# CHAPTER - III A

# RADIATION DOSE MEASUREMENT

Radiation can be defined as the form of energy which a material body can emit into space or alternatively can acquire from space without material transfer. The different type of radiations known are uv, light, heat, x-rays, alpha, beta, and gamma-rays etc. It has been very well established that these different types of radiations are manifestations of the same kind of electromagnetic radiations, differing from each other only, in frequency. There is in reality no sharp dividing line among these forms of radiant energy. It is convenient, however to separate these forms into distinct groups because of the nature of the physical and biological effects which they produce and becuase of special techniques required for their production detection and measurement. The high energy, alpha-, beta-, and gamma radiations are obtained from radioactive materials. The general properties of these ionizing radiations and radioactive substances are listed below:

1 The radiations emitted by radioactive substances found to possess a high penetrating power, affect photographic plates, ionize gases, cause scintillations on fluorescent screens, develop heat and produce chemical effects.
2 Emission of radiations is spontaneous, unaffected by any external agent.
3 As the radiations are given out, new elements are formed in an irreversible process, each element having its own characteristic radiations.
4 The emission is not instantaneous but prolonged i.e.

delayed action, extended over a certain period of time, otherwise it cannot have been discovered at all.

5 There is nothing abnormal about the radioactive elements as regards their physical and chemical properties, all of them have their places in periodic table. Thus for instance, radium, except for a special feature of activity fits in at the ends of the second group of periodic table having chemical and spectral properties similar to calcium, strontium and barium, the other members of the same group.

6 The process of separation of radioactive substances from the original mineral ores is an exceedingly difficult task, a ton of uranium ore, for instance, yielding a few decigrams of radium, hence the high cost of radium.

**A Radiation and its Hazards**

Ionizing radiation is defined as an imparted energy that can ionize matter directly or through the action of secondary radiation. Ionization occurs when a sufficient quantity of energy is transferred to a material to eject electrons from the atoms or molecules. Referring to radiation as being ionizing, it is, however, important to emphasize that this is not the only process by which radiation energy may be imparted to matter. A second important process is excitation where an atom or a molecule is raised to higher energy state by the radiation, but where the transferred energy is too small to permit the escape of an electron. The ionization and excitation processes can have important physical and chemical consequences in matter. The biological systems, in particular, are very sensitive to events initiated by radiation.

Today the uses of radiations are numerous. We may mention some of these applications here (i) Dating of geological and archaeological material, (ii) Industry & Engineering, (iii) Agriculture and biology, and (iv) Medicine.

The danger to human body from radiation arises from the latter's ability to ionize the molecules of the living tissue. Man has always been exposed to radiation both externally and internally. Soon after the discovery of radioactivity it was found that exposure to high concentration of $^{226}Ra$ and $^{222}Rn$ from medical treatments and self-luminous paints resulted in early death vis enemia, bone lesions and tumour. It is now generally accepted that excessive radiation exposure can be a cause factor in amongst others, cases of erythema, epilation, transepidermal injury, cellular damage, cancers, tumours, kidney damage, degeneration of central nervous system, lung fibrosis, loss of fertility, genetic mutations and early death. However, if a sub-lethal dose of radiation is administered, various biological phenomena occur. These phenomena and their time of onset will vary in different species, and as a result of different dosages and quality of radiation.

As mentioned earlier that radiation causes alteration of physiological mechanism and, eventually, death in biological system. The primary events producing injury in a cell is the production of ionization. Excitation plays a relatively small part, since radiations which cause excitation without ionization, such as ultraviolet, are much less effective in causing cell damage. The extent of the initial damage is usually small and a dose of radiation which kills a cell may cause ionization in only one molecule in $10^8$. The damage finally observed is much greater than would be expected from the energy absorbed and there are several theories concerning the mechanism by which this situation arises. However, it is generally agreed that under normal conditions of irradiation the damage results from a mixture of direct and indirect effects.

