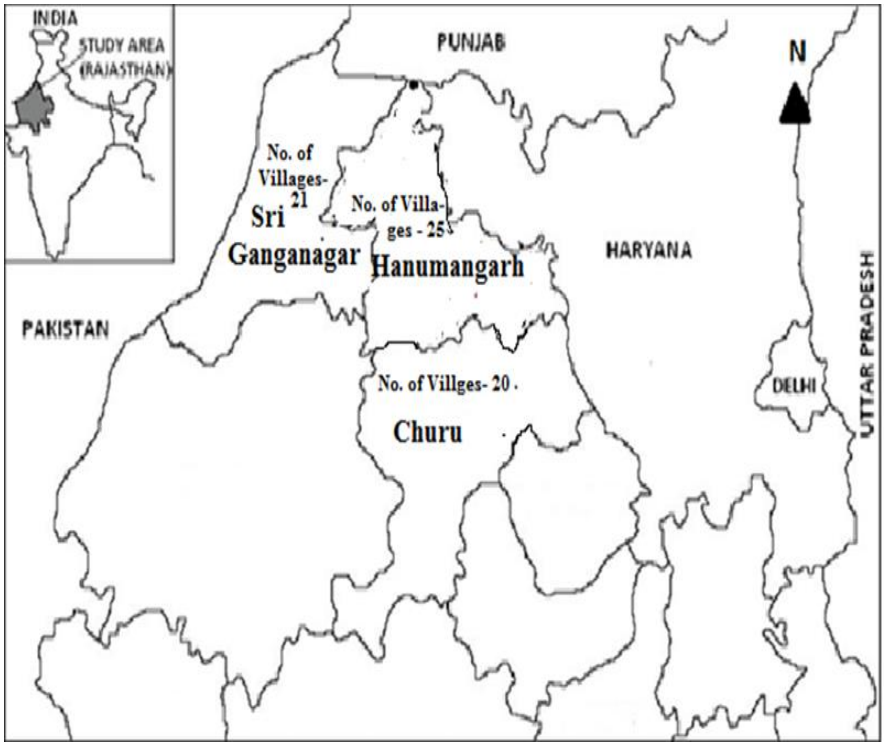

Figure 1.7: Map of study area (Hanumangarh, Sri Ganganagar and Churu districts)

The water used for drinking is predominantly derived from both groundwater as well as surface water. The Ghaggar River, which is the only river in the district, is ephemeral in nature. However, the Indira Gandhi canal network, which was constructed to bring the water from perennial Himalayan rivers flowing through Punjab to the arid regions of Rajasthan, takes care of the water needs of the area. In case of groundwater, it occurs both under water table and in confined aquifers. The principal aquifer in the district is alluvium comprising sand, silt, clay, and gravel. Its thickness varies from 100m to 400m. The bed rock below alluvium is made of Palana or Nagaur series of rocks, consisting of mudstone, sandstone and basal evaporations sequence. The thickness of water table aquifer varies from a few meters to about 80m. Deeper confined aquifer is found both in the alluvium and in underlying Palana and Nagaur rocks. The first confined aquifer is encountered at depths ranging from 80 to 100m (Central Ground Water Board (CGWB), 2013).

The public water supply schemes in both urban and rural areas primarily depend upon surface water source from the canal system. Groundwater derived from tube wells and bore wells is main source of drinking water for majority of households in rural areas

as also in a number of households in urban areas. Urban areas of Hanumangarh and Pilibanga also have water supply schemes from groundwater.

1.11 OBJECTIVES

The objectives of the present work include monitoring of radioactive radon, thoron, and their progeny in the indoor and outdoor environment viz., soil, air, and water samples in the three Northern districts of Rajasthan, India.

The main objectives are as follows:

1. To measure the radon, thoron gas concentration using passive techniques of time-integrated monitoring through pin-holes based radon/thoron discriminating twin-cup dosimeters in indoor environments for seasonal study.
2. To measure the level of radon/thoron decay products in indoor environments through DRPS/DTPS (deposition based direct radon/thoron progeny sensors) for direct Equilibrium Equivalent Concentrations (EEC) estimation and equilibrium factor (EF) studies.
3. To measure the attached and unattached fractions of radon/thoron decay products in indoor environments through wire-mesh capped DRPS/DTPS.
4. To measure level of radon in water sources by using Smart RnDuo monitor with water bubbler for ingestion dose analysis.
5. To measure radon-thoron mass and surface exhalation rate from soil samples and their correlation with indoor dwellings using mass exhalation chamber arrangement with Smart RnDuo monitor.
6. To calculate the annual effective dose received by population of the study area from the above measured value of radon/thoron for health risk assessment.