CHAPTER - III

THERMOLUMINESCENCE

DOSIMETRY,

RADIATION HAZARDS

AND UNITS
Indeed today the uses of thermoluminescence are numerous. Besides the measurement of radiation exposures in nuclear plants and medical fields; it is used in archaeology for determining the age of the ancient objects and for checking whether an archaeological object is genuine or fake; in geology, it is used for dating and deciding the origin of geological formation and possibly, even for ore prospecting and earthquake prediction. It can also be used in forensic sciences and in wide range of quality control and analysis.

The thermoluminescence application to radiation dosimetry is the major application of it and is discussed in this chapter along with radiation hazards and units.

A. THERMOLUMINESCENCE DOSIMETRY

While radiation effects on living organisms have been studied since the discovery of X-rays, it was only since 1940 that intensive experimentation and interest was developed. With the likelihood of future nuclear detonations and the certainty of increase in nuclear power facilities, it is vital that human exposure to radiation is strictly controlled and minimised. For this purpose the accurate measurement of radiation dose is the basic need.

Radiation dosimetry deals with the sensitive detection and accurate measurement of ionizing radiations. All the methods of detection are based on the ability of radiation to cause ionization i.e. to produce charged particles from the initially neutral atoms.
and molecules. Radiation detectors can be characterised as below on the basis of interaction of radiation with the detector:

(i) **Ionization:**

This is the most commonly used phenomenon for radiation detection and measurement. The well known ionization chambers, proportional counters and G.M. counters come under this category.

(ii) **Excitation and Molecular dissociation:**

These phenomena in combination with ionization, can produce luminescence as in the case of scintillators and thermoluminescence phosphors and the latent image in photographic emulsions.

The measuring or dosimetric system can be classified as active or passive. In the active system, the detector and the measuring system are coupled to each other and information is recorded during exposure to radiation. The ionization chambers, scintillators, proportional counters and G.M. Counters come under this category. In passive system, the detector alone is present during exposure and the evaluation is done later by using appropriate electronic instruments. Photographic films, chemical systems and thermoluminescence dosimeters fall under this category. The passive dosimeter probe comprises of simply a piece of material in which an effect is integrated. No measurements or connections are necessary during irradiation. This results in several advantages such as ease of positioning of dosimeters and exposing
them under field conditions, ability to integrate over long periods etc. Thermoluminescent dosimeters in particular have the advantages of high sensitivity, small size, ease of positioning, stability under varying climatic conditions (temperature, humidity etc.) compared to other passive systems.

Thermoluminescence radiation dosimetry (TLD) offers a very inexpensive and sensitive method of measuring atomic radiations. The TL dosimeters are based on the property that certain materials when irradiated by ionizing radiations, store some of the absorbed energy in the crystal lattice. If the irradiated materials are subsequently heated, some of the stored energy is released in the form of light, which can be detected and measured using photomultiplier tube and related to the radiation dose it received. The same TLD material is reused unlike the photographic films. Even very low levels of radiations, like the natural radiation background can be measured by exposing TLD material for long periods, say a week or a month or even a year, and evaluating the total dose received over a particular period.

During the last two decades the application of thermoluminescence dosimetry has grown steadily in parallel with the worldwide progress made in the development of solid thermoluminescence dosimeters and TL reader instrumentation. Today, TLD is the dominant dosimetric method for the measurement of doses to human extremities, and further, roughly one third of the
personnel monitoring services operating today use a TLD badge exclusively for beta/gamma whole body monitoring. For environmental monitoring TLD presents new possibilities for long-term monitoring on a broad scale.

The areas of application of thermoluminescent dosimetry fall into personnel dosimetry and environmental monitoring, Radiation therapy dosimetry and Diagnostic Radiology dosimetry.

B. RADIATION HAZARDS

Man has always been exposed to radiation both externally and internally. Soon after the discovery of radioactivity it was found that exposure to high concentrations of $^{226}$Ra and $^{222}$Rn from medical treatments and self-luminous paints resulted in early death viz. enemia, bone lesions and tumours. 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 sublethal 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 event 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 - standard 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 involves 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.

**C. RADIATION QUANTITIES AND UNITS**

International Commission on Radiation Units and Measurements (ICRU), since its inception by the International Congress of Radiology in 1925, has had its principal objective of development of internationally acceptable recommendations regarding quantities and units of radiations and radioactivity.

The units of interest are

(i) Exposure

(ii) Dose

(iii) Dose equivalent

(iv) Radioactivity
(i) Exposure:

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 change 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 1 R is 86.9 ergs per gram.

(ii) Dose:

The definition of Roentgen limits it to X- and gamma-radiations in air. A unit for the measurement of other radiations e.g. α and β 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 \( \frac{d\bar{e}}{dm} \) 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.

\[
D = \frac{d\bar{e}}{dm}
\]

The amount of X- or gamma radiation that would cause a
certain ionization in air would alternatively 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.

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D = 0.869 \frac{\left(\frac{\mu_{en}}{\rho}\right)_{med.} \text{ Rad}}{\left(\frac{\mu_{en}}{\rho}\right)_{air} \text{ R}}
\]

Where \( \left(\frac{\mu_{en}}{\rho}\right) \) 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 SI 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, \( H = D Q N \)

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 neutrons and 20 for heavy recoil nuclei. The SI unit of dose equivalent is Sievert.
(iv) **Curie**:

It is the unit of radioactivity and is the quantity of radionuclides which gives $3.7 \times 10^{10}$ disintegrations per second. The SI unit of radioactivity is Becquerel (1 Bq = $2.705 \times 10^{-11}$ Ci).