STUDY OF THERMO LUMINESCENCE DOSIMETER READER AND GAMMA ATTENUATION IN TLD BADGE

A dissertation submitted in partial fulfilment of the requirements

for the degree of

MASTER OF TECHNOLOGY

in

NUCLEAR SCIENCE AND ENGINEERING

By

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CERTIFICATE

This is to certify that the major project work entitled "**Study Of Thermo Luminescence Dosimeter Reader And Gamma Attenuation In TLD Badge**" is a bonafide and authentic work carried out by **Mr. Harpreet Singh (2K13/NSE/01)** in partial fulfilment of Master of Technology (M. Tech) degree in Nuclear Science and Engineering of Delhi Technological University (Formerly Delhi College of Engineering), Delhi during the year 2014-2015. It is certified that all corrections/suggestions indicated for Internal Assessment have been approved as it satisfies the academic requirements in respect of major project prescribed for Master of Technology (M. Tech) degree.

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(*Signature of the HOD*)
Name: Prof. Suresh Sharma
Date:

DECLARATION

I, here state that the work which is being presented in the major project, entitled **Study Of Thermo Luminescence Dosimeter Reader And Gamma Attenuation In TLD Badge** is an authentic record of my own work carried out under the guidance of **Mr. J Narender Reddy**, Managing director, Nucleonix, Hyderabad and **Dr. Nitin Kumar Puri**, Assistant Professor, Department of Applied Physics, Delhi Technological University (Formerly Delhi College of Engineering), Delhi. The work contained in this major project has not been submitted in part or full, to any other university or institution for carrying out the project in the past.

This dissertation work is submitted to Delhi Technological University (Formerly Delhi College of Engineering) in partial fulfilment for the Master of Technology (M. Tech) in Nuclear Science and Engineering during the academic year 2014-2015.

Harpreet Singh

ACKNOWLEDGMENT

Abstract

The Semi-Automatic TLD Badge Reader TL1010S is a personnel monitoring system, developed & manufactured by Nucleonix Systems is primarily designed to read the TLD card (TL dosimeters) worn by radiation workers. Several Personnel radiation monitoring systems such as photographic films, pocket ionization chambers and thermoluminescent dosimeters (TLD) have been used for the routine evaluation of radiation exposures to personnel. Recently there has been a rapid increase in the use of TLD for personnel monitoring of radiation workers. This Semi-Automatic TLD Badge Reader is primarily designed to read Bhabha Atomic Research Centre (BARC) developed $CaSo_4$ (D_4) PTFE disc dosimeter based TLD cards. These cards utilize three dosimeters.

The TLD personnel monitoring system essentially consists of two major parts: TLD badge and TLD badge reader. The TLD Badge comprises of a plastic cassette containing a TLD Card made of aluminum with three Teflon TLD discs (13.3mm and 0.8mm thick) that are mechanically clipped on to circular holes (12.0mm) punched on it (52 x 30 x 1mm). Each TLD Card also comprises of a unique punched hole ID which is readout during the acquisition cycle for identifying the wearer of the TLD.

The TLD Badge Reader is designed to measure X, Gamma and Beta radiation dose. The metal filter combination (1mm Al + 0.9mm Cu) is provided to reduce the photon energy dependence of the TL discs. The TL badge reader is calibrated such that the TL output of the disc under the metallic filter reads directly the gamma radiation dose. The radiation workers wear the dosimeter & the radiation exposure is estimated on the basis of TL dosimetric reading. Thermoluminescent dosimeters make use of the property of certain materials, which absorb energy when exposed to X, Gamma or Beta radiation. On heating, the absorbed energy is released in the form of visible light. A plot of light intensity emitted against temperature is known as a glow curve.

Contents

about.

NUCLEONIX SYSTEM PVT LTD

Nucleonix Systems founded in the year 1990 is a well-recognized and established company, engaged in design, development, manufacturing and supplying of nuclear radiation measuring & allied Instrumentation. It carries rich product design & manufacturing experience.

Nucleonix Systems offers instrumentation with state-of-art electronic circuit designs with built-in powerful embedded code to fulfill required instrument functionality, fault diagnostics features, user specific calculations/report generation.

Many of these products have capability of PC communication through Serial Port for data transfer and networking operation. Some of these products are PC based / controlled systems.

Nucleonix Systems has well established production facilities in a spacious building with a built-up area of16000 sq. feet. It has a compact development team of dedicated Engineers.

This company is primarily established to meet the partial requirements of the above said instrumentation in the following market segments-

- University Education & Research.
- Nuclear Research & Industry, Cancer Hospitals.
- Atomic Mineral Exploration & Mining Industry.
- Environmental Radiation Monitoring.
- Home Land Security.
- Steel & Forging Industry.
- Testing Labs.

Many of these products are manufactured confirming to ANSI N42.17A to meet performance specifications. Also these products are EMI/EMC compliant as per IEC61000; firmware is tested based on IEEE Std: 1012, in respect of these products. Further all portable radiation monitors are CE compliant & are offered with CE marking.

The product range manufactured & offered by Nucleonix Systems includes -

Radiation Detectors / probes such as G.M. Detectors, Scintillation Detectors / Probes, Alpha Probes, Beta-gamma probes, plastic scintillator based Beta Probes, NaI detector based gamma probes etc.

Nuclear Counting Systems (Microcontroller based) which include both Integral and NIM Standard Modular systems such as G.M. Counting Systems, Alpha, Beta & Gamma Counting Systems, Gamma Ray Spectrometers, Low background Beta counting system, Liquid Scintillation Counting System etc. Some of these products are also manufactured to meet performance specification conforming to ANSI N42. 17A & IEC standards.

NIM Instrumentation such as NIM Standard Bins & Power Supplies, MINIM Bins & Power Supplies, NIM Modules such as Detector Bias, High Voltage Units, Linear Amplifier, Spectroscopy Amplifiers, Single Channel / Counter Timers (Single, Dual & Six Channel) and other special functional modules.

Portable Radiation Monitors (Alpha, Beta & Gamma) these include Radiation survey meters & Contamination Monitors for measurement of gamma, Beta-Gamma, Alpha using variety of detector probes, offered in different ranges. These are type tested to meet ANSI & IEC standards for

performance specifications. These meters are offered with $C\epsilon$ marking. These include products specially, designed to measure low level Radioactive Contamination (RaC) in castings / steel products / Engineering components etc.

Area Gamma Monitors - Nucleonix systems manufactures wide range of Area Gamma Monitors to measure from very low level, dose rates such as 1µR/hr upto 1000 R/hr, using variety of detectors. All these Area Gamma Monitors are manufactured confirming to ANSI N42.17A, standards to meet performance specifications. They are also EMI/EMC compliant as per IEC61000. Structural designs including accessories are seismic qualified confirming to IEEE-3444STD. Instrument enclosure & detector probe assembly is IP-54 compliant. Units are radiation tolerant upto 10^4 R, plus firmware is tested based on IEEE Std : 1012.

Personnel Monitoring Instruments / systems - Designed / manufactured by Nucleonix systems include Beta-Gamma Hand Foot and clothing Monitors, Alpha hand monitors with state of art design features using single board microcontroller board, colour graphic display to show up mimic icons for contamination of Hand, foot & clothing etc., Built-in RS485/Ethernet connectivity, multi-lingual audio message pronunciation features. The other personnel monitors manufactured include - Whole body Portal Monitors, TLD Badge Readers, Pocket Dosimeters with dose records data management software, Alpha and Beta Contamination Monitors (Friskers) etc. Most of these products are manufacture conforming to ANSI N.17A, IEC Standards and meet performance specifications.

Continuous Air Monitors, Stack & Duct monitors - Continuous air, stack & duct monitors are manufactured for monitoring Alpha, Beta, Krypton & Iodine in atmospheric air in radiochemical & reprocessing facilities & reactor buildings. Nucleonix systems offer these systems with state of art electronic design features with built-in RS485 port for networking. These products are type tested & meet performance specifications as per ANSI / IEC standards.

Software products include Data Communication Products (Instrument to PC) and Networking software for Area Monitors [such as 'Gamma Link' through RS485 network] and other networking software for counting systems such as 'Count Net' etc. Software tutors for G.M experiments, experiments with Gamma Ray spectrometer & MCA.

PC based nuclear & allied data acquisition systems offered include -

- 8K Multichannel Analysers with software.
- PC Controlled TLD Reader (Research).
- Four Channel Gamma Ray Spectrometer etc.
- PC Controlled TLD badge Reader for personal monitoring.

Nucleonix Systems manufactures the following products based on the technology received from Bhabha Atomic Research Center, a premier Nuclear Research Institute in India.

- 8K Multichannel Analyser Card (PC Based) with software includes isotope search library
- Spectroscopy Amplifier etc.
- Semi - automatic TLD badge reader etc.

Nucleonix systems have **Radiation Calibration Labs** approved by **Bhabha Atomic Research Centre** which provides calibration services apart from using this facility for calibrating all the Radiation Monitors manufactured in-house.

Nucleonix Systems is dedicated for supplying the most reliable, **quality instrumentation** with best possible designs. At Nucleonix we are constantly striving and are committed to keep pace with the technological revolution to offer the **latest technology based products.**

Nucleonix Systems can undertake design and development of new projects /products & offer Nuclear Instrumentation to user specific requirement. Nucleonix Systems has a few products which are not listed in the website or catalog, or you may have specific requirements which are not met by listed products. In all such cases please revert back to us with your application to enable us to offer you a solution.

Nucleonix Systems is a **support oriented company** which offers instrumentation solutions and also cares to provide excellent customer support

introduction
to
luminescence.

INTRODUCTION

The spontaneous emission of light upon electronic excitation (e.g. excitation by ultraviolet radiation) is called photoluminescence. Luminescence is a common phenomenon among inorganic and organic as well as in semi-conductors. However, nonradiative relaxation processes may also predominant in some compounds. In those cases where spontaneous light emission does occur, its spectral and temporal characteristics carry a lot of important information about the metastable emitting state and its relation to the ground state. Luminescence spectroscopy is thus a valuable tool to explore these properties. By studying the luminescence properties we can gain insight not only into the light emission process itself, but also into the competing nonradiative photophysical and photochemical processes.

Luminescence is the emission of optical radiation (infrared, visible, or ultraviolet light) by matter. This phenomenon is to be distinguished from incandescence, which is the emission of radiation by a substance by virtue of it being at a high temperature (blackbody radiation). Luminescence can in occur in a wide variety of matter and under many different circumstances. Thus, atoms, polymers, inorganic, organic or inorganic metallic molecules, organic or inorganic crystals, and amorphous substances all emit luminescence under appropriate conditions. The various luminescence phenomena are given their names, which reflect the type of radiation used to excite and to get the emission.

The main characteristic of luminescence is that the emitted light is an attribute of the object itself, and the light emission is stimulated by some internal or external process. This process is quite different to the incandescence seen in an ordinary light bulb filament. In this case the energy from a current of electricity is transferred directly to the metal atoms of the wire. This causes them to vibrate and hence heat up. The wire can then glow white hot, as in an incandescent light bulb. A characteristic of this type of light is that it is accompanied with a great deal of heat! The electrical energy is converted into radiation with an efficiency of about 80%, but the visible light being emitted is less than 10% of the total radiation. The remaining radiation is mainly in the form of infra-red heat. The spectrum of radiation emitted from a hot wire, or any other object, is not sensitive to the attributes of the object. All hot objects emit light and heat with very similar characteristics and this is well described by models based on a generic blackbody.

Light is a form of energy. To create the light another form of energy must be supplied. There are two common ways for this to occur, incandescence & luminescence.

- **INCANDESCENCE**

    It is the light from heat energy. If you heat something to a high enough temperature it will begin to glow. When an electric stove's heater made up of metal is put in a flame, it begins to glow "red hot", and that is incandescence. When Tungsten filament of an ordinary incandescent light bulb is heated still hotter, by passing an electric current, it glows brightly 'white hot' by same means. The sun and stars glow by incandescence too.

- ## **LUMINESCENCE**

The term luminescence implies luminous emission which is not thermal in origin i.e. luminescence is 'cold light', light from other sources of energy, which takes place at normal and lower temperature. In luminescence, some energy sources kicks an electron of an atom of its ground state (lowest energy) into an exited state (higher energy) by supplying extra energy, then as this excited state is not stable electron jumps back to its ground state by giving out this energy in form of light.

We can observe the luminescence phenomenon in nature like, in glowworms, fireflies, and in certain sea bacteria and deep-sea animals. This phenomenon have been used in various fields by different scientist all over the world like, Archaeology, Geology, Biomedical, Engineering, Chemistry, Physics, and various Industrial Application for Quality Control, Research and Developments.

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LUMINESCENCE AND STOKE'S-LAW

In the process of luminescence, when radiation is incident on a material some of its energy is absorbed and re-emitted as a light of a longer wavelength (Stokes law). In the process of luminescence Wavelength of light emitted is characteristics of a luminescent substance and not on the incident radiation. The light emitted could be visible light, ultra-violet, or infrared light.

This cold emission i.e. luminescence, that does not include the emission of blackbody radiation thus involve two steps.
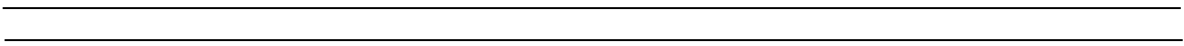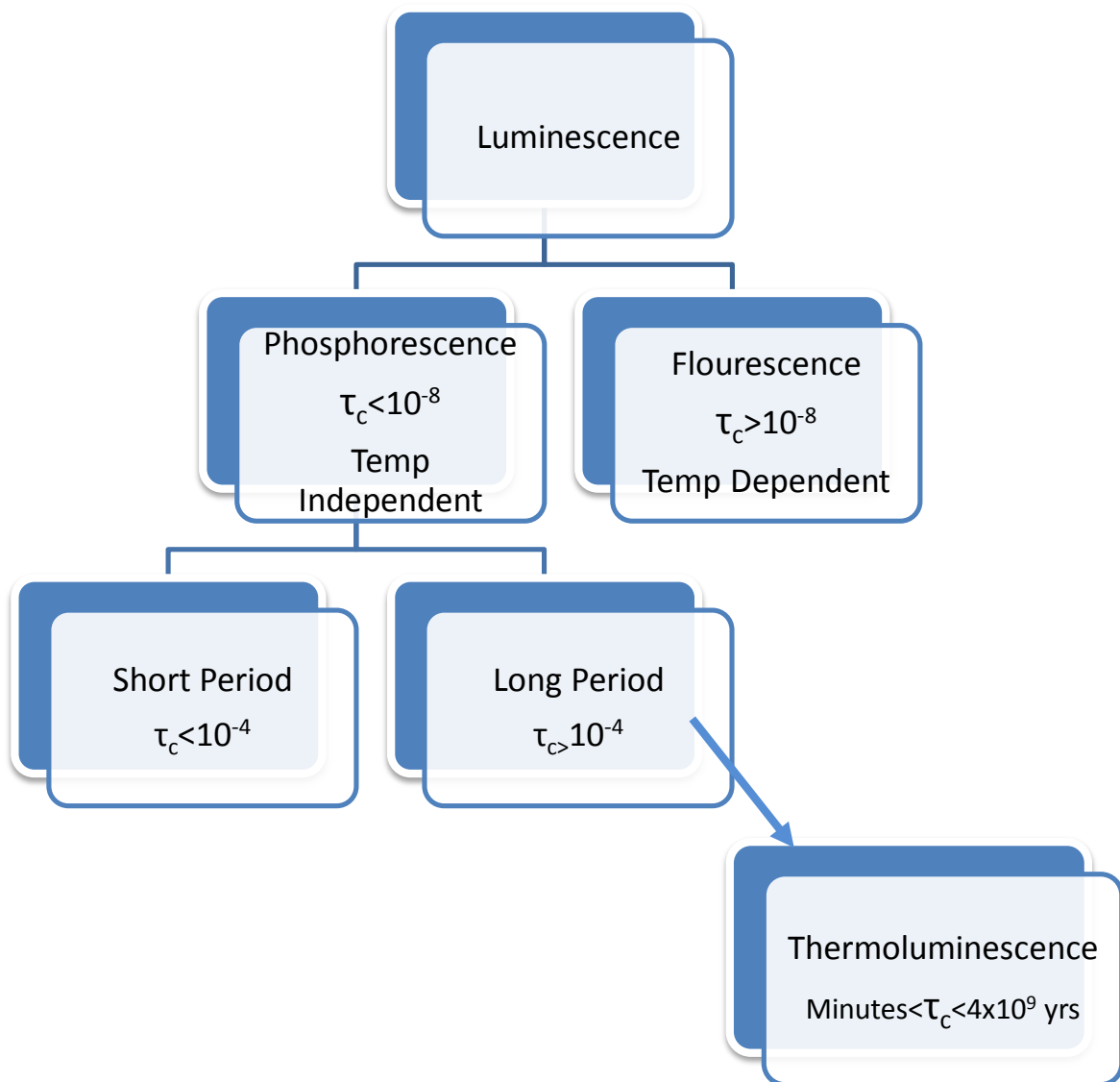1) The excitation of electronic system of a solid material to higher energy state and
2) Subsequent emission of photons or simply light.

The emission of light takes place at characteristics time 'τc' after absorption of the radiation, this parameter allows us to sub classify the process of luminescence into fluorescence and phosphorescence as shown in figure1.

Thus, if the characteristic time 'τc' is less than 10^{-8} sec, then it is known as Fluorescence & if the characteristics time 'τc' is greater than that of 10^{-8} sec, them it is known as Phosphorescence. A large number of substances both organic and inorganic show the property of luminescence, but principal materials used in various application of luminescence, involves inorganic solid insulating materials such as alkali and alkaline earth halides, Quartz ($SiO2$), Phosphates, Borates, and Sulphate etc.

Luminescence solids are usually referred to as Phosphors.

Fig 1: The Family Tree of Luminescence Phenomena

Luminescence

Phosphorescence
$\tau_c < 10^{-8}$
Temp Independent

Flourescence
$\tau_c > 10^{-8}$
Temp Dependent

Short Period
$\tau_c < 10^{-4}$

Long Period
$\tau_{c>} 10^{-4}$

Thermoluminescence
Minutes $< \tau_c < 4 \times 10^9$ yrs

The Fluorescence emission is seen to be spontaneous as 'τc'<10-8sec, thus fluorescence emission is seen to be taking place simultaneously with absorption of radiation and stopping immediately as radiation ceases.

Phosphorescence on the other hand is characterized by delay between the radiation absorption and the time 'tmax' to reach full intensity. Also phosphorescence is seen to continue for some time after the excitation has been removed.

If the delay time is much shorter it is more difficult to distinguish between fluorescence and phosphorescence. Hence phosphorescence is subdivided into two main types, namely, short period (τc< 10-4sec) & long-period (τc >10-4 sec) Phosphorescence.

Fluorescence is essentially independent of temperature, whereas decay of phosphorescence exhibits strong temperature dependence.

- ## **FLUORESCENCE**

   Fluorescence is the emission of light take place with a characteristic time tc<10-8 sec. in which emission takes place from an excited singlet state and the phosphorescence (tc > 10-8 s), in which emission occurs from an excited triplet state. To clarify between fluorescence and phosphorescence is to study the effect of temperature upon the decay of the luminescence. Fluorescence is essentially independent of temperature; whereas the decay of phosphorescence exhibits strong temperature dependence.

