Film dosimetry

Film dosimetry

Radiographic film

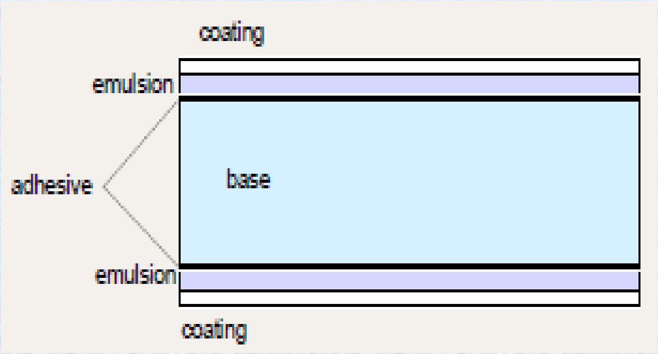
❖ Radiographic x-ray film performs several important functions in diagnostic radiology, radiation therapy, and radiation protection.

❖ It can serve as radiation detector, relative dosimeter, a display device, and archival medium.

❖ Unexposed x-ray film consists of a base of thin plastic with a radiation sensitive emulsion (silver bromide grains suspended in gelatin) coated uniformly on one or both sides of the base.

❖ Ionisation of silver bromide (AgBr) in the grains, as a result of radiation interaction, forms the latent image in the film. Image becomes visible only after development.

❖ A thin plastic base layer (200 μm) is covered with a sensitive emulsion of AgBr crystals in gelatine (10-20 μm).

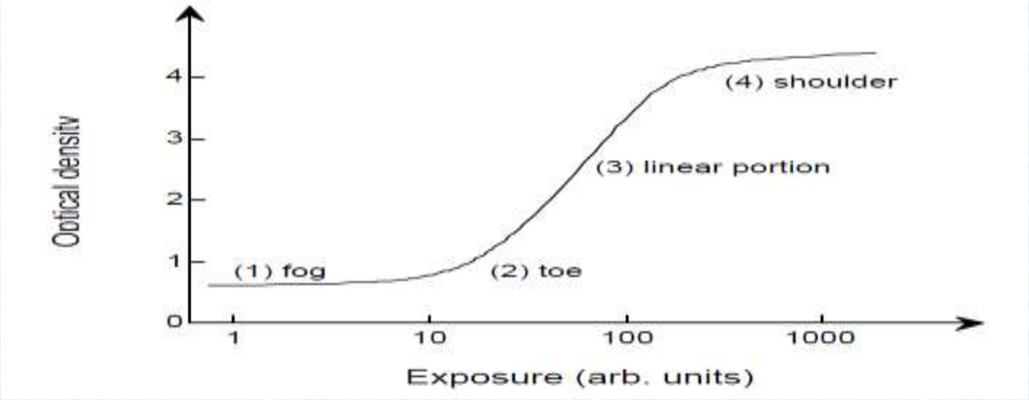


- During irradiation, the following reaction is caused (simplified):
    - ✓ Ag Br is ionized
    - ✓ Ag+ ions are reduced to Ag: $Ag^+ + e^- = Ag$
    - ✓ The elemental silver is black and produces a so-called latent image.
- During the development, other silver ions (yet not reduced) are now also reduced in the presence of silver atoms.
- This means: If one silver atom in a silver bromide crystal is reduced, all silver atoms in this crystal will be reduced during development.
- The rest of the silver bromide (in undeveloped grains) is washed away from the film during the fixation process.
- Light transmission is a function of the film opacity and can be measured in terms of optical density (OD) with devices called densitometers.
- Film gives excellent 2-D spatial resolution and, in a single exposure and useful dose range of film is limited; energy dependence, difficult to control parameters.

❖ Typically, films are used for qualitative dosimetry but with proper calibration, careful use and analysis, film can also be used for dose evaluation.

❖ Various types of films are available for radiotherapy work (e.g., direct exposure non-screen films for field size verification, phosphor screen films used with simulators, metallic screen films used in portal imaging, etc.).

❖ A typical H&D curve for a radiographic film is



It has four regions:

(1) Fog (at low or zero exposures)
(2) toe
(3) linear portion at intermediate exposures and
(4) shoulder and saturation at high exposures.

❖ The linear portion is referred to as optimum measurement conditions; the toe is the region of underexposure, and the shoulder as the region of overexposure.

- Unexposed film would exhibit a background optical density called the fog density (OD^f). The density due to radiation exposure called the net optical density can be obtained from the measured density by subtracting the fog density.

$$OD = \log^{10} (I^o/I) \text{ and is a function of dose.}$$

Where I^o is the initial light intensity and I is the intensity transmitted through the film.

Advantages:

- ✓ High spatial resolution and
- ✓ Relatively inexpensive

Disadvantages:

- ✓ Light sensitive
- ✓ Oversensitive to low energy photons
- ✓ Dependence on film batch, processor conditions, digitizer
- ✓ Need to measure response curve for each measurement session

- ❖ Important parameters of film response to radiation are: gamma, latitude and speed.
  - ✓ The slope of the straight line portion of the H&D curve is called the gamma of the film.
  - ✓ The exposure should be chosen to make all parts of the radiograph lie on the linear portion of the H&D curve to ensure the same contrast for all optical densities.
  - ✓ The latitude is defined as the range of exposures over which the densities will lie in the linear region.
  - ✓ Speed of a film is determined by giving the exposure required to produce an optical density of 1.0 greater than the OD of fog.
- ❖ Typical applications of a radiographic film in radiotherapy are qualitative and quantitative measurements, including electron beam dosimetry, quality control of radiotherapy machines (e.g., congruence of light and radiation fields, deter-mination of the position of a collimator axis, so called star test), verification of treatment techniques in various phantoms and portal imaging.

