

## Analysis of Some Dosimetry Methods and the Importance of Their Applications in Medicine

### Abstract

In health physics, or the science of radiation protection, the term "radiation dosimetry" refers to a field of study that measures, computes, and evaluates the amount of radiation that is absorbed by the environment or the human body. It is used in many different industries, including medicine and therapy. Dosimeters are compact instruments used to determine an individual's dosage. They are often passive instruments that, when subjected to ionising radiation, undergo physical and chemical changes that may be read and analysed later. Various dosimeters have long been utilized in radiation therapy centers. The last type of them were film dosimeters until 1970, consisting of a simple film in a light-resistant container that was simply sensitive to different forms of radiation. Finally, the film was displayed and read to evaluate the received dose. In general, most film badges have a minimum resolution of about 30 mrem. Owing to the vast progress in this field until today, most of the dosimeters currently used are thermoluminescence dosimeters and other sensor-based dosimeters. They use electron crystal entrapment capability to measure absorbed dose. The minimum detectable dose level is reduced to 5-10 mrem using this new technology, a range that is considered a major improvement over older film badge methods.

**Keywords:** *Dosimetry, Medicine, Radiation, Radiation therapy*

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### Introduction

The computation of absorbed dosage and optimisation of dose delivery in radiation treatment is known as medical dosimetry, and it is typically carried out by licenced health physicists with specific training in that area. Dosimetry is used in medicine in two areas: imaging and radiation therapy. Radiation therapy is based on dosimetry, where dosimetric considerations depend on its quality and calibration. Dosimetry calculations are performed daily, weekly, and yearly. The more accurate and reliable the health centers do the dosimetry calculations, the closer they are to an optimal treatment with a low percentage error, with the lowest dose (damage) to the healthy tissue and the highest dose to the tumor. A dosimetry system consists of two parts, i.e., hardware and software, which uses different instruments. Radiation therapy employs two types of dosimetry systems: absolute dosimetry and relative dosimetry. The former is used to ensure the accuracy of radiation intensity given to cancer tissue. On the other hand, the latter is applied to ensure the accuracy of radiation shape and to minimize healthy tissue's exposure to radiation, as well as to analyze how the radiation intensity is distributed in the irradiation target area (1).

There are two kinds of radiation: non-ionizing radiation (non-IR) and ionizing radiation (IR). Non-ionizing radiation

includes background radiation, including solar ultraviolet (UV) radiation and electromagnetic radiation from radio waves and microwaves. It is now well established that non-IR sources, such as (solar/tanning bed) UV radiation can damage biological tissues. Nonetheless, because IR may cause atomic ionisation, it interacts with biomolecules far more aggressively than non-IR. Alpha particles, beta particles, X-rays, and gamma radiation are the four main categories of infrared radiation. Gamma radiation exposure causes greater biological harm than alpha or beta particle exposure because gamma radiation is more permeable than X-rays and is thus more able to pass through physical barriers like an aluminium plate or sheet of paper. The former may be blocked by physical barriers like these. Nevertheless, all four radiation types may seriously harm cells and are effectively employed to achieve therapeutic objectives (2).

Knowledge of radiation dose requires the development of different dosimetry methods. Therefore, devising novel methods of detection and ionizing radiation dosimetry is still considered one of the most important research topics in research centers around the world. Zaki et al. (2019) conducted a study called "Gamma Radiation Dosimetry Using the Selective Data Acquisition Method from Sodium Iodide Detector." Radiation detection is necessary to

determine the radiation dose. Detection may be performed at different levels according to the type of detector and dose determination method. The minimum level of detection is counting the number of pulses. Normally, the output of a radiation detector cannot be directly used to determine the radiation dose.

A relationship or proportionality is established between the detector output and the equivalent dose by changing or modifying the response function or detector output. For this purpose, several hardware and software methods are employed to determine equivalent dose values. Hardware methods use layers such as modulators, compensators, decelerators, etc. On the other hand, software methods employ data acquisition and processing methods, such as retrieval, convolution, deconvolution, etc. The present study utilizes a software method, i.e., selective data acquisition from several energy channels. In this method, photon dosimetry response is obtained in the energy range of 0.411-3 MeV based on the data obtained from a sodium iodide detector. A detector response function (DRF) is determined for gamma radiation using MCNPX code simulation, and then calibration coefficients are computed to determine the dose. Finally, the energy response of the sodium iodide detector for gamma radiation dosimetry is determined for several energy channels. The results show that the presented method has high accuracy in gamma radiation dosimetry (3).

