International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: 6.614
Available Online at www.journalijcar.org
Volume 8; Issue 12 (B); December 2019; Page No.20684-20689
DOI: http://dx.doi.org/10.24327/ijcar.2019.20689.4050

Research Article

THER MOLUMINESCENT DOSIMETER: A MINI REVIEW

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A R T I C L E I N F O

Article History:
Received 15th September, 2019
Received in revised form 7th October, 2019
Accepted 13th November, 2019
Published online 28th December, 2019

Key words:
Thermoluminecence, Thermoluminescent Dosimeters (TLD), Dosimetry.

A B S T R A C T

A dosimeter is a device that is used to measure the amount of radiation to which a radiographic personnel is exposed. Thermoluminescent dosimeters work on the principle of luminescence, by absorbing a amount of ionising radiation to which it is exposed and later emitting the absorbed radiation in the form of light which is displayed on the machine in the form of a glow curve when the dosimeter is read. It is a method of personal radiation monitoring which should be followed by all individuals working in radiation fields, as it also provides an assessment of the usefulness of radiation protection measures being followed.

INTRODUCTION

Radiation dosimetry is fundamental in the applications of the radiation and radioisotopes, especially in Medical Physics. Ionizing radiations frequently used indiagnosis and radiotherapy are X-rays, gamma radiation and beta particles; however, high-energy electrons, heavy particles and neutrons are used in the major medicalcentres. Dosimetry in Medical Physics involves the patients and phantom dosimetry aswell as that for the occupationally exposed personnel and the environmental monitoring in hospitals. In the former case, radiation exposures are intentional inorder to obtain a direct benefit to the patient's health; then, the radiation field is welldefined. Its purpose is to evaluate the risk or the effectiveness of the radiation exposure.[3]

A radiation dosimeter is a device, instrument or system that measures or evaluates, either directly or indirectly, the quantities exposure, and related quantities of ionizing radiation. A dosimeter along with its reader is referred to as a dosimetry system. The amount of X-radiation that reaches the body of the dental radiographer can be measured through the use of a personnel monitoring device known as radiation monitoring badge.[1]

In radiography, monitoring is defined as periodic or continuing measurements to determine the dose rate in a given area or the dose received by a person.

Radiation has four qualities that make accurate measurements possible, it affects photographic emulsions, produces ionization in air, produces a rise in temperature and causes certain salts to fluorescence. All measuring devices make use of one of these qualities.

Historical Review

The credit of discovering thermo luminescence goes to Robert Boyle, in the year who reported to the Royal Society in London on 28th October, 1663 and observed that a glimmering light was emitted on heating diamond in the dark. Weidemann in the year 1895, was the first to report the use of thermo luminescence, from artificially prepared CaSO4 Mn for the detection of radiation due to an electrical discharge. This method was again used by Lyman in the year 1935 for measurements in the far ultraviolet range. Tousey *et al* in the year 1951, used thermo luminescence for measurement of UV and X-ray radiations encountered in V-2 rocket flight. Randall and Wilkins in the year 1945 and Garlick and Gibson in the year 1949, provided a sound understanding of thermo luminescent process. Cameron *et al* in the year proved the value of LiF from the Harshaw Chemical Co, USA, for the measurement of X rays, B rays, gamma rays and thermal neutrons. [2]

Radiation Monitoring- Radiation monitoring involves the measurement of radiation dose or radionucleide contamination for reasons related to assessment or control of exposure to radiation or radioactive substances, and the interpretation of the results.[4]

Methods of Monitoring Radiation-[4]

There are two methods to measure the levels of radiation and potential exposure.

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A certified radiation equipment safety officer performs a radiation survey using ionization chambers to determine radiation levels during exposure at all locations in the office. This type of survey checks the reliability of the x-ray machine and protective barriers. It does not monitor the day by day activity of the concerned personnel.

The second method is to have personnel wear monitoring devices such as pocket dosimeters or film badges.