Radiochromic film

- Radiochromic film is a new type of film in radiotherapy dosimetry. The most commonly used is a GafChromic film. It is a colorless film with a nearly tissue equivalent composition (H 9.0%, C 60.6%, N 11.2%, and O 19.2%) that develops a blue color upon radiation exposure.
- Radiochromic film contains a special dye that gets polymerized upon exposure to radiation. The polymer absorbs light and the transmission of light through the film can be measured with a suitable densitometer.
- Since the radiochromic film is grain less, it has a very high resolution and can be used in high dose gradient regions for dosimetry (e.g., near brachytherapy sources, in measurement of dose distributions in stereotactic fields, etc).
- The dosimetry with GafChromic films has a few advantages over the radiographic films, such as the ease of use, not requiring dark rooms, film cassettes or film processing; dose rate independence; better energy characteristics except for low energy x rays (25 kV); insensitivity to ambient conditions (although excessive humidity should be avoided).
- GafChromic films are generally less sensitive that radiographic films and are useful at higher doses, although the dose-response non-linearity should be corrected for in the upper dose region.

Radiochromic film

Advantages

- **Does not require processing**
- **Not sensitive to indoor light**
- **Nearly tissue equivalent**
- No quality control on film processing needed.
- Radiochromic film is grainless
- Very high resolution
- Useful in high dose gradient regions for dosimetry such as in:
  - ✓ Stereotactic fields
  - ✓ Vicinity of brachytherapy sources
- Dose rate independence
- Better energy characteristics except for low energy x rays (25 kV)

Disadvantages

- ❑ **Low** optical density **(OD) at clinical doses**
- ❑ GafChromic films are generally less sensitive than radiographic films

Radio-chromic dosimeter

Also called colorimetric dosimeters, these have radiation sensitive film mounted in a credit card format.

The film darkens with radiation exposure and a color matching scale printed on the card can be used to visually estimate the radiation dose received.

Radio-chromic dosimeters are also field readable ID holder.

They are intended to indicate emergency dose levels rather than lower doses in routine occupational monitoring.

Variability in individual interpretation of the color may affect precision.

They do not require batteries and are relatively inexpensive and durable, with a shelf life of about one year.

They include a protective cover to avoid continuous exposure to bright light.

Film can also serve as a **monitor of neutron doses.**

- **Thermal neutrons:** Cadmium window absorbs thermal neutrons and the resulting gamma radiation blackens the film below this window as an indication of the neutron dose.
- **Fast neutrons:** Nuclear track emulsions are used. The neutrons interact with hydrogen nuclei in the emulsion and surrounding materials, producing recoil protons by elastic collisions. These particles create a latent image, which leads to darkening of the film along their tracks after processing.

Personal monitoring devices:

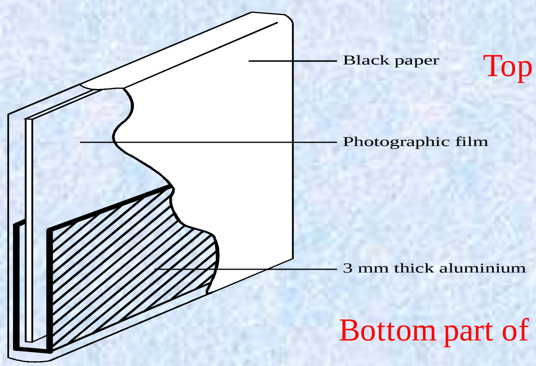
1. Film Badge
2. TLD
3. OSL
4. RPL
5. Pocket dosimeter

1. Film badges

Another kind of solid state detector is photographic emulsion. The active material is a grain of silver bromide. Incident radiation raises an electron from an energy level in the valence band to an energy level in the conduction band, leaving a hole in the valence band. Both the electron and hole diffuse through the silver bromide grain and become trapped at irregularities in the crystal structure of the grain. If a single grain accumulates more than about four electron-hole pairs it becomes possible to change the silver bromide crystal to a pure silver crystal by photographic development.

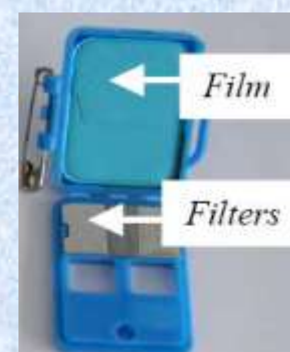
Film Badges

- Film badges are used to monitor the radiation dose workers in the nuclear industry receive: Radiographers, Dentists and Pilots (recently)
- The film is checked on a regular basis
- The radiation dose the person wearing it received is calculated
- Beta and gamma radiation have different penetrating power
- X and gamma rays affect film like light
- Ionizing radiation “exposes” silver bromide and darkens film
- Permanent record (can be re-read), Not reusable, Dose response saturates based on film and Dose response is flat
- The badge may contain “filters”
- **Filter system is therefore required to adjust the energy response.**
- One filter is adequate for photons of energy above 100 keV.
- **Multiple filter system is used for lower energy photons.**
- Filters may stop beta radiation



Top part of film affected by radiation

Bottom part of film NOT affected by radiation



Film Badge: It is used to measure the individual dose from

- X rays, Beta particle, Gamma radiation, Thermal neutrons
  - Photographic film
  - Filters
  - Badge Holder