   Several types of luminescence can be recognized. Some objects, when illuminated by light of one color, are stimulated to emit light of another color. This is called fluorescence. A common example is the chemical residue left behind in clothes by some types of washing powders. These powders emit visible light when stimulated by invisible ultra-violet (UV) light found in sunlight. Thus the clothes containing the residues appear brighter because of the combined effect of the reflected visible sunlight and the fluorescence from the washing powder residues. Another example is the fluorescent chemicals that coat the inside of fluorescent tubes. In these tubes the UV light comes from excited mercury vapour inside the tube. The energetic UV light excites electrons in the fluorescent chemicals which then emit visible light (with a small amount of heat) upon decaying back to their original states. The term photoluminescence is sometimes also applied to this type of luminescence which is stimulated by light of another colour.

   Another example of fluorescence is in the modern machines for producing medical x-ray images. A screen that produces a lot of visible light called fluorescence when irradiated with x-rays is used to form an image which can then be photographed with films which are sensitive to visible light. This process is more sensitive than using the film to record the xrays directly, thus minimizing the dose of x-rays to the patient. The following are few important applications of fluorescence.

APPLICATIONS OF FLUORESCENCE

The substances emitting the luminescence are called phosphors. Some phosphors are basically semiconductor describable in terms of energy band model. These are in biological forms. They may be in micro or macro forms. Professional have examined the PL of different materials and developed many macro and microscopic luminescence based devices. The brief account of applications of fluorescence is given below.

- Medical application
- Microscopy
- Fluorescent
- Biological Application
- Fluorescence in Chemical analysis
- Luminescent Devices as radiation service
- Mechanical behavior of materials through Luminescence

• **PHOSPHORESCENCE**

In some materials, electrons excited by the original radiation can take some time to decay back to their ground states. The decays can take as long as few hours to few or days. This type of fluorescence is called phosphorescence and the material continues to emit visible light for a while after the original radiation has been switched off. If the duration is very short, around 10-4s, then the material is a short persistence phosphor. If it lasts for seconds or longer it is a long persistence phosphor. Objects displaying phosphorescence are sometimes said to be luminous. Most luminous toys, stickers and watch dials are coated with long persistence phosphors.

$\leftarrow$------$\rightarrow$
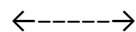
Some other types of Luminescence are given below:

- Bioluminescence
- Cathodoluminescence
- Chemiluminescence
- Electroluminescence
- Ionoluminescence
- Lyoluminescence
- Mechanoluminescence (triboluminescence or piezoluminescence)
- Optically Stimulated Luminescence (OSL) Photo stimulated Luminescence (PSL) :
- Radioluminescence (or scintillation)
- Sonoluminescence

MECHANISM OF LUMINESCENCE

The most important characteristic of luminescence is that it is an attribute of the material producing the light, and not the method used to excite it. The production of luminescence from a solid material can be understood from the band theory for solids. This is a theory based on elementary atomic physics and quantum mechanics. The theory is briefly introduced here.

An isolated atom carries its collection of electrons in its orbitals surrounding the nucleus. These orbitals are analogous to the orbits of the planets around the Sun, although in that case gravity binds the system instead of the electromagnetic force as in an atom. The electrons can only occupy special orbits that allow them to orbit without loosing energy. These allowed orbits may be determined from the laws of quantum mechanics. Also, owing to the fact that electrons can share their orbitals with at most one other electron of the opposite spin (the Pauli Exclusion Principle), some electrons must occupy orbitals far from the nucleus because the lower energy orbitals closer to the nucleus are already occupied.

Vacancies can be created in occupied orbitals by dislodging the occupied electron with a pulse of radiation such as from a photon, a fast electron or some other process. When this occurs, an electron from an outer level will fall down to reoccupy the inner, lower energy, level. The excess energy is radiated away as a photon. For some transitions, this photon can be within the visible spectrum. Gases in discharge tubes that are bombarded by currents of electricity can display a spectrum characteristic of the transitions between the allowed energy levels in the solitary gas atoms.

In a solid, the situation is more complicated. When individual atoms are joined together to make a solid, the atoms must be pushed relatively close together. When this happens, the outer electron orbitals begin to overlap. Since no more than two electrons can occupy the same level, the energy levels begin to split into sub-levels. If six atoms are joined together to make a small lump of material, the orbital of the outermost electron overlaps with the adjacent atoms and splits into six to accommodate all electrons. These new orbitals are associated with the entire lump, rather than just a single atom. Millions of atoms are joined together to make a sizable lump of material. The outer orbitals overlap and split into a number of sub-levels, all with slightly differing energies.

In practice, the energy levels are so close together, and there are so many of them, we can speak of the orbital now consisting of an energy band.

On a small scale, the solid consists of a crystal with all atoms occupying lattice sites. Some normal solids, of interest here, consist of large assemblages of microscopic crystals. The luminescent properties of the solids depend on the properties of the crystal structure.

The formation of energy bands occurs regardless of whether the energy levels are occupied by electrons or not. Therefore, in a typical material, the outermost electrons occupy a band called the valence band, above which is the next higher energy band called the conduction band. The energy difference between the highest energy (top) of the valence band and the lowest energy (bottom) of the conduction band is called the band gap energy.

If the valence band is completely full of electrons and conduction band is completely empty, the material is an insulator, since to conduct electricity the electrons must pick up energy and move to a slightly higher level. Since all available levels in the valence band are full, they cannot do this, and the material is an insulator.

If the valence band is only partially occupied, then the material is an electrical conductor since there are free energy levels available for the electrons to carry the electric current. Owing to the fact that the valence band is formed from the outermost occupied orbitals of the atoms, which can contain either one electron or two electrons of opposite spins, the valence band in any material is always either entirely full (insulators), or just half full (conductors).
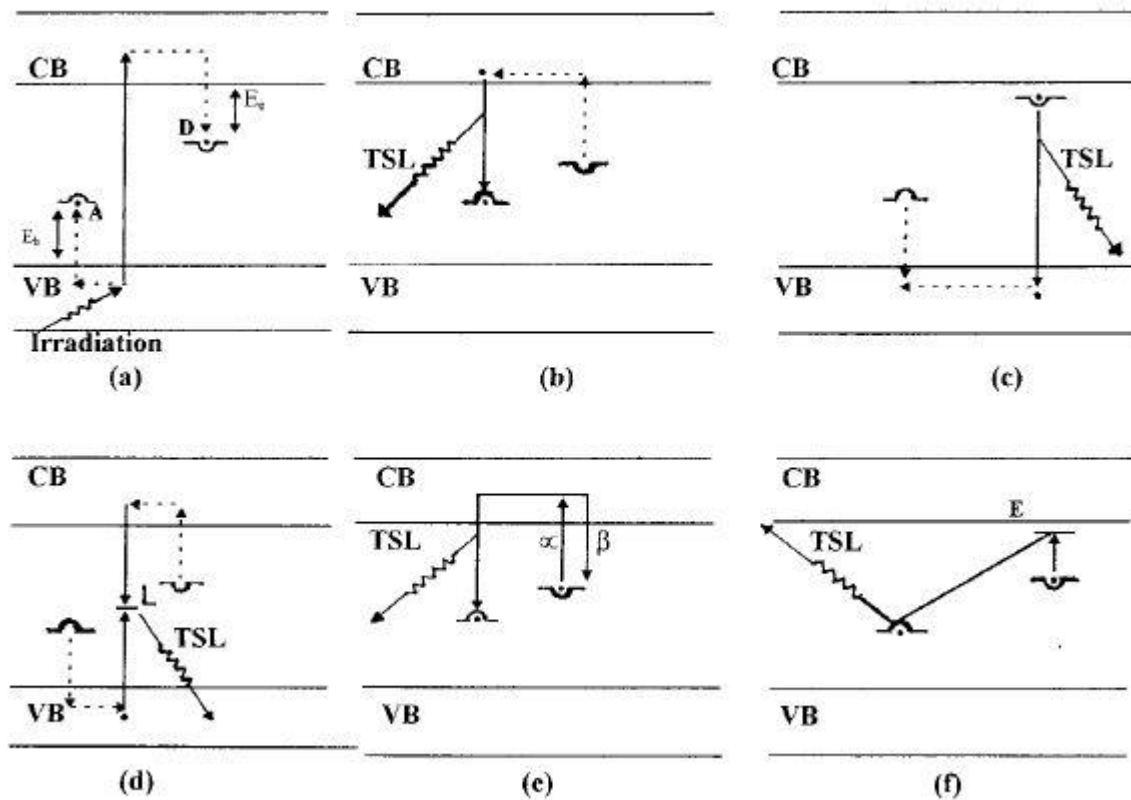
Fig 2: Processes involved in radiation induced electron/hole trapping and subsequent recombination on thermal stimulation with associated luminescence emission.

>   VB- Valence band,
>   CB - Conduction band,
> E_h - Trap depth for hole,
> E_e - Trap depth for electron,
>   L - Luminescent center, A - Hole trap and D - Electron trap.

(a) On gamma irradiation, electrons and holes are produced and trapped at electron hole traps.
(b) On thermal stimulation, trapped electron is released and recombines at trapped hole site.
(c) e-h recombination at trapped electron site.
(d) e-h recombination at luminescent center site.
(e) Process of de trapping and re trapping (second order kinetics, a − de trapping probability and p- re trapping probability);
(f) e-h recombination via an excited state 'E' and tunneling.

In some materials, the gap between the fully occupied valence band and the empty conduction band is very narrow. So narrow in fact that ordinary heat energy at room temperature can promote

electrons from the valence band into the conduction band. Such materials are semiconductors. These are generally poor conductors compared to metals.

When any solid material is excited by energetic radiation, electrons can be excited out of the valence band into the conduction band. This leaves behind a hole in the valence band. The electron in the conduction band can dissipate excess energy as small amounts of heat until it reaches the lowest energy (bottom) edge of the conduction band. It can then fall back into the hole in the valence band, radiating the energy difference as a photon.

Band gap energies, and associated band gap transition wavelengths, for some semiconductors. 'd' indicates that a transition directly across the band gap can conserve momentum and is therefore possible. 'L' indicates that a direct transition is not possible and a lattice vibration, or phonon, is necessary to conserve momentum and so only indirect transitions are possible.

DOPING

It is known fact that the band gap energies of few materials have band gaps where the band width corresponds to the visible spectrum. However, materials with a relatively wide band gap can be made to luminesce in the visible. This is possible by the addition of different atoms or imperfections into the crystal. The additional atoms, called dopants have a different electron orbital structure compared to the host crystal lattice. Therefore, in regions of the crystal around the dopant atom, additional energy levels become available. That is, within the forbidden band gap of the material, energy levels can co-exist that can accommodate electrons or holes. These levels can be close to the conduction band, in which case the dopant is called a donor, or close to the valence band, in such case it is called an acceptor. Transitions between these levels can give rise to visible luminescence in such case the dopant is known as an activator. In most cases, the activator is present in extremely small concentrations, ranging from as much as one dopant atom in 5000 host atoms down to as little as one dopant atom in 1 million host atoms.

Sometimes the excited electron can find their ways to dissipate its energy. Several nonradiative recombination mechanisms are also possible. These are usually associated with defects in the crystal, or levels in the middle of the band gap, called deep levels, introduced by impurities called inhibitors. Still other defects in the crystal can result in shallow levels which are close to the edge of either the valence or conduction bands. Shallow levels in the band gap can trap the excited electrons. Certain characteristics of these shallow level prevent the electron from decaying immediately back into the valence band. Instead the decay may only occur after a very long time. However a small amount of heat may dislodge the electron back into the conduction band from where it can readily decay back to the valence band. This is the mechanism behind the technique of thermoluminescence.

thermoluminescence.

THERMOLUMINESCENCE (TL) OR THERMALLY STIMULATED LUMINESCENCE (TSL)

TL or more specifically Thermally Stimulated Luminescence (TSL) is stimulated thermally after initial irradiation given to a phosphor by some other means ($\propto$ rays, β -rays, γ - rays, UV rays and X-rays). Thermally stimulated luminescence (TSL) is the phenomenon of emission of light from a solid which has been previously exposed to ionizing radiation under conditions of increasing temperature. Unlike other luminescence process such as Electroluminescence, Chemiluminescence, here heat is not an exciting agent, but it acts only as a stimulant. Hence it is better known as thermally stimulated luminescence (TSL). Excitation is achieved by any conventional sources like ionizing radiation, $\propto$rays, β-rays, γ- rays and UV rays and X-rays. TSL is exhibited by a host of materials, glasses, ceramics, plastics and some organic solids. By far insulating solids doped with suitable chemical impurities, termed as activator, are the most sensitive TL materials.

The band theory of solids is normally used to explain this phenomenon. When a solid is irradiated, electrons and holes are produced. The defects in the solid results in the presence of localized energy levels within the forbidden gap. On irradiation, electron and holes can be trapped at these defect sites. When the solid is heated, these trapped electrons/holes get enough thermal energy to escape from the trap to the conduction band (or valence band). From here they may get re-trapped again or may recombine with trapped holes/electrons. The site of recombination is called recombination center. If this recombination is radiative, then center is called luminescence center. Alternatively a trapped hole can be released by heating which can recombine with a trapped electron resulting in luminescence. These features are shown diagrammatically in **Fig.1.1**. It is not required that all charge recombination should result in luminescence, they may be non- radiative too.

The plot of intensity of emitted light versus the temperature known as a TL glow curve. A glow curve may exhibit one or many peaks depending upon the number of electron/hole traps with different trap depths, present in the lattice. These peaks may or not be well separated. The position, shape and intensity of the glow peaks therefore are characteristic of the specific material and the impurities and defects presents. Therefore each TSL peak corresponds to the release for an electron (or hole) from a particular trap level within the band gap of the material. The nature of the TL glow peaks gives information about the luminescent centers present in the material.

It may be mentioned that TSL is highly sensitive to structural imperfections in crystals. Defects densities as low as 10^7/ cm^3 also can give measurable TSL if radiative recombinations are dominant whereas techniques such as EPR and OAS are sensitive only for relatively higher defect concentrations such as 10^{12}/ cm^3. The first step towards understanding the mechanism for TSL glow peaks is the identification of the trapping center and the recombination centers for the observed light emission. Apart from being a tool for the study of defects in solids, TSL has also found widespread use in radiation dosimetry, archeological dating of pottery, ceramics, minerals etc; and meteorite research.

- **PHASE CHANGE THERMOLUMINESCENCE (PCTL)**

  Some of the organic molecules, agricultural products and few minerals (zeolites) containing water molecules in their structure do exhibit the thermoluminescence without prior irradiation. This phenomenon is known as Phase Change Thermoluminescence (PCTL). Using this phenomena one can find the phase transitions of that material.

  Thermoluminescence (TL), more appropriately called thermally stimulated emission (TSL), is the emission of light from an insulator or semiconductor when it is heated. But it must have absorbed high energy radiation prior to its stimulation by heat.

  Thus three essential ingredients necessary for the production of Thermoluminescence are:

- The material must be an insulator or a semiconductor (metals do not exhibit luminescent properties)
- The materials must have at some stage absorbed energy during exposure to radiation.
- The luminescence emission is triggered by heating the materials

One particular characteristics of thermoluminescence is that, once heated to excite the light emission, the materials cannot be made to emit thermoluminescence again by simply cooling the specimen and again reheating. In order to exhibit the luminescence the material has to be re-exposed to radiation and then raising the temp will once again produce light emission.

PHOSPHORESCENCE v/s THERMOLUMINESCENCE

Luminescence is the emission of light from a material following the initial absorption of energy from an external source – e.g., ultraviolet or high-energy radiation. The emission can be categorized as either fluorescence or phosphorescence, depending upon the characteristic lifetime between absorption of the excitation energy and emission of the luminescence. The distinction between the two processes is not always clear and is perhaps most easily made using the temperature dependence of luminescence. Consider a ground-state energy level e, illustrated in Fig 3 (a). Fluorescence is the emission of light that follows the excitation of an electron from g to e and its subsequent return to level g. on the other hand if the return to the ground state is delayed by a transition into and out of a metastable level m, then delays between excitation and emission can result (Fig 2(b)), and in this case the process is known as phosphorescence. If the transition into level m occurs at a temperature T, where the energy E of separation between m and e is such that E> several kT (k is Boltzmann's constant), then the electron is likely to reside in m for a considerable period. In this case, assuming a Boltzmann distribution of energies, the probability PL per unit time for thermal excitation from the trap is exponentially dependent upon temperature according to Eq. (a), and the time between excitation and final relaxation back to the ground state can be considerably delayed by the residence of the electron in the metastable state. The temperature dependence described by Eq. (a) provides a means for distinguishing between the weakly temperature-dependence process of fluorescence and the strongly temperature dependent process of phosphorescence.

