FABRICATION OF A REUSEABLE PLASTIC BASED X-RAY DOSIMETER FOR RADIOTHERAPY

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Introduction

Deposition of radiation energy within the interacting material is termed as dose, whose unit is Gray (Gy), defined as joule of deposited energy per unit mass(kg) (Khan, 2010).Dosimetry is the measurement or estimation of dose, ideally at a defined point within the interacting material, but it could also be performed for a plane of 2D or for a volume of 3D.The goal of radiation therapy is to deliver uniform and homogeneous prescribed dose to treatment volume but at the same time, save the adjacent healthy tissues from radiation exposure or keep the doses to un-avoidable healthy tissues, well below their radiation tolerance (Khan, 2010). The treatment plans are made with the patients radiographic images X-rays, CT scan and MRI. Due to current treatment complexity raising the risk for target miss or unnecessary irradiation of healthy tissues, pre-treatment dosimetric verification of each treatment plan is highly recommended.

Now a days a variety of radiation dosimeters are used serving different purposes. Examples of the commonl used dosimeters are,Ionization chambers, Silver halide Radiographic films, Radiochromic films, Thermoluminescence dosimeters, Optically stimulated dosimeters, Semi conductor detectors. Frick dosimeter, Gel dosimetry, Plastic dosimeters and some Natural and synthetic materials.

Objectives

The aim of the study is to fabricate a reusable tissue equivalent plastic composite dosimeter with acceptable accuracies, that could serve the routine dosimetric requirements of a

radiation therapy centre.First, this work seeked to identify the most suitable material to be used as the ingredient in the plastic composite mix. Secondly, this work seeked to determine whether the sensitivity of any of these materials can be improved by synthetic introduction of crystal defects. Thirdly, methods of sample preparations were to be evaluated. Finally, these samples would be evaluated for their radiation dosimetric properties using X-ray photon beam from a linear accelerator. They would be evaluated mainly for radiation sensitivity, repeatability, fading, and dose linearity.

Methods and Materials

To prepare the samples in which radiation sensitive material grains were uniformly embedded within the body of the plastic, different techniques were tried and finally N1(pure sodium chloride) samples were made with Haake polydrive internal mixing and hot press technique. Samples prepared by, spraying plastic solution with grains of material, with solution casting of plastic and material grains and b using hot plate with solution casting and to melt plastic grains was found unsuitable for further experiments.

Results

The final sample of N1 and PMMA composite in 40/60 ratio (wt/wt) has shown good sensitivity for 3 Gy of 6 MV photons with very linear dose response up to 10 Gy. From 10 Gy to 15 Gy the sensitivity of the plastic dosimeter was found to be decreased. For the next observed dose of 20 Gy, the dosimeter appeared to regain its sensitivity. The doses were delivered for alternate 4 days post optical bleaching of 18 hours. The area of dip in the percentage transmission curve, corresponding the absorbed dose was found to have an average value of 96.4 arbitrary area units with standard deviation of 4.85 %. The peak values of the dips were found to be between 460 nm to 472 nm. The fading in response for 5 Gy of 6 MV photons was found to be 16.93% in one week and 48.07% in one month. Dosimetric evaluation of the materials were conducted with the

study of their optical properties pre and post irradiation of 2 Gy of 6 MV photons, using Shimadzu UV 1800 Spectrophotometer.

Conclusions

Z_{eff} of the fabricated N1 PMMA composite dosimeter is 10.51.Linear response from 3Gy to 10Gy,and then from 15Gy till the observed dose of 20Gy was observed. The fading in response for 5 Gy of 6 MV photons was found to be 16.93% in one week and 48.07% in one month. Dose repeatibility for 5Gy of 6 MV photons was found to have standard deviation of 4.85 %.

Dr. Ahmad Lutfi Yuosoff Supervisor

Professor Dr. Ahmad Zakaria Co Suprvisor

Professor IR.Dr Mariatti Binti Jaafar Co Supervisor

Dedication

I would like to dedicate my thesis to my beloved parents; Noor Jehan Begum and Muhammad Ashab uddin (may Allah rest their souls in peace) whom deep love for me and encouragements was always my source of inspiration and strength, to my loving and extremely caring wife; Nausheen Fatima, who always stand with me in facing any kind of trouble and with her utmost efforts either physical or emotional, made situations favourable for me.

I also want to dedicate my work to my elder brother; Ajaz Tariq to me who is the sincerest friend and reflection of my father, my loving sisters; Seema Tabassum and Shabana Anjum; their families, and my sincere in laws, who always remained concerned and pray for me and my family.

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BANG	BIS Acrylamide Nitrogen Gelatin
BeO	Beryllium Oxide
CT	Computed Technology
CW-OSL	Continuous waves optically stimulated dosimetery
CCD	Charge coupled device
EBT	External Beam Therapy
E9	9 MeV Electrons
HDR	High Dose Rate
HVLP	High volume low pressure
IMRT	Intensity modulated Radiation Therapy
LM-OSL	Linearly modulated optically stimulated luminescence
LVLP	Low volume low pressure
MOSFET	Metal Oxide semi-conductor Field Effect Transistor
MRI	Magnetic Resonance imaging
MV	Million volt
OCT	Optical CT scan
OD	Optical Density
OSL	Optically stimulated luminescence
PC	Poly carbonates
PE	Poly ethylene
PMMA	Poly methyl meta acrylate
PMT	Photo multiplier tube
PVA	Poly vinyl alcohol
RIA	Radiation induced attenuation
RTC	Relative transparency curve
SRS	Stereo radio surgery
TL	Thermoluminescence
TLD	Thermo Luminescence dosimeter
TPS	Treatment planning system
UV	Ultra violet
XO	Xylenol Orange
X6	6 MV photons

FABRIKASI DOSIMETER GUNASEMULA SINAR-X BERASASKAN PLASTIK UNTUK RADIOTERAPI

ABSTRAK

Tujuan kajian ini adalah untuk menghasilkan dosimeter komposit plastik untuk mengukur dos sinaran foton sinar-X yang digunakan dalam radioterapi. Kriteria untuk dosimeter yang dicadangkan adalah kos yang rendah, penggunaan yang mudah, bahan bukan toksik, dan boleh diguna semula. Sebagai dosimeter, ia harus mempunyai sensitiviti dan kebolehpercayaan yang cukup dalam lingkungan ukuran dos kepentingan dalam radioterapi.