Pocket dosimeter: it is a device which resembles a fountain pen and attaches to a garment with a clip. The dosimeter contains a small sealed container of ionizable air. The dosimeter can only be read when it is inserted to a equipment called a charger-reader. Measurements are read through the movements of a spring electroscope. Dosimeters are very useful in installations with a high work load because they can be recharged every morning and read at the end of the day. Their major disadvantage is that no permanent record is made. They are not practical in the dental office.

Film badge: a descendent of the paper clip device. Films provide a film badge service on a subscription basis each subscriber is supplied with a badge loaded with a radiosensitive film. The plastic/ metal holder is lined with various thickness of filter of different materials. That make it possible to measure the types of radiation received. Film badges are not accurate at very low exposures.

Thermo luminescent Dosimeter (TLD) film badges are now being replaced by a new radiation detection device called a thermo luminescent dosimeter (TLD) (from greek word "therme" means head, and latin words "lumen" means light and "ascent" meaning any giving off of light). TLDs are worn to record cumulative whole body dose (mSv) received from occupational exposures to ionizing radiation including x-ray producing machines, high energy beta and gamma emitting isotopes. Information obtained from exposure reports is useful to evaluate the effectiveness of protective measures. These devices have crystals usually lithium fluoride that absorbs energy when exposed to radiation, energy in the form of visible light is given off. The total light emitted is proportional to the amount of radiation energy absorbed by the crystals. TLD's are extremely accurate.

Principle of Luminescence-[1]

Some materials, upon absorption of radiation, retain part of the absorbed energy in metastable states. When this energy is subsequently released in the form of ultraviolet, visible or infrared light, the phenomenon is called luminescence. Two types of luminescence, fluorescence and phosphorescence, are known, which depend on the time delay between stimulation and the emission of light. Fluorescence occurs with a time delay of between 10^{-10} and 10^{-8} s;phosphorescence occurs with a time delay exceeding 10–8 s. The process of phosphorescence can be accelerated with a suitable excitation in the form of heat or light.[1]

- ✓ If the exciting agent is heat, the phenomenon is known as thermo luminescence and the material is called a thermo luminescent material, or a TLD when used for purposes of dosimetry.
- ✓ If the exciting agent is light, the phenomenon is referred to as optically stimulated luminescence (OSL).

Thermo luminescence is defined as phenomenon of light emission caused by heating a pre-irradiated thermo luminescence material. It is also defined as "thermally activated phosphorescence.[2]

Thermo luminescent dosimeters contain inorganic crystalline and poly crystalline materials dopped with suitable activators.[2]

Thermo luminescence sensitivity- is defined as the amount of light released per unit of radiation dose.[2]

Characteristics of a Thermo luminescent material-[2]

- ✓ A simple glow curve structure (a single glow peak at around 200 C is ideal).
- ✓ High gamma ray sensitivity.
- ✓ Negligible fading of TL signal on storage for a few months at room temperature.
- ✓ Emission spectrum around 400 C
- ✓ Linear response dose versus TL
- ✓ Simple annealing procedure for reuse.
- ✓ Chemical stability and inertness to extreme climatic variations.
- ✓ Effective atomic number, close to tissue.
- ✓ Insensitivity to daylight.

Dosimeters

A radiation dosimeter is a device, instrument or system that measures or evaluates, either directly or indirectly, the quantities exposure, kerma, absorbed dose or equivalent dose, or their time derivatives (rates), or related quantities of ionizing radiation. A dosimeter along with its reader is referred to as a dosimetry system. Measurement of a dosimetric quantity is the process of finding the value of the quantity experimentally using dosimetry systems. The result of a measurement is the value of a dosimetric quantity expressed as the product of a numerical value and an appropriate unit.[1]