If the metastable level is an electron trap, at an energy Et below the conduction band. The activation energy for the phosphorescence E = Et for typical numerical values of Et = 1.5 eV and s = 1012 s-1, the calculation of p at 298 K using Eq.(a) indicates that, for all practical situations, the trap would never thermally release its trapped electron, and as a result phosphorescence would never be observed at this temperature. However if the temperature were to be raised, the temperature may be reached at which the p is high enough to ensure that electron release occurs and luminescence is observed. For e.g., at T = 300 K and using the above values for the E and s, one can calculate the lifetime $\tau = 1/p$ of 5.06x105 years, in contrast at 500 K, T = 0.36 sec. thus, consider rising the temperature of the system at some arbitrary rate $\beta = dT/dt$. As the T rise so p increases, producing enhance luminescence emission. Unlike phosphorescence, which is normally assumed to occur at a fixed temperature, this emission is stimulated in a non-isothermal situation and is thus termed as thermally stimulated luminescence (TSL), or more popularly thermoluminescence (TL). As the temperature continues to rise, so the TL intensity increases until such time as the population of trap electron in metastable state is sufficient depleted, at which point the TL intensity decreases with further increase in the temperature.
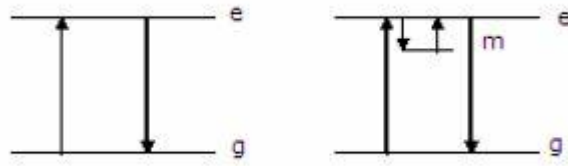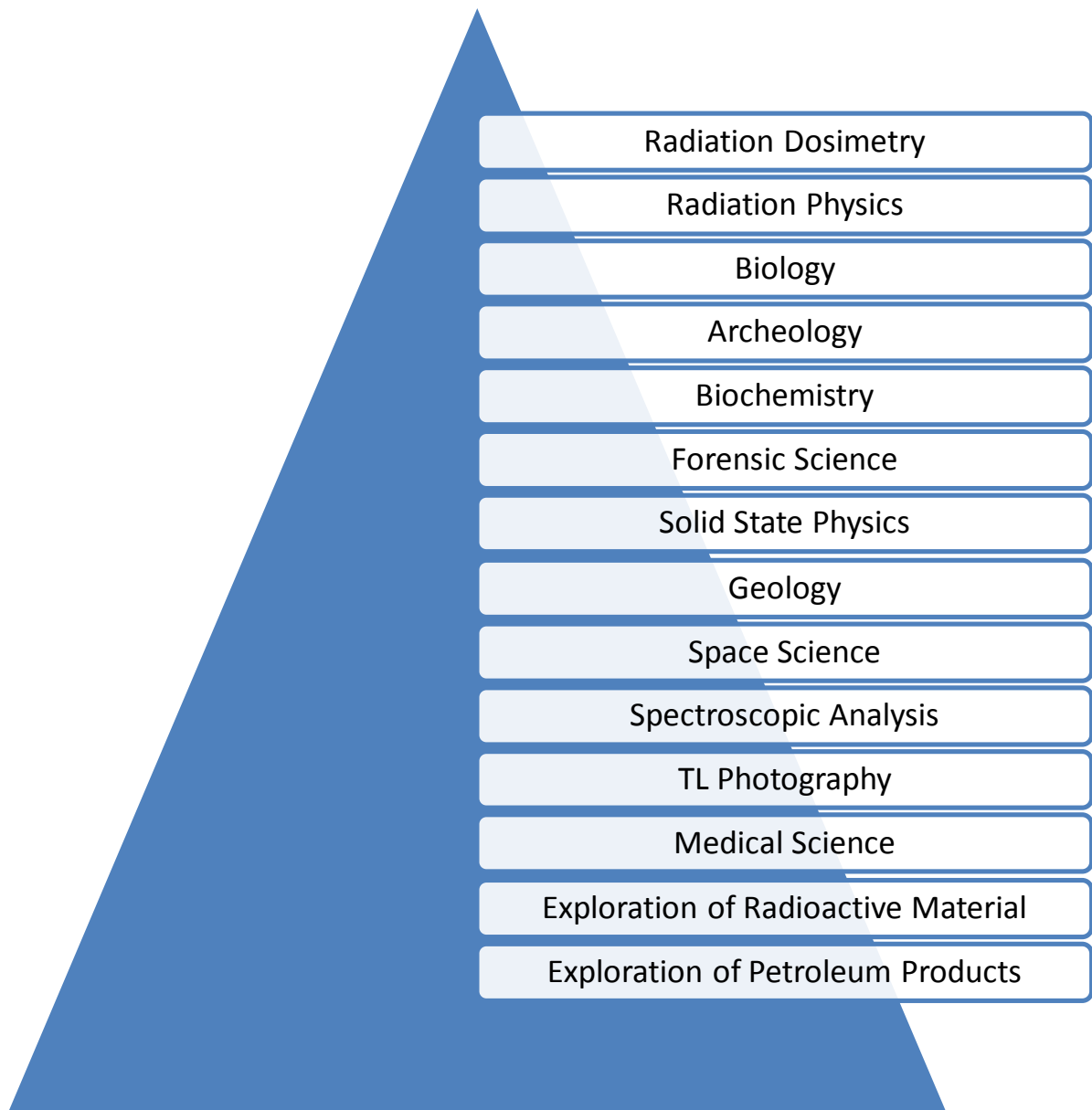
Figure-3 (a) & (b)

The result is the characteristics TL peak (glow peak) for which the temperature at the peak maximum is related to trap depth E_t, the frequency factor s, the rate of heating β. Here we see the metastable localized level (level 1) at an energy E_t below the conduction band and a deep level (level 2) assumed to reside below the system Fermi level (E_f). Prior to irradiation level, is assumed to be empty, and level 2 is assumed to be full. During irradiation electrons are excited across the material's band gap and become trapped at level likewise, holes become localized at level the result is a non equilibrium excess of electrons above E_f, and deficiency of electrons below E_f.

APPLICATION OF THERMOLUMINESCENCE

The phenomenon of TL has been extensively studied by many investigators. The understanding of the mechanism of occurrence of thermally stimulated emission is the important field of fundamental research. Many researchers have suggested their views for TL mechanism for pure and impurity activated materials. With expanding knowledge of solid state physics, it is a topic of research to give latest plausible mechanism of TL. However, the present understanding of TL has explored very high application potential of it in various fields. The modernization and development in the

instrumentation; and better understanding of TL have helped the professional to solve their problems in many fields. The applications of the TL are summarized in the following **Fig 4.**

Radiation Dosimetry

Radiation Physics

Biology

Archeology

Biochemistry

Forensic Science

Solid State Physics

Geology

Space Science

Spectroscopic Analysis

TL Photography

Medical Science

Exploration of Radioactive Material

Exploration of Petroleum Products

Fig 4: APPLICATIONS OF THERMOLUMINESCENCE

BASIC CONCEPT OF THERMOLUMINESCENCE [TL OR TSL]

Thermally stimulated luminescence (TSL) is the phenomenon of light emission during warming a previously irradiated substance with uniform heating rate. When a material is exposed to ionizing radiation like; alpha, beta, gamma and X-rays or UV-rays or when it undergoes certain chemical reactions or mechanical stress, a certain percentage of the liberated charge carriers (electron and holes) may be trapped at certain imperfections in the lattice, which are called traps. If these traps are deep enough, the charge carriers remain trapped for a long time [thousands of years] before they are

released by sufficient stimulation. This stimulation can be achieved by supply of optical or thermal energy to these excited solids.

The return of these trapped charge carriers to a stable state due to the stimulation by external energy (e.g. heat) is always associated with the release of absorbed energy (by the charge carriers), mostly in the form of heat. A small fraction of the absorbed energy is also released in the form of light during this process. This form of emission of light is called Thermoluminescence (TL). The TL from the material is very sensitive to;

- The amount and nature of impurity.
- Thermal history.
- Pre-thermal, mechanical and radiation effect.
- Size of material particle.
- Crystallization history.
- Defect pattern present in the material.
-

Theory states that no electron can exist in the material with energy states falling in the forbidden gap. When the material is excited by any ionizing radiations (**Fig 2(a)**) some electrons (originally in the valence band) are excited and they attain energy states corresponding to the conduction band. Normally, these electrons cannot remain excited indefinitely, that is the lifetime of an electron in the conduction band is very short and the electron attains its ground state immediately giving away the energy to warm up the crystal lattice or in the form of light.

However, an impurity atom (with an appropriate ionic size and charge) present in the material can have energy states in the forbidden band. These are the metastable energy states having appreciable lifetime. An excited electron can find itself in this state, rather than getting back to its normal valence band state. Now, one says an electron is 'trapped'. In analogy, it is also visualized that a 'hole' (absence of an electron) is trapped at an energy state very close to the valence band. Depending upon the energy level of the electron trap with respect to the conduction band (or the hole trap with respect to the valence band)-called the trap depth.

This stage corresponds to a energy storage after the initial excitation of a material .If now the material is warmed, the heat supplied is able to stimulate the electron out of the traps (detrapping) and the electrons return to the ground state, if the conditions are favorable (for example, the particular atom has a light emitting property) for the emission of light in this 'return process' then thermoluminescence occurs (**Fig 2(b)**). Alternatively, a hole may be excited into the valence band where it wanders until it combines with an electron at the trapped counter- part emitting the TSL. (**Fig 2(c)**).

If the traps are not very deep, de-trapping and recombination may already occur at a substantial rate around room temperature resulting in a short half-life of the stored energy. This is called phosphorescence but strictly speaking it is thermoluminescence at the room temperature. Only, if the traps are the deep enough to result in sufficient storage stability at room temperature (half-lives of trapped electrons at least several months normally corresponding to glow peak temperature greater than about 150oC), the effect becomes of dosimetric interest .The glow curve generally exhibits many peaks, each corresponding to a trap with a different energy depth.

In many phosphors it is possible that the electrons and holes are de-trapped more or less simultaneously and they recombine at an entirely new site (**Fig 2(d)**) which is called luminescence center or recombination center. The TL glow curve will in this case represent an effective thermal activation energy needed by the trapped electron / hole to surmount a potential barrier between the

trap and recombination center. In reality, a trapped charge when de-trapped has a finite probability of getting re-trapped as in Fig.1.1e.When this re-trapping probability is significant, the shape of the glow curve is different from the case when it is absent. Also the recombination probability for the de-trapped charge carrier may in most cases charge with time (i.e. as the heating proceeds) depending on the number of available unused recombination centers. Such a process is called a second order or bimolecular process usually while the simplest case where the recombination has a constant probability with time, is called a first order or monomolecular process. There are also practical situations where the de-trapped charge carriers recombine directly without having to be excited into the conduction / valence bands. This is a, case of TL involving isolated luminescence center and process follows first order kinetics (**Fig 2(f)**). All the foregoing discussions take into account only the ionization effects of the excitation irradiation; one should not however forget about the displacement effects resulting from elastic/inelastic collisions of the atom of the phosphors with the impinging radiation. This effect is more significant for the case of particular radiations (like alpha, beta, gamma, neutron, cosmic rays). The important thing about this displacement effect is that atoms are physically moved which results in the creation of interstitials, and vacancies. In relation to thermoluminescence, these constitute defects, which have potential to influence the trapping and emission processes.

APPLICATIONS OF THERMOLUMINESCENCE IN :

- **ARCHAEOLOGY**

    Thermoluminescence technique has been found to be highly successful in dating ancient pottery samples. This method is suitable because of the following reasons:

> ➤ It gives the exact date of kiln firings of the sample (the other methods mostly depends on the shape and style of the pottery and hence correlate with the civilization to which it belonged).
> ➤ TL dating is possible even beyond 30000 years, but minimum age is 50years with an accuracy of ±1 year.
> ➤ Authentication and detection of forgery can be quickly and easily done by using this method.

The TL/OSL dating is done from a quartz grain which is collected from pottery or brick by reading the TL-output. The TL from the specimen is mostly due to TL sensitive mineral inclusions (mostly quartz) in the host clay matrix of the pottery. The technique of the dating pottery is very much similar to that done in geological samples. In archaeology, a more precise and definite event is the basis – the kiln firing. The pottery must have fired in the kiln sometime in the long past. That event is considered to be the starting of the 'TL clock ' for archaeological dating. Whatever TL has been stored earlier in the mineral inclusion due to internal and external irradiations over the geological times (since crystallization) is considered to be erased during the kiln firing.

After the onset of the 'TL clock' (kiln firing) the pottery starts building up TL due to internal irradiation from radioactive emanation of uranium (U), thorium (Th), and potassium (K), contents in the clay and external radiations from the cosmic background at the excavation site. Typically the total irradiation rate is of the order of 1 rad per year of which the major part is from internal radiations and the remaining due to soil irradiation and cosmic rays. Once an accumulated TL in the specimen has been measured and expressed in terms of absorbed dose by proper calibration techniques and if the total irradiation rate for the specimen could be established, the archaeological age can be obtained by simply dividing the former by the latter.

$$Age = \frac{Accumulated\ dose}{Annual\ Dose\ Rate}$$

But in practice many complicating factors come in the way of evaluating the age.

- **BIOLOGY AND BIOCHEMISTRY**

Application of TL technique in the study of biological and biochemical systems is increasingly favoured in recent times and necessarily all the measurements are done in the LNT-RT range. The attempts have been successful in the study of hydroxy and aminobenzoic acids, proteins, nucleic acids, plant leaves, algae and bacteria. The TL results could indicate the proper stability of the or the orthoform of the benzoic acid, the inter and intra molecular transfer of radiation damage in nucleic acids, proteins and their constituents could be correlated with their TL behaviour; the photosynthetic electron transport routes in the Z diagram could be correlated with TL and additional routes delineated and the interaction between salts and proteins could be understood from the TL patterns.

- **FORENSIC SCIENCE**

The major study in forensic sciences is to evolve and standardizes methods to compare evidentiary materials with similar materials of known origin, which are invariably available

only in minute quantities and are required to be analyzed nondestructively for evidence purposes. Thermoluminescence can offer an attractive technique in selected materials that are commonly encountered in the criminal cases viz; glass, soil, safe insulation terials, etc . This can be used as an exclusionary evidence i.e. when the TL characteristics do not match it can be said with certainty that a particular sample has not come from a known source .To reduce the probability of any coincidental matching and improve the confidence of the TL measurements whose signal to noise ratio may be bad, examination may be made of the TL glow curves from the virgin samples as well as after a heavy artificial gamma or X-ray irradiation and also of the emission spectra.

- **GEOLOGY**

  Geology is one of the earliest disciplines to accept the TL technique in its fold in a variety of applications, such as dating of mineralization, igneous activities, sedimentation and evaluation of growth rate of beaches and sand dunes.

  The TL technique has been found useful in dating specimens of geologically recent origin where all other conventional methods fail. In a geological specmen, the TL would starts building up from the time of its crystallization and would normally continue throughout its existence due to the radioactivity present within the minerals and in the surrounding materials, till its saturates. If one selects a material with a negligible radioactivity in it (e.g. quartz) the accumulated TL mostly represents the environmental dose rate at a place from where the geological specimen was collected.

  Accumulation of TL can be affected by natural light especially its ultraviolet component. In geology the sunlight bleaching is considered to be the basis for dating the geological event. The exposure of sand grains to sunlight during their weathering and transport through wind and water results in bleaching of their geological TL. This bleaching is effective enough to reduce thermoluminescence level to a negligible value. These bleached sand particles, once embedded in a sand dune or bleach, get shielded from further exposure to sunlight. This helps particles to acquire more TL due to radiations exposure from their new environment within the sand dune or on the seashore. At present using single grain technique age of geological samples can be estimated upto 50 million years with an accuracy of +5% or –5%.

- **QUALITY CONTROL IN INDUSTRY**

  As early as 1938, the application of TL in the control of feldspars in ceramic products has been described. The amount of TL given out by a ceramic after artificial irradiation is directly indicative of its feldspar contains at trace levels where any other type of quantitative analysis is time consuming. Thus in ceramic industry where a particular process is repeated many number of times to produce batches of the some materials, any controllable variations in the feldspar contents can be checked quickly and efficiently.

  The efficiency of certain surface catalyst like Al_2O_3 can be quickly and efficiently evaluated by their TL sensitivities .The lattice defects which permit the adsorption reactions might also nplay a role in the TL emitted by these substances and the nature and intensity of TL may be gainfully correlated with the catalytic activity. The TL glow curve in such a cases could be used as criterion in controlling the preparative parameters of a desired catalyst. In principle, TL method could be employed in the quality control of many of the glass, ceramics and

semiconductor products; recently it has been shown in the case of textile fibers that the low temperature TL glow curve changes can be correlated with the structure differences and / or chemical tracer impurities. However these have not yet received the attention of the industries.

- **RADIATION DOSIMETRY**

In the present scientific world, ionizing radiations have been found very useful in engineering, medicine, science and technology. Professionals used them at every walk of life. In all the applications, the exact amount of absorption of radiation energy in the exposed material is important factor to get the desired results. The better use can be achieved mostly by accurate determination of energy absorbed from the radiation field and it possible the distribution of this absorbed energy within the material. Measurements of these quantities form the basis of radiation dosimetry and systems used for this purpose are referred as dosimeters. Professionals have worked in this direction, investigated and standardized many analytical methods to estimate the doses of radiations. The important techniques developed and employed are as under;

- ➢ Fluorescence technique.
- ➢ Lyoluminescence method.
- ➢ Diffused reflectance technique.
- ➢ Thermally stimulated luminescence technique [TLD].
- ➢ Optically stimulated luminescence technique [OSL].
- ➢ Electron paramagnetic resonance technique [EPR dosimetry].

The main basis in the Thermoluminescence Dosimetry (TLD) is that TL output is directly proportional to the radiation dose received by the phosphor and hence provides the means of estimating unknown irradiations. Also, TL can provide a perfect passive measurement i.e. integrated irradiation levels over extended periods of the order of even years. Thus, it finds immense use in the monitoring of doses received by radiation workers on a routine basis; weakly/ monthly /yearly depending upon whatever a situation many warrant. It should however be borne in mind that most of the TL phosphors are not tissue equivalent (in terms of energy absorption by irradiation) and hence the relevant dose which is medically significant to a radiation worker from protection point of view is not readily obtained. Some of the phosphors like LiF, $Li_2B_4O_7$, BeO etc which are nearly tissue equivalent score 4 definite points over others like $CaSO_4$, CaF_2 Mg_2SiO_4 etc which are however more sensitive. Many phosphors have been developed for TLDs.

The application potential of TL-dosimeter is very high. They have been found very useful in many fields on account of several favorable characteristics such as high sensitivity, small size, ability to cover wide range of exposure / dose, reusability, insensitive to environmental conditions. In the past professionals had used the film budge technique in real practice. Later on they found that TLD technique is better for many reasons. And hence during last three to four decades they have developed and established the TLD technique. This is became popular now-a-days prominent applications of thermoluminescence dosimetry and radiation protection. The dosimeters have been widely used for in-phantom and in-vivo dosimetry, in medical applications. Another area, where thermoluminescence dosimeters have found use is personal monitoring of radiation workers.

On account of their ability to integrate over long periods of time and measure very low exposure, they have been widely employed for environmental monitoring of doses of the order of a few micro gray. The TLDs have been employed in protection monitoring for measurement such as leakage radiation levels on and around source containers, air scatter measurement around open top installations, area monitoring around radiation installations etc. Rapid fading ratio of main TL low temperature peal of certain phosphors such as CaSO4: Dy has been using for the estimation of time of exposure after irradiation.

It has been found that this technique can also detect and assess the thermal and fast neutron doses. Since TL phosphors insensitive to thermal neutrons are also available, combination of dosimeters can be employed for estimation of gamma and thermal neutron dose in mixed field. Besides this, TL dosimetry also include archaeological dating i.e. dating of ancient potteries and ceramics, space dosimetry, dosimetry of non-ionizing radiations such as UV and microwave dosimetry. If UV dosimeter has sensitivity close to the thermal response of the human skin, it would provide a measure of the thermally effective value of the UV energy.

On the other hand TLDs can also find useful in agriculture. In this field they use mainly concerned with high level photon dosimetry such as dose measurement in food preservation, radiation sterilization of seed, pest control etc. Formally, the dose measurement in agriculture relied heavily on chemical dosimeters e.g. the ferric (Fe^{2+}, Fe^{3+}) system. TLDs constitute a less expensive method and are applicable in the dose range of 10^{-4} to 10^{8} rad.