Dalam membuat dosimeter berasaskan plastik, zarah bahan aktif yang sensitif kepada sinaran tertanam secara seragam, di dalam posisi yang tetap, dalam plastik lut sinar. Perubahan dalam spektrum transmisi optik bagi bahan telah digunakan sebagai kaedah bacaan, menggunakan Shimadzu UV 1800 spektrofotometer. Perubahan nilai ini dikalibrasi untuk mendapatkan nilai dos serapan. Pelunturan optik sampel yang telah menerima dedahan sinaran dilakukan dengan menggunakan dua buah mentol biasa berkuasa 100 watt dengan dedahan selama 18 jam.

Antara tiga belas bahan yang telah dipilih untuk kajian kesesuaian mereka sebagai bahan aktif terhadap sinaran, natrium klorida tulen gred penyelidikan didapati merupakan bahan yang paling sesuai. Bahan-bahan lain yang turut dikaji ialah berilium oksida, tujuh jenis garam yang boleh dimakan dari di pasaran tempatan, aluminium oksida tulen, kalium alum (tawas), ammonium klorida (Noshadar) dan garam buluh. PMMA (polymethyl metaacrylate) telah dipilih sebagai bahan hos. Sampel plastik yang baik telah dapat dihasilkan menggunakan Haake poly drive pencampur dalaman dan mesin tekan panas, berbentuk lembaran plastik setebal

2 mm, dengan zarah natrium klorida (125 μm) tertanam secara seragam dalam nisbah berat 40/60 natrium klorida kepada PMMA. Kesemua penilaian bahan aktif telah dijalankan dengan sampel diletakkan di dalam botol plastik lutsinar yang mengandungi minyak yang lut sinar. Botol plastik ini didapati mempunyai ciri-ciri optik yang sangat dekat sampel PMMA tanpa bahan aktif. Pemerhartian mendapati bahawa rawatan sampel menggunakan dos elektron 9 MeV, sehingga 2800 Gy, tidak mengubah sensitiviti sampel terhadap sinaran. Sampel plastik akhir yang dinyatakan di atas, mengandungi natrium klorida yang dilabelkan sebagai N1, telah menunjukkan tindak balas kepada foton 6 MV, dengan tindak balas dos didapati linear dalam julat 3 Gy hingga 10 Gy. Sensitiviti kelihatan menurun antara 10 Gy hingga15 Gy, selepas itu sensitiviti kelihatan kembali untuk dos terakhir yang dinilai, iaitu 20 Gy. Penurunan sensitiviti pada 15 Gy berkemungkinan besar berpunca daripada pengurangan elektron terperangkap, sepatutnya menghasilkan penyerapan optik dalam julat 395 kepada 550nm, disebabkan penukaran-ke atas pendarfluor hasil daripada penyerapan semasa ukuran, dalam julat 570-625 nm. Nilai Z_{eff} bagi dosimeter berasaskan plastik PMMA yang mengandungi 40% N1 mengikut berat telah dikira dan dipastikan sebagai 10.51 amu. Sampel N1 yang mendapat dos sinaran 5 Gy 6 MV foton telah menunjukkan nilai kepudaran 16.92% untuk satu minggu dan 48.06% untuk satu bulan. Kebolehulangan dos dianggarkan daripada tiga ujian menggunakan tiga sampel yang berasingan dengan nilai dos serapan 5 Gy 6 MV foton. Dos sinaran telah diberikan selang 4 hari selepas pelunturan optik selama 18 jam. Kawasan lembah pada spektra transmisi optik yang sepadan dengan dos serapan didapati mempunyai nilai purata 96.4 unit-arbitrari dengan sisihan piawai 4.85%. Kawasan lembah di dalam lekuk transmisi tersebut terletak dalam julat 460 nm hingga 472nm. Dosimeter berasaskan plastik yang

terhasil didapati mantap, murah, mudah untuk digunakan dan boleh diguna semula. Ia didapati sesuai untuk mengukur dos X-ray foton, dalam julat respons dos linear, dari 3 Gy hingga 10 Gy, dan untuk julat dos 15 Gy dan 20 Gy.

FABRICATION OF A REUSEABLE PLASTIC BASED X-RAY DOSIMETER FOR RADIOTHERAPY

ABSTRACT

The aim of this study was to fabricate a plastic composite dosimeter for the measurement of radiation doses of X -ray photons used in radiotherapy. The criteria for the proposed dosimeter were low cost, ease of use, non toxic, and reusable. As a dosimeter, it should have acceptable sensitivity and reliability in the dose measurements range of interest in radiotherapy.