To function as a radiation dosimeter, the dosimeter must possess atleast one physical property that is a function of the measured dosimetric quantity and that can be used for radiation dosimetry with proper calibration. In order to be useful, radiation dosimeters must exhibit several desirable characteristics. For example, in radiotherapy exact knowledge of both the absorbed dose to water at a specified point and its spatial distribution are of importance, as well as the possibility of deriving the dose to an organ of interest in the patient. In this context, the desirable dosimeter properties will be characterized by accuracy and precision, linearity, dose or dose rate dependence, energy response, directional dependence and spatial resolution.[1]

Properties of Dosimeters-[1]

Accuracy and precision- The precision of dosimetry measurements specifies the reproducibility of the measurements under similar conditions and can be estimated from the data obtained in repeated measurements. High precision is associated with a small standard deviation of the distribution of the measurement results. The accuracy of dosimetry measurements is the proximity of their expectation value to the 'true value' of the measured quantity.

Linearity-the dosimeter reading should be linearly proportional to the dosimetric quantity. However, beyond a certain dose range a non-linearity sets in. The linearity range and the non-linearity behaviour depend on the type of dosimeter and its physical characteristics.

Dose rate dependence-the measured dosimetric quantity should be independent of the rate of that quantity.

Energy dependence-The response of a dosimetry system M/Q is generally a function of radiation beam quality (energy).Ideally, the energy response should be flat (i.e. the system calibration should be independent of energy over a certain range of radiation qualities).

Directional dependence-The variation in response of a dosimeter with the angle of incidence of radiation is known as the directional, or angular, dependence of the dosimeter. Dosimeters usually exhibit directional dependence, due to their constructional details, physical size and the energy of the incident radiation.

Spatial Resolution and Physical size- Since the dose is a point quantity, the dosimeter should allow the determination of the dose from a very small volume (i.e. one needs a 'point dosimeter' to characterize the dose at a point). The position of the point where the dose is determined (i.e. its spatial location) should be well defined in a reference coordinate system.

Readout Convenience-Direct reading dosimeters (e.g. ionization chambers) are generally more convenient than passive dosimeters.

Convenience of use- Ionization chambers are reusable, with no or little change in sensitivity within their lifespan. Semiconductor dosimeters are reusable, but with a gradual loss of sensitivity within their lifespan; however, some dosimeters are not reusable (e.g. films, gels and alanine). Some dosimeters measure dose distribution in a single exposure (e.g. films and gels) and some dosimeters are quite rugged (i.e. handling will not influence sensitivity, for example ionization chambers), while others are sensitive to handling (e.g. TLDs)

MATERIALS USED IN DOSIMETERS

The most commonly used TL phosphorous are:[2]

1. LiF; (Mg,Ti
2. MgB4O7 Dy
3. Li2B4O7 Mn
4. Li B4O7 Cu, Ag
5. Li2B4O7 Cu

The phosphors with a high atomic number are-[10]
CaF2 Dy, CaF2 Mn, CaF2 (natural form), Mg2SiO4 Tb, CaSO4 Mn, Al2O3, CaSO4 Tm, CaSO4 Dy

TLD Dosimeters

1. Lithium Fluoride (TLD-100, TLD-600, TLD-700)
2. Calcium Fluoride Dysprosium (TLD – 200)
3. Aluminum Oxide (TLD-500)
4. Calcium sulfate Dysprosium (TLD-900)
5. Calcium Fluoride Manganese (TLD-400)

CaSO4: Mn has the highest sensitivity, it has the disadvantage of fading rapidly and hence unsuitable for long term dose measurements.[9]

Mg2SiO4: Tb, is next highest in TL sensitivity, is sensitive to UV light.[9]

LiF: (Mg, Ti) is perhaps the most widely used TL phosphor. The detectors is used widely because of its compatibility in terms of atomic number. LiF atomic number 8.1, which is near to the atomic number of soft tissue (7.4), than silver (Z=47). It can also store energy during exposure to ionizing radiation and subsequently release it as light when heated. The disadavantage of this material is that it has, a complicated peak structure (as many as 12 glow peaks) and complications in reuse procedure (the glow curve structure is sensitive to thermal history) and the need for sophisticated instrumentation for the measurement of low doses (0.01 mGy). In LiF: (Mg, Ti) fading of dosimetric glow peaks is not the same for different types of radiation due to change in glow curve structure and transfer to high energy traps. If LiF dosimeters are contaminated with fine dust particles of highly sensitive thermo luminescent materials such as Al2O3 and CaF2, they show a high TL reading. Advantages are lower effective atomic number, small fading rate, chemical innertness, commercial availability in different isotopic compositions.[2]