METHODS FOR EVALUATING PARAMETERS FROM THERMALLY STIMULATED GLOW CURVE

In the majority of cases a number of peaks are observed during the heating of the sample in a certain temperature range in more favorable cases the overlapping is minimum so we can treat as individual peak. In some of thermally stimulated phenomena the kinetics of the process is usually simple being of first order, second order or general order .Once one is satisfied that the peak under investigation is of such a simple nature , the evolution involved only of three parameters – the activation energy , the pre exponential factor and the order of kinetics. Many of the methods discussed in the present chapter

were developed for the simple particular cases of two or three parameters dependent single TL peak. Some of these can quite easily be adapted, to peaks of the other thermally stimulated processes. Values of the parameters, which seem to be most important to the investigator, are:

1. E- Activation energy
2. s- The frequency factor
3. b- Order of kinetics

It is expected that these parameters are independent of each other and of concentration parameters. This means that one hopes, for example, that for a particular electron trap, the activation energy, the attempt to escape frequency factor and the retrapping probability are not dependent on the concentration of the trap. Most of these methods were developed for the evaluation of the activation energy which, therefore in many cases, be calculated by a number of methods witch thus provide a cross check on the results. In the following section we will discuss the various methods developed for the evaluation of trapping parameters. In a rough way, one can divide the methods for evaluating parameters by peaks of thermally stimulated phenomena into the following groups:

- Heuristic methods: Methods developed mainly in the early stages of investigation of thermally stimulated curves based on empirical ground or otherwise unproved methods which turned out to be useful for certain cases.
- The initial rise method: This method is used particularly all the thermally stimulated phenomena for evaluating the activation energy.
- Curve fitting methods: This method based on many measured points in a broad temperature range. The initial rise method is, in a way, special case but due to its extensive use it can be taken as a separate group.
- Peak shape methods: It is based on the maximum temperature and two half intensity temperature or, alternately, on the two inflexion points.
- Various heating rate methods
- Isothermal decay methods

- ## **HEURISTIC METHOD**

  The methods included in the present section should be considered as being mainly of historical values or as first approximation for the evaluation of activation energy. Although admittedly, the use of other methods usually involves approximations as well, the accuracy expected in this method is generally poor. Assuming that in a given sample, the frequency factor is more or less the same for different peaks, one would expect that the bigger the activation energy the higher the maximum of the peak. The equation given by Urbach is:

$$E \text{ (eV)}= T_m(K)/500 \qquad\qquad 1$$

  This can be written as in the form of Eq(2):

$$E \text{ (eV)}=23kT_m \qquad\qquad 2$$

  And for the special case i.e. for NaCl it is the Eq(3):

$$E \text{ (eV)}=38kT_m \qquad\qquad 3$$

- ## **VARIOUS HEATING RATE METHODS**

A number of related methods, all based on the repeated measurement, of a certain peak at different heating rates and keeping all other parameter equal, have been independently developed in the research of practically all the thermally stimulated phenomena. These methods can be most easily introduced by studying the equation for the maximum of first order peak can be written as in Eq(4):

$$\beta = \left(\frac{sk}{E}\right) T_m^2 \exp\left(-\frac{E}{kT_m}\right) \qquad\qquad 4$$

- **PEAK SHAPE METHODS**

This method is based on a small number of points along the curve have been developed mainly in investigation of thermoluminescence. This however can very easily be applied to other thermally stimulated process also. The points used are in most cases the maximum temperature **Tm,** the half intensity temperature at low and high part of the peak **T1 & T2** respectively and are shown in figure-1.3. In small number of cases two inflexion points are utilized rather than half intensity ones. Lushchik (1956) developed methods for evaluation of E by using the high temperature half width of the peak.

GLOW CURVE SHAPE

The glow curve shape methods extract information from the glow peak by utilizing the peak temperature Tm and two temperatures T1 and T2 on either side of Tm corresponding to half peak intensity at the low and high temperature sides of the peak as well as half width parameters and the symmetry properties.
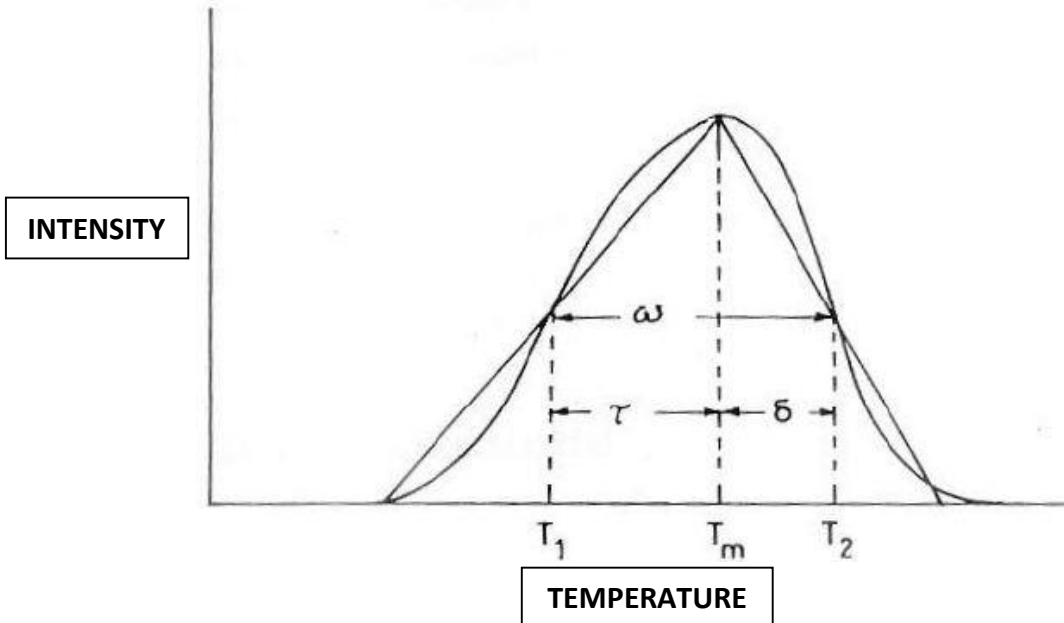
Fig 7

The equation is given by

$$E = 2kT_m^2 / \delta \qquad\qquad 5$$

Chen (1969) questioned the "triangle assumption" and tested its validity for a wide range of activation energies and pre-exponential factors for both first and second order peak. Instead of the Lushchik assumption which can be written as:

$$\delta I_m / \beta n_m = c_\delta \qquad\qquad 6$$

Chen has also given Eq(7) below, which is summation of all the equations and it was found to be the most appropriate in calculating the Activation energy.

$$E_\alpha = C_\alpha \left(\frac{kT_m^2}{\alpha}\right) - b_\alpha(2kT_m) \qquad\qquad 7$$

Where α stands for δ,ω or τ. The values of c_α and b_α for the three methods and for first and second order are shown in the table.

	First Order			Second Order		
	τ	δ	ω	τ	δ	ω
C_α	1.51	0.976	2.52	1.81	1.71	3.54
b_α	1.58 + a/2	a/2	1 + a/2	2 + a/2	a/2	1 + a/2

Table 1: Various Co-eff
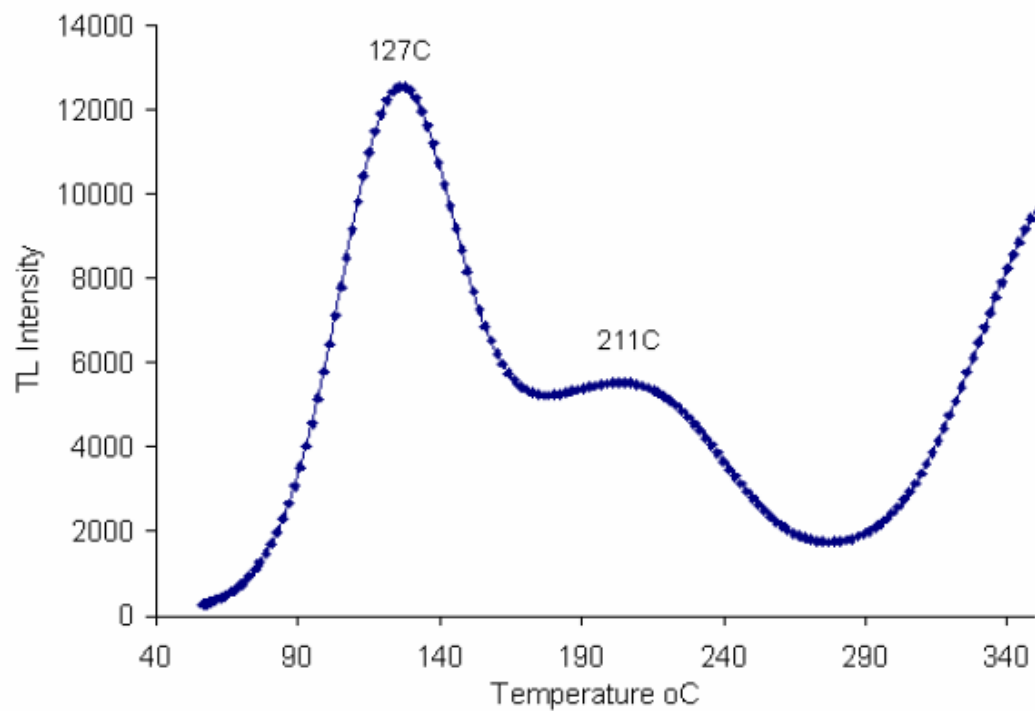
Fig 8: TL glow curve for the beta irradiated NaCl

ANALYSIS OF GLOW PEAKS

The glow curve for the beta irradiated sample for NaCl is shown in **Fig 8** . The glow curve shows well-resolved glow peaks around 127°C and another at 211°C. The TL was recorded by keeping the eating rate at 2°C/sec. The analysis of any TL glow curve i.e. the analysis of trap parameters by various methods and to see what kind and nature of traps are there, is an important tool to know about the nature of the material. The analysis of the same can be done from the various methods that are

described as below and the analysis of the study was done on the same. The activation energy, the frequency factor, and the shape alone i.e. the order of kinetics can dwell so much of information to the nature and the type of the glow processes taking place in the specimen and one can conclude the mechanism for it too. The study had been extensively done by Chen et. al. and Mckeever et. al. and is still carried out till today, as the model proposed for the same are of interest to the physicists. The values for the beta irradiated NaCl peak has been tabulated in table-2. It can be seen from the valuated results that for the different equations as proposed by different scientists, different values were obtained for all the methods. The oldest one which was proposed by Urbach is the easiest as it require only the peak temperature Tm of the glow curve. The activation energy calculated by various methods vary from 0.65 to 0.76eV for peak -1 but the equation given by Halperin et al , specially for NaCl, gives the value as 1.25 eV. For Peak-2 the activation energy was found to be varying from as low as 0.39 to 1.6 eV, the values calculated for activation energy by Chen's equation are considerably very low compared to all the other equations. We feel that this fluctuations in the activation energy for the Chen's equation for peak 2 are due to the experimental errors or overlapping of many peaks. We found out that all the other methods except the Chen are very approximate so one has to consider the values coming from the Chen's equation as correct.

The frequency factor was calculated by Randall & Wilkins equation i.e.

$$E = k\ T_m\ \ln s.$$

The frequency factor, s, has also been calculated for Peak -1 and Peak-2 and are tabulated in Table 2. It was found that the frequency factor for Peak -1 varied from 3.93×10^8 to 3.12×10^{16} / sec. But as there was variation in activation energy for Peak-2 due to that it was found that there was also drastic variation for the frequency factor of Peak -2. The reasons for the variations were the same as stated above.

TL characteristics of beta irradiated NaCl give rise to interesting results like generation of two well resolved peaks at 381 and 498K. The trapping parameters namely, activation energy, frequency factor was calculated using various methods available. It was found that the Peak-1 at 381.58 K by the Chen's equation was most appropriate. Whereas for the peak-2 there was a drastic variation of E and s values. Since the commercial NaCl consists of many impurities which leads to mixed TL peaks and generation of the many types of traps. However the values calculated using the equation E(eV) =38kTm are simply doubled which may be due to approximation done by the Urbach.

S.No	Equations	For Peak 1: T_m = 381.58 K		For Peak 1: T_m = 498.7 K	
		Energy (ev)	Freq. Factor (Sec^{-1})	Energy (ev)	Freq. Factor (Sec^{-1})
1	E(eV) = T_m(K)/500	0.763	1.7×10^{10}	0.9974	1.18×10^{10}
2	E(eV) = $23kT_m$	0.7569	0.97×10^{10}	0.9892	0.98×10^{10}
3	E(eV) = $38kT_m$	1.250	3.12×10^{16}	1.634	3.16×10^{16}
4	E = $2kT_m^2/\delta$	0.6520	4.01×10^8	1.479	8.66×10^{14}
5	$E = C_\tau(kT_m^2/\tau) - b_\tau(2kT_m)$	0.657	4.68×10^8	0.4224	1.8×10^4
6	$E = C_\delta(kT_m^2/\delta) - b_\delta(2kT_m)$	0.6636	5.72×10^8	0.44	2.77×10^4
7	$E = C_\omega(kT_m^2/\omega) - b_\omega(2kT_m)$	0.6513	3.93×10^8	0.397	1.0×10^4

Table 2: Tabulated form of the activation energy and the corresponding frequency factor as calculated form the various equations given in the text.

application of TLD systems for personnel monitoring.

APPLICATION OF TLD SYSTEMS FOR PERSONNEL MONITORING

INTRODUCTION

Personnel monitoring is based on the international recommendations of the ICRP. The primary objective of individual monitoring for external radiation is to assess, and thus limit, radiation doses to individual workers. Supplementary objectives are to provide information about the trends of these doses and about the conditions in places of work and to give information in the event of accidental

exposure [1]. Depending on the kind of radiation hazard, the ICRP recommend maximum permissible dose (MPD) values. These are the maximum dose equivalent values, which are not expected to cause appreciable body injury to a person during his lifetime. With respect to the various MPD values, the following quantities should be measured in personnel monitoring:

a) Skin dose or the surface absorbed dose to assess the dose equivalent to the basal layer of the epidermis at a depth of 5-10 mg cm-2, if only non-penetrating radiation has to be considered (x-rays<15 keV, γ-rays);

b) Whole body dose or the equivalent at a depth of 400-1000 mg cm-2 below the surface of the body to assess or over-estimate the effective dose equivalent or the average dose equivalent in the critical organs for the case of penetrating radiation and whole body irradiation (x-rays>15 keV, γ-rays, neutrons);

c) Extremity dose to assess the maximum value of the dose equivalent (skin dose) in tissue to any part of the hands, forearms, feet or ankles.

In contrast to film dosimetry, approximately tissue-equivalent TL detectors of small size and high precision in measurement are available which may serve as an ideal extremity dosimeter and as a basic dosimeter for the dose estimation of photons in the energy range of interest as well as for the detection of γ-rays and neutrons. In addition, a multi-detector badge offers practical possibilities for short-term and long-term monitoring periods, for separate indication of skin dose and body dose and finally for the estimation of radiation quality.

The role of TLD for an individual monitoring service is based on the following features:

a) TL phosphors are available in solid form as chips, extruded ribbons or in a Teflon matrix; the dose reading of some materials is approximately tissue-equivalent and largely independent of the angle of radiation incidence;

b) The dose reading is practically independent of dose rate up to 1011 rad s-1 and proportional to the dose up to several hundred rem;

c) In some TL materials the fading at room temperature is so small, especially after a post irradiation annealing, that they can be used for issue periods of up to 1yr;

d) TL detectors are convenient to wear, suitable for postal service, flexible in issue period, can be evaluated in less than 1min and can be re-used, although a regeneration procedure prior to re-use is often necessary;

e) TLD lends itself to automation; with an on-line computer the calibration factor for individual dosimeters can be stored and also the shape of the glow curve may be checked to verify the radiation-induced TL.

f) For the reassessment of the dose recorded, a redundant detector can be included in the badge design.

TLD, the most advanced and most intensively studied integrating dosimeter system, has now reached the stage at which it may replace or supplement film dosimetry. Primarily for applications in personnel monitoring, various suppliers offer a number of commercial TLD systems with manual or automatic evaluation systems.

- ## APPLICATION OF TLD SYSTEMS FOR ENVIRONMENTAL MONITORING

A significant aspect of environmental monitoring is the limitation of radiation exposure values in man from the nuclear power fuel cycle. In the case of gaseous radionuclides released to the environment from a nuclear installation, the acceptable limit of exposure is based on an annual dose equivalent of 30 mrem, a value about a third that from natural terrestrial and cosmic radiation. An increasing amount of public interest in environmental monitoring programmes is being focused on the environmental impact of radiation arising from nuclear power operations and the corresponding detection of slight variations in the natural radiation background.

TLD systems are widely applied to environmental monitoring programmes near nuclear installations. TLD systems with high reproducibility in the milliroentgen dose range are required in order to measure exposures equal to that resulting from an exposure rate of 10µR h-1 during field periods of from several days up to a year. For the application of TLD systems in environmental monitoring, therefore, special performance criteria and techniques for selecting, testing, calibrating and using a TLD system have been established:

a) The ANSI N545-1975 standard [1] specifies the minimum acceptable performance of TLD and outlines test methods for compliance. To meet these requirements, each laboratory has to carry out tests for determining their own limits of error.
b) On the basis of a standard test programme [41] and an inter-laboratory comparison, the performance and quality of a broad spectrum of TLD systems can be compared with respect to variations in the properties of reader, TL material, read-out method and annealing technique adopted in the laboratories.
c) Annual control exposures as well as inter-comparison experiments organized by the ERDA serve as a valuable way to compare one's own results with the international level [3].

This chapter reviews the properties of TLD systems and the common techniques used in the application of TLD in environmental monitoring, taking into account the results of a test programme and recent investigations of the long-term fading as well as the calibration technique and the interpretation of experimental results.

➢ **PERFORMANCE SPECIFICATIONS**

In contrast to the application in personal monitoring, TLD systems for environmental monitoring have to fulfill high requirements, such as

a) Good precision and reproducibility of measurement over the exposure range of interest (10-100 mrem);
b) Low fading over the field exposure period (3-12 months);
c) Insensitivity to environmental parameters, i.e. temperature, moisture, humidity, light;
d) Approximate tissue equivalence in dose reading;
e) Low self irradiation due to natural radio nuclides in the TLD phosphor or holder;
f) Encapsulation in a plastic holder to provide secondary electronic equilibrium, shielding against â-rays and light as well as water tightness;
g) Calibration techniques for each field cycle to guarantee the highest precision for the conversion to exposure and to correct for fading, transit exposure and zero-dose reading.

• **APPLICATION OF TLD IN MEDICINE**

There are two important areas of absorbed dose measurement in medicine:
  i. Absorbed dose measurement in radiotherapy.

ii.   Absorbed dose measurement in diagnostic radiology.

➢ RADIOTHERAPY MEASUREMENTS

The difficulties of accurately predicting absorbed doses in radiotherapy by calculation have in the past led to the development of in vivo measurement techniques. While entrance and exit absorbed doses could be measured using films and conventional ionization chambers, intracavitary measurements were limited by the minimum size of available ionization chambers (typically 20mm x 5mm diameter).

 When Daniels first developed thermo luminescence as a practical method of assessing ionizing radiation exposure, it was realized that the technique could be applied in the field of clinical measurement. Brucer used some of Daniel's single crystals of Harshaw LiF to make internal in vivo measurements in cancer patients injected with radioactive material.

The arrangement of radiotherapy treatment fields is conventionally carried out using a combination of calculations involving standardized geometries together with depth dose and transverse dose measurements in phantoms. The final check on the absorbed dose delivered to the patient can be carried out by in vivo dosimetry. Similarly, absorbed doses to organs not involved in the treatment, which should be kept to the minimum, can be measured.

Thermo luminescence dosimetry has proved a useful technique for a variety of purposes in radiotherapy, including measurements of therapy machine output, beam uniformity checks and the measurement of absorbed dose in phantoms and in vivo for both internally and externally applied fields. Thermo luminescent dosimeters have a high precision, provide rapid retrieval of information (using on-site readers), have good environmental stability, have good water or tissue equivalence and have a wide range of sensitivities. The last characteristic is particularly important for in vivo measurements of absorbed dose. Because of their small size, thermo luminescent dosimeters also give good special resolution. This is of particular value in many radiotherapy techniques where the absorbed dose has a rapid special variation. Thermo luminescent dosimeters may also be used to measure the absorbed dose to experimental animals.