In making plastics based dosimeters, radiation sensitive material grains were uniformly embedded in transparent plastic host where they are kept spatially fixed. Changes in optical transmission spectra of the materials was used as readout method, using Shimadzu UV 1800 spectrophotometer. These changes were than calibrated to get the absorbed doses. Optical bleaching of the irradiated samples were performed with two 100 watts ordinary bulbs for 18 hours. Among the thirteen materials that were selected for the study of their suitability as the embedding material, research grade pure sodium chloride was found to be the most suitable material. Other materials studied were beryllium oxide, seven different types of edible salts available in local markets, un doped aluminium oxide, potash alum (tawas), ammonium chloride (Noshadar) and bamboo salt. PMMA (polymethyl metaacrylate) was chosen as the host material. The final plastic sample was produced using Haake poly drive internal mixer and hot press machine, as 2 mm thick plastic sheet, with uniformly embedded grounded (125μm) pure sodium chloride grains in 40/60 sodium chloride to PMMA wt/wt ratio. All the evaluations of embedding materials were carried out with their samples placed inside a transparent plastic vial

containing optically clear oil. This plastic vial was found to have optical properties very close to the final, material free, PMMA sample. It was observed that treatment of samples using 9 MeV electron doses of up to 2800 Gy does not changed their sensitivity. The aforementioned final plastic sample, containing sodium chloride labelled as N1, have shown response to 6 MV photons with a linear dose response from 3 Gy to10 Gy. The sensitivity appeared to be decreased between 10 Gy to15 Gy, after which appeared to recover for the last observed dose of 20 Gy. The decrease in 15 Gy response is postulated to be due to the depletion of the trapped electrons of interest, supposed to produce optical absorption at 395 to 550nm, due to fluorescence up-conversion resulting from 570 to 625 nm absorption during measurements. The Z_{eff} of the PMMA plastic based dosimeter containing 40% N1 by weight was calculated to be 10.51 a.m.u. The N1 samples irradiated with 5 Gy 6MV photons has shown fading of 16.92% and 48.06% for one week and one month respectively. The dose reproducibility was estimated with the average response of three fresh samples to 5 Gy 6 MV photons. The doses were delivered for alternate 4 days post optical bleaching of 18 hours. The area of dip in the percentage transmission curve corresponding the absorbed dose was found to have an average value of 96.4 arbitrary area units with standard deviation of 4.85%. The peak values of the dips were found to be between 460 nm to 472 nm. The fabricated plastic based dosimeter was found to be robust, cheap, easy to use and reusable and suitable for measuring doses of X-ray photons, in the dose ranges of linear responses, 3 Gy to10 Gy and for observed higher doses, 15 Gy and 20 Gy.

CHAPTER 1

INTRODUCTION

1.1 Background

A variety of dosimeters are in use for different purposes these days. They vary in their sensitivities for different radiations, range of measurable doses, physical form and suitability for a particular usage. Although achievements have been made in developing materials that are very sensitive and can work at very high doses but they fall in the advanced materials category and have very costly.

Some introduced dosimeters have high dose threshold and they are difficult to develop due to, their toxicity (plastic dosimeters), their sensitivity to impurities and atmospheric conditions (Fricke chemical dosimeters and Fricke gel dosimeter, polymer gel dosimeter).

To use chemical and gel dosimeters the introduction of the container not only made its routine usage difficult but required corrections in dose estimation made its usage difficult . Further the extraction of dose information in most of the dosimeters required diagnostic machines such as MRI, CT scan and Ultra sound which may be difficult due to availability of these machines at for immediate dosimetric use. Regarding reusability only ionization chambers, OSLD's and TLD's are reusable.

1.2 Statement of the problem

Although the radiation dosimeters used these days have covered specific dosimetric requirements of a particular usage, none of them fit in the criteria of a tissue equivalent, reusable, easy to use, low cost and reliable dosimeter for routine dosimetry of therapeutic ranges of doses.

For example Ionization chambers with all of their merits for dosimetry, have drawbacks in terms of size, requirements of correction factors and stable electrical. On the other hand semiconductor dosimeters such as diodes, and MOSFETS, are non tissue equivalent and their performances are, affected by temperature, dose rates and cumulative doses.

Among the tissue equivalent dosimeters, the diamond detectors are affected by dose rates and the cumulative doses, Silver halide and radio chromic films on the other hand are sensitive to dose rates and require energy corrections. Furthermore silver halide films showed non linear behaviour that needs to be corrected.

Tissue equivalent synthetically prepared dosimeters such as, LiF:Mg,Ti, LiF:Mg,Cu,P, $Li_2B_4O_7$:Mn although are good for the therapeutic range of dosimetry, but are expensive and require dedicated readout systems for their dose data acquisitions. Other tissue equivalent dosimeters, such as chemical and plastic dosimeters have shown high dose thresholds. The gel dosimeters, although provides good results in the therapeutic range of doses, suffered with the corrections required for its containers.

Recently introduced, tissue equivalent plastic dosimeter, PRASAGE (Z_{eff} varies from 6.4 to 16.3 depending on the compositions), has established as a good dosimeter qualifying for dosimetry of therapeutic range of doses.

The methods of producing all these tissue equivalent dosimetrs are not simple and in most of the cases, handling of toxic materials and steps of preparation has potential hazards for health. The simple and non toxic preparation and the reusability of a dosimeter results in its low cost.Except ionization chambers, doped materials, diodes and MOSFETS, all the tissue equivalent materials are one time useable. Furthermore their readout methods require either expensive dedicated equipments or sophisticated diagnostic machines, which cannot be used on routinely in most medical centres.

Hence, fabrication of a tissue equivalent radiation dosimeter, which could be used on routine basis in radiation therapy centres with acceptable accuracy and reliability in its dose measurements of therapeutic ranges, which is reusable, non toxic, using easily available low cost ingredients , easy fabrication method and have ease in use, is still a challenge for the researchers.

1.3 Purpose of the study

It was planned to fabricate a tissue equivalent, nontoxic, easy to develop, low cost and robust dosimeter, which should be capable of handling therapeutic dose ranges with acceptable accuracy and confidence of reproducibility in its routine use. The purpose of the study is to develop a tissue equivalent robust plastic composite dosimeter suitable for validating dose ranges used in radiotherapy. Its non-toxicity, ease in its, preparation, handling, simple readout method and its reusability was of prime concern.Search for the most suitable low cost materials and simple methods for the preparation and dose data acquisitions were also considered.

1.4 Objectives of the study

The aim of the study is to fabricate a reusable tissue equivalent plastic composite dosimeter with acceptable accuracies, that could serve the routine dosimetric requirements of a radiation therapy centre. The simple preparation technique easy read out methods were of prime concern. The cost of the dosimeter was also considered. The sample was supposed to be of PMMA, uniformly embed sieved grains of the selected radiation sensitive material. To achieve this goal, smaller goals for this work have been identified.

