Chapter one

Introduction and Literature Review

1.1] Introduction

Natural radioactivity is wide spread in the earth's environment, it exists in soil, plants, water and air. Environmental natural gamma radiation is formed from terrestrial and cosmic source.

The exposure of human beings to ionizing radiation from natural sources is a containing and inescapable feature of life on earth. For most individuals, this exposure exceeds that from all man-made sources combine. There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust and are present every where in the environment, including the human body itself. Both external and internal exposures to humans arise from these sources. The natural radioactivity comes mainly from the ^{238}U, ^{232}Th decay series and natural ^{40}K, respectively [1].

The earth is continually bombarded by high–energy particles that originate in outer space. These cosmic rays interact with the nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic ray exposures that decrease in intensity with depth in the atmosphere, from aircraft altitudes to ground level. The cosmic ray interactions also produce a number of radioactive nuclei known as cosmogenic radionuclides, best known of these are ^{3}H and ^{14}C.

The average activities of ^{238}U and ^{232}Th in the undifferentiated earth crust are in the range of 25–50 Bq kg^{-1}, but due to their large ion radius, both elements may be especially concentrated in late crystallizing rocks such as granites and other alkaline magmatic ores, often accompanied by other incompatible elements like Rare Earth Elements (REE).

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Uranium is characterized by both radio toxicity and chemical toxicity, but it is the latter which limits its exposure to humans whereas thorium is to be considered as only radiotoxic [2].

The health hazards associated with these radionuclides stem from their ability to accumulate in human tissues. During the nuclear transformation processes, the radionuclides emit gamma rays as well as high charged particles, thereby causing intensive damage to the tissues where they are localized and, to a lesser extent on the neighbouring organs. Radionuclides of both the uranium and thorium decay series can be often present to a high degree in the materials occurring in frame of tin mining activities, which are then to be considered as TENORM ‘‘technologically enhanced naturally occurring radioactive materials’’.

Modern technology uses a lot of electrical and field energies. Mobile phones, phone masts, power lines, wireless networks are all human technologies that involve field-effects. All these technologies use the electromagnetic spectrum. All energy, in fact, exists somewhere on that spectrum, including visible light, micro waves, and dangerous high-energy gamma radiation. Some people fear the effects of electromagnetic radiation on the human body [3].

1.2] Types of Radiation

Radiation is a form of energy. There are two basic types of radiation. One kind is particulate radiation, which involves tiny fast-moving particles that have both energy and mass. Particulate radiation is primarily produced by disintegration of an unstable atom and includes alpha and beta particles.

Alpha particles are high energy, large subatomic structures of protons and neutrons. They can travel only a short distance and are stopped by a piece of paper or skin. Beta particles are fast moving electrons. They are a fraction of the size of alpha particles, but can travel farther and are more penetrating (Fig. 1.1) [4].

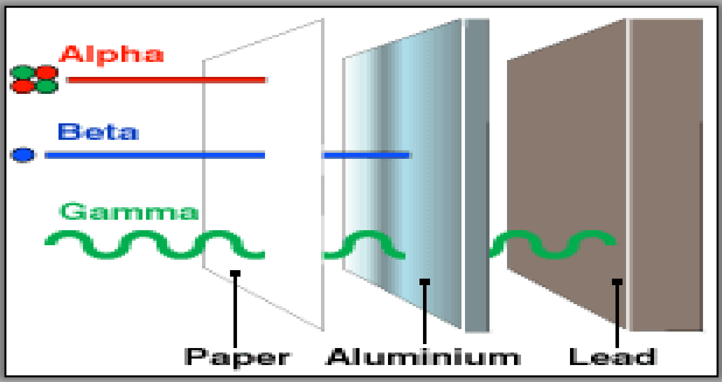

Fig. (1.1): Types of Radiation

Particulate radiation is of secondary concern to industrial radiographers. Since these particles have weight and are relatively large, they are easily absorbed by a small amount of shielding. However, it should be noted that shielding materials, such as the depleted uranium used in many gamma radiography cameras, will be a source of beta particles if the container should ever develop a leak. If a leak were to occur, the material could be transferred to the hands and other parts of a radiographer's body, causing what is known as particulate contamination. This is the reason periodic "leak" and "wipe tests" are performed on equipment.