Direct Effects are those which result from an ionization or excitation within a biologically functional molecule. The occurrence of an ion cluster within such a molecule releases sufficient energy to make it probable that biological function will be abolished. The principal effects observed with protein are aggregation and loss of solubility and some degree of fragmentation, while DNA, RNA and polysaccharides exhibit fragmentation and some cross linking. With double-stranded DNA break occurs principally when both strands are affected in the same region. Although the effects depend to some extent on the fragility of long chain molecules, cross linking is the important in the abolition of biological activity since it prevents the uncoiling of closely coiled structures such as DNA and introduces immobile configurations in open chain molecules. It is probable that energy transfer can occur over a maximum chain length of about 12 carbon atoms, to produce damage in the weakest molecular bonds.

Indirect Radiation Effects result from the radiolysis of intracellular water, which comprises about 80 percent of most cells, and of any extracellular water which may be present. The reaction involved are complex in nature. The facts that oxygen generally enhances radiation damage and that many substances which protect against radiation are reducing agents lead to the conclusion that the principal effects are oxidative and oxidation may result from reactions with the hydroxyl and hydroperoxy free radicals, with hydrogen peroxide and under some conditions, with the hydrogen radicals.

## B Radiation Units

Certain quantities and units are particularly used in the area of applications of ionizing radiations. The units such as Curie, Roentgen, Rad and Rem which are adopted previously are not coherent with the S.I. Units, but their temporary use with the S.I. Units takes place. The International Commission of Radiation Units (ICRU) and International Commission Radiological Protection (ICRP) have adopted the special names; Bacquerel (Bq), Gray (Gy) and Sievert (Sv) for the S.I. derived units of activated energy, absorbed dose or dose equivalent.

(i) Exposure Unit

The most familiar unit is based on the amount of ionization produced in air by x-rays and gamma rays and is called the Roentgen in honor of the discoverer of x-rays. The Roentgen (R) is defined as the amount of gamma or x-ray radiation which produces ions in air carrying one electrostatic unit of charge of either sign per 0.001293 gms. of air (equal to one cubic centimeter of air at standard temperature and pressure). Mathematically, it can be defined as the quotient of dQ by dm, where dQ is the absolute value of the total charge of one sign produced in air when all the electrons liberated by photons in a volume element of air having mass dm are completely stopped in air.

$$X = \frac{dQ}{dm}$$

The Roentgen unit is valid only for (a) air as medium, (b) X- and gamma rays of energy less than 3 MeV. Energy deposition for an exposure of IR is 86.9 ergs per gram.

(ii) Absorbed Dose

The definition of Roentgen limits it to X- and gamma radiations in air. A unit for the measurement of other radiations e.g. alpha and beta particles, as well as the ionizing effects in materials other than air, led to the need of another unit of absorbed dose, the rad. The rad is defined as the amount of radiation which deposits 100 ergs of energy in each gram of material. Or it is the quotient of dE by dm, where dE is the mean energy imparted by ionizing radiation to the matter in a volume element and dm is the mass of the matter in that volume element.

$$D = \frac{dE}{dm}$$

The amount of X- or gamma radiation that would cause a certain ionization in air would alternately result in a certain energy deposited in some other materials. Hence, the rad and the Roentgen can be related to one another, once the material is specified, by comparing the absorption of radiation in the material to the absorption in air.

$$D = 0.869 \frac{(\mu_{en}/\rho)\ \text{med.}}{(\mu_{en}/\rho)\ \text{air}} \times \frac{\text{rad}}{\text{R}}$$

where $(\mu_{en}/\rho)$ is the mass energy absorption coefficient of the medium or air. The unit 'rad' is valid for any medium, all types of radiations and all energies. The new S.I. unit for the rad is called the Gray (1 Gray = $10^2$ rads).

(iii) Dose Equivalent

For the same dose of different ionizing radiations, the biological effect can be different and will depend on the pattern of energy distribution i.e. spatial distribution of ion pairs and on the irradiation conditions. This phenomenon is generally expressed quantitatively in terms of the "relative biological effectiveness (RBE)" of the different kinds and energies of radiation. The RBE varies not only with the different radiations but also with the biological effect considered. Since biological effects depend on microscopic details of how the dose is absorbed, a third unit "rem" has been introduced. The rem is intended to gauge the biological harm or alternation that a radiation will produce. The rem is defined as the product of the absorbed dose (rads) and other modifying factors which quantify the relative biological effectiveness.