First, this work seeked to identify the most suitable material to be used as the ingredient in the plastic composite mix. This could be achieved through independent evaluations of the respective materials for their responses to radiation in term of changes in their optical properties.

Secondly, this work seeked to determine whether the sensitivity of any of these materials can be improved by synthetic introduction of crystal defects. This can be done by using high dose of particulate radiation such as neutron or electron.

Thirdly, methods of sample preparations were to be evaluated. The aim of this evaluation is to determine the most suitable technique that can produce plastic composite samples having favourable properties such as uniform physical dimensions and uniform distribution of the embedding materials. Once the sample preparation technique has been identified, the fourth minor objective is to actually fabricate the samples for the rest of evaluation needed in this work.

Finally, these samples would be evaluated for their radiation dosimetric properties using X-ray photon beam from a linear accelerator. They would be evaluated mainly for radiation sensitivity, repeatability, fading, and dose linearity. Further dosimetric studies, such as energy and dose rate dependency, would be studied if time allowed.

1.5 **Scope of the study**

The selected radiation sensitive material grains should be embedded uniformly in the body of the plastic as the optical response depends on it. Non-uniformities in either the number of particles per unit mass of the plastic composite or the thickness of the sample may cause error in observations.

Since the selected materials are supposedly light sensitive, any exposure to light even for a small duration, from the time of irradiation until readouts may result in loss of response signal. Performing the whole procedure in light tight condition helps in getting the true dose versus response relationship.

The UV Spectrophotometer, which uses intensity based CCD detectors, is a less sensitive instrument compared to fluorescence spectrophotometer, which uses PMT's as detectors. Hence the radiation sensitivity of the final plastic composite dosimeter may appear to be less with UV spectrophotometer than with fluorescence spectrophotometer.

CHAPTER 2

LITERATURE REVIEW

2.1 Radiation dose and dosimetry

Ionizing radiations interacts with matter in different ways. The possibility of a mode of interaction depends upon the type and energy of radiation and the physical properties of the interacting matter. Ionizing radiations may lose its energy in matter either by ionizing, exciting or by making the atoms or molecules vibrate. Deposition of radiation energy within the interacting material is termed as dose, whose unit is Gray (Gy), defined as joule of deposited energy per unit mass(kg) (Khan, 2010).

Dosimetry is the measurement or estimation of dose, ideally at a defined point within the interacting material, but it could also be performed for a plane of 2D or for a volume of 3D. The properties of ionizing radiations, their interacting mechanisms, and the relationship between doses versus different material's responses, has been successfully exploited in health services, different industries, scientific research and technologies. The use of ionizing radiation in plastic industry, sterilizing of medical stuff and food items, quality assurance of different goods such as metal sheets, environmental monitoring, archaeological and geological dating, forensic applications, development of new materials for space crafts and in medical sciences are examples of its usage.

2.2 Medical dosimetry

The dose measurements in medical sciences was rapidly advancing and becoming ever complexing. The needs of radiation dosimetry for, personal monitoring or radiation protection, diagnostic radiology or for therapeutic radiology were different leading to different methods, and related sophistications. Although the basic concern of medical dosimetry is to estimate the biological damages resulting from ionizing radiation exposures, the radiation therapy differs in that, the exposures were pre planned.

The goal of radiation therapy is to deliver uniform and homogeneous prescribed dose to treatment volume but at the same time, save the adjacent healthy tissues from radiation exposure or keep the doses to un-avoidable healthy tissues, well below their radiation tolerance (Khan, 2010).

2.3 Importance of dosimetry for radiation therapy

The challenges in radiation dosimetry is due to the variety in cancer tumours, types, its anatomical site, its shape, and adjacent healthy tissues. The diagnostic images used for marking treatment volumes may not be used for a particular radiation treatment plan as the geometries of organs may change during the planned posture. The cure or control of cancerous tumour, depends upon the coverage of the treatment volume in the prescribed dose. Hence radiation treatments were needed to be planed and must be validated prior to the actual treatments to optimize the goals of radiation therapy.

Ideally, the 3D dose distribution of a treatment plan, within a tissue equivalent phantom, similar to patients treated anatomy, is needed to be validated. New types

of radiation therapy machines and techniques generally made the dose delivery faster and its distribution over a treatment volume more precise, however due to the sophistications involved, it is increasingly desirable that the actual dose delivered to the patient be checked possibly for each treatment plan.

In more complicated treatment techniques such as stereotactic radio surgery, conformal radiotherapy, Intensity modulated radiation therapy (IMRT), Brachy therapy, in which are situations may arise where junctions between two fields or regions of steep dose gradient exists, or the un-avoidable inclusion of some vital organ or healthy tissues in the prescribed radiation fields. In such conditions 3D dosimetry will be very useful, with spatially detailed point to point accurate dose measurements, for the quality assurance of a treatment plan and hence to get the ultimate benefits of the radiation therapy.

2.3.1 Treatment planning, treatment planning systems and dosimetry

The treatment planning systems (TPS) used the dose distribution data in water phantom. These doses were delivered with standard protocols and field sizes, used in therapeutics. The TPS then interpolate or extrapolate the dose values for different depths to calculate three dimensional doses distributions for a particular treatment plan.

The beam data of every machine for a given field size is generally different, due to different scatter factors, may be due to different machine design and variations during production. Since TPS used interpolated or extrapolated values of parameters, it might show different dose distributions, from the actual treatment machines even for standard field sizes.

Serious dosimetric errors such as under dosing, over dosing, missing the treatment volume or inclusion of healthy tissues or vital organs, which were considered in the treatment plan but may wrongly appeared in TPS. Such errors especially may occurred at the junction of different density tissues or at the field junctions where dose gradient appeared. Such errors ultimately cause unsuccessful treatment.