➢ DIAGNOSTIC RADIOLOGY MEASUREMENTS

The collective dose from medical exposure has been estimated to represent the largest single man-made contribution to both the somatic and the genetically significant dose equivalent to the population of the United Kingdom as illustrated in figure representing some 31% of the total somatic dose and 9% of the total genetic dose, and 95% and 85% respectively of the man-made contribution. In other developed countries, the estimated figures are similar. By far the largest contribution is from diagnostic radiology, estimated as 10 times the sum of the contributions from nuclear medicine and radiotherapy.
New radio diagnostic techniques have been introduced, some involving the use of complex machines such as the head and body scanners (computerized axial tomography, CAT). Thermo luminescence dosimetry has proved to be a useful method in the comparison of patient absorbed dose from these new techniques as well as from the more traditional ones. Diagnostic absorbed dose measurements are important for:

i.   Improving the design of equipment to reduce patient absorbed dose, and

ii.   Improving radiographers' techniques in the use of equipment to reduce patient absorbed dose, and for providing a measurement database for epidemiological analysis of population radiation absorbed dose from diagnostic radiology.

Thermo luminescent phosphors such as LiF: Mg, Ti and particularly the more tissue equivalent Li2B4O7: Mn have been used for such measurements. Thermo luminescent dosimeters have three main advantages over ionization chambers for this type of measurement:

a) They are small and unobtrusive,
b) They are radio-transparent to most x-radiation, and
c) They do not require connecting leads and are easily attached to the patient.

FACTORS IN THE CHOICE OF DOSIMETERS FOR CLINICAL USE

A number of factors have to be considered in the choice of the material and form of the dosimeters for clinical dosimetry. The most important factors are:

i.   Estimated absorbed dose range of the intended measurements,
ii.   Estimated equivalent photon energy or linear energy transfer (LET) of the radiation,
iii. Immediate environmental conditions around the dosimeter, and spatial resolution.

- **ABSORBED DOSE RANGE**

The sensitivity of any thermo luminescent dosimeter is proportional to the mass of active phosphor present, within limits imposed by geometrical and thermal considerations relevant to the readout system. Dosimeters, which contain only thermo luminescent material, e.g. powder, extruded ribbons and rods, have a much higher sensitivity than dosimeters consisting of a phosphor held in a matrix of binder material, e.g. PTFE-based discs, tape and micro-rods.

The range of absorbed doses encountered in clinical and biological irradiations is very large. In diagnostic radiology, absorbed doses may range from less than 10 µGy to 100 mGy to the gonads and from approximately 100 µGy to about 100 mGy to the skin. Hence, at the lower end of the diagnostic radiology range, there is a need for a sensitive form of dosimeter, e.g. powder or extruded forms. However, in therapy dosimetry, a single treatment fraction of absorbed dose may be several grays, and, in many animal or cell irradiations, tens of grays may be required. Less-sensitive forms of dosimeter can be used, especially those incorporating the phosphor powder in PTFE as discs, tape and micro-rods. The measurement of high-absorbed doses will often necessitate using the dosimeter above the linear thermoluminescence absorbed dose response region. Under these conditions, the degree of supralinearity needs to be determined. Often, in radiotherapy, simultaneous measurements of absorbed dose in the treatment region and the much smaller absorbed dose in the shadow of shielding may be required. In such cases, two types of dosimeter, such as extruded rods and PTFE-based rods, may be used in parallel. This particular combination of dosimeters, if appropriately oriented with respect to the absorbed dose gradient, should provide good spatial resolution.

- **PHOTON ENERGY RANGE AND LET OF RADIATION**

Modern routine radiotherapy and radio diagnostic techniques use a wide range of photon energies from conventional x-ray machines of approximately 10 keV to200 keV, from 137Cs (0.67

MeV) and 60Co (1.25 MeV) teletherapy units and from accelerators producing highenergy electrons and mega voltage photons.

The total light emitted by an irradiated phosphor is proportional to the total radiation energy absorbed by it. In tissue, the absorption of Compton-scattered electrons is the most important absorption process in the photon energy range from approximately 20keV to 10 MeV. For elements such as lithium, boron, oxygen, fluorine, etc, of low atomic number, and for photon energies up to about 15 keV, the photoelectric effect is dominant. Thereafter, up to 10 MeV, Compton scattering is most important. For elements of high atomic number, such as those used as dopants (e.g. Li, Mg, Mn, etc), the photoelectric effect is dominant up to several hundred kilo electron volts.

The advantage of using materials consisting mainly of atoms of low atomic number with only a few dopant atoms of higher atomic number is obvious because of their good approximation to tissue and air. This is particularly true of phosphors based on lithium borate.

In order to evaluate the absorbed dose to a phantom or patient using thermo luminescent dosimeters, it is essential to know the relative energy responses of the dosimeters throughout the range of energies used. The primary response calibration of dosimeters is usually carried out using a 60Co source (1.25 MeV) and the responses at all other energies and for all other radiations are expressed as multiples or fractions of this. For clinical applications, the response is most usefully expressed as the light emitted per unit-absorbed dose in tissue or water. This will be a function of radiation energy and of the physical form of the dosimeter. The beam quality has to be known. Photon-beam quality determination, although in principle relatively straightforward to determine in free air, is difficult to determine uniquely in water or solid phantoms because of two effects:

i.   The contribution from lower-energy scattered radiation from the phantom and external shielding material, e.g. the applicator cone at short focus-to-skin distances (also at low photon energies the effects of dosimeter orientation and self shielding become increasingly important), and
ii. The effective 'hardening' of the beam with increasing depth in the water or solid phantom.

The thermo luminescence absorbed dose (water and polystyrene) response of LiF: Mg, Ti to high-energy radiations, of which those of principal interest in clinical applications are mega voltage photons and high-energy electrons, has been widely investigated and reported in the literature. The results have often been inconsistent. Some investigators have measured approximately 10% reduction in response to high-energy radiations compared with that to 60Co gamma radiation, and others have not found any reduction. Much discussion has revolved around the application of various generalized cavity theories to attempt to explain the observed effects and to reconcile the differences.

- **ENVIRONMENTAL FACTORS**

Absorbed dose range and radiation energy considerations apart, environmental factors such as temperature, humidity, contact with body fluids, insertion into catheters, sterilization, etc, influence the choice of dosimeter form and packaging. If dosimeters are not protected from their environment, the result is often low precision and sometimes gross error in absorbed dose measurement.

> **TEMPERATURE AND HUMIDITY:**

During exposure under clinical conditions, dosimeters may come into contact with heat (human body core temperature is 37oC) and/or high-humidity environments. If implanted or introduced into body cavities, they can come into contact with body fluids. Some phosphors (especially in powder form) have been shown [14] to be affected by humidity as well as by storage at elevated temperatures, which induces fading.

> **OTHER AGENTS:**

If dosimeters in solid form are attached directly on to the skin using adhesive tape, care should be taken to remove all traces of adhesive from the dosimeters before readout. Adhesives often exhibit thermo luminescence following exposure to visible light and/or ultraviolet radiation. The simplest way of avoiding these effects is to seal the dosimeters inside protective envelopes (e.g. polythene).

- **STERILIZING OF DOSIMETERS**

Occasionally, a clinician or biologist will require dosimeters to be sterilized. The three common methods of sterilizing. i.e. autoclaving, chemical sterilizing and irradiation with 254 nm ultraviolet radiation, can all have a gross effect on the inherent sensitivity of the dosimeter or may induce spurious luminescence. In general, provided the phosphor is effectively sealed in a protective envelope or catheter, which is opaque to the sterilizing ultraviolet radiation, either chemical or ultraviolet sterilizing at normal ambient temperature is recommended. Normal ambient temperature is emphasized, as the effects of elevated temperatures on the normal sensitivity of phosphors, especially LiF: Mg, Ti, can be significant. The effects of autoclaving can be particularly severe.

- **SPATIAL RESOLUTION**

Good Spatial resolution of absorbed dose measurement is generally useful, and is essential in the determination of high-absorbed dose gradients. Thermo luminescent dosimeters are available in many shapes. Powder acts like a fluid and will adopt the shape of its container. The micro-rod and extruded ribbon (and hot pressed) dosimeters are so small, 1 X 1 X 6 mm3 and 3.2 X 3.2 X 0.9 mm3, respectively, that the effective size of the dosimeter is often limited in practice by the requirement to have adequate build-up to ensure electronic equilibrium.

RADIOTHERAPY ABSORBED DOSE MEASUREMENTS

A. SIMPLE GEOMETRY PHANTOMS

In radiotherapy, the specification of the complete absorbed dose distribution within the radiation beam in a phantom is a prerequisite to ensuring that the prescribed absorbed dose is delivered to the target volume in the patient. A common method is to employ published depth dose data and an isodose chart. An example of such a chart is illustrated in figure. This chart refers to a section

containing the beam axis parallel to one side of a 60Co 10 X 10 cm2 therapy beam for a fixed source-to-skin distance (SSD) of 80cm. The lines mapped on the chart link points of equal absorbed dose expressed as a percentage of a peak absorbed dose. In the case of 60Co radiation, the peak-absorbed dose occurs at the optimum 'build-up depth' in water, 5 mm. For x-ray beams produced with generating potentials of less than 400kV, the depth doses are conventionally expressed as a percentage of the surface absorbed dose. Similar charts are used for fixed source-axis distance (SAD) beams. However, in these, the isodose values are expressed as a percentage of the absorbed dose at the target deep within the phantom. SAD isodose charts are used when the target volume is located on the axis of rotation of the tele-therapy machine. The selection of an appropriate isodose chart can be difficult, as the absorbed dose distribution in the phantom depends on the beam dimensions, SSD or SAD, the radiation quality, the source size, the geometry of the beam and the positioning of the beam collimators. The International Commission on Radiological Units (ICRU) [15] therefore recommends the use of isodose charts, which are exactly specified for the particular equipment being used. This criterion can be established, as ICRU recommend, by a series of single measurements using an ion chamber or thermo luminescent dosimeters.

In their simplest form, the measurements consists of:

a) Measuring the depth dose distribution along the central axis of the beam in a water or water-equivalent phantom, and
b) Choosing one particular phantom depth (which in the case of 150 keV to 10 MeV and 137Cs and 60Co teletherapy beams, ICRU recommends as 5 cm) and measuring the radiation absorbed dose profile across the beam at this depth.

After normalization of the depth dose measurements at 5cm depth, the published dose data which one intends to use can be compared with them and corrected accordingly. Similarly, the measured beam profile can be compared with that obtained from the published isodose chart.

Since 1968, the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) have been running a programme of inter comparison of 60Co teletherapy units in the various radiotherapy centers throughout the world. This resulted from investigations carried out in 1965 which revealed that there was no suitably calibrated radiation measuring instrument in use in about 30% of the radiotherapy centers investigated. A simple test procedure based on thermo luminescence dosimetry is used to assess the accuracy of delivered absorbed doses in the centers.

LiF: Mg, Ti power dosimeters contained in PTFE capsules are sent to radiotherapy centers.

The measurement technique used in this study illustrates:
i. The practical use of thermo luminescent dosimeters for radiotherapy depth dose measurements in a simple phantom, and
ii. Methods to eliminate effects of fading and other variable environmental factors.

Participant centers are sent four sets of dosimeters. They are requested to irradiate one test set (A) with an absorbed dose of 2 Gy in water at 5 cm depth on the central axis of a 60Co 10 X 10 cm2 therapy beam with an 80 cm SSD. Another test set (B) is to be irradiated under similar conditions for 2min. A control set (C) which has been given a known absorbed dose by IAEA and a control set (D) which is unexposed accompany sets A and B at all times except during irradiation. Sets C and D provide information about any environmental or spurious effects, such as thermal fading, unintentional irradiation, etc, which might adversely affect the test dosimeters. In addition, reference sets (R) are irradiated by IAEA in a standardized 10 X10 cm2 60Co beam (SSD 80cm) at a depth of 5cm in water. The absorbed dose rate expressed in grays per minute in water is obtained

from a measurement of the exposure rate in free air using a calibrated ionization chamber. All dosimeters are then read out together, eliminating possible calibration errors due to fading and effectively standardizing the readout procedure for all dosimeters.

B. IN VIVO MEASUREMENTS

While the measurement of complete absorbed dose distribution in a phantom is essential in planning the treatment of a patient, the ultimate check on the absorbed dose delivered to the patient can only be made by in vivo absorbed dose measurements. Thermo luminescent dosimeters have proved to be particularly useful for this purpose.

The relevance of in vivo dosimetry is illustrated by the flowchart shown in figure. This flowchart is a simplified form of that used by ICRU [15] to illustrate a systems approach to radiotherapy. In vivo measurements verify that the absorbed dose prescribed by the clinician, and calculated and set up by the physicist and the radiographer, has been delivered. Further, it may be used to monitor any change in field uniform it caused by changes in the many treatment parameters.

In vivo measurements can be divided into four classes.

- **Class 1 – entrance absorbed dose measurements.** These are used mainly to check the machine output, the absorbed dose distribution profile across the patient, particularly in the penumbra of shielding, and the positioning of shielding in relation to the patient. If the measured values are at variance with those prescribed and calculated, the cause can be investigated and appropriate corrective action taken. The spatial resolution afforded by thermo luminescent dosimeters is particularly useful in these measurements.

- **Class 2 – exit absorbed dose measurements.** These are used mainly to check the absorbed dose delivered to points deep within the body. The measurements should agree with calculations for exit-absorbed doses. For such measurements, the dosimeters should be provided with sufficient backscatter material. Again, good spatial resolution may be important.

- **Class 3 – intracavitary absorbed dose measurements.** The absorbed dose within a body cavity, e.g. the mouth, nasopharynx, oesophagus, vagina, rectum, etc, can be measured using dosimeters sealed inside a catheter as shown in figure. The position of the dosimeters may be checked using radio-opaque markers and exposing an x-ray film. The increase in scattered radiation resulting from the presence of radio-opaque markers of high atomic number can cause uncertainties of a few percent in the absorbed dose to the dosimeter. This can be measured and allowed for.

- **Class 4 – individual spared organ absorbed dose measurements.** The absorbed dose to spared (shielded) organs can be measured, but often no build-up can be used as this would initself result in an increased adsorbed dose to the organ.

EXAMPLES OF THE USE OF TL DOSIMETERS IN RADIOTHERAPY

Thermo luminescent dosimeters are routinely used for a number of different types of in vivo radiotherapy measurements in centers throughout the world. The following examples illustrate some of the principles of their use.

A. MEASUREMENT OF ABSORBED DOSE DURING 'MANTLE THERAPY' FOR HODGKIN'S DISEASE

The radiotherapy treatment of Hodgkin's disease involves the irradiation of a large area of the body. The treatment field is designed to deliver a therapeutic or prophylactic absorbed dose to the axillary, cervical and mediastinal lymph nodes. Many different treatment fields have been used, but one commonly used configuration consists of anterior and posterior parallel and opposed fields as illustrated in figure. There is also the need to shield presumed healthy organs, e.g. lips, eyes, lungs, kidneys, bone joints, etc, and for posterior irradiation the spinal cord needs to be shielded. To avoid excessive exposure of the skin (skin sparing), the treatment is carried out using either 60Co or mega voltage x-ray photons and the shielding is positioned some distance (typically 20 to 50 cm) above the entrance surface of the body. This is achieved using 'individually tailored' moulds of polystyrene, one anterior and one posterior, with appropriately cut out channels containing lead-shot shielding. Alternately, appropriately shaped lead absorbers, placed on a Perspex plate and positioned above the body, have been used. The technique is termed the 'Gothic arch' or 'mantle' technique. A typical four-week course of treatment involves a total prescribed absorbed dose of between 30 and 40 Gy delivered in 20 fractions.

Thermo luminescent dosimeters, usually LiF extruded ribbons or rods or PTFE-based discs or micro-rods sealed in thin protective polythene sachets, are attached to the body under moulded blocks of wax or in small Perspex containers. The dimensions of the wax or Perspex are chosen to provide build-up appropriate to the photon energy of the beam and to ensure electronic equilibrium. With the use of high-energy photon radiation, e.g. 42MV x-rays, Ruden [10] recommends the use of a maximum build-up of 15mm Perspex and an experimentally derived factor to correct the apparent absorbed dose.

B. INTRACAVITARY ABSORBED DOSE MEASUREMENT

The small size and shape of the extruded and PTFE-based micro-rod dosimeters have enabled in vivo measurements of absorbed dose inside body cavities, which hitherto were often difficult and sometimes impossible. As illustrated in figure, these dosimeters can easily be inserted and sealed in catheters.

A very good example of such applications is the in vivo measurement of absorbed dose distribution in the pelvis during intracavitary 226Ra and external beam therapy for carcinoma of the uterine cervix.
The dosimeters are introduced into the pelvis via the external femoral veins. In one technique [17], sterile PTFE catheters are first inserted in the veins. This process can be monitored using x-ray fluoroscopy and television. Inner tubes containing gold radio-opaque markers are then introduced into the catheter to assess accurately the intended positions of the TL dosimeters. The radium is then applied and its position in relation to the dosimeter markers can be assessed. The marker catheter tubes are then removed and replaced by two others, each containing 15 micro-rod dosimeters spaced some 16 mm apart. Using this technique of outer and inner catheters, there is no need to sterilize the inner dosimeter catheters.

DIAGNOSTIC RADIOLOGY ABSORBED DOSE MEASUREMENTS

In the diagnostic range of photon energies, LiF phosphor can over-respond by as much as 40% compared with tissue. However, $Li_2B_4O_7$: Mn is an extremely good match for tissue over this range of photon energies and, by adjustment of the fractional amount of manganese present, the response can be 'trimmed' to match more closely that of air, water or tissue; e.g. Jayachandran [20] suggested 0.34% w/w for air equivalence and Christensen [21] 0.45% w/w. Langmead and Wall [22] found that, using $Li_2B_4O_7$: Mn powder containing 0.15% w/w of manganese, they could measure absorbed dose

in tissue, from x-rays of unknown quality, with a predicted error associated with photon energy of not greater than +/- 5% and an overall uncertainty of not more than +/-15%. This is an important characteristic of Li2B4O7: Mn phosphor because, while the effective energy of the primary beam can be assessed, at least in air, by half-value layer measurements, the quality of the lower-energy scattered radiation and the magnitude of its contribution to absorbed dose are difficult to assess. Li2B4O7: Mn is therefore particularly suited for such measurements. While sensitive solid forms of Li2B4O7: Mn, such as extruded ribbons, are commercially available, they are relatively expensive and this tends to exclude them from large-scale measurements programmes. Loose powder is probably most suitable for this application at present.