Dose Equivalent, $H = DQN$

where Q is the quality factor,

D is the absorbed dose

N is the product of any other modifying factors.

Modifying factors take into account the modification of biological effect due to non-uniform distribution of internally deposited radionuclides. For external radiation N is taken to be unity.

Quality factor 'Q' is the 'linear energy transfer' dependent factor by which absorbed doses are to be multiplied for purposes of radiation protection, a quantity that expresses on a common scale for all ionizing radiations, the net radiation effect incurred by the exposed persons. The quality factor is generally taken as 1 for X-, gamma-, and beta rays, 10 for fast neutrons, 20 for alpha rays, 3 for thermal neutron and 20 for heavy recoil nuclei. The S.I. unit of dose equivalent is Sievert (Sv).

$$1 Sv = 1 J\ kg^{-1}$$

and 1 Rem = $10^{-2}$ Sv

(iv) Curie (Activity Unit)

It is the unit of radioactivity and is the quantity of radionuclides which gives $3.7 \times 10^{10}$ disintegrations per second. The S.I. unit of radioactivity is Bacquerel (Bq).

$$1 Bq = 2.705 \times 10^{-11} Ci$$

C **TLD and its Applications**

Radiation is an important tool in nuclear and medical research programmes. Since radiation is hazardous, it is necessary to limit the dose to workers who are involved with such programmes. There are many devices to measure the radiation dose. Film badges were used earlier by radiation workers in all nuclear installations, X-ray clinics, etc. They have been or are being replaced by Thermoluminescent Dosimeters (TLDs) in recent years because of its manifold advantages over film badge.

On account of several favourable characteristics such as high sensitivity, small size, ability to cover wide range of exposure/dose, reusability, insensitive to environmental conditions, thermoluminescence dosimeters find applications in several areas.

TLD has the property of emitting light upon heating after having been exposed to ionizing radiation. The radiation releases electrons, some of which are captured by the impurity atoms or other defects in the crystal, where they stay bound for sometime. When heated, these charge carriers return to their normal positions in the lattice, generating light in the process.

Several materials exhibit the property of TL. New materials are investigated and reported every year. The applications of TLDs in various field are expanding and progressing.

Predominant applications of thermoluminescence dosimeters have been in the field of radiation dosimetry, radiation protection and control. During normal and emergency operation of nuclear facilities, the radiation dose is needed to be measured due to direct exposure, external exposure as a sequence of released radioactivity, and internal exposure after the intake of radioactive materials. TLDs can be used in personal monitoring and safety of people working with reactor particle accelerators, X-ray machines and radioactive sources. They can detect alpha, beta, gamma, X-ray, neutrons, and heavy ions etc.

The application of TLDs in health physics and biomedical sciences refer to the absorbed dose measurement in radiotherapy and diagnostic radiology, the dosimetry applied in this field is known as clinical dosimetry. Measurement of the radiation output of therapy machines, beam uniformity checks, and the measurement of absorbed dose in phantoms and in vivo can be performed with the help of TLDs.

As mentioned earlier during the normal and emergency operations, dose in the vicinity of nuclear facilities should be measured. One of the measurements in the external exposure as a sequence of released radioactivity. However, the accurate determination of variations in environmental radiation levels, particularly those arising from nuclear facility emissions, requires a high precision radiation dosimeter. For this, a suitable environmental monitoring dosimeter should be chosen with a linear dose response. The self irradiation, fading and the directional response should also be at a minimum. Energy and dose rate dependence, fading at elevated temperature, and aging effects should be considered and investigated. As TLDs can partially fulfill the requirements mentioned above with least costs, they are extensively used in environmental monitoring. This application can also be extended to space monitoring as well.

The application of TLDs in agriculture are mainly concerned with high level photon dosimetry such as the dose measurement in food preservation, radiation sterilization of seeds, pest control, etc. While in industry the applications are concerned with radioactive contamination in liquids, radiation treatment of municipal waste, radiation sterilization of medical equipment, estimation of damage to concrete building by fire, and nuclear power industry.