2.3.2 Requirement of validating treatment plan

The treatment plans are made with the patients radiographic images X-rays, CT scan and MRI. The requirement for validating a treatment plan is also to match the patient's planed and the actual treatment setup. This matching of the patient's planned treatment positioning with the actual treatment set-up is very important as the treatment volumes are related to the surface marking of the beam entrance points. This set up matching has to be done with a tissue equivalent phantoms similar to the patient's treatment anatomy, whose 3D dose measurement will then validate a treatment plan. Further, in the cases where the treatment volume or the surface anatomy changed post irradiations, any modification in the plan needed to be verified the same way. Due to current treatment complexity raising the risk for target miss or unnecessary irradiation of healthy tissues, pre-treatment dosimetric verification of each treatment plan is highly recommended.

Ideally, validations of the treatment plans are performed on real treatment machines with real treatment parameters using tissue equivalent phantoms that faithfully represents the anatomy of the patients treatment volume .The 3D dose distribution in these phantoms should accurately indicates the actual dose distribution.

2.4 Over view of the dosimeters

Generally, dosimetry is performed using radiation sensitive volumes, whose responses should be dose dependent and measurable using suitable read out system. The response of any new dosimeter should be able to be confirmed and calibrated with a standard dosimetry system, i.e. using ionization chambers and electrometers. The performance of a dosimetry system is the net performances of its two components, that is the radiation sensitive material and its response read out system.

2.4.1 Ionization chambers

Among all types of dosimeters, ionization chambers are accepted to standard dosimeters in clinical applications. Generally, ionization chambers have basic construction of a cylindrical shell of air equivalent material that contain a suitable gas of known volume and density. There is a fine electrode at the centre of this cylindrical construction, maintained at high voltage, normally around 300-400 volts (Khan, 2010).

The thickness of the solid shell was made such that all the charges produced by the ionization due to photons within a range of specified energies, reached the electrodes and an electronic equilibrium establishes between the outgoing and incoming electrons in measuring volume. The charge collected was proportional to absorbed dose.Using relation between average energy required for producing an ion pair in air as 33.85 eV / ion pair (Khan, 2010), amount of charge collected can be converted to absorbed dose.

The doses of different energy photons could by measured by using a build up cap whose thickness corresponds with the range of electronic equilibrium to the

measuring volume of the chamber. Ionization chambers with build-up caps were near to tissue equivalent and considered as standard point dose detectors .For dose measurement temperature pressure and humidity corrections are required.

2.4.2 Film dosimetry

Radiographic film was originally used for diagnostic radiography, later it found its uses in personal monitoring. Now the use of radiographic films were also common for portal imaging in therapeutic radiology.

2.4.2.1. Silver halide Radiographic films

Radiographic films consists of a transparent thin base cellulose acetate or polyester resin sandwiched between emulsion layers put together using thin layers of adhesive. The emulsion is a mixture of gelatine and photosensitive grains of silver halide micro crystals. The finished surfaces of film was protected with layers known as super coating. The silver iodo bromide crystals embedded in layers are sensitive to light and ionizing radiations. Unfortunately, the sensitivity to ionizing radiations is generally much more lower to that of light. The crystal defects enable silver ions Ag^{+} which moves freely with in the crystal. Upon radiation exposure, bromide ion of the crystal absorbs light and gives off electron, and left in gelatine as neutral bromide atom.

The electrons are then captured by the wandering silver ions converting them to silver atoms. Depending on the amount of radiation received ,the silver atoms form clumps together, forming latent image, i.e. a map of the radiation intensity. Upon irradiation the exposed crystals were reduced to grains of metallic silver. During the fixation of film processing, the unexposed grains are washed away,

leaving behind a clear film. The silver grain within the film appeared black hence, areas with higher radiation exposures have higher accumulation of silver grains, leading to appearance.

Densitometers with suitable calibration are used to estimate the doses of the different areas of exposed film, using the varying optical transparencies in a unit known as optical density (Akselrod *et al.*) (Thomas III *et al.*, 1984).

Although the radiographic film's response to radiation is nonlinear and depend on radiation energy and processing parameters, their ease of use, inexpensiveness, high spatial resolution and long period record keeping capability, keeps them in use for general dsoimetric field checks of megavoltage therapy machines, both for photons and electrons (Khan, 2010). With suitable choice of filters, radiographic films served as personal monitoring device.

2.4.2.2. Radiochromic films

Radio chromic films are commonly used in therapeutic dosimetry. These films are transparent and almost tissue equivalent. They contain grain less dye, which upon irradiation gets polymerized and turn to blue colour. The change in optical transparency was then determined with densitometer with proper calibration, the results can be used to estimate absorbed dose. These films are self-developing, thus they do not require chemical processing.

The response is dose rate independent. In standard to ambient conditions ,i.e. except excessive humidity, they are comparatively less energy dependent than silver halide films. Although radio chromic films are generally less sensitive than silver halide films, however they provide higher resolution dose measurement, attributed due to grain less feature of the dye, therefore they are found to be valuable in validating

multi field radiotherapy plan with high dose gradient regions. Gafchromic HS (high sensitivity), EBT (External beam therapy), films were found to be useful in the dose ranges 0.1 Gy to 8 Gy and 0.5 Gy to 40 Gy and ranges respectively (Jordan, 2006). These and many other radio chromic films with little differences in, sensitivity, energy dependency, linearity and read out methods were successfully used in therapeutic radiology.

2.4.3. Luminescence dosimetry

Luminescence is the process of emission of visible and near visible light from certain materials, upon stimulation . A more detailed classification of luminescence according to the with emission delay includes fluorescence and phosphorescence with emission times ~ 10^{-8} s and >> 10^{-8} s respectively. It was found t hat some solids, after irradiating with ionizing radiations upon heating or illuminating with lights of suitable frequencies, emits light. In most cases, the light intensity was found to be proportional to the absorbed doses.