A. <u>HUMAN PHANTOM MEASUREMENTS</u>

In contrast with simple homogeneous phantoms, a most useful phantom for absorbed dose measurements in radiotherapy and diagnostic radiology is one which is designed, as far as is practicable, to simulate the structure of human body. The torso and head and neck of such a phantom are shown in figure. In proportion, it is equivalent to an 'average man' 1.75 m tall and weighing 73.5 kg. It is made from tissue-equivalent synthetic rubber and contains a complete human skeleton, lung- equivalent material and airways corresponding to the maxillary sinuses, nasopharynx, trachea, etc. it is composed of a number of 25 mm thick transverse sections each containing a matrix of 5 mm diameter holes spaced 3 cm apart. Each hole can accommodate a dosimeter holder/capsule or a solid plug of tissue- equivalent material. The complete phantom contains over 3000 holes and additional ones can be drilled if required. Suitable Perspex or polythene capsules can each contain approximately 35 mg of powdered phosphor.

Human-like phantoms are extremely useful for absorbed dose measurements in diagnostic radiology where their human form allows not only precise and realistic positioning of 'the patient' in the beam but also positioning of dosimeters to measure the absorbed dose to specify organs, including the gonads. Combined with the use of thermo luminescent dosimeters, they have proved especially useful in the assessment of 'patient' absorbed dose imparted by computerized axial tomography (CAT). The recent measurements by Wall were performed using Li2B4O7: Mn powder dosimeters contained in plastic containers and inserted in the phantom slices as illustrated in figure. In these examinations, regions of dosimetric interest included not only the section of the patient (phantom) undergoing radiological examination at a particular instant in time but also the adjacent sections which are irradiated as a result of the divergence and scatter of the primary beam. Wall et al [5] also included measurements of absorbed dose to the lens of the eye, thyroid, gonads and skin. For these they used Li2B4O7: Mn powder in polythene sachets.

B. <u>IN VIVO MEASUREMENTS</u>

While measurements using human-like phantoms are extremely useful in the assessment of absorbed dose in diagnostic radiology, the measurements are not performed under entirely realistic conditions. The information gained from these measurements takes no account of the skill and experience of the radiographer, the quality and suitability of equipment and differences in shape and size of patients. In vivo measurements on patients undergoing routine radiological examinations in hospitals provide a much more realistic assessment under everyday practical conditions. Li2B4O7: Mn dosimeters are especially useful for these measurements. They are

tissue-equivalent and radio-transparent except on high quality mammograms. In general they do not interfere with the diagnostic quality of the image and cause little inconvenience to patient, radiographer and radiologist.

Langmead et al [23] used Li2B4O7: Mn powder dosimeters, which were the same as those shown in figure, for the measurement of absorbed doses to patients undergoing various forms of radiological examinations including cardiac catheterization, barium enemas, intravenous pyelography and mammography. Maximum skin and gonad-absorbed doses were measured.

This series of measurements constituted a pilot survey of absorbed doses to patients, and recently this work has been extended to include other radiological techniques.

semi automatic TLD badge reader (TL 1010S)

INTRODUCTION

The improved Semi-Automatic TLD Badge Reader TL1010S is a personnel monitoring system, developed & manufactured by Nucleonix Systems is primarily designed to read the TLD card (TL dosimeters) worn by radiation workers. Several Personnel radiation monitoring systems such as photographic films, pocket ionization chambers and thermoluminescent dosimeters (TLD) have been used for the routine evaluation of radiation exposures to personnel. Recently there has been a rapid increase in the use of TLD for personnel monitoring of radiation workers. The TLD systems are preferable over other systems because of several reasons such as,

  a) The availability of a variety of highly sensitive TL phosphors.
  b) Wide measurable range.
  c) Reusability of the dosimeters.
  d) Good post irradiation stability.
  e) Rapid read-out capability and
  f) Low cost and ease of preparation.

The TLD personnel monitoring system essentially consists of two major parts:

  I.   TLD badge and
  II.   TLD badge reader.

The TLD Badge comprises of a plastic cassette containing a TLD Card made of aluminum with three Teflon TLD discs (13.3mm and 0.8mm thick) that are mechanically clipped on to circular holes (12.0mm) punched on it (52 x 30 x 1mm). Each TLD Card also comprises of a unique punched hole ID which is readout during the acquisition cycle for identifying the wearer of the TLD.

This Semi-Automatic TLD Badge Reader is primarily designed to read Bhabha Atomic Research Centre (BARC) developed $CaSo_4$ (D_4) PTFE disc dosimeter based TLD cards. These cards utilize three dosimeters.

The TLD Badge Reader is designed to measure X, Gamma and Beta radiation dose. The metal filter combination (1mm Al + 0.9mm Cu) is provided to reduce the photon energy dependence of the TL discs. The TL badge reader is calibrated such that the TL output of the disc under the metallic filter reads directly the gamma radiation dose.

The TLD Badge Reader system is designed using state of art electronics, stepper motor based electro-mechanical system, embedded code and software to load and read the TLD cards for TL glow curve / dose along with personnel ID. The system facilitates entry / printout of Dose records and glow curve for the personnel. TL dosimeter is heated by hot gas (N_2) jet to 285°C using a Nichrome heater assembly & TL output is recorded using PMT whose integral of the current output is proportional to the dose.

In this thermoluminescent dosimeter based personnel-monitoring system, the radiation workers wear the dosimeter & the radiation exposure is estimated on the basis of TL dosimetric reading. Thermoluminescent dosimeters make use of the property of certain materials, which absorb energy when exposed to X, Gamma or Beta radiation. On heating, the absorbed energy is released in the form of visible light. A plot of light intensity emitted against temperature is known as a glow curve. For a given heating rate, the temperature at which the maximum light emission occurs, is called the glow-peak temperature and it is characteristic, of the individual TL material (also called phosphor).

The quantity of the visible light emitted (TL output) is found to be proportional to the energy absorbed by the TL material. The estimation of radiation exposure may be based either on the height of the glow curve (differential method) or the area under the glow curve (integral method).
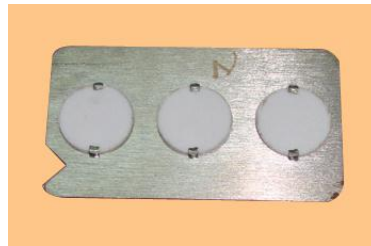
Front View

Rear View

Fig 9: Front and Rear View of TLD Badge Reader

<u>**ACCESSORIES**</u>

1. Light Source Card
2. TLD Card
3. Cassette
4. Magazine
5. Nitrogen Cylinder
6. Gas Regulator

Light Source card

TLD card

TLD cassette

TLD Magazine

Gas Regulator

Nitrogen Gas Cylinder

Fig 10: Various Accessories

HARDWARE SPECIFICATIONS

Dosimeter
Three-element BARC $CaSO_4$ (Dy) PTFE disc dosimeter badge

Light Measurement System
Photo-multiplier tube (R6095 or its equivalent) bialkali Light measuring system (LMS)

Dark current
Dark current is 1µSv ($CaSO_4$) equivalent with software-based sampling & subtraction.

Heater Element
Nichrome wire heater assembly.

Heating Method
Hot gas (N_2) heating.

Nitrogen flow rate measurement
Digital flow rate meter

Heating Cycle
The temperature is raised to 280° C in 8-10 sec and clamped at 280°C

Dose Range
Reader is capable of reading badges from 5µSv to 2.0Sv automatically and the dose response is linear over the entire range.
50µSv – 1.0Sv (Gamma) and
100µSv – 10Sv (Beta)

Dose Threshold
<50⁯Sv

Readout time
100 sec. per badge

Residual TL
8 to 12% of initial TL in the linear dose range specified.

Light source
A Ni63 based light source card is provided for PMT check & gain adjust.

Flow Rate Measurement
A digital flow measurement system is provided for flow rate measurement & failure check.

Facilities Available
Entry of personnel for badges editing of calibration factor etc. Storage of dose and glow curve data of badges in database. Stepper motor based drive assembly is provided for magazine & TLD card transport in a magazine. Digital linear actuators are used for TLD card raise & shutter control.

Software
Win 7 compatible software developed on .net platform for storage of readings in a database and display of glow curves, computations of dose & generation of dose reports.

Temperature Monitoring
Two Chromel Alumel thermocouples in hot gas stream, one called 'Heater Thermocouple' inside heater & the second called 'Air Thermocouple', in hot gas stream.

Range Selection
Auto-changeover

Calibration
Coarse adjustment by varying the EHT through a potentiometer in the EHT circuit; fine through software.

Safeguards
Heater/Gas flow failure
The heater and gas flow are checked for failure in every dosimeter readout cycle. In the event of failure of heater or gas flow the readout is terminated and a message indicating heater / gas flow failure is flashed on the PC monitor.
Mechanical Failure
Any mechanical failure during readout cycle is sensed by the software and the cycle is terminated with an option for the user to restart the cycle. EHT & input circuit (I-F converter) are also sensed and reading cycle is terminated in case of failure.

Nominal Power Supply
Power supply : 230V, 50Hz : +/- 10%
Power requirements: 500 VA (max including PC).

PC Requirements
Suitable latest PC configuration with win 7 Operating system or as requested.

Applications
Personnel Monitoring of radiation workers in Nuclear power stations, Isotope laboratories, Industrial radiography installations, diagnostic & therapeutic radiology centres, etc.

TLD CARD

TLD badge is based on $CaSO_4$:Dy thermoluminescent phosphor as a radiation detector. The concentration of Dy dopant to the extent of 0.05 mol.% in CaSO4 makes it highly sensitive Thermoluminescent (TL) phosphor (about 40 times that of the most popular LiF TLD-100). The response to neutrons remains negligible (only 3.8 mGy equivalent Co-60 gamma ray response per 1010 thermal neutron cm-2). The phosphor exhibits a main TL glow peak at about 220°C (TL peak of $CaSO_4$: Dy Teflon Disc occurs at about 240 °C) with very small satellite glow peaks on higher and lower temperature sides of the main peak. The TL response is linear and glow curve structure remains stable for both low and high LET radiation in the dose range of interest in radiation protection. The response and the chemical form are highly stable to the climatic variations. Though the TL signal fades faster when exposed to bright sunlight, exposure to normal room light does not affect the response. However, the response of TLDs contained in paper wrapper and polythene pouches, is not affected by exposure to sunlight. In order to obtain large number of integrated dosimeters having the same TL sensitivity, $CaSO_4$:Dy phosphor was embedded in Teflon (polytetrafluoroethylene PTFE) to make TLD discs. Teflon is a plastic which can withstand temperatures necessary for TL readout and annealing process for repeated use and thus provides rugged and handy dosimeter suitable for field use. Some of the characteristics of the $CaSO_4$:Dy Teflon embedded TLD discs are given below.

The TLD badge comprises of a TLD card and plastic cassette / holder. TLD card has three Teflon TLD discs (13.3 mm dia. and 0.8 mm thick) that are mechanically clipped onto circular holes (12.0 mm diameter) punched in an aluminium plate of size 52.5 x 30 x 1 mm3. An asymmetric "V" cut is provided in the card to ensure its orientation. The card wrapped in a thin paper wrapper (thickness 10 mg/cm2) containing printed information regarding the user, service period and type of radiation etc. is put in a thin plastic pouch (thickness 3-4 mg/cm2) before loading it in the plastic cassette. The paper wrapper protects the TLD discs from exposure to light whereas plastic pouch prevents contamination of the TLD card. Specifications of TLD cassette are given in Appendix-C. Specifications of paper wrapper and plastic pouch are given in Appendix-F. There are three well-defined regions in the plastic cassette / holder corresponding to three TLD discs of the TLD card. The asymmetric "V" cut of the card permits its loading in the plastic cassette in only one orientation and ensures proper positioning of three discs as follows: (i) Disc D1- sandwiched between a pair of filter combination of 1.0 mm thick Al and 1.0 mm thick Cu (Copper filter nearer to the disc), (ii) Disc D2- sandwiched between a pair of 1.6 mm thick (180 mg/cm) plastic filters and (iii) Disc D3- under a circular open window. For identification purposes, photograph of the user could also be permanently fixed on the central transparent region of the badge.

There are three types of TLD badges / cassettes in use namely, 1- Chest Badge, 2- Wrist Badge and 3- Head Badge. Though the dosimeter and design of all the three types of TLD badges are same, they have different attachment (clip/strap) for wearing purpose depending on their use.
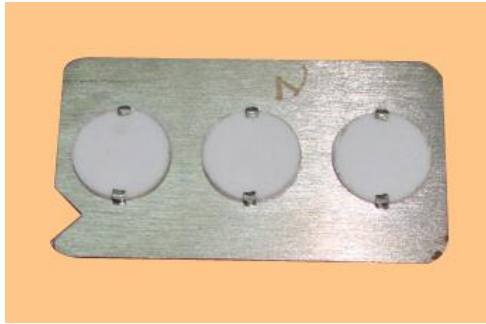
Fig 11: TLD Badge

Characteristics of CaSO$_4$: Dy Teflon TLD disc

Ratio of CaSO$_4$: Dy and Teflon	:	1: 3
Effective Atomic Number (Z)	:	15.1
Density of the TLD Disc	:	2.52 g/cm3
Softening Point of Teflon	:	330° C
Main Glow Peak Temperature	:	230° C
Sensitivity of TLD Disc	:	About 30-40 times more than LiF TLD-100
Fading	:	2-3% in six months
Climactic Effect	:	Negligible
Effect of Sunlight	:	Negligible when covered by paper wrapper & polythene pouch and loaded in the badge
Useful Linear Dose Range	:	0.10 mSV to 20 SV (linearity within + 10%)
Reusability	:	20 cycles
Beta Response	:	60% of 60Co gammas for Nat.U (effective energy 0.8Mev)
Thermal Neutron Response	:	60Co gamma ray equivalent to 2.4 mGy per 1010 n/cm2
Fast Neutron Response	:	Negligible

TLD CASSETTE

There are three well-defined regions in the plastic cassette / holder corresponding to three TLD discs of the TLD card.

1. Disc D1- sandwiched between a pair of filter combination of 1.0mm thick Cu (Copper filter nearer to the disc).
2. Disc D2- sandwiched between a pair of 1.6mm thick (180mg/cm2) plastic filters.
3. Disc D3- under a circular open window.

Asymmetric "V" cut of the card permits its loading in the plastic cassette in only one orientation and ensures the proper positioning of the discs.

For identification purposes, photograph of the user could also be permanently fixed on the central transparent region of the badge.

There are two types of TLD badges/ cassettes in use namely,

1. Chest Badge for whole body monitoring.
2. Wrist Badge for extremity dosimetry.

Though the dosimeter and design of both TLD badges are same, they have different attachment (clip/strap) for wearing purpose depending on their use.

TLD CASSETTE DIMENSIONS

In this design of the TLD cassette, dimension of some of the filters are altered and crocodile clip is replaced by a smaller size clip. The cassette is made of ABS plastic (white) and filters were embedded into the plastic body.

Fig 13: TLD Cassette

KEY HARDWARE FEATURES

- Digital flow rate meter indication.
- Precision stepping motors for (a) Disc positioning (b) Magazine movement.
- Linear actuator control for shutter opening and badge Rise.
- Compact microcontroller based electronic circuit boards.
- All PCB interconnections are through mother board for better reliability & leading to minimal wiring.
- SMPS power supplies are use to achieve minimum size & also to accept wider mains input voltage range.
- Highly reliable electro-mechanics, to eliminate any TLD card skipping or strucking problems.
- Design ensures identicality of Auto & Semi-Auto TLD reader Electro-mechanical system, excepting for change of 'Magazine' & personal ID sensor electronics majority of electronics hardware embedded code & software is same in both cases, but for the additional required changes.
- Advantage of this system design is if one buys semi-auto reader they can get it upgraded to auto TLD badge reader with minimal changes & cost. This system design uses minimal parts. No adjustments or alignments required, as was the case in the old design.

Fig 14: Semi-auto TLD reader setup with PC & Nitrogen gas cylinder adjacent

PMT housing

Fig 15(a): Top inside view of the Semi-Automatic TLD Badge Reader

SEMI-AUTOMATIC TLD BADGE READER

Magazine loading door

Digital flow rate meter

LCD dot matrix display (16x2) status LCD display indicates, (card position, Temperature OK, EHT OK, Flow rate etc.)

Fig 15(g): Outer View of TLD Reader

SPECIFICATIONS

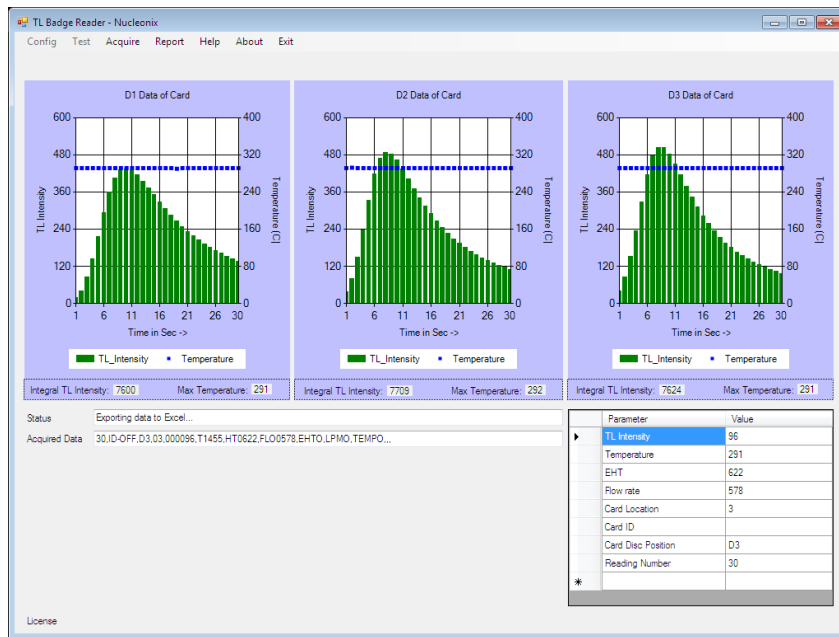|		
Dosimeter	:	Three-element BARC $CaSO_4$ (Dy) PTFE disc dosimeter badge with personnel ID.
Light Measurement System	:	Photo-Multiplier tube (EMI 9125B-bialkali) Light measuring system (LMS).
Dark current	:	Dark current is $1\mu Sv$ ($CaSO_4$) equivalent with software-based sampling & subtraction.
Heater Element	:	Nichrome heater assembly.
Heating Method	:	Hot gas (N_2) heating
Nitrogen flow rate measurement	:	Digital flow rate meter
Heating Cycle	:	The temperature is raised to 285°C in 8 sec and clamped at 285°C
Dose Range	:	$50\mu Sv$-2Sv (Gamma) and $100\mu Sv$-5Sv (Beta)
Dose Threshold	:	$<50\mu Sv$
Readout time	:	Approx 100 sec per badge
Residual Signal	:	$\leq$10% of reading
Facilities Available	:	Entry of calibration factor, etc. Storage of dose data and glow curve data of badges in the Hard Disk. Stepper motor driver assembly for automatic feeding of 50 dosimeter cards loaded in a magazine.
Software	:	Windows 7 (32 bit) / XP-SP3 compatible software facilitates storage and display of glow curves, computations of dose & generation of dose reports, transfer of data to user defined file, etc.
Temperature Monitoring	:	Chromel-Alumel thermocouple in hot gas stream.
Range Selection	:	Automatic
Calibration	:	Coarse adjustment by varying the EHT through a potentiometer in the EHT circuit.
Safeguards	:	Heater / Gas flow / EHT / Card ID failure: The heater temperature, gas flow rate, card ID and EHT are checked for failure in every dosimeter readout cycle. In the event of failure of heater or gas flow rate or EHT or card ID, the readout is terminated and a message indicating corresponding failure message is flashed on the PC monitor.
Mechanical Failure and failure message	:	Any mechanical failure during readout cycle is sensed online & cycle is terminated with an option for the user to restart the cycle. EHT or the input circuit (I-F converter) is sensed and reading cycle is terminated in case of failure.
Nominal Power Supply	:	Power supply: 230V, 50Hz: Power requirements: 500VA (max including PC)
Minimum PC Requirements	:	Intel Core 2 Duo 2.8 GHz Intel G31, 2GB DDR2, 500 GB SATA, internet ready optical scroll, 19" TFT monitor, Windows 7 Licensed OS CD & LaserJet printer (Monochrome).
Applications	:	Personnel monitoring of radiation workers in Nuclear power stations, Isotope laboratories, Industrial radiography installations, diagnostic & therapeutic radiology centers, etc.