Photography Film

- Photography film is a sheet of transparent plastic film base coated on one/both side with a gelatin emulsion containing small light sensitive silver halide crystals.
- Film size is 4 x 3 cm wrapped inside by a light tight polythene or paper cover
- There are two films in the badge one is slow and another is fast
- Supply of films is for a period of one calendar month (4 weeks)

Film holder has 6 windows

1) First window

- Without any filter
- It detects alpha particles
- Due to minimum penetration power of alpha particles no metallic filter is used
- Thickness of filter is 1 mm

2) Second window

- Filter is made of plastic
- Light white colour
- It detects beta partiles

3) Third window

- Filter is made of cadmium
- Yellow in colour
- It detects thermal neutrons

4) Fourth window

- Filter is made of thin copper
- Green in colour
- It detects low energy thermal neutrons

5) fifth window

- Filter is made of thick copper
- Pink in colour
- It detects high energy x rays

6) sixth window

- Filter is made of Lead
- Black in colour
- It detects gamma rays

Film holder Photographic film Filters

Film badge consist of stainless steel holder, photographic film and all six filter fixed in particular window

Working: When radiation exposes the film after passing through the filters it cause formation of latent image on the film.

- Latent image has regions of different density under the different filters due to their different penetration power
- After each months (4 weeks) it is returned to the agency where the film is processed and the optical density under different filters is measured by a densitometer.
- Dose under each filter is evaluated using the standard calibration curve
- After processing the film badge monthly dose report is sent to the institution. This report contains current months report and uo to date cumulative dose of the current year.
- Dose is reported in mSv.
- Each institute should keep on e film badge as control to assess background radiation level.
- This badge should be kept in cool, dry and control area.

Advantages:

- It gives permanent record
- Wide exposure range
- Independent of dose rate
- Type of radiation and energy can be evaluated
- Least expensive device
- Small, light weight, easy to handle

Disadvantages:

- Can’t give instantaneous reading
- It’s film fades at high temperature and humidity
- High sensitivity to light, pressure and chemicals
- Complete dark room procedure
- Limited shelf life (one month)

TLD & OSLD

★ Luminescence: Emission of photons (visible light, UV, X ray) after absorption of energy. Energy deposition in the material by

★ Light ➔ Photoluminescence

★ Heat ➔ Thermoluminescence

★ Sound ➔ Sonoluminescence

★ Electric energy ➔ Elektrolumineszence

★ Mechanical deformation ➔ Triboluminescence

★ Chemical reactions ➔ Chemoluminescence

★ Living organism ➔ Bioluminescence

★ Scintillation: Emission of photons following the excitation of atoms and molecules by radiation (γ, or particle radiation).

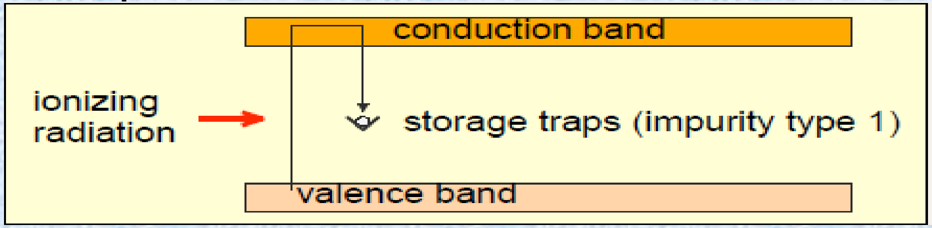
★ Fluorescence: emission of light by a substance that has absorbed light or another electromagnetic radiation of a different wave length. In most cases the emitted light has a longer wavelength. The emission follows shortly after (appr. 10 ns).!

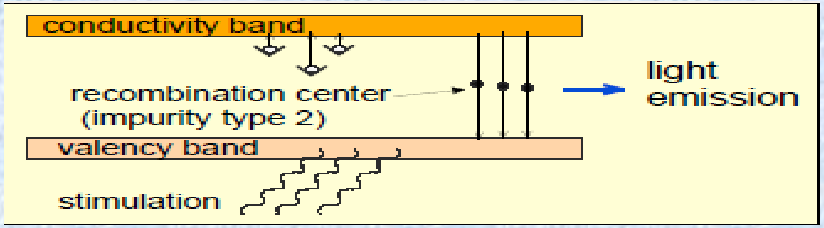
★ Phosphorescence: Similar to Fluorescence, however the re-emission is not immediate. The transition between energy levels and the photon emission is delayed (ms up to hours).

LUMINESCENCE DOSIMETRY

- Upon absorption of radiation, some materials retain part of the absorbed energy in metastable states.
- When this energy is subsequently released in the form of ultraviolet, visible or infrared light, this phenomenon is called Luminescence
- There are two types of luminescence:
  - Fluorescence
  - Phosphorescence
- The difference depends on the time delay between the stimulation and the emission of light:
  - Fluorescence has a time delay between 10^{-10} to 10^{-8} s.
  - Phosphorescence has a time delay exceeding 10^{-8} s.

Principle:





❖ Upon radiation, free electrons and holes are produced

❖ In a luminescence material, there are so-called storage traps

❖ Free electrons and holes will either recombine immediately or become trapped (at any energy between valence and conduction band)

❖ Upon stimulation, the probability increases for the electrons to be raised to the conduction band and to release energy (light) when they combine with a positive hole (needs an impurity of type 2)

❖ The process of luminescence can be accelerated with a suitable excitation in the form of heat or light.