Maleki et al. (2018) carried out a study entitled "An Experimental Comparison of Detection and Dosimetry Responses of Polyvinyl Alcohol-Tungsten Oxide (WO<sub>3</sub>) Micro- and Nanocomposites to Gamma and Neutron Radiation." In this experimental research, WO<sub>3</sub> particles were dispersed in two forms, i.e., nano and micro, in a polyvinyl alcohol (PVA) matrix (20wt%). WO<sub>3</sub>-PVA composite (20wt%) was made using the solution method. The FESEM test was used to examine the morphology of the aforementioned composite, and the results verified that WO<sub>3</sub> nano/microparticles were dispersed across a polymer substrate. The MCNP code was utilised to compute the attenuation quantum efficiency of gamma photons associated with the <sup>60</sup>Co source for the composite. The results showed satisfactory agreement with the XCOM findings. The changed electric current of the composite as a result of radiation absorption is one of the variables influencing the detection and dosimetry responses of this class of composites. By employing the double probe (two-probe) method with an electrometer set at 100 and 400 V for <sup>60</sup>Co and <sup>241</sup>Am-Be sources, respectively, the dark current and radiant current of WO<sub>3</sub>-PVA nano/microcomposites under gamma and neutron radiations were measured. When compared to microcomposite, the measurement findings showed that nanocomposite was more sensitive to gamma radiation.

Furthermore, the nanocomposite sample's signal-to-noise ratio (SNR) for gamma radiation grew linearly from 5 to 40 in the dose-rate range of 90–138 mGy/min, but the composite showed no discernible reaction to neutron radiation (4).

Jahani et al. (2017) conducted a study entitled "Conceptual Design and Parametric Analysis of a Wrist Dosimeter for Gamma and Beta Radiation." This research investigated the problem of measuring beta and gamma radiations around industrial users and researchers. It has been attempted to improve the directly effective parameters on the application of detectors on the human body by studying the most important problems ahead. Among the most critical of these measurement parameters are low-energy beta-rays. A physical/objective schematic diagram of the final design that can be installed on the wrist is provided with optimal dimensions (radius: 7 cm; height: 14 cm). Data computing and convergence specify that the larger the system size, the higher the probability of radiation entering the container, and consequently, the system will be able to detect and measure lower-dose radiation (5).

In the year 2023, Kołacz and colleagues conducted research titled "Air Pollution and Radiation Monitoring in Collective Protection Facilities with Electrochemical Biosensors." Ion mobility spectrometry (IMS) includes the detection of chemical warfare agents (CWAs). Geiger-Müller tubes are used to detect radiation dangers, while electrochemical sensors are used to identify toxic industrial chemicals (TICs). The purpose of this technology is to shield the crew from pollution. Air filtering using a carbon filter is initiated when radioactive or chemical pollution is found in the shelter's air intake. The process of testing the filter's condition continuously is now underway at the filter output with an air test technique. The process of replacing the damaged carbon filter can begin as soon as the system detects pollution in the filter output and stops the air pumping. The laboratory testing findings for the ALERT gas alarm detector are presented in this document. The results demonstrate high measurements for key characteristics, such as sensitivity, repeatability, accuracy, and speed (2006).

In 2021, Alanazi et al. conducted research named "Quartz Tuning Fork Sensor-Based Dosimetry for Sensitive Detection of Gamma Radiation." The overall topic of this work is nuclear sensors, especially the use of an ultrasensitive quartz tuning fork (QTF) sensor for nuclear and electromagnetic radiation detection. The goal was to use QTF to quickly identify low levels of gamma radiation. The sensitivity of three distinct types of QTFs (uncoated and gold-coated) to gamma radiation was examined in this work. The outcomes demonstrated that, in comparison to uncoated QTF, a thick layer of gold may improve the quality factor and raise the resonance frequency from 32.7 to 32.9 kHz. Additionally, the

findings demonstrated that the QTF's sensitivity to radiation may be greatly increased by expanding the gold coating's surface area. Applying scanning electron microscopy (SEM) both before and after irradiation, the characteristics of uncoated and gold-coated QTFs were investigated. Spectroscopic ellipsometry (SE) was utilised to investigate the optical characteristics of SiO<sub>2</sub> wafers, also known as quartz. The mechanical characteristics of QTF can be impacted by even minor alterations in the material's microstructure brought on by gamma radiation, which can result in a shift in the resonance frequency, as demonstrated by the SE experiments. Overall, the