PHOTOMULTIPLIER TUBE

6095 PMT of ETL is used for detection of the light signal. The light signal is converted to proportional current signal by the PMT. The 9125b is a 29mm (1.13") diameter, end window photomultiplier with blue-green sensitive bialkali photocathode and 11 high gain, high stability, SbCs dynodes of linear focused design.

FEATURES

- High Gain.
- Low operating voltage.
- Good SER.
- Good pulse height resolution.

SOFTWARE FOR TLD BADGE READER

Personnel computer system loaded with the software for TL Badge reader serves as comprehensive 'TL Dose records management software'. It is user-friendly, reliable and feature rich. It has powerful fault diagnostics reporting capabilities.

Fig 16: TL Badge Reader Software

KEY FEATURES OF SOFTWARE

- Provides Commands for complete fault diagnostics of the Reader that includes checking of Light Source, Dark Current, Heater, Gas flow, EHT, Mechanical movements.
- Provides screen to enter Institution, Personnel and Card details prior to acquisition.
- Acquisition of up to 50 cards can be done in one go.
- Acquisition can be paused & resumed without any loss of data.
- Fault checks are performed during acquisition and reported to user.
- Calibration factors for Reader and D1, D2, D3 positions can be set.
- Dose calculator is provided for calculation of Dose by manually entering Integral TL values for D1, D2, D3 positions.
- Glow curve data is stored in Text file and can be optionally exported to Excel.
- Glow curve data can be viewed at a later data individually for each card.
- Dose values for each card, Personnel numbers are written to a batch file.
- Dose information can be optionally written to Nucleonix Dose Records management database and User wise Cumulative Dose reports can be generated.

INSTRUMENT BLOCK DIAGRAM & DESCRIPTION

Semi-Automatic TLD Badge Reader is specifically designed to measure TL output of the discs fixed on to the card. It utilizes the integral method of TL measurement as it involves less stringent requirements on heating rate. The reader basically provides a programmed heating cycle to the TL dosimeter and senses the instantaneous light emitted by the dosimeter (glow curve signal) and displays the total integrated light output in terms of μSv (unit of equivalent dose).

CONTROLS

The mechanical assembly & the microcontroller based control circuits are housed in the instrument enclosure. Apart from a digital flow meter with a control knob for the adjustment of the gas flow and a 16x2 character LCD display for status information the instrument panel does not have any operating controls. All the operations are carried out from the PC connected to the instrument through a USB link. The status indication LCD indicates the instrument ON status.

BLOCK DIAGRAM & SYSTEM DESCRIPTION

As the block diagram shown indicates, this product is a PC based system where the primary commands are issued to a micro-controller board through USB port (Virtual communication port is used). Based on the commands issued, the micro-controller responds accordingly by executing the required function and sends back acknowledgement code.

The system essentially comprises of the following:

a) Stepper & DLA motor based Electro-mechanical system along with optical sensors for precise noise-free motion & feedback.
b) Ni chrome Heater based gas heating assembly along with digital flow measurement system.
c) Photomultiplier Tube, along with heat absorbing glass as a light measurement system.
d) Data acquisition & control circuits comprising of micro-controller circuits, heater controller circuits, high voltage module, I to F convertor module, Stepper / DLA motor drivers module & LV power supplies. Majority of the circuits are EURO type PCBs sitting on a mother board PCB. This facilitates easy maintenance in the event of breakdown.
e) Personal Computer (PC) system with TLD data acquisition analysis & report generation software.

STEPPER / DLA MOTORS & DRIVER UNITS

The magazine positioning is controlled by a stepper motor based on the feedback received from the 2 optical sensors underneath the magazine.

The optical sensors sense the grooves made on the magazine which generates signature code for home position & each channel advance. Using this method, precise noise-free positioning at any of the 50 positions can be done.

Once positioned at a specific card location, the TLD card can be raised by using the card raise DLA motor for taking readout of the current card.

In the next step, the card is drawn through a optical sensor arrangement so that personnel ID can be readout. This is followed by positioning at D1, D2 or D3 positions using the belt drive stepper motor. Before acquisition can begin for a TLD card, the shutter can be opened using shutter DLA motor. After this acquisition begin.

Using the above motors positioning for readouts TLD card are done.

TEMPERATURE CONTROLLER BOARD DESIGN REQUIREMENT

The design principle of the heater system is such that the temperature should rise to 285°C within 10-12 seconds and remain clamped till completion of 30 seconds in disc read mode. The temperature of the disc also is required to rise upto 285°C.

To raise the temperature of the disc to 285° C, the air thermocouple should attain 12mV (44 mV/$^\circ$C Cr-A1, K-type thermocouple) in a leakage free air path. The TL disc emits the glow curve peak at 240°C. But for getting maximum glow curve emission the TL Disc is heated upto 285°C. The temperature controller board is designed to meet the above requirement.

The problem in the temperature section of the TLD system may be due to solenoid malfunctioning, thermocouple wires and heater element breakdown and leakages in the path and loose connections leading to erratic switching of solenoid valve. In case of breakdown replace the faulty component with new one in heater assembly. In due course of time TC board may have to be calibrated. If there is a variation observed in the readings.

On receiving the command(Hi to Lo signal) from the microcontroller through the transistor driver circuit, solid state relay(SSR2) opens the solenoid valve and the Nitrogen gas starts to flow through the flow system consisting of Digital Flow Meter and is let into the Heater assemble.

DATA ACQUISITION & CONTROL CIRCUITS

The Data acquisition & control circuits are powered by SMPS supplying +5V, +/- 12V. The rest of the electronics like digital circuits, analog section, stepper motors, high voltage etc. are also powered by the same SMPS. The heater assembly is powered by a separate linear transformer mounted on it.

The data acquisition and control unit essentially comprises of a micro-controller board at the heart which essentially controls all hardware during acquisition or otherwise. Micro-controller receives commands from PC based on which it responds. It works in slave configuration with PC. Micro-controller board generates signals for precise motion of stepper and DLA motors based on optical feedback received from corresponding optical sensors during data acquisition.

The following movements are controlled by the micro-controller by the aid of optical sensors :

- Magazine Eject / Home.
- Magazine move option.
- Card raise / lower.
- Card position Home / D1 / D2 / D3.
- Shutter Open / close.

Once positioning is complete, the acquisition of TL card / light source card / Dark current is done by the micro-controller. Before acquiring for TL card, the solenoid & heater controller are turned ON to enable gas heating upto 285°C. Once gas temperature is reached, the TL card is moved to position D1 or as selected and acquisition is carried out. After each disc's readout, the card is moved to next disc position & acquisition repeats for that disc. After all readouts are completed solenoid & heater are turned OFF automatically.

All the above motors are driven by stepper driver modules located on stepper drive card based on signal received from micro-controller. The PMT is biased by a miniature HV module located on the mother board. The PMT o/p is processed and converted to frequency o/p by an I to F convertor module which is located in the micro-controller board.

A Ni63 based Light source TLD sized Card is provided separately which can be used for stability check of the PMT during the acquisition cycle. A light source check command may be issued after pausing acquisition cycle to check for stability. The Light source TLD card has to be placed in Magazine Position 1 before carrying out light source check and after acquisition it has to be removed before proceeding for personnel dosimetry.
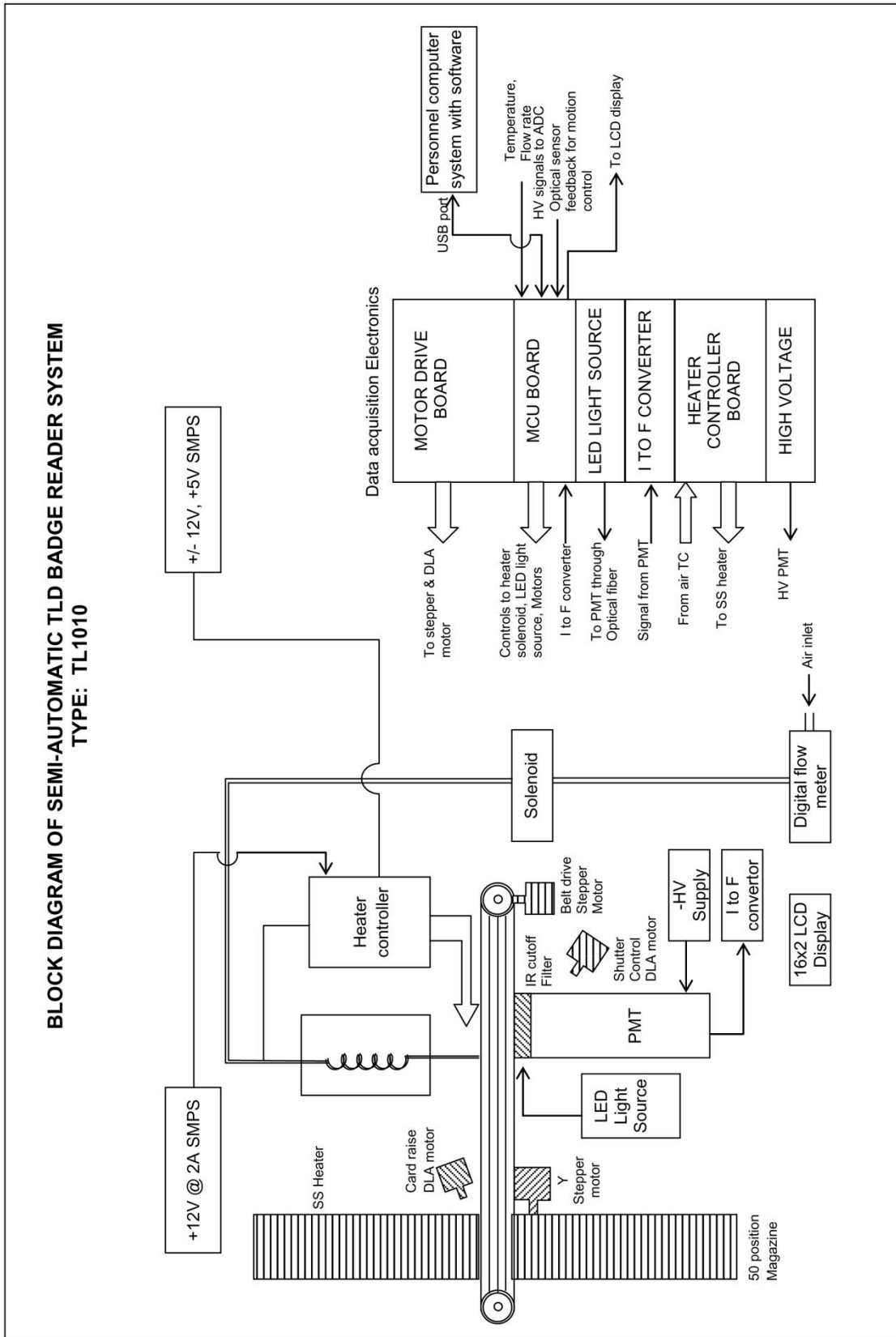
Fig 17: Block Diagram of TLD Reader

DOSE EVALUATION

Dose evaluation is carried out using some empirical relations which have been arrived at after thorough experimental work. Usually a minimum reporting value (RV) is decided on the basis of the uncertainties in the dose evaluation process including those inherent in the basic dosimetry. After calculation of the dose, if the computed value is less than the RV (default values is 0.2 mSv), dose is reported as zero.

A 16 digit ID code is used for the personnel number. The first 4 digits are assigned for the Institution to which the person belongs. The last four digits are the personal ID number of the person. The middle four digits are to indicate the service month (two digits, 1 to 12), frequency of service (one digit, 1 for monthly, 2 for bimonthly & so on) and the nature of radiation environment (one digit, 1 for gamma, 1 for beta / gamma, 2 for X rays / gamma and 4 for diagnostic X-rays) in which the person works. The dose evaluation software evaluates the dose depending on the code entered as per the following relation:

Key to abbreviations:

D1: reading of dosimeter under Cu-Al filter

D2: reading of dosimeter under plastic window

D3: reading of dosimeter under open window

RV: reporting value.

D1', D2', D3' are D1, D2, D3 minus the control card reading. The control card reading are the background reading i.e. almost 80-100.

D1', D2', D3' are equated to zero if less than RV.

RV   = 0.2 mSv for gamma

= 0.5 mSv for beta

 = 0.05 mSv for Low energy X-ray

 Depending on the nature of the radiation, the following algorithm is used.

1. **Gamma Ray Dose**: If the ratio of D3' to D1' is less than 1.3, only gamma ray dose should be evaluated using the value of D1' i.e.

Gamma Dose   = D1' (equated to zero if less than RV)

2. **Beta Dose:** If the ratio of D3' to D1' is more than 1.3, also the ratio of D3' to D2' is more than 1.3 and D1' is very close to background reading, then beta dose should be evaluated as follows.

Beta Dose   = BMF x (D3' - 1.3 x D1')

= Zero if less than RV.

Where BMF is the Beta Modification Factor and is dependent on the energy of beta radiation (e.g. BMF =1.6 for Natural Uranium).

3. **Beta and Gamma Ray Doses:** If the ratio of D3' to D1' and D2 to D1 are more than 1.3 also ratio of D3' to D2' is more than 1.2 and D1 is significantly higher than background, both beta and gamma doses should be evaluated.

> Gamma Dose   = D1' (equated to zero if less than RV)

Beta dose should be calculated as per the calculation shown above taking appropriate value of BMF from the ratio of D2 & D3

4. **X and Gamma Ray Doses:**

Case –I

If the ratio of D2' to D1' is less than 1.3, gamma ray/ X-ray (>200 keV) dose should be evaluated using the value of D1' i.e.

> Dose   = D1' (equated to zero if less than RV)

Case –II

If the ratio of D2' to D1' is more than "1.3" but less than or equal to "5" (i.e. $1.3 < D2'/D1' \leq 5$) which indicates that the TLD badge is exposed to X rays of energy between 40 keV to 200 keV or TLD badge is worn under lead apron and exposed to diagnostic X-rays. In this case X-ray dose should be evaluated as follows

> Dose = D1'x $(A_0 + A_1 R_{12} + A_2 R^2_{12} + A_3 R^3_{12} + A_4 R^4_{12})$,

Where R_{12} = D1'/ D2' and $A_0 = 2.6017$, $A_1 = -15.8861$, $A_2 = 45.5412$, $A_3 = -53.2834$ and $A_4 = 22.5612$

Case -III

If the ratio of D2' to D1' and D3' to D1' are more than "5" and D2~D3 (within 20%), which means the TLD badge is exposed to X rays of energy less than 40 keV or the badge is worn over the lead apron. Dose should be evaluated as follows:

> Dose   = (D2' + D3') / 20

Note:

1. In case there is any ambiguity in the ratio of D2'/D1', D3'/D1' etc., information on the type of radiation source handled by the worker should be obtained and accordingly the dose should be evaluated.

2. Beta & Gamma doses are evaluated when it is ensured that photons of effective energy less than 60 keV are not encountered significantly.

3. X ray doses are evaluated when it is ensured that beta radiation is not encountered.

4. For the algorithm example of Case-II, other tested methods developed by individual TLD units could also be used. It may be noted that Dose = D1 (Case-I) remains valid even for this category (Case-II) if over estimation up to 50 % could be tolerated.

5. Evaluated doses in all the above cases should be rounded off to the nearest multiple of 0.05 in the dose report.

DOSE DATA MANAGEMENT

When the dose evaluation software is executed four files are generated or appended (if already existing). Two files 'RED.DAT' & 'RD.DAT' in the format given below are created as a fresh, every time the dose evaluation software is executed. Both these files are used as a temporary input files during the dose evaluation routine.

FILE FORMAT OF TEMPORARY FILES RD.DAT & RED.DAT.

9906100620010001	00007547	00064086	00053152
9906100620010011	00007407	00063076	00063151
9906100620010021	00007443	00074086	00059959
9906100620010031	00006678	00068089	00063758

The third file generated is the "PERS.DAT" file which contains the entire dose readout details such as the 16-digit personnel number, the three dosimeter readings and the evaluated dose. A typical PERS.DAT file format is shown below.

Inst No.	Pers No.	Serv Mon.	Serv Yr	Serv Freq	Loc code	Disc-1	Disc-2	Disc-3	Gamma mSv	Beta mSv
000011	1200	01	99	1	0	00007547	00064086	00053152	7.5	
000011	1201	01	99	1	1	00007895	00077920	0007986	7.9	
000011	1201	01	99	1	1	00000658	00000621	00000593	0.6	
000011	1202	01	99	1	2	00000548	00000520	00000507	0.5	0.0
000011	1203	01	99	1	3	00000464	00000464	00000441	0.5	
000011	1204	01	99	1	3	00000385	00000376	00000357	0.4	
000011	1205	01	99	1	0	00000386	00000456	00000645	0.4	

The fourth file generated is the "DOSE.DAT" file that contains just the personnel number and the evaluated dose. The following is a typical DOSE.DAT file. This file gets appended every time the dose evaluation is done for a set of cards. This file is called in the 'Print dose report' option. The format of the 'dose.dat' file is shown below.

0000110110120096	7.5	
0000110111120196	7.9	
0000110111120196	0.6	
0000110112120296	0.5	0.0
0000110113120396	0.5	
0000110113120496	0.4	

THE DOSE REPORT FILE "DOSE.REP"

This file is created (appended if already exists) when the "Print Dose Report" option is invoked from the print menu. During this operation, three files **'DOSE.DAT'** (generated in the dose evaluation menu). **"INSTIT.FLE & PERSN.FLE"** (generated using the "Create File" utility) are used. The Institution name, address and the personnel name are obtained using the appropriate codes in the 16-digit personnel identification code. The dose stored against this personnel identification code in the 'dose.dat' file is printed and also stored in the "DOSE.REF" file. During the process a temporary file 'IPSN' is created in the current working directory. A typical dose report print-out is shown below.