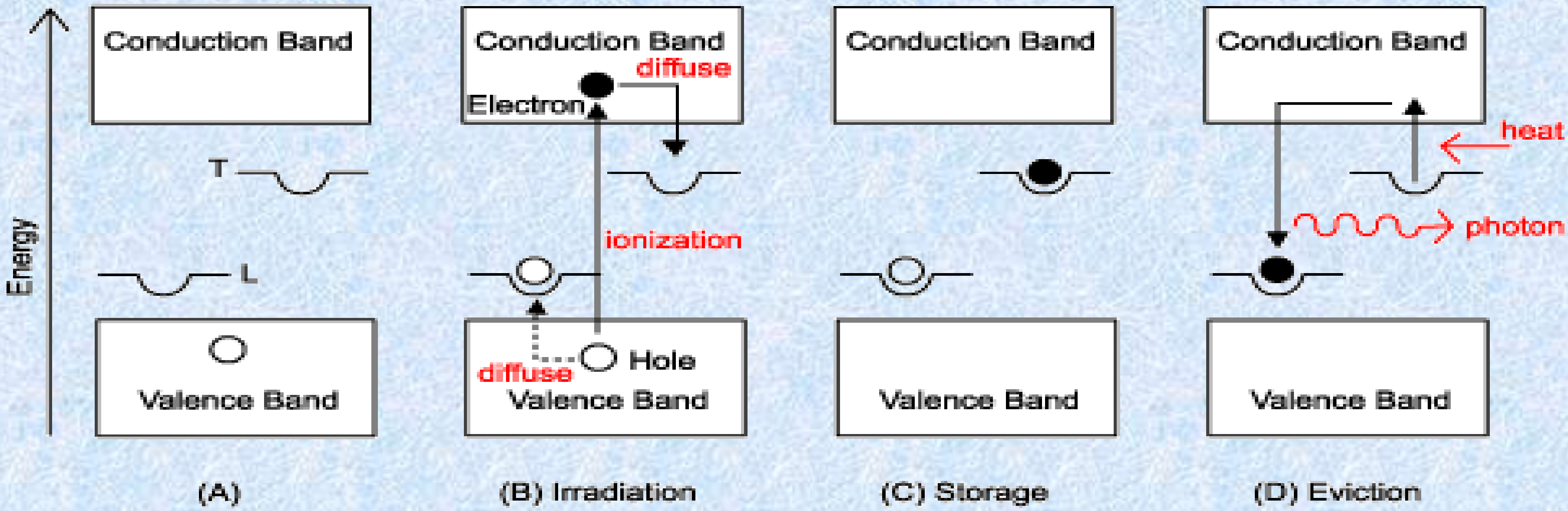
❖ If the exciting agent is heat, the phenomenon is known as thermoluminescence

❖ When used for purposes of dosimetry, the material is called Thermoluminescent (TL) material or Thermoluminescent dosimeter (TLD).

❖ If the exciting agent is light, the phenomenon is referred to as optically stimulated luminescence (OSL).

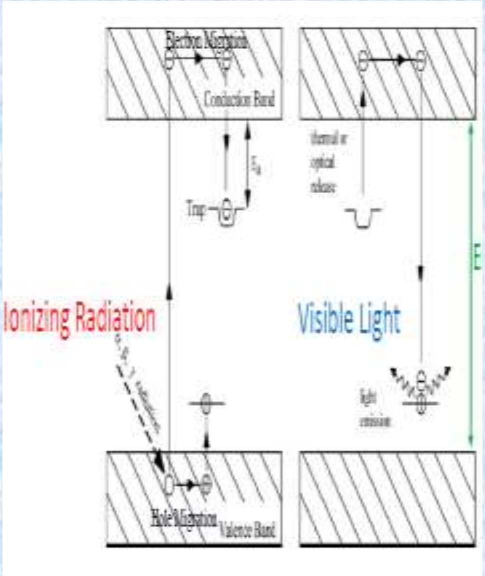
❖ Thermoluminescence (TL) is thermally activated phosphorescence

❖ Its practical applications range from radiation dosimetry to archeological pottery dating (natural impurities in fired clay and storage process by natural irradiation which starts just after firing).



Thermoluminescent Dosimeter

- Crystal retains this energy until heat is applied.
- The "trapped" energy is then released in the form of light, as the atoms of the crystal return to their "ground state"
- The light emitted is then correlated to dose received
- Once the TLD has been "read" memory is cleared
- TLD is then available for re-use



TLD systems

- TL dosimeters most commonly used in medical applications are LiF:Mg,Ti, LiF:Mg,Cu,P and $Li^2B^4O^7$:Mn, because of their tissue equivalence. Other TLDs, used because of their high sensitivity, are $CaSO^4$:Dy, Al^2O^3:C and CaF^2:Mn.
- TLDs are available in various forms (e.g., powder, chips, rods, ribbon, etc.).
- Before they are used, TLDs have to be annealed to erase the residual signal. Well-established reproducible annealing cycles should be used including the heating and cooling rates
- A basic TLD reader system consists of a planchet for placing and heating the TL dosimeter; a photomultiplier tube (PMT) to detect the TL light emission, convert it into an electrical signal, and amplify it; and an electrometer for recording the PMT signal as charge or current.
- The TL 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 TL 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 TL thermogram.

Thermoluminescence dosimetry

Principle:

- Radiation creates metastable, excited states in a solid crystal.
- When the crystal is to be “read” it is heated. Some of the metastable excited states deexcite by photon emission. This light is detected.
- The heating of TLD crystals must be optimised with respect to temperature and temperature gradient.
- For every crystal, there is a particular temperature (Tm) where optimal signal (”brightness”) is achived for the emitted light.
- These crystals are excellent for personnel dosimetry, but also for “tougher” applications.
- When the reading is done, the crystals can be used agein several times. Since the reading is nondestructive it is a very economic method, compared to film.
- TLD is today dominating in personnel dosimetry.