Characteristics of a Tld

TL dosimeters exhibit certain characteristics, which make appropriate forusing them for in vivo or in phantom dosimetry. One of the most importantcharacteristics of TLDs is their small size which allows to be adhered to the patientwithout causing it discomfort or interfering with its movement. Furthermore, it is notvery probable that TLDs produce an image on the radiographic film that couldprovoke interference whit some useful diagnosis information.These advantages contrast with the use of ionization chambers, which commonlyare greater than TLDs and require a permanent connection to an electronic system.Consequently, it is difficult to be adhered to the patients limiting severely themovement of the patient and causing great interference with the radiographs.[3]

Other characteristics of TLDs, which make appropriate for dosimetry are thefollowing:Good tissue equivalence, Low fading, High sensitivity, Good precision and accuracy, Good stability under standard environmental conditions (temperature andhumidity)[3]

Tld Badge[11]

The typical TLD badge is small, light- weight has a clip for attachment to the clothes or uniform and should be worn throughout the workday. These badges are easy to load and have no dials to set or read. Each badge is identified by a number, the wearers name and the date on which the badge will be used. All that is necessary is to periodically replace the packet of crystal and mail it in to be read.

Them luminescent dosimeters (TLDs) are worn to record cumulative whole body dose (mSv) received from occupational exposures to ionizing radiation including x-ray producing machines, high energy beta and gamma emitting isotopes. Information obtained from exposure reports is useful to evaluate the effectiveness of protective measures.[4]

The TLD gives a measurement of dose absorbed in the TLD in (mGy) with an accuracy of about 10%. However what we need to know is not the absorbed dose in the badge, but the deep equivalent dose Hp (10) in (mSv) in tissue.[4]

Working of a Tld[1]

A 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).

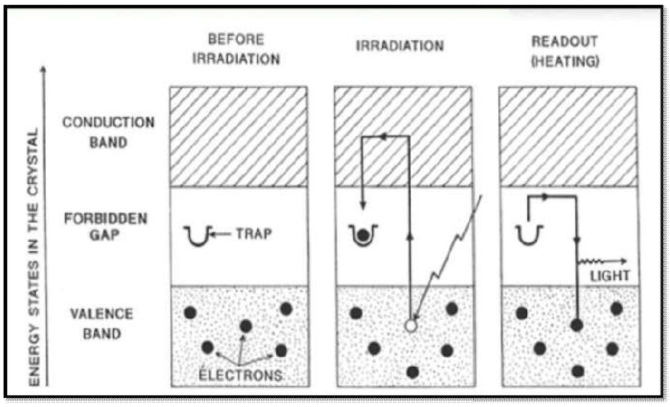

Figure 1

Structure of Tld[1]

A TLD badge consist of two main parts a- TLD card and a TLD cassette.

Parts

1. 1.Plastic holder
2. 2.Nickel-coated aluminum card with TLD discs
3. The discs are made of a thermo luminescent material, commonly calcium sulphate doped with dysprosium (CaSO4:Dy) or lithium fluoride (LiF), nearly tissue equivalent, although not at all x-ray energies. The discs are 0.8 mm thick and have a 1.35 cm diameter
4. Three filters against each disc
   top: aluminum and copper
   middle: perspex
   lower: open window.
5. Filters- Cu+Al, Plastic and open window.
6. 1st Disc- sandwiched between pair of filter combination of 1mm Al and 0.9mm Cu
   2nd disc- sandwiched between pair of 1.5mm thick plastic filters (180 mg/cm2)
   3rd Disc- positioned under circular open window.
7. A TLD card consist of three discs made up of CaSO4: Dy-[10]
8. 1st disc- cuts off hard β rays- gives thermo luminescence.
   2nd disc- cuts off soft β rays- gives x-rays and γ rays
   3rd disc- no filter, records all radiation.