The second basic type of radiation is electromagnetic radiation. This kind of radiation is pure energy with no mass and is like vibrating or pulsating waves of electrical and magnetic energy. Electromagnetic waves are produced by a vibrating electric charge and as such, they consist of both an electric and a magnetic component. In addition to acting like waves, electromagnetic radiation acts like a stream of small "pockets" of energy called photons. Electromagnetic radiation travels in a straight line at the speed of light (3×10^8 m/s) [5].

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1.3] Natural Radioactivity

Radioactivity surrounds us. Radioactivity is an integral part of our environment. All living beings have been exposed to a constant flux of natural radiation for as long as they walked the planet: to no negative effect.

Even the food we eat or the air we breathe contains radioactive elements – either formed thanks to the intervention of cosmic rays, or as old as the solar system itself. There is absolutely no escaping it: even we are radioactive. Eight thousand atoms of potassium- 40 or carbon- 14 disintegrate in our bodies every second [6].

The most powerful natural source of radioactivity is a rare gas known as radon. One of the products of uranium decay, radon is an ‘inert gas’ that can participate in no chemical reaction. This would seem to make it completely harmless, were it not for the fact that radon’s own radioactive decay produces gases poisonous to humans. The nature of the soil you live on, the construction tools used to build your house and the quality of its air conditioning are all crucial factors in determining radon exposure [6].

1.3.1] Cosmogenic Radioelements

The earth is constantly being bombarded by 'cosmic rays', highly energetic particles coming from the depths of space. These particles (known as primary) can be either electrically charged - with protons making up 86% of charged particles, alphas making up 13% and the remainder consisting of heavy nuclei - or neutral, in which case they primarily consist of photons and neutrinos (Fig. 1.2).

A primary cosmic particle which enters the earth's atmosphere gives rise to a shower of secondary particles. Collisions with nuclei of oxygen or nitrogen create some radioactive nuclei such as radiocarbon or tritium. Some of these secondary particles will reach the ground and hundreds of them pass through our bodies every second. This cosmic bombardment makes up a part of the natural radioactivity we are constantly exposed to them [7].

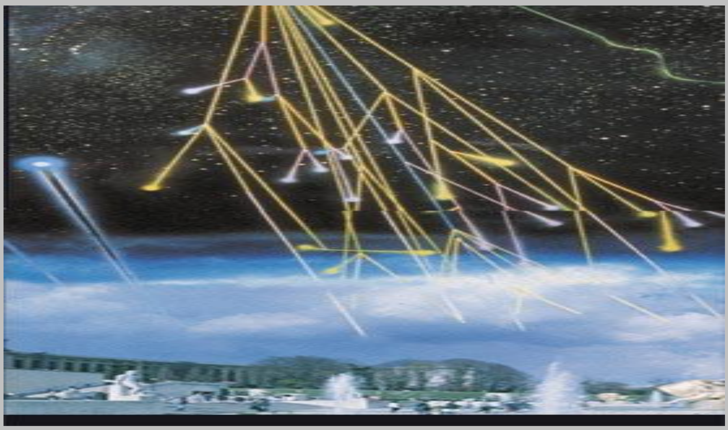

Fig. (1.2): Cosmic Rays Collisions

The energy of these cosmic rays varies enormously, as the variable magnetic field of the stars is capable of accelerating certain charged particles to energies of over 1 billion electron volts and much more. When these particles then approach the earth they are deflected by our planet's magnetic field, which serves as a giant shield against these extraterrestrial bombardments.

Upon entering the higher layers of the atmosphere the cosmic rays start colliding with nuclei, causing an explosion of pieces of subatomic shrapnel which in turn crash into other atoms. This chain reaction of collisions produces a host of 'secondary' particles, some of which will reach the earth's surface like muons (particles similar to electrons, but 200 times heavier and highly unstable) and neutrinos.

Muons interact little and does not produce radioactivity. Neutrinos, which are capable of passing unhindered through an object as wide as a star, very rarely produce any secondary particles[8] .