This property of stimulated luminescence was exploited for dosimetry and named according to the used mode of stimulation, as thermally simulated and optically stimulated, luminescence dosimetry. The stimulated luminance used for dosimetry was explained with the band theory of solids (Podgorsak, 2003).

2.4.3.1. Thermoluminescence dosimetry (TLD)

In solids insulators, defects in the crystal lattice modifies the forbidden energy bands between valence and conduction band by creating discontinuous energy levels within the forbidden band, and create cites (L,T) where a hole or electron could be tapped. Figure 2.1 gives a simplified model of these defects in term of the energy

band. These defects may be intrinsic, extrinsic or result of some ionizing radiation exposures, causing displacement of negative ion and hence generating a vacancy for an electron. When such an insulator is irradiated with ionizing radiations, the generated electrons and holes from the valence band may trapped in these sites.

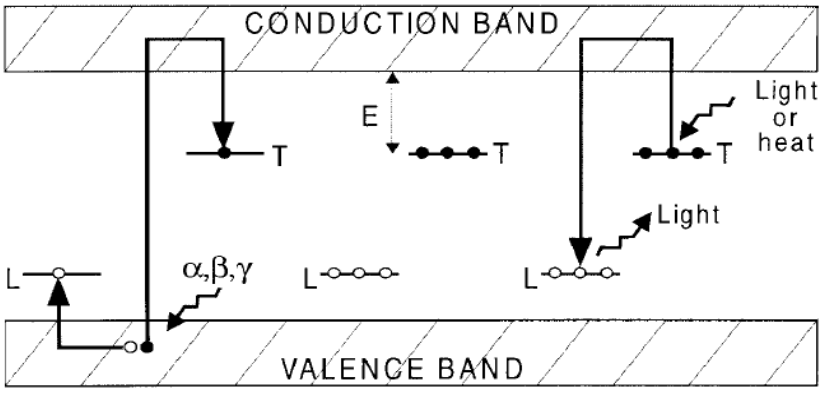

Figure 2.1. Model for thermo luminescence

If the natural de-trapping is negligible and the energy depth 'E' of the electron trapping site below the conduction band is large, the life time of the trapped electrons would be significantly large, establishing a meta stable state. When the irradiated material is heated with constant rate of elevating temperature trapped electrons get energized after receiving their energy from lattice vibrations leading to electron ejection. The radioactive recombination of these liberated electrons with the trapped holes, known as luminescence centres, gives out luminescence that corresponds with some temperature is known as glow peaks. These glow peaks could give information about the traps and the structural defects of the material (Mandavia, 2011).

After heating the TLD to a specific high temperature, all the traps are emptied. The TLD was then termed as zeroed as it was prepared for its re usage . Thermo luminescence was originally used for measuring nuclear radiations by

Daniel in early 1950's. Successful use of TLD for archaeological dating was done in 1960's by Aitken and Mejdahl and for geological dating in 1980's by Wintle and Huntley, (Botter-Jensin, 1997).

TLD's having favourable properties such as high sensitivity, reusability, reliability and ease of use are now established as a popular tool for dosimetry. Nowadays commercially TLD'S are available that varies in the physical forms(rods, tablets , ribbons, small size grain, powder), tissue equivalency, sensitivity, operational conditions making them suitable for a wide range of dosimetric application . In medical dosimetry, near tissue equivalent TLD's such as LiF: Mg, Ti, LiF: Mg, Cu, P, $Li_2B_4O_7$: Mn and non tissue equivalents such as $CaSO_4$: Dy, Al_2O_3: C, CaF_2:Mn , as most sensitive dosimeters, are in common use (Mandavia, 2011).

2.4.3.2. Optically stimulated dosimeters

The phenomenon of optically stimulated luminescence is the same as thermally stimulated luminescence except that the mode of de-excitation which is optical rather than thermal. This technique was originally used for dating by Huntley in 1985, and further studied by, Hutt in 1988 , Aitken and Smith in 1988, Spooner and Questiaux in 1990, Poolton and Bailif in 1989, Bùtter-Jensen in 1991. Bùtter-Jensen and Duller in 1992, established it as a tool for dating, and Godfrey-Smith and Haskell in 1993, Haskell in 1993, Bailiff in 1995, Bøtter- Jensen in 1995 used for dosimetry for Hiroshima and Chernobyl nuclear events. An insulator with defects in its lattice, either by some impurity or dislocation of an ion, naturally present or synthetically produced, when irradiated with ionizing radiation, generates electrons by leaving behind holes in the valence band.

These electrons and holes may get trapped at the cites of defects, below the conduction band and above the valence band respectively. Upon Illumination with suitable frequency of light, luminescence may be observed. The emitted light may be longer or of shorter wave length than stimulation wave length. The emitting light is a characteristic of the material but the intensity was found to be proportional to the absorbed dose. Different modes of optical excitations used were namely, Continuous wave optically stimulated dosimetry (CW-OSL), Linear modulated (LM-OSL) and Pulse OSL (P-OSL).

2.4.3.2.a. CW- OSL

In this mode of stimulation, samples were stimulated with constant intensity light source which may be either laser or a broad band source. The luminescence was measured simultaneously with the stimulating illumination. The luminescence wavelength are distinguished from excitation wave lengths, using mono chromoters. The decay curve of luminescence may or may not be exponential, revealing different de trapping modes of trapped electrons and information about the lattice defects. The total luminescence i.e. the total area under luminescence curve, was proportional to the absorbed dose (McKeever, 2001).

2.4.3.2.b. LM-OSL

In this technique, instead of constant intensity of excitation wave lengths, continuously increased intensity was used. The continuous increase in the intensity of light, emptied trapped electrons, at their different intensity values and hence can easily distinguished. This intensity with verses emptied electrons gives information about the depth of the traps. The luminescence peaks at different points in time

of a linearly increased intensity ramp, gives information about the contribution of different electron traps of different photo ionization cross section ,to the total luminescence (McKeever, 2001).