Other applications of TL dosimetry include archaeological dating i.e. dating of ancient potteries and ceramics and in forensic sciences as well.

# CHAPTER - IIIB

# BETA RADIATION

In the present research work the excitation of the material has been made with the radiation from $Sr^{90}$ beta source. Therefore, the brief account of production, properties and applications of beta radiation is given in the following description.

**A General Aspects of Beta Radiation**

Lord Rutherford, Mme Curie, William Crooks, Becquerel and Villard did systematic research work on the radiation emitted from radiative materials. They found three types of radiations, namely; alpha-, beta-, and gamma-rays, differing in penetration power and other physical properties. Mme Curie was the first to demonstrate the existence of these three distinct types of radiation through simple experiment. Her experimental arrangement is shown in Fig.III-1. She placed a small amount of radium preparation R at the botom of a lead block. A small hole was drilled in the lead block so that a fairly parallel beam of radiation from R can be issued at the orifice S. A photographic plate "P" was placed at a short distance above the lead block to receive the rays. The whole arrangement was placed in an air-tight chamber 'C' which was kept evacuated by a vacuum pump in order to avoid absorption of the rays. She observed three different kind of radiations; one without any deviation, the other deviated on the left side, and the third deflected on right side of the central undeflected radiation, when a strong magnetic field was applied at right angle to the plane of the figure, and directed away from the reader. She concluded that

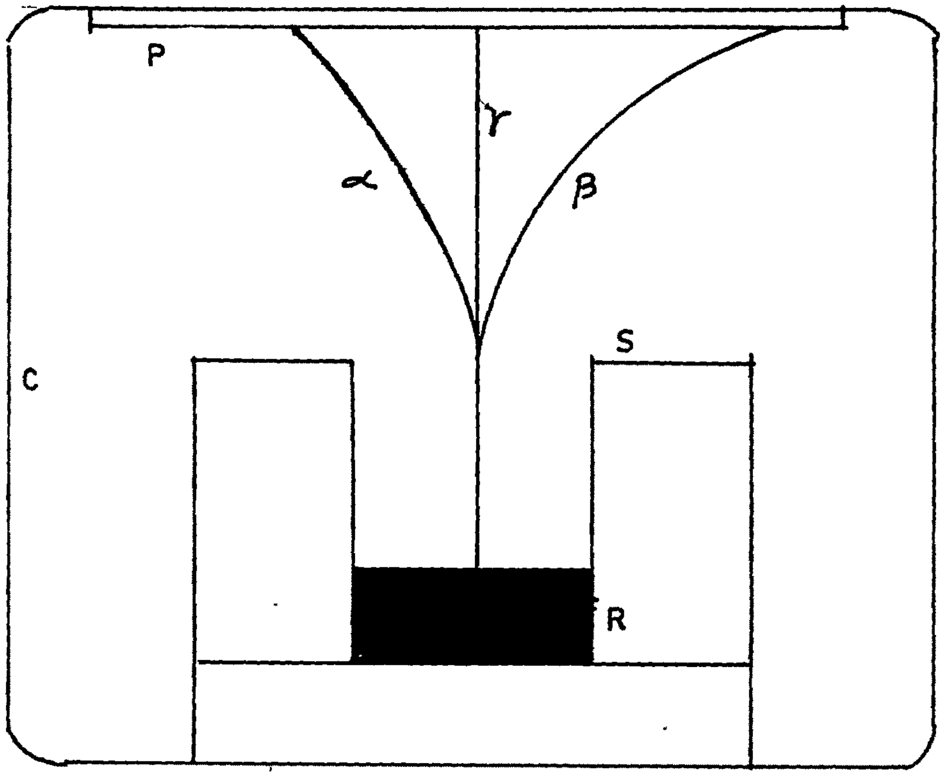


FIG. III-1 ARRANGEMENT USED TO DIFFERENTIATE α, β & γ RAYS the undeflected radiation is gamma ray made up of uncharged particle, photon. Further, she established that the radiations deflected on right and on left sides are respectively made up of negative and positive charged particles of very light mass. She referred them respectively as beta and alpha rays. Since then scientists worked in this field and found out properties of these radiations. Among them the special properties of beta radiation are given below.