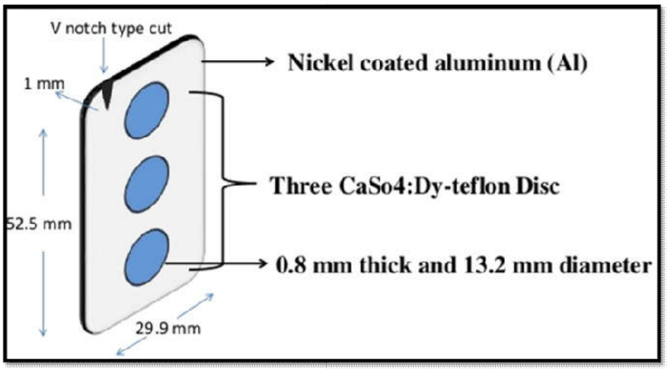

Figure 2

When the card is fitted inside the cassette and the TLD is assembled all the three disc of the card correspond to the three filters of the cassette. A 'V' shaped notch present on the superior aspect of the card, acts the guide for placing the card in the cassette.

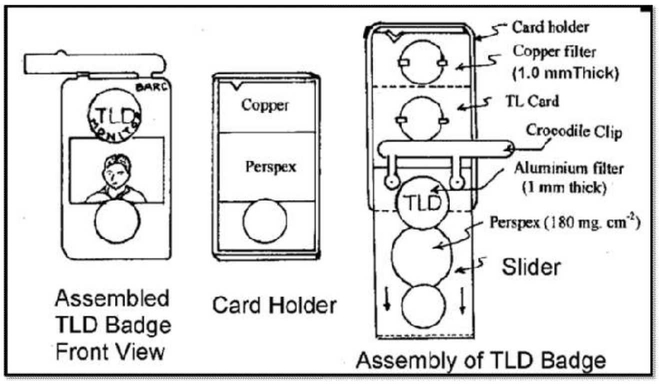

Figure 3 TLD assembly

Reading of a Tld [1]

A basic TLD reader system consists of a planchet for placing and heating the TLD, a PMT to detect the thermo luminescence light emission and convert it into an electrical signal linearly proportional to the detected photon fluence and an electrometer for recording the PMT signal as a charge or current. The thermo luminescence intensity emission is a function of the TLD temperature T. Keeping the heating rate constant makes the temperature T proportional to time t, and so the thermo luminescence intensity can be plotted as a function of t if a recorder output is available with the TLD measuring system. The resulting curve is called the TLD glow curve. In general, if the emitted light is plotted against the crystal temperature one obtains a thermo luminescence thermogram The peaks in the glow curve may be correlated with trap depths responsible for thermo luminescence emission. The main dosimetric peak of the LiF:Mg,Ti glow curve between 180ºC and 260ºC is used for dosimetry. The peak temperature is high enough so as not to be affected by room temperature and still low enough so as not to interfere with black body emission from the heating planchet. The total thermo luminescence signal emitted (i.e. the area under the appropriate portion of the glow curve) can be correlated to dose through proper calibration. Good reproducibility of heating cycles during the readout is important for accurate dosimetry. Thethermoluminescence signal decreases in time after the irradiation due to spontaneous emission of light at room temperature. This process is called fading. Typically, for LiF:Mg,Ti, the fading of the dosimetric peak does not exceed a few per cent in the months after irradiation. Thethermoluminescence dose response is linear over a wide range of doses used in radiotherapy, although it increases in the higher dose region, exhibiting supralinear behavior before it saturates at even higher doses.