2.4.3.2.c. Pulsed OSL

In Pulsed OSL, the excitation wavelengths are used to illuminate the samples for such short intervals of time that suits the life time of the luminescence (Bøtter-Jensen, 1997).

Since luminescence does not depleted much in a short pulse, multiple observations could be made for single dose (McKeever, 2001). Further, since measurement was done after illumination, the stimulation and emitted wavelengths are easily distinguishable without any aid of filters, which simplifies the method and increased the measuring efficiency of the luminescence.

2.4.3.3. OSD VERSUS TLD

The general features of the two modes of luminescence dosimeters i.e, TLD and OSLD can be summarized as follows **:-**

1. Thermo luminescence dosimetry, as a single time dose measuring technique, with comparatively complex method and thermal quenching, is a less sensitive technique than non-destructive optically stimulated luminescence dosimetry, which offers multiple observations for single dose .

2. Thermoluminescence output is a whole sample's response, where as in OSL, with thin laser beams as optical exciting tool, even a grain could be selected from the whole sample to get an optical response. This ease of site selection from a sample for dose estimation could be exploited in re assessment of absorbed or in dose mapping .

3. It was observed that TL observations could be taken after taking OSL observations from the same sample and that in many cases separate samples with same dose gave same response, either use TL or OSL. This suggests that the electron traps for TL and OSL may not be the same.

2.4.4. Semi conductor detectors

Semi-conductors have offered a good choice for many dosmetric applications. Commonly used semi-conductor radiation detectors includes, PN diodes, MOSFET (Metal-Oxide Semiconductor field effect Transistor), and Diamond detector (Rosenfeld, 2011).

2.4.4.a. Diodes

Semiconductor diodes has been used as radiation detectors since last 30 years. Due to their merits, of being very small sized and hence offering high resolution, and ease of use for real time dosimetry, they are popular dosimeters for quality assurance in radiation therapy (Podgorsak, 2003).

2.4.4.b. PN diodes

Silicon diodes are commercially available as n-type and p-type. They are fabricated by counter doping the surfaces to produce opposite type material. The pn junction in semi-conductor diodes, provides an in build, very high electric field **(**103 V/m) across the junction.

When diode was exposed to ionizing radiations, electrons and holes pairs were generated in the diode, which then diffused through the pn junction and collected by an electrometer. This induced current through the diode was known as radiation

current and was proportional to dose rate. The total current was proportional to absorbed dose rate in silicon. The silicon diode and MOSFET have near tissue equivalency in MV energy range as silicon to water mass stopping collision power ratio is almost independent of energy in MV range for photons and electrons conventionally used in radiotherapy. There small sensitive volume and low ionization energy compare to that of air made them 18000 times more sensitive than same volume ionization chamber (Rosenfeld, 2011).The Diodes are commonly used in vivo dosimetry as relative dosimeter, for example in bladder and rectum dose measurements, entrance and exit dose. It is used with beam entrance dose measurements routine checks of treatment parameters and setup errors such as correct technique (SSD OR SAD), use of correct radiation and applicator, dose rate change are able to be performed (Yorke *et al.*, 2005).

As a relative dosimeter, they have proven to be suitable for dose measurements in phantoms , especially for small field, high dose gradient regions as in radio surgery, for depth dose measurements and for beam profiles of photons and electrons, in commercially available 2D and 3D systems serves as quality assurance tools for IMRT treatment plans. In spite of its merits, commercially available diodes could not be used for surface dosimetry, because of its packing which behaves as build up region. Diodes responses are sensitive to dose rate, temperature, accumulated doses and the material used. Diodes suffers radiation degradation over time, the degree of which depend on type of radiation and dose. Hence the use of diodes as radiation detectors needs calibration against many factors. The response of diodes were found directional dependent and also affected by spectral composition of beam (Rosenfeld, 2011).

2.4.4.c. MOSFET

MOSFET Metal-Oxide Semiconductor Field Effect Transistor, due to its very small size 1μm, and sensitivity to full range of photons and electrons, has been successfully used for measuring relative doses in brachy therapy, radio surgery, surface dose measurements diagnostic radiology.

These short life detectors have the same drawbacks as the diodes detectors have Their responses were dependent on temperature, dose rate, direction of detection, radiation quality, absorbed doses, and bias voltage during irradiation (Podgorsak, 2003).

2.4.4.d. Diamond detector

Diamonds, either natural or artificial, when exposed to ionizing radiations, shows change in its resistance. The detector with a suitable biased voltage 100 V and charge integrating amplifier, when exposed to ionizing radiations gives signal proportional to the charge induced electron hole pair, which in turn proportional to the absorbed dose.

Diamonds are low Z material and near to tissue equivalent therefore almost no energy correction is required. These detectors, have small effective volumes order of few mm^3,very small directional dependency, negligible ; dose rate and temperature 0.1 % per ^oC dependence and high radiation damage resistance. Prior irradiation of the detectors were required for stable responses for each usage, (Podgorsak, 2003).These detectors are specially suitable for small field high dose gradient regions such as in radio surgery (SRS), routine treatment set up checks, and relative dosimetry, (Rosenfeld, 2011).

2.4.5. Chemical dosimetry

Chemical dosimeters are the oldest of all kinds of dosimeters. Originally the chemical dosimeters were in liquid form but now later it was modified as a gel dosimeters

2.4.5.a. Frick dosimeter

Fricke & Morse 1927 developed a ferrous sulphate solution as radiation dosimeter with the irreversible oxidation of ferrous ion to ferric ion by ionizing radiations (Nemtanu *et al.*, 2008). The absorbed doses were measured by the Fe^{+3} ion concentration which changes the absorption of UV radiation of wave lengths 224 nm and 303 nm with spectrophotometer. The absorbance of light at those particular wavelengths and is directly proportional to the absorbed dose. It was used for the determination of the doses between 40 Gy to 400 Gy (Soares *et al.*, 1987). The dosimeter was dose rate radiation quality (photon and electron) independent and relatively temperature 0.12% per ^{0}C. It was also found to be very precise 0.15%. However it is easily affected by contaminations and does not show very good stability over the periods of few years.