Dose report

INST. CODE   :   0011
ADDRESS   :   Bhabha Atomic Research Centre
                     RPIS, RPhD
                     Mood Labs, Trombay
                     Bombay, PIN : 400 085

Pers. No.	Name	Month / Year	Radia. Field	Dose (mSv) Whole Body	Skin	Remarks
1200	Mr. S.J. Gandhi	01/96	Gamma	7.5	0.0	
1201	Ms. P.T. Jain	01/96	X-Gma	7.9		
1201	Ms. P.K jadhav	01/96	X-Gma	0.6		
1202	Mr. C.M. Katoch	01/96	Bt-Gm	0.5		
1203	Mr. D. Suresh	01/96	Dia-X	0.5		
1204	Mr. M.R. Patil	01/96	Dia_x	0.4		
1205	Mr. K.R. Nair	01/96	Gamma	0.4		

A file named "DREP.MSG" stored as a text file in the current working directory is accessed at the end of "Print Dose Report" routine. This file is to be created by the user in the dos edit mode. The contents of this file will be printed at the end of the dose report. In this file the user can store any message, note, user identity etc. which he would like to be printed at the end of the dose report.

These files can be used with appropriate software packages for updating & maintaining the dose records of the personnel.

TESTING OF TLD BADGE READER

1. Light Leakage : Check the readout of freshly annealed card in bright room as well as in the dark room.

2. EHT to PM Tube : After warm up time of 30 minutes, EHT should not vary by more than ± 1v throughout the read out process.

3. Light Source Reading : The repeated LS reading can be taken in the reader test mode. The light source reading should not vary by more than $\pm$ 5% throughout the day.

4. Read out temperature : The clamping temperature as per the display should be around 285°C. ± 2°C and should reach within 50-60s from the start of heating cycle. The flow rate of N_2 gas should be set in between 5-6 lpm. Changes in the flow rate may cause significant variation in the readout.

5. Glow Curve & Uniformity : Expose 10 (Selected) TLD cards sandwiched between perspex build-up plates (thickness 4-5 mm) to about 4-5mSv of Cs-137 gamma rays. TL readouts of all the cards should be taken and uniformity of gas heating can be checked by recording glow curves and comparing their stability.

6. Residual TL check : Second readout of the above cards should be taken to check the residual TL. The second readout should not be more than 10-12% of the first readout. If it is more either flow rate or air temperature point has to be adjusted.

7. Reproducing the TL Readout: For this test, atleast 10 selected TLD cards should be used. The cards are to be annealed, exposed in build-up plates and read after one day after the exposure. Cycle to cycle variation of average TL readout should be within ± 10% and incase of any significant change, the response should have an established trend. Minimum three cycles of annealing, exposure and readout has to be carried out.

8. Minimum Measurable Dose : The readout of some freshly annealed TLD cards (atleast 10 cards) should be taken. The minimum measurable dose can be obtained from the value of 2σ.

9. Linearity test : Expose freshly annealed cards (a minimum of 5 doses, 5 cards for each dose) in the dose range from 0.3mSv to 1Sv of Cs-137 gamma rays and readout of all cards should be taken in similar

conditions. The TL response (average TL/mSv) should be within $\pm$ 10% in the entire dose range covered.

CALIBRATION OF TLD BADGE READER

1. Setting of TLD Reader: The TLD readers should be kept "ON" for atleast half an Hour for warm-up before starting the actual measurements on it. After LS measurements, readout of 2-3 dummy TLD cards should be taken to check the temperature and heating profile. Then take readout of three exposed calibration cards to confirm the calibration of the reader and if required either Reader Calibration Factor (RCF) should be changed or EHT to the PM tube should be adjusted to indicate the counts in desired proportion to dose (1µSv – 1count).

2. Intermittent check of TLD Reader Sensitivity: The reading of ^{63}Ni light source TLD Card & Calibration Cards can be taken intermittently in a day.

REUSE OF DOSIMETERS

There is a 10% left over TL after the 30 sec readout in the reader. The cards, therefore, are required to be annealed before reuse as per the following procedure.

TLD cards are first cleaned in acetone to remove grease, dust particles, if any, sticking to the dosimeter discs. This done by keeping the cards immersed in acetone container for about an hour. Thereafter, acetone is removed by pouring out into another container. The cards are kept overnight in the container so as to completely remove traces of acetone. These cleaned cards are transferred to a stainless steel tray and introduced into a programmable temperature oven with air circulation. The oven is then switched on and the temperature of the oven is raised to 230°C +/-2°C in about 60 minutes. The temperature is maintained at 230°C for 3 hours and then the oven is allowed to cool to less than 50°C. The cards are then taken out and are ready for reuse.

CALIBRATION STANDARDS LAB & FACILITY

There are two calibration labs at Nucleonix Systems Pvt. Ltd.

1. Low Level Calibration Lab.
2. High Dose Rate Calibration lab.

LOW LEVEL CALIBRATION LAB

This has a Cs-137, 165 mci standard "Gamma Survey Instruments Calibrator" from Amersham.

This calibration service has NIST Traceability standard. Calibration of all TLD Cards, portable radiation monitors, survey meters, contamination monitors, Area monitors etc., is carried out in this lab upto 1 R/hr max dose rates.
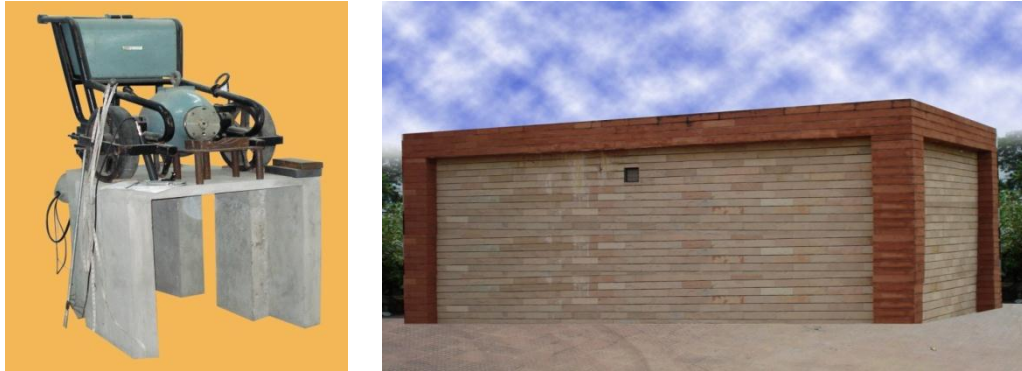

Fig 18: Calibration Standard Lab 1

Gamma Survey instruments calibrator has Cs-137 source 161.5 mCi as on 05 Aug 2002. It is basically a gamma survey instruments calibrator procured from AEA Technologies UK/USA. Has NIST traceability accuracy within +/- 7%.

HIGH DOSE RATE CALIBRATION LAB

This lab has a 8 Ci, Co-60 standard housed in a CRC-2 camera, operated remotely viewed through CCTV arrangement. High dose rate survey meters, High level Area monitors etc are calibrated in this lab. This CRC-2 camera is housed in a separate concrete building. All the radiation monitors manufactured by Nucleonix Systems are authentically calibrated at this facility, before they are shipped / dispatched.

Fig 19: Calibration Standard Lab 2

CRC-2 camera has Co-60 standard obtained from Bhabha Atomic Research Centre, Mumbai. It is a certified source.

study of gamma attenuation in tld badge

INTRODUCTION

The Gamma Attenuation was studied using the Thermo Luminescence Badge which were exposed to different radiation doses using a Cobalt-60 source. The Co-60 is a gamma emitting source emitting two major gamma rays i.e. at 1.173Mev and 1.333Mev, so the average gamma energy considered is 1.125Mev.

The dose evaluation was done using the BARC dose evaluation algorithm provided and then was compared to the theoretical value in order to confirm the efficiency of the TLD Badge and the Nucleonix made Semi-Automatic TLD Badge Reader (TL1010S). The Thermo Luminescence Dosimeters used were the $CaSO_4$:Dy disc dosimeter specially built following the procedure that the BARC have decided to maintain the uniformity of the $CaSO_4$:Dy TLD cards available at different sites all over India.

Firstly the TLD Badge reader was fully assembled from scratch and some test were run to see if all the connections and all the electronic parts and mechanical parts were working fine. Then the Semi-Automatic TLD Reader was calibrated before reading the TLD cards for studying gamma attenuation. TLD Cards with different doses were read and the EHT to Photomultiplier tube was adjusted, the temperature settings of the heater was adjusted to meet the standards, dark current readings were taken, light source (Ni-63) reading were taken and the readings were checked to be in range and if not then EHT to PMT was adjusted or I to F convertor was adjusted.

After calibration work, all the exposed $CaSO_4$:Dy TLD badges which were previously exposed to Co-60 source were read and the glow curves recorded through the TLD Badge reader software were studied and the Dose Evaluation algorithm was used to get the Gamma doses absorbed by the cards. A C++ code was written to calculate the dose using the BARC algorithm provided. Also the theoretical Gamma dose calculation was built into the code and the calculations were carried out and those these results were compared to each other.

Theory on Gamma Attenuation

The attenuation of gamma radiation (shielding) can be described by the following equation:

$$I = I_o e^{-\mu \rho t} \text{ or } I = I_o e^{-\mu d}$$

<div align="right">

where: I = intensity after shielding

Io = incident intensity

μ = mass absorption coefficient (cm^2/g)

d = thickness of absorber (g/cm^2)

ρ = density of absorber (g/cm^3)

t = physical thickness of absorber (cm)

</div>

In practical terms, I is the intensity of gamma radiation after interaction with the shielding material. I is dependent on I_o, the initial intensity of the gamma radiation (before shielding), μ, the mass absorption coefficient for the shielding material, and d, the "thickness (g/cm^2)" of the shielding material (alternatively written as a product of the density (g/cm^3) and the physical thickness (cm) of the shielding material).

The mass absorption coefficient is dependent on the energy of the incident gamma radiation and the elemental composition of the shielding material. Mass absorption coefficients can be determined by measuring I and Io for a shielding material of known thickness (d) and are available for a wide range of elements and composite. Once the mass absorption coefficient is known, the physical thickness (cm) of a given type of shielding material required to reduce the gamma radiation intensity to a desired level (ratio of I/Io) can then be calculated by solving the shielding equation for t:

$$t = \ln(I/I_o) / (-\mu \rho)$$

Comparing the thicknesses of different materials needed to achieve the shielding requirements for a particular application, along with other factors, such as the cost, weight, and chemical and physical durability of the materials, will then allow one to choose the most appropriate type of shielding.

Physical interactions leading to attenuation

Shielding of gamma radiation primarily involves the interaction of gamma radiation with matter via three main processes:

- Photoelectric Absorption
- Compton scattering, and
- Pair production.

In the photoelectric effect, a gamma ray interacts with an atom resulting in the ejection of an electron from the atom. The electron receives all of the energy of the gamma ray, minus its atomic binding energy, and may induce secondary ionization events. The probability of the photoelectric effect is proportional to the atomic number (Z) of the absorbing element and inversely related to the energy of the gamma ray. Therefore, the photoelectric effect is most important for low energy gamma rays interacting with heavy elements such as lead and tungsten.

Compton scattering is similar to the photoelectric effect, in that it involves the interaction of a gamma ray with an atomic electron, resulting in the ejection of the electron from the atom. However, in Compton scattering, only a portion of the energy of gamma ray is transferred to the electron. As with the photoelectric effect, the probability of Compton scattering is proportional to the atomic number of the absorbing element (Z) and inversely proportional to the energy of the gamma ray. Compton scattering is most likely to occur for gamma rays in the 600-4000 keV range and results in a continuum of scattered gamma ray energies from 250 keV below the highest energy of the incident gamma radiation (Compton gap) down to a minimum value dependent on the energy of the incident radiation. The minimum energy resulting from Compton scattering can be determined using the following equation:

$$\text{Energy}_{\text{minimum}} \text{ (in keV)} = 511 * \text{Energy}_{\text{incident}} / (511 + 2 * \text{Energy}_{\text{incident}})$$

Pair production is less common than the photoelectric effect or Compton scattering and occurs only for very high energy gamma rays (>1022 keV). In pair production, a gamma ray is transformed into matter near the nucleus of an absorber atom in the form of an electron-positron pair. Incident gamma energy in excess of 1022 keV is transferred to the electron-positron pair as kinetic energy. The positron will eventually undergo annihilation, producing two 511 keV gamma rays, and the electron may also induce addition ionization reactions. The likelihood of pair production, for gamma rays greater than 1022 keV, is proportional to the square of the atomic number of the absorbing atom and the logarithm of the incident gamma energy.

Shielding of 200-1500 keV gamma radiation with materials containing high Z components, such as lead and tungsten, is achieved with a significant contribution from both Compton scattering and photoelectric absorption. However, shielding with materials containing low Z components, such as iron and water, is achieved primarily with Compton scattering.

DETAIL OF SOURCE USED

The Co-60 source used is a standard source was obtained from Bhabha Atomic Research Centre, Mumbai that was available at the facility. It is a BARC certified source. The source was procured in 2008 with an activity of 5.1954 Ci on the procured date.

Co-60 disintegrates by β⁻ emissions level of Ni-60. The various details are listed below:

Half Life	5.27 years (99.88)
Radiation Decay Mode	Beta
Major Beta	0.318 Mev
Major Gamma	1.173 Mev (99.85), 1.333 Mev (99.98)
Max. Beta Range in Air	74 cm
Max. Beta Range in Water	0.1 cm
Main Production Mode	Co – 59 (n,y) Co-60

The details of the source present at Nucleonix Systems Pvt. Ltd. are:

Radioisotope	Co-60
Half Life Period	5.27 years
Procured Date	10 Dec 2008
Activity on Procured Date	5.1954 Ci

Date	11 May 2015
Activity on this Date	2.262 Ci

The various distance the TL cards should be kept for various doses are:

Dose rate (R/hr)	Distance from Source (cm)
1	172.80
5	77.30
10	54.60
20	38.60
30	31.50
50	24.50
100	17.30

Calibrating TL1010S

- ## Exposure of TLD Cards for Reader Calibration

  During every monitoring period, about 100 annealed TLD cards from freshly annealed batches (minimum of 20 cards from each batch, depending upon batch size) planned for use in the cycle, should be taken and kept for calibration purpose. These calibration cards, wrapped in paper wrapper (with identification of batch number) and sandwiched between perspex build up plates of thickness 4 -5 mm should be exposed to known dose (about 5 mSv) of 137 Cs gamma rays at a minimum distance of 50 cm. The source should be kept at the centre and the TLD badges should be placed on the circumference of the circle on a perspex ring / wooden table. The height of the perspex ring / wooden table should be more than 1 meter from the floor. Exposure time for the geometry to be used, should be calculated from the measured air-kerma rate of the source in order to deliver dose in the range of 3-5 mSv. Exposure of calibration cards should be carried out at least 15 days in advance for monthly service and 30 days in advance for quarterly service before their actual use for calibration of the TLD readers.

- ## Setting of TLD Reader

The TLD readers should be kept 'ON' for at least half an hour for warm-up before starting the actual measurements on it. The EHT and initial temperature should be noted. The Dark Current of the reader should be noted by taking the readout in the 'Test' mode with heater in 'OFF' position and without inserting any TLD card. Then light source reading should be taken to check the performance of the PMT of the reader. For this, minimum three readings with an external 63 Ni light source in 'TEST' mode should be noted. All the data should be recorded in the log book with date, model, serial number of TLD reader etc.

After LS measurements, readout of 2-3 dummy TLD cards should be taken to check the temperature and heating profile. Then minimum three exposed calibration cards should be read to confirm the calibration of the reader and if required either Reader Calibration Factor (RCF) should be changed or EHT to the PM tube should be adjusted to indicate counts in desired proportion to dose (10 µSv - 1 count). If EHT is adjusted, calibration should be verified from readout of more number of exposed calibration cards. The relative ratio of readings from three discs of each exposed card should also be recorded and maintained in the logbook.

- ## Intermittent Check of TLD Reader Sensitivity

The reading of 63 Ni light source and exposed calibration card should be taken intermittently in a day (at least once in the after-noon), in between the readout of routine service cards to confirm the stability of PM tube and calibration of the reader. In case of semiautomatic TLD reader, exposed calibration cards (at least two) are kept at fixed positions in the magazine to verify the sequence of cards. This will ensure the calibration of reader also.

Linearity of CaSO₄:Dy Discs

Commercial TL Dosimetry discs $CaSO_4$:Dy are taken for TL measurements. Two TL Dosimetry discs $CaSO_4$:Dy are exposed various doses of gamma irradiation of Co-60 as a radiation source. The gamma dose given is 5, 10, 20, 30, 50 Rads from a Co-60 calibrated gamma source. The TL curve between 60 sec and 120 sec is selected for the present study. TL research reader is used to check the linearity of the discs.

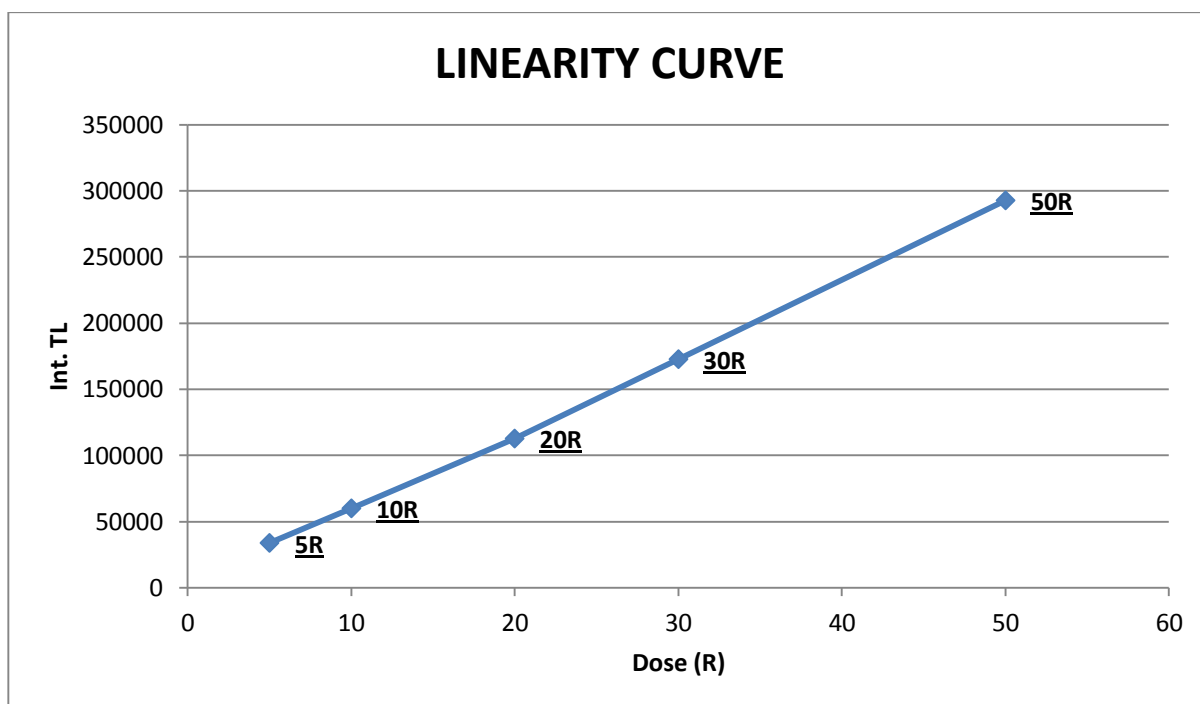| Dose (R)	Int.TL
5	33638
10	59779
20	112779
30	172565
50	292553

Fig : Linearity plot of CaSO₄:Dy Discs