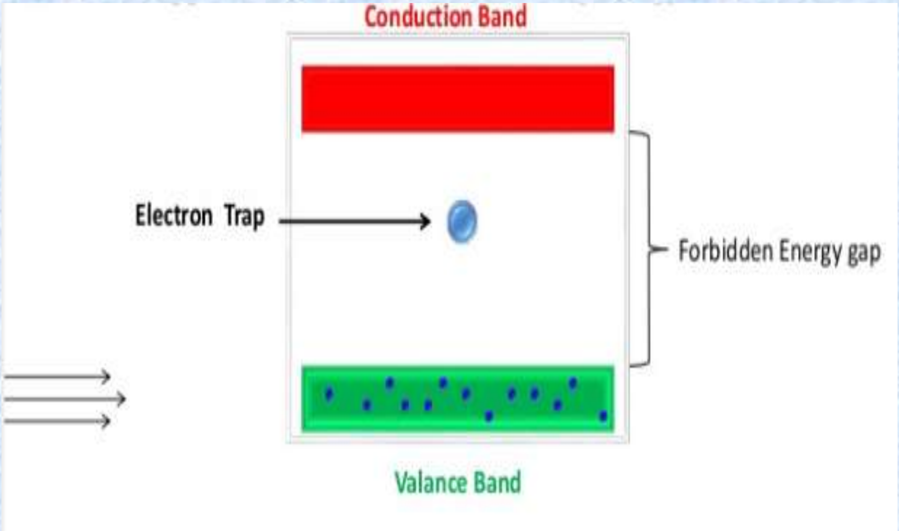
Working: Exposing the TLD and reading the TLD

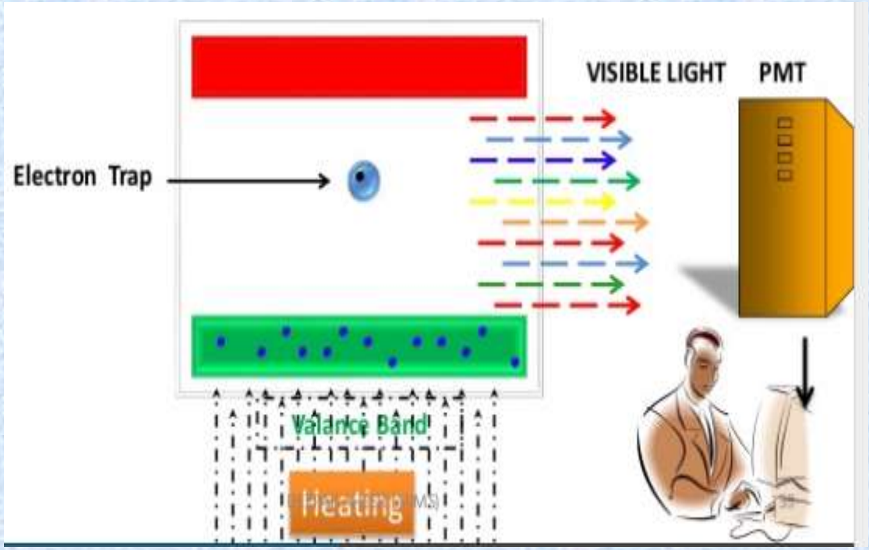
Exposing the TLD:

- When the TLD is exposed to the radiation, electrons absorb the energy and jump to conduction band from the valance band
- Excited electrons loose a part of their energy and are trapped in the forbidden energy gap
- These trapped electrons store the remaining energy

Reading the TLD

- When this TLD card is heated in TLD reader
- Trapped electrons absorb energy and are released from trap zone and are returned to their ground state
- While returning to the ground state light is emitted which is captured by PMT tube and convert into digital signal.





The system may approach thermal equilibrium through several means:

(1) Free charge carriers recombine with the recombination energy converted into heat.

(2) A free charge carrier recombines with a charge carrier of opposite sign trapped at a luminescence center, the recombination energy being emitted as optical fluorescence.

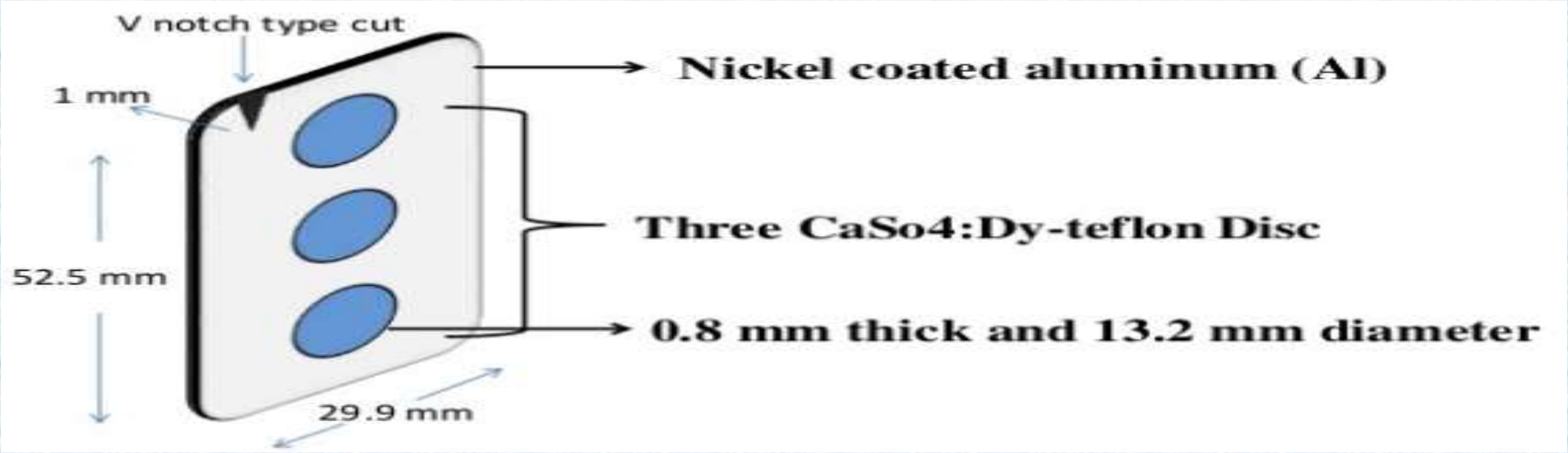
(3) The free charge carrier becomes trapped at a storage trap, and this event is then responsible for phosphorescence or the TL and OSL processes.