Being a contamination sensitive solution dosimeter it is difficult to use it on a routine bases. Furthermore the Fricke dosimeter could not be used for measurement requiring high spatial resolution. Since it is an irreversible chemical process Fricke dosimeter could not be recycled. Other chemical dosimeters includes ferrous–cupric dosimeter measurable range of doses 5×10^2 to 10^4 Gy, with accuracy of ±02% and found to be LET dependent, Ceric sulphate dosimeter dose range 10^2 to 2×10^5 with accuracy ±02% and the ethanol – chloro benzene dosimeter dose range 4×10^2 Gy to 5×10^2 6×10^4 Gy, accuracy ±03%.

2.4.6. Gel dosimetry

Gel dosimetry is relatively a new technique. Many different kinds of Gels are used for the purpose . Most of them are modified formulas of the few basic gels originally introduced. They offer 3D dosimetry with good accuracy.

2.4.6.a. Fricke gel dosimetry

Fricke chemical dosimeters Ferrous sulphate solution could be considered as the first dosimeter with potential to be extended as 3D dosimeters .Gore in1984, have showed that Fricke dosimeters could be probed with MRI to have 3D dose distribution , (Baldock *et al.*, 2010).

Gels such as gelatine, Agarose were used with infused ferrous sulphate ions to have some stable 3D dose distribution, the concentration of radiation induced Fe^{+3} ions, which is proportional to the absorbed doses, changes the colour of gel. The Fe^{+3} concentration remained fix in gelatine matrix for some time and could be probed with suitable technique such as MRI, OCT, Ultra sound. (Baldock *et al.*, 2010) Fricke gels are water equivalent, hence considered as tissue equivalent, for a large range of therapeutic radiation (Schreiner, 2004a). It is easy to prepare, inexpensive, non-toxic since it is prepared in liquid form the dosimeter can have complex phantom shapes and shows very good reproducibility.

However the Fricke gels have high threshold such as 50 Gy to 75 Gy making it not suitable for low or intermediate radiation doses applications as encountered in hospitals. Furthermore, the ferrous ions tends to diffuse in the gel after irradiation, losing the spatial distribution information within a few hours. Attempts to solve the problem of ferrous ion diffusion were made through the use of different gels such as gelatine, agarose, sephadex and polyvinyl alcohol PVA.

Chelating agent agents such as Xylenol Orange XO were tried, which made a small improvement in the stability (Baldock el at 2010) but reduces the sensitivity of the dosimeter (Schreiner, 2004b)**.**When optical CT (OCT) was used noticed for that readout the dose sensitivity depends on the wave lengths chosen. Optical CT for dose readout of Fricke-Agarose –Xylenol Orange gel uses a fast CCD camera to acquire the image. (Luciani *et al.*, 2006).

The results of OCT readout were found to have good linear relationship in the dose range up to 10 Gy and with spatial resolution approximately 0.5 mm (Viti *et al.*, 2006). It was observed that the use of MRI for dose data acquisition requires relatively longer time than OCT readout , hence the optical technique was better in limiting the effect of diffusion the 3D gel dosimeter.

2.4.6.b. Polymer gel dosimetry

Historically, the polymer gel dosimetry was successfully introduced by Hoecker and Watkins in 1958. Boni in 1961, used poly acrylamide as a gamma dosimeter. (Baldock *et al.*, 2010).

The polymer gel dosimetry was based on radiation induced polymerization in solutions of monomers and polymers (McJury *et al.*, 2000). The polymerization was proportional to the absorbed dose. The extent of polymerization thus changes the density of the set materials. This change in density is proportional to the absorbed dose. The change in density detectable upon viewing with X-ray CT scanners. The colour or opacity of irradiated gels also changes and hence could be detected and measured with optical devices such as optical CT OCT. Additionally MRI was also used as a readout method. Maryanski in 1996 introduced polymer gel dosimetry which was based on the polymerization of acrylamide AAm and

Bis monomers infused in an aqueous agarose matrix.

He gave it the name BANANA, (Baldock *et al.,* 2010). The dosimeter was found to be a tissue equivalent and its performance evaluation a 3D dosimeter was done using stereotactic radio surgery and HDR brachy therapy plans. MRI scans were used for 3D dose data acquisition and was found in good agreement with the planned doses (Maryanski *et al.,* 1996). With small change in the formulation of BANANA, Maryanski in 1994 introduced BANG. This name later changes to PAG to distinguish it with from the in house manufactured gels, (Baldock *et al.*, 2010). BangTm3 and PAG gels were investigated for use in 3D dosimetry with XCT (Oldham *et al.*, 2001) OCT and MRI (Audet *et al.*, 2002), and was found good for the purpose. Although the polymer gels were tissue equivalent and do not have the problem of ion diffusion as in Fricke gels, it is very sensitive to atmospheric oxygen which inhibited the polymerization process. For this reason the polymer gels has to be prepared in oxygen free environment. This is found to be an in-convenient procedure for daily use.

Fong in 2001, introduced a normoxic gel 'MAGIC' in which atmospheric oxygen was bounded in metallo organic compound matrix without the gel for its preparation (Baldock *et al.,* 2010). Thus gel does not require for an Oxygen free environment.

Different gels with little changes in the formulation were investigated with different techniques. Mather in 2002 make use of Ultrasound for acquiring 3D dose distribution data, Rintoulet in 2003 showed how to use Raman spectroscopic technique to probe depth dose distribution in electron beams for PEG (Baldock *et al.*, 2010). Bheag gel (Rabaeh *et al.*, 2008) uses MRI to evaluate its dosimetric performance, Anthromorphic Barex (Duthoy *et al.*, 2004) was