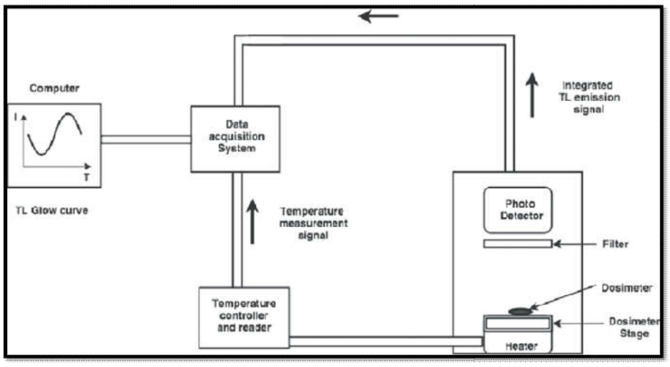

Figure 4 Reading of TLD

TLDs need to be calibrated before they are used (thus they serve as relative dosimeters). To derive the absorbed dose from the thermo luminescence reading a few correction factors have to be applied, such as those for energy, fading and dose response non-linearity. Typical applications of TLDs in radiotherapy are: in vivo dosimetry on patients (either as a routine quality assurance procedure or for dose monitoring in special cases, for example complicated geometries, dose to critical organs, total body irradiation (TBI), brachytherapy); verification of treatment techniques in various phantoms (e.g. anthropomorphic phantoms); dosimetry audits (such as the IAEA–World Health Organization (WHO) TLD postal dose audit programme).

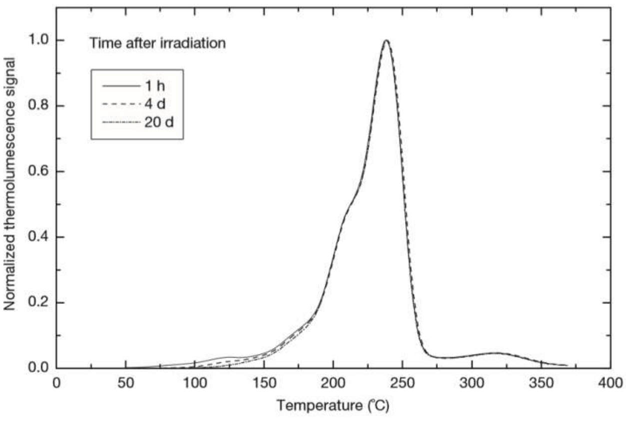

Figure 5 Glow Curve[1]

Extremity TLD[9]

The dosimeters are designed to measure doses from x ray, beta and gamma radiations to the skin of the extremities in terms of the radiation quantity. Worn on the fingers or taped to the ankles to measure the external equivalent dose to the extremities ie., hands, forearms, feet and ankles. Extremity TLD are designed to measure beta radiation at a depth equivalent to that of the sensitive basal layer of the skin (about 0.3mm). Small discs of LiF which are sealed in plastic holders. The holder shields the TLD from the lower energy betas which cannot penetrate to the basal layer.[4]

When to wear extremity TLDs[9]

Whenever you handle unshielded beta sources. When working with the whole body shielded except for the hands. When handling small non-shielding gamma sources for decontamination jobs when beta contamination is present, for iodine source operations.

Storage of TLD

Store your badge in a safe place, at work rather than at home. Be sure to store badges away from sources of radiation. If you store your badges clipped to your lab coat, make sure that your lab coat is not contaminated. Store your badges away from sources of heat (TLDs show some sensitivity to environmental factors like heat). Badges left in cars over hot summer weekends may give false exposure readings.[2]

Shelf Life of TLD

The dosimeter is capable of retaining the stored dose information for extended periods before assessment, with no measurable changes in response over at least six months. The dosemeter can also withstand exposure to high temperature (40°C) and relative humidity (over 90%) for continuous periods of over 48 hours. Issue periods of up to 13 weeks can be offered, thus keeping the cost of monitoring low.[2]

Re-assessment of TLD-[8]

Thermo luminescence glow curves of all dosimeter readings are kept for at least five years. This allows retrospective investigation in the event of a customer query. The glow curves for dosemeters with assessments in excess of 15 mSv are all checked. For higher doses, it is possible to verify the original assessment by examining the small amount of signal remaining after read-out.