Thermo-luminescent Dosimeter (TLD)

TLD Badge

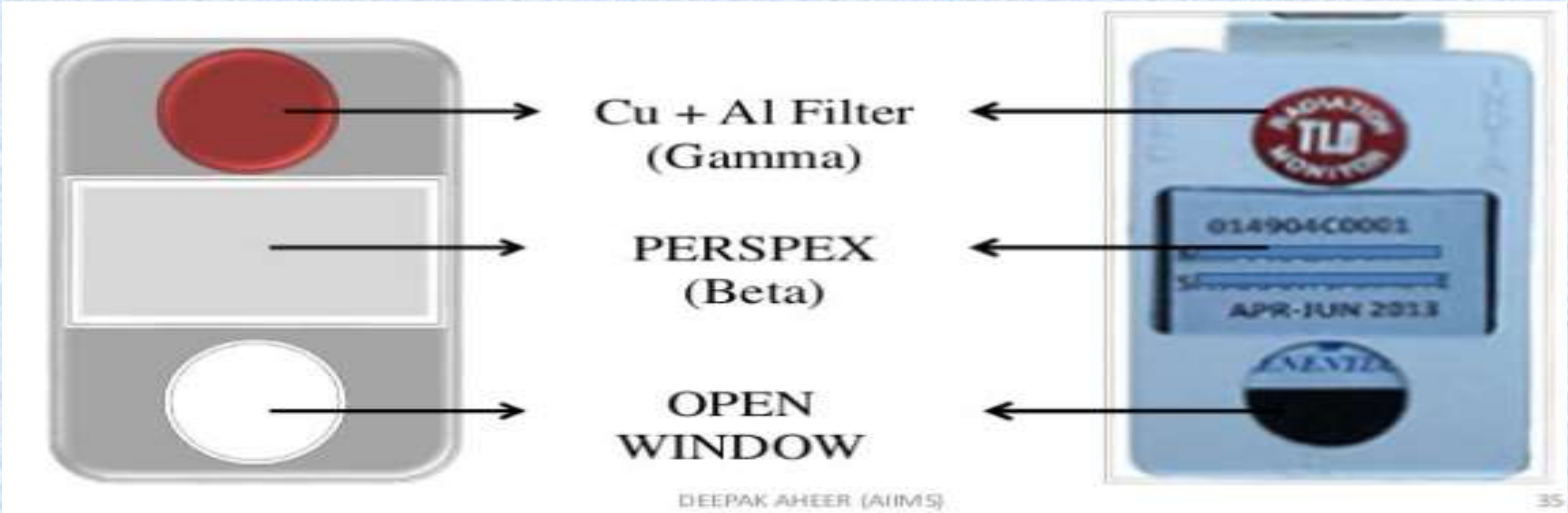
- TLD card and TLD cassette

TLD card :

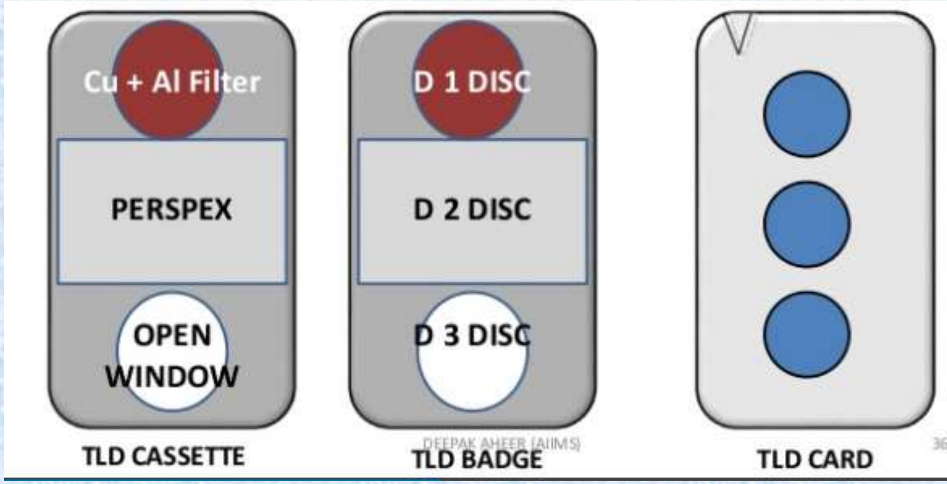


- A cut is provided at one end of the card to ensure a fixed orientation of a card in the TLD cassette
- This card is enclosed by a paper wrap on which user's personal data and period of use is written
- This pouch protects the card from radioactive contamination while working with open sources
- Disc is reusable after proper annealing