**B Properties of Beta-Rays**

(i) Beta-rays are shot out from radiactive substances with very high velocities ranging from 1% to 99% of the velocity of light. The velocity of all the beta-particles given out by a substance is not the same.

(ii) Beta-rays produce ionization in air but the number of ions produced is hardly 1/100th of those produced by gamma-rays. Although their velocity is very large, they possess a comparatively small mass (1/7400 of an alpha-particle) and hence have a small kinetic energy. As beta particles are slowed down by collision with the atoms of the gas and change their path, their tracks in Wilson cloud chamber are scattered and not continuous as those for the beta-particles.

(iii) They affect a photographic plate and their effect is greater than those of alpha-rays.

(iv) Beta-rays produce fluorescence in barium platinocyanide, calcium tungstate Willemite etc.

(v) Beta-rays can penetrate through large thickness of matter e.g. they can easily pass through 1 cm thickness of aluminium sheet.

(vi) Beta-rays are more readily scattered when they pass through matter, because their mass is very small as compared to the mass of the atomic nuclei.

(vii) Beta-rays are affected by electric and magnetic fields. Their direction of deflection indicate that they are negatively charged particles. The e/m value has been found on the same lines as for cathod rays which indicates that beta-rays are fast moving electrons.

C **Application of Beta-Rays**

Radioactivity of radioactive sources are used in luminescent paints. A carefully prepared mixture of radio-thorium (alpha-emitter) with zinc-sulphide exhibits a more or less permanent luminescence and is used for coating the pointers and figures of clocks and watches for rendering visible signs in theatres and so on.

In purely physical and chemical fields, indicators have been used in the determination of the solubility of sparingly soluble materials, measurements of rate of diffusion in solid systems, study of phenomena at boundary surfaces and of intermolecular exchanges, etc. The medical applications have also been made, for instances, in the treatment of syphillis, by employing RaE as indicator the retention of bismuth in the organism has been investigated in detail and it has been found that for a long time after treatment a considerable amount of bismuth remains in the body maintaining an antisyphillitic effect. But the major application of isotropic tracers at present is in biological researches where artificially produced radio elements are used with ease and economy. With their aid, the rate place and sequence of formation of the organic constituents of a living body, the permeability of cell walls, the metabolism of phosphorus in human, animal, and plant systems, the rate of lymph circulation etc. have been investigated.

The rays from radium like beta-rays though harmful to healthy skin, produce satisfactory improvement in various skin diseases. They also have a healing effect on internal diseases.

### D Estimation of Energy and Doses of Beta-Radiation

Beta-rays have continuous energy spectrum, which has raised a very difficult problem in nuclear physics. There exist two chief methods for determining the energies of the beta particles emitted by radioactive substances, viz.

1. The Magnetic Spectrograph, and
2. The Wilson's cloud chamber.

The energies of beta-rays emitted by radioactive substances are measured by means of a beta-rays spectrometer. The kinetic energies of the negatrons and positrons in beta decay cover a