Guidelines for use.[8]

Never share your badges or wear another person's badges. Do not intentionally expose badges to radiation. No matter how curious you are, do not wear your badges when you receive a medical x-ray or other medical radiation treatment. Your badges are intended to document occupational dose, not medical dose.[5]

Radon dosimeters are used in rare situations where, although radon levels are elevated, no cost effective remediation measures are available. This is usually in underground workplaces.[5]

Merits and Demerits of TLD-[2]

A TLD system has many advantages over the photographic film method. The main inherent problems of film are pronounced fading at higher temperatures and humidities, poor reproducibility, and the need for rather complex darkroom procedures involving many potential sources of error. Some important merits and demerits of TL Dosimeters are listed in table 1.

Table 1

Merits of TLD.	Demerits of TLD
1. Reusable and hence low cost	1. Information lost in a single readout and hence no permanent record to produce if user chooses to argue the readout.
2. More accurate, sensitive, reliable, and stable.	2. Low information content regarding the nature of exposure to determine the genuineness of exposure.
3. Linear in a wider dynamic range	3. Slow screening by manual readout system
4. Possibility of automation for readout	4. Needs sophisticated reader system.
5. Energy independence.	5. Accounting and storage of dosimeters for reuse.

Regulatory Bodies- [7]

Radiation Safety Officer-The RSO maintains complete, accurate and organized records. The RSO is responsible for making necessary amendments and notifying the regulatory agency of these amendments.The RSO will keep the safety program updated as to any changes in the regulations.The RSO is the person responsible for radiological safety in conjunction with the use, handling, and storage of radioactive materials in a program licensed by the Nuclear Regulatory Commission (NRC) or Agreement State. It is the duty of the RSO to ensure that all licensed activities are carried out in compliance with the requirements of the license and the applicable rules and regulations.The RSO will authorize and ensure that only properly trained individuals will operate the gauges and prepare and transport gauges.

BHABHA- TheBhabha Atomic Research Centre (BARC) is India's premier nuclear research facility, headquartered in Trombay, Mumbai, Maharashtra. BARC is a multi-disciplinary research centre with extensive infrastructure for advanced research and development covering the entire spectrum of nuclear science, engineering and related areas.

BARC's core mandate is to sustain peaceful applications of nuclear energy, primarily for power generation. It manages all facts of nuclear power generation, from theoretical design of reactors to, computerised modelling and simulation, risk analysis, development and testing of new reactor fuel materials, etc. It also conducts research in spent fuel processing, and safe disposal of nuclear waste. Its other research focus areas are applications for isotopes in industries, medicine, agriculture, etc. BARC operates a number of research reactors across the country.[7]

AVENTEC- Personnel monitoring of all individuals working in the radiation area is mandatory by AERB regulation (Atomic Energy Regulatory Board, Govt. of India). Every individual, working in the radiation environment, such as Doctors, Radiographers, Nurses, Operation Theatre Assistants and Industrial X-Ray Technicians etc. should register themselves with BARC and enroll into personnel monitoring services to monitor the radiation dose received by them.Under Accreditation from Bhabha Atomic Research Centre (BARC, Govt. of India), Mumbai, Avanttec Laboratories is the first private laboratory in the southern part of India, providing ‘Personnel Radiation Monitoring services’ for all the personnel associated with the radiation environment of Industrial and Medical fields.[7]

CONCLUSION

In X-ray diagnostic radiography, the radiation received by the skin of a patient undergoing X-ray investigation is a mixture (wide spectrum) of the primary beam and lower energy radiations backscattered from tissue. The TLD dosimeters are found to be very convenient for monitoring cumulative dose. The main advantage of TLD in medical applications are the availability of detectors in various shapes and sizes and the ease with which they are practically worn for radiation monitoring.

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