During the development of the shower of particles that follows the initial collision, many of the atomic nuclei in the atmosphere that serve as a target could be broken, protons and neutrons emitted. These neutrons can penetrate into the nuclei of other atoms, mainly oxygen and nitrogen, to make them radioactive. These radioactive nuclei, by products of cosmic radiation, are called cosmogenic.

One of these neutrons entering a nucleus of nitrogen from the air triggers the ejection of a proton or a proton bound to two neutrons (a tritium nucleus). In the first case, the nitrogen is transformed into radioactive carbon-14; in the second case the nitrogen is transformed into stable carbon-12 but is accompanied by radioactive tritium.

Among the “cosmogenic” nuclei created in these atmospheric collisions, some are radioactive: notably carbon-14, tritium, beryllium-7 and beryllium-10. Some of these decay rapidly whereas others, such as carbon-14 (created from nitrogen found in the air) live for longer. Molecules of this carbon-14 are therefore often absorbed by plants alongside ordinary carbon, meaning that all living matter contains traces of this radioisotope [9].

1.3.2] Natural Exposure

All exposure to radioactivity, whether natural or artificial, is measured in doses which take into account the biological effect the radiation can have. This is the effective dose, which has one given value for the whole body. For small amounts of radiation, the relevant unit is the thousandth of a sievert or millisieverts (mSv).

In a country like France or Belgium, the annual dose is calculated to be around 3.5 mSv per person in this first decade of the 21st Century. One hundred years ago that value would have been at 2.4 mSv [10]. This rise is largely due to the development of radiation techniques in medicine; as the doses of natural exposure have undergone no variation.

The high dose of radiation one receives in a medical scan is applied over a very short period of time. Exposure to natural radioactivity, however, is permanent. Spread over a period of days, months, years or decades, the chronic dose we absorb is fortunately comparatively low. The long time periods over which the absorption takes place also allows the cells of our body to repair the damage they undergo as a result [11].

Natural radiation comes from a variety of sources: the telluric radiation emitted by rocks (0.45 to 0.54 mSv), cosmic rays (0.30 to 0.36 mSv), from the body's own radioactivity (0.25 to 0.30 mSv) and, most significantly, from radon gas (1.0 to 1.2 mSv) [11].

A radioactive descendant of uranium which escapes from the rocks around us. Ranges are given rather than precise values because measurements of exposure levels vary depending on the body that carried them out or the period in which the tests were conducted.

Radon and its radioactive decay products are the principal contributors to the natural radioactivity we absorb. The radioactivity of the human body is mainly caused by the presence of two natural radioisotopes; potassium-40 and carbon-14 (which undergoes 8,000 disintegrations per second) [12].

In France, natural exposure is responsible for an average dose of 2 mSv. A part from our bodies' own radioactivity, the ratios of the other sources can vary dramatically depending on where we humans live in the world – without having to go the extremes of astronauts who absorb greater doses of cosmic rays or villagers in Kerala, who have greater exposure to telluric rays [13] (Fig. 1.3) .