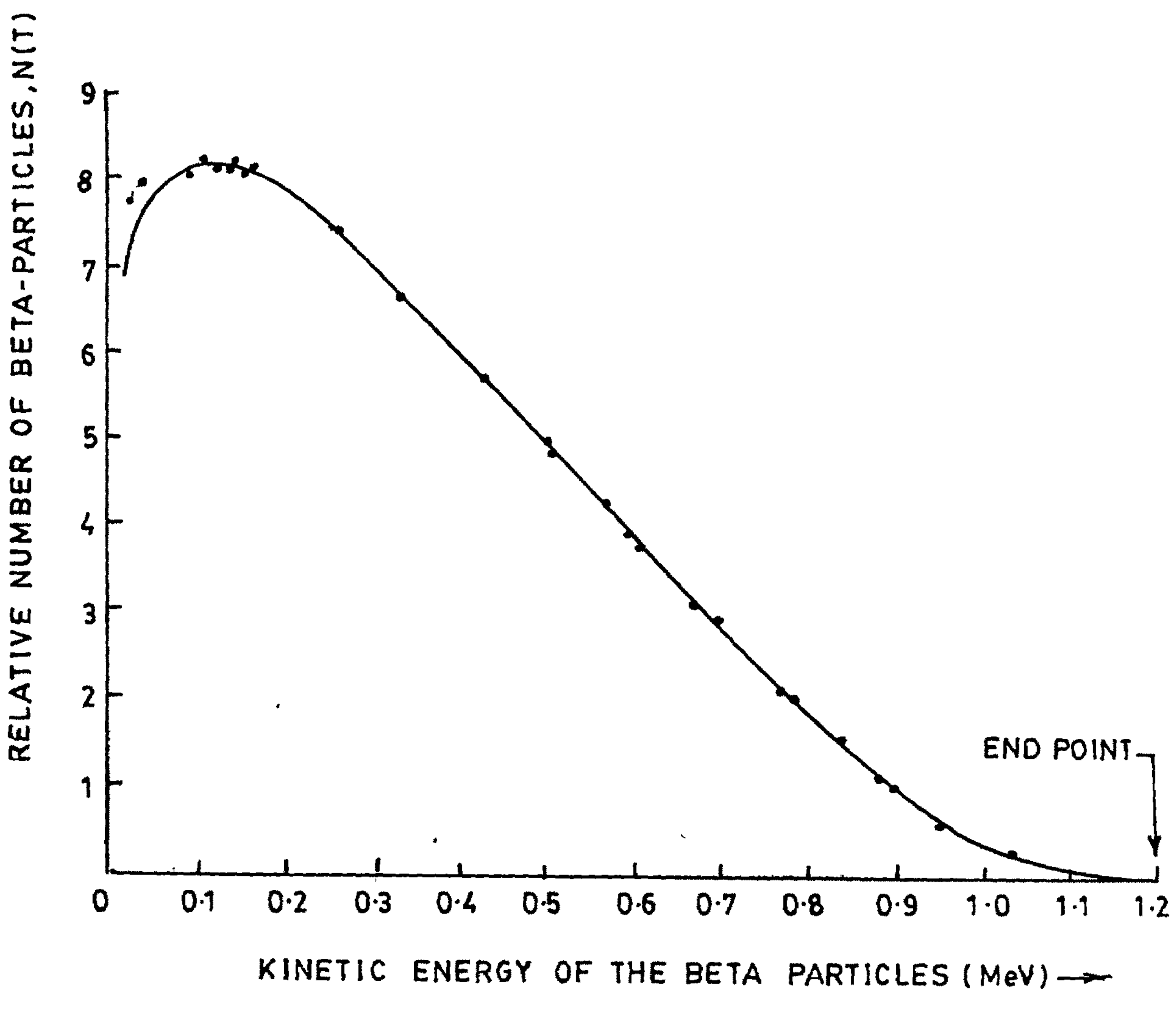


FIG. III-2: BETA PARTICLE SPECTRUM OF RaE continuous range from zero upto a maximum value which is the characteristic of the beta active isotope. The maximum kinetic energy E, corresponds closely to that expected from the exact rest mass energies of the parent and daughter atoms.

A typical beta-rays spectrum is shown in Fig. III-2. This type of spectrum shows that beta-rays have a maximum energy, $E_{max}$ below which there is a continuous spectrum with average energy usually less than half the maximum, the height and position of which depend on the nucleus emitting the particles. There is also a definite upper limit or end point of energy for beta-particles emitted by the nucleus which is different for different beta-emitting nuclides. Due to uncertainty of the measurements on the low energy particles the shape of the curve at low energy end is not known correctly. The maximum kinetic energy varies over a wide range throughout the list of beta-unstable nuclei smallest (18 kev) for tritium and largest (13 = MeV) for isotope $B^{12}$. The methods have been realized to be very expensive, time consuming and laborious. In last decade, scientists developed different techniques to measure energy of beta radiation and absorbed beta dose by material. The most suitable method that has been established recently for the estimation of beta dose is thermoluminescence technique. This technique is described in detail in the chapter of discussion of this thesis.