TLD Cassette



- When the TLD card is placed properly in the cassette
- First disc (D1) is sandwiched between pair of metallic filter
- Second disc (D2) is sandwiched between plastic filter
- Third disc (D3) is positioned under a circular open window (x rays and beta)

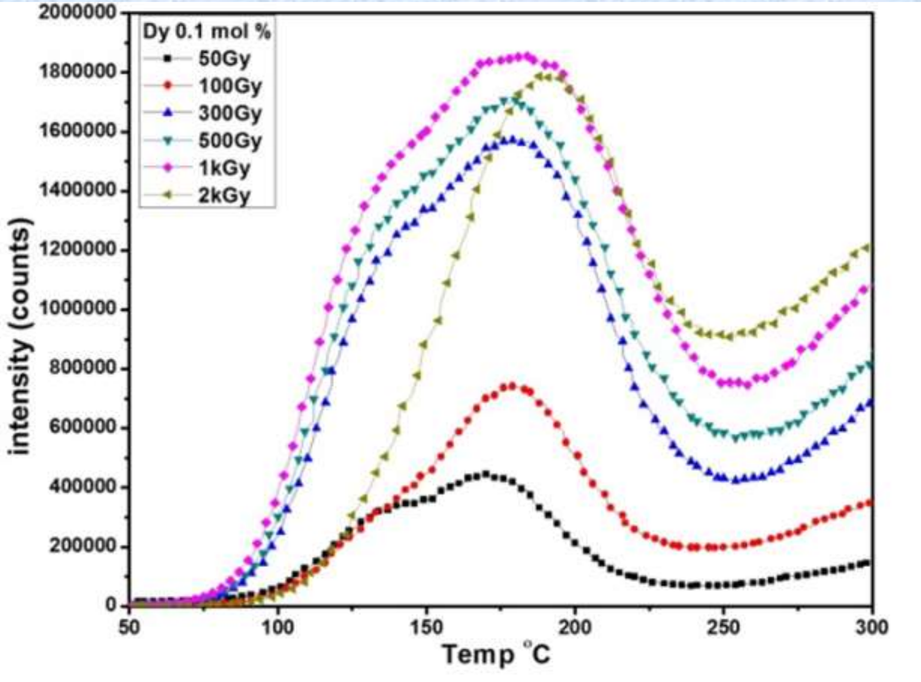


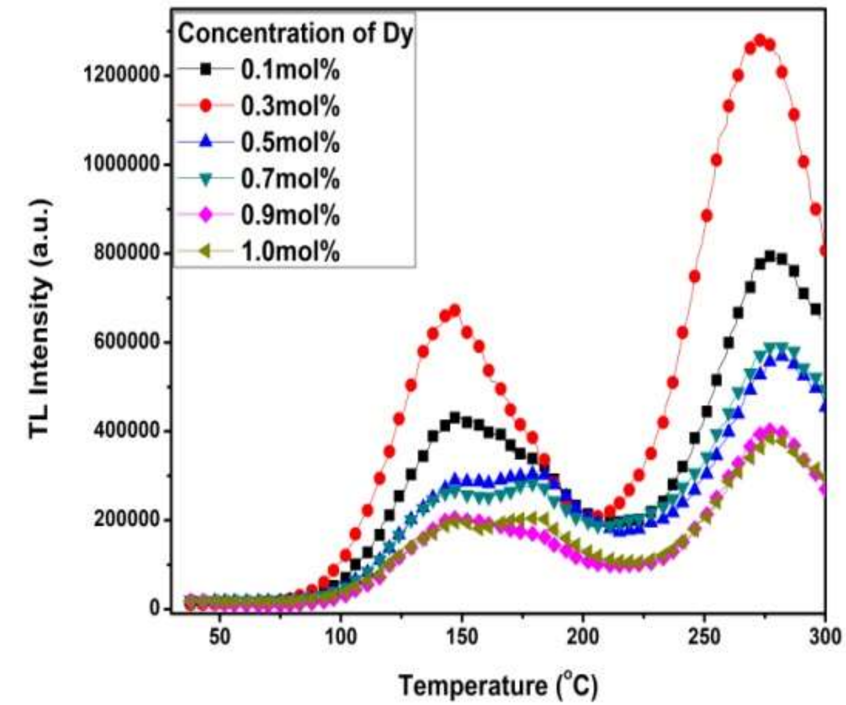
TLD reader

- As the name suggests, TLD reader is the instrument which is sued to read TLD card
- Reader has a heater, PMT, amplifier and a recorder
- TLD disc is placed in the heater cup or planchet, where it is heated for a producible heating cycle.
- While heating, the electrons return to their ground state with the emission of light.
- This emitted light is measured by PMT which converts light into electric signal
- PMT signal is amplified and measured by a recorder
- The reader is calibrated in terms of mR or mSv, so that we can get direct dose estimation.

TLD glow curve

- Several prominent peaks occur in graph because of a specific electron transition in TL crystal
- Bothe the height of the peak and total area under curve are directly proportional to energy deposited in TLD by ionizing radiation.
- TLD analyzer are electronic instruments designed to measure the height of glow curve or area under curve
- Exposure or dose can be calculated from this using a conversion factor


Dy 0.1 mol %
50Gy
100Gy
300Gy
500Gy
1kGy
2kGy
intensity (counts)
Temp °C
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
50
100
150
200
250
300


Concentration of Dy
0.1mol%
0.3mol%
0.5mol%
0.7mol%
0.9mol%
1.0mol%
TL Intensity (a.u.)
Temperature (°C)
1200000
1000000
800000
600000
400000
200000
0
50
100
150
200
250
300

Type of TLD badges

Advantages:

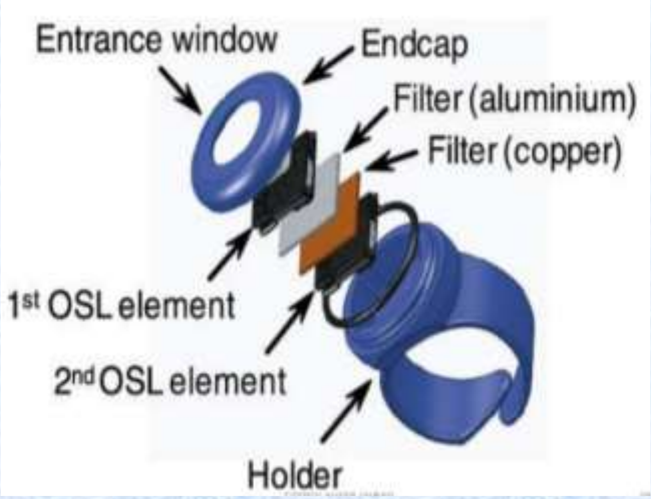
- Relatively good energy independence
- Atomic number is approximate tissue equivalent
- Unaffected by visible light, moisture and mechanical vibration
- It is reusable, one TLD card can be used 100 times, so one card can be for 300 months (25 years)
- Its more sensitive and more accurate than film badge and give reliable result because no fading is observed due to changes in environmental conditions.
- Properly calibrated TLD monitors can measure exposure as low as 5 mR
- Can be worn for intervals up to 3 months at a time.

Disadvantages:

- Dose not provide permanent record like film badge
- Dose not give instantaneous result
- Primary disadvantage of TLD personnel monitoring is cost but due to reuse it is cost effective
- Instrumentation for reading TLD badge is expensive
- Price is perhaps twice that of film badge monitoring
- Skilled trained experts are required to run the service

OSL Dosimeter

- Dosimetry using Optically Stimulated Luminescence (OSL) is also available now a days alternative to TLD.
- Measures radiation using a thin layer of aluminum oxide (Al2O3:C) as the detecting medium
- Tiny crystal traps and stores the energy form exposure ionizing radiation
- Amount of exposure can be determined by shinning green laser on crystal and measuring the intensity of blue light emitted
- The principle of OSL is similar to TLD except the heating
- Instead of heating, laser is used to stimulated light emission
- Small, lightweight, fast and efficient service
- Minimum reportable level is 10 μSv for both x rays and gamma radiation
- Range of OSL is from 5 keV to 40 Mev
- Wide dose ranges from 10 μSv to 10 Sv
- OSL dosimeter can be used several times



Optically stimulated luminescence (OSL) systems

- ➢ OSL is based on a principle similar to that of the TLD. Instead of heat, light (from a laser) is used to release the trapped energy in the form of luminescence.
- ➢ OSL is a novel technique offering a potential for *in vivo dosimetry* in radiotherapy.
- ➢ A further novel development is based on the excitation by a pulsed laser (POSL)

- ❖ OSl is now commercially available also for measuring personal doses.
- ❖ The most promising material is Al2O3:C
- ❖ OSL dosimeters contain a thin layer of aluminum oxide (Al_2O_3:C).
- ❖ To produce OSL, the chip is excited with a laser light through an optical fiber and the resulting luminescence (blue light) is carried back in the same fiber, reflected through a 90° by a beam-splitter and measured in a photomultiplier tube.
- ❖ During analysis the aluminum oxide is stimulated with selected frequencies of laser light producing luminescence proportional to radiation exposure.
- ❖ OSL is a high sensitivity, particularly suitable for individual monitoring in low-radiation environments.
- ❖ OSL dosimeters can be re-analysed several times without loosing the sensitivity and may be used for up to one year.

OSL systems

✓The integrated dose measured during irradiation can be evaluated using OSL directly afterwards.

✓ The optical fibre OSL dosimeter consist of a small (~1 mm^3) chip of carbon-doped aluminium oxide (Al^2O^3:C) coupled with a long optical fibre, a laser, a beam-splitter and a collimator, a PM tube, electronics and software. To produce OSL, the chip is excited with a laser light through an optical fibre and the resulting luminescence (blue light) is carried back in the same fibre, reflected through a 90^o by the beam-splitter and measured in a PMT.

✓ The optical fibre dosimeter exhibits high sensitivity over the wide range of dose rates and doses used in radiotherapy. The OSL response is generally linear and independent of energy as well as the dose rate, although the angular response requires correction.

✓ Various experimental set-ups exist, such as pulsed OSL or OSL used in conjunction with RL (radio-luminescence). RL is emitted promptly at the time of dosimeter irradiation and provides information on the dose rate during irradiation while the OSL provides the integrated dose thereafter. This technique, although not yet used routinely in radiotherapy, may prove to be a valuable tool for in vivo dosimetry in the future.

TLD and OSL dosimeter

- Thermoluminescence dosimeters (TLDs) and optically stimulated luminescence (OSL) dosimeters contain materials that trap electrons released during radiation exposure which can later be freed by stimulation with heat (TLD) or light (OSL).
- This stimulation is done in a processing laboratory and the resulting light emission provides a measure of the radiation dose received.
- TLDs and OSL dosimeters are widely used in worker radiation safety programs.
- **TLD and OSL devices do not provide a visual display of the accumulated dose. They must be processed with specialized equipment before the dose is known.**
- **They measure a wide dose range from routine through emergency levels with high precision.**
- **Badge designs are clipped on to clothing, while cards can be carried with ID.**
- **They have no batteries and the unit cost is relatively inexpensive.**