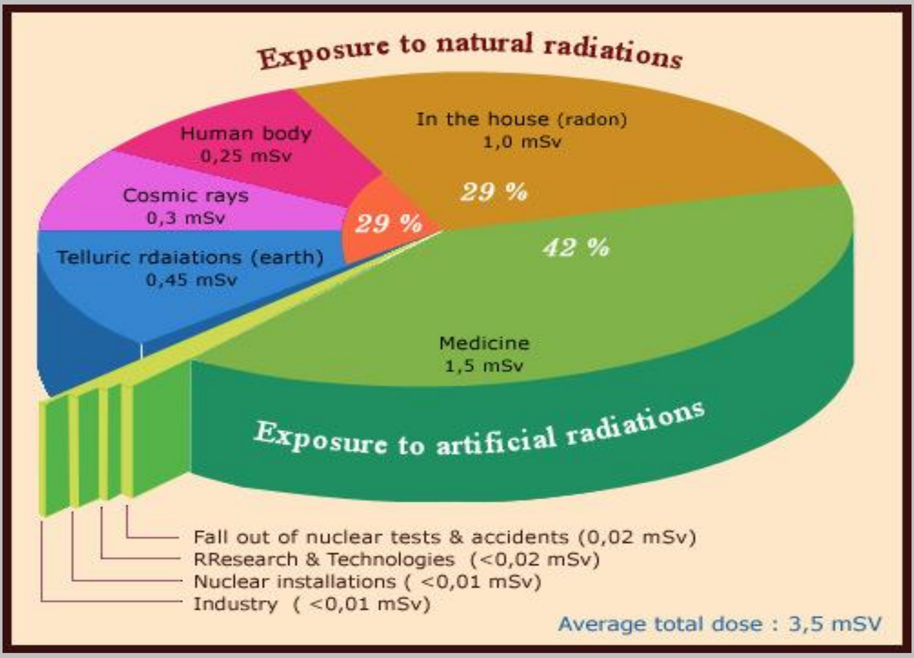

Fig. (1.3): Average Breakdown of Radiation Exposure in France.

1.3.3] Radioactive Activity (Strength) and Intensity

Different radioactive materials produce radiation at different rates and at different energy levels. The strength of a source is called its activity, which is defined as the rate at which the isotope decays. Specifically, it is the number of atoms that decay and emit radiation in one second.

The intensity of a radioisotope is related to the level of energy being given off and is a characteristic of the atomic structure of the material. Different elements have different intensities. A number of radioactive sources are used in industrial radiography. Two of the more common industrial gamma ray sources are iridium-192 and cobalt-60. These isotopes emit radiation in two or three discreet wavelengths [14].

1.3.4] Uranium-238 and Uranium-235 (A radioactive and strategic radioactive atom)

Uranium can be found in the earth's crust at 3 parts per million [15], particularly in granite and volcanic rocks. Certain uranium compounds (hexavalent ones) are highly soluble whereas others (tetravalent) are not.

As a particularly heavy element, uranium's isotopes are primarily alpha emitters, these radiations are often accompanied by the production of gamma rays [15].

Uranium -235 is the only natural nucleus that can easily undergo fission. Highly sought-after, it can be used as a fuel in nuclear reactors and as an explosive in atomic bombs.

The more abundant uranium-238 is sometimes called 'fertile'. Fission occurs comparatively rarely, and even under bombardment with energetic neutrons the probability of fission remains very low. What happens more frequently is that a neutron capture causes the nucleus to become unstable. After a few days, the uranium-239 has transformed into plutonium-239, a radioisotope with a half-life of 24,000 years. Plutonium-239 is highly fissile and can also be used as a nuclear fuel or an atomic explosive [16].

1.3.5] Plutonium-239

Plutonium-239, an artificial fissile nucleus, highly sought-after and feared. Plutonium, the ninety-fourth element in Mendeleyev's periodic table, is an artificial radioactive nucleus produced in large quantities by reactors when nuclei of uranium -238 capture an extra neutron apiece.

Plutonium-239 is primarily an alpha emitter, easily transforming into uranium-235, another readily fissile nucleus. The fission of a plutonium nucleus generates an average of 2.91 neutrons, even more than are emitted by uranium-235. Plutonium is therefore an ideal fuel.

Like all heavy atoms, plutonium is a chemical poison. More toxic even than uranium, plutonium is fortunately insoluble in its oxidized state and comparatively immobile. It enters the body through the respiratory more frequently than the digestive system, where it can attach itself to bones or organs like the liver or the lungs with a biological half-life of decades [17].

1.3.6] Thorium-232

Thorium is a naturally-occurring, slightly radioactive metal. It is found in small amounts in most rocks and soils, where it is about three times more abundant than uranium. Soil commonly contains an average of around 6 parts per million (ppm) of thorium.

Thorium exists in nature in a single isotopic form Th-232 which decays very slowly. The decay chains of natural thorium and uranium give rise to minute traces of Th-228, Th-230 and Th-234, but the presence of these in mass terms is negligible.

When pure, thorium is a silvery white metal. Glass containing thorium oxide has a high refractive index and dispersion and is used in high quality lenses for cameras and scientific instruments. The most common source of thorium is the rare earth phosphate mineral, monazite, which contains up to about 12% thorium phosphate, but 6-7% on average. Monazite is found in igneous and other rocks but the richest concentrations are in placer deposits, concentrated by wave and current action with other heavy minerals. Thorium recovery from monazite usually involves leaching with sodium hydroxide at 140°C followed by a complex process to precipitate pure ThO_2 [16].

1.3.7] Potassium-40

Potassium-40 is a curiosity of nature and a very long lived beta emitter. The potassium-argon method is frequently used to date lava flows whose age is between a million and a billion years. When an atom of potassium-40 decays into argon 40, the argon atom produced is trapped by the crystalline structure of the lava (Fig. 1.4). It can only escape when the rock is in its molten state, and so the amount of fossilized argon present in lava allows scientists to date the age of the solidification.

Fig. (1.4): Argon- 40, A gas Held Prisoner by Lava.

Potassium-40, an isotope that can be found in trace amounts in natural potassium, is at the origin of more than half of the human body's activity: undergoing between 4 and 5,000 decays every second for an 80 kg man. Along with uranium and thorium, potassium contributes to the natural radioactivity of rocks and hence to the earth's heat. This isotope makes up one ten thousandth of the potassium found naturally. In terms of atomic weight, it is located between two more stable and far more abundant isotopes (potassium -39 and potassium- 41) that make up 93.25% and 6.73% of the earth's total potassium supply respectively. With a half-life of 1,251 billion years, potassium -40 existed in the remnants of dead stars whose agglomeration gave rise to the solar system as we know it.

Potassium-40 has the unusual property of decaying into two different nuclei: in 89% of cases beta-negative decay will lead to calcium-40, while 11% of the time argon-40 will be formed by electron capture followed by gamma emission at an energy of 1.46 MeV [14].

This 1.46 MeV gamma ray is important, as it allows us to identify when potassium-40 decays. The beta electrons leading to calcium, however, are not accompanied by gamma rays, have no characteristic energies and rarely make it out of the rocks or bodies that contain the potassium-40. Beta-negative decay indicates a nucleus with too many neutrons, electron capture a nucleus with too many protons [16].

The very slow decays of potassium-40 into argon are highly useful for dating rocks, such as lava, whose age is between a million and a billion years. The decay of potassium into argon produces a gas atom which is trapped by the crystallization of lava. The atom can escape when the lava is still liquid, but not after the solidification. At that moment, the rock contains a certain amount of potassium but no argon. After a single disintegration, the trapped gaseous argon accumulates very slowly. Measuring the amount of argon-40 formed since the solidification of the lava allows for an accurate measure of the rock's age [17].

1.3.8] Radium-226

The new element was christened radium, found to have 88 protons and a variety of isotopes. The most important of these, radium -226, is an alpha and gamma emitter with a half-life of 1600 years. Traces of radium-226 can be found in uranium ore – of the order of one atom per three million. This particular radioisotope is the fifth radioactive descendant of uranium-238, which in turn transforms into a radioactive noble gas, radon-222, with a half-life of 3.8 days.

The uranium reserves which exist under the oceans are about a thousand times more abundant than the reserves found in high quality minerals on land. The underwater uranium, however, is almost impossible to use [14].

1.4] Controlling Radiation Exposure

When working with radiation, there is a concern for two types of exposure: acute and chronic.

An acute exposure is a single accidental exposure to a high dose of radiation during a short period of time. An acute exposure has the potential for producing both nonstochastic and stochastic effects. Chronic exposure, which is also sometimes called "continuous exposure," is long-term, low level over exposure. Chronic exposure may result in stochastic health effects and is likely to be the result of improper or inadequate protective measures [16].

The three basic ways of controlling exposure to harmful radiation are: 1) limiting the time spent near a source of radiation, 2) increasing the distance away from the source, 3) and using shielding to stop or reduce the level of radiation (Fig. 1.5) [17].

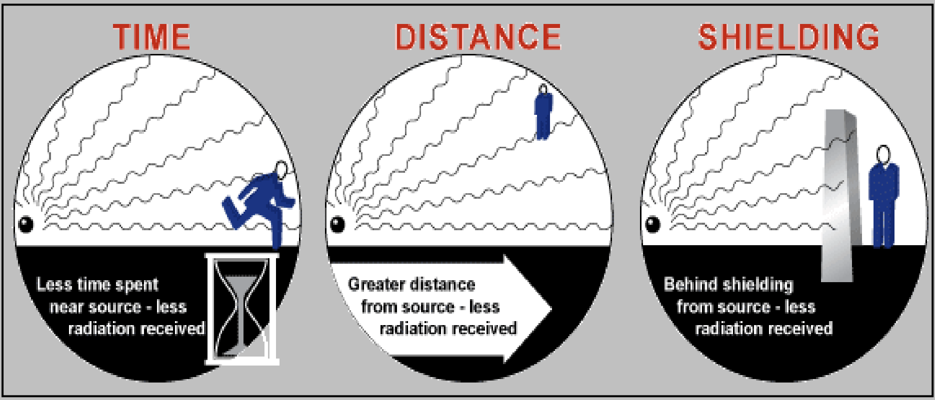

Fig. (1.5): Controlling Radiation Exposure.

1.4.1] Time

The radiation dose is directly proportional to the time spent in the radiation. Therefore, a person should not stay near a source of radiation any longer than necessary. If a survey meter reads 4 mR/h at a particular location, a total dose of 4mR will be received if a person remains at that location for one hour. In a two hour span of time, a dose of 8 mR would be received. The following equation can be used to make a simple calculation to determine the dose that will be or has been received in a radiation area.

Dose = Dose Rate x Time $\longrightarrow$ **(1.1)**

When using a gamma camera, it is important to get the source from the shielded camera to the collimator as quickly as possible to limit the time of exposure to the unshielded source. Devices that shield radiation in some directions but allow it pass in one or more other directions are known as collimators [18].

1.4.2] Distance

Increasing distance from the source of radiation will reduce the amount of radiation received. As radiation travels from the source, it spreads out becoming less intense. This is analogous to standing near a fire. The closer a person stands to the fire, the more intense the heat feels from the fire. This phenomenon can be expressed by an equation known as the inverse square law, which states that as the radiation travels out from the source, the dosage decreases inversely with the square of the distance [18].

Inverse Square Law: $D_1 / D_2 = d_2^2 / d_1^2$ $\longrightarrow$ **(1.2)**

where D_1, D_2 : Dose rate absorbed from two sources.

d_1, d_2: The distance from two sources.

1.4.3] Shielding

The third way to reduce exposure to radiation is to place something between the radiographer and the source of radiation. In general, the denser the material the more shielding it will provide. The most effective shielding is provided by depleted uranium metal. It is used primarily in gamma ray cameras. The circle of dark material in the plastic see-through camera (below right) would actually be a sphere of depleted uranium in a real gamma ray camera. Depleted uranium and other heavy metals, like tungsten, are very effective in shielding radiation because their tightly packed atoms make it hard for radiation to move through the material without interacting with the atoms. Lead and concrete are the most commonly used radiation shielding materials primarily because they are easy to work with and are readily available materials. Concrete is commonly used in the construction of radiation vaults. Some vaults will also be lined with lead sheeting to help reduce the radiation to acceptable levels on the outside [18].

1.5] Sources of High Energy Radiation

There are many sources of harmful, high energy radiation. Industrial radiographers are mainly concerned with exposure from x-ray generators and radioactive isotopes, but let's start by considering sources of radiation in general. It is important to understand that eighty percent of human exposure comes from natural sources such as outer space, rocks and soil, radon gas, and the human body. The remaining twenty percent comes from man-made radiation sources, such as those used in medical and dental diagnostic procedures [12].

Radioactive material is also found throughout nature. It occurs naturally in soil, water, plants and animals. The major isotopes of concern for terrestrial radiation are uranium and the decay products of uranium, such as thorium, radium, and radon. Low levels of uranium, thorium, and their decay products are found every where. Some of these materials are ingested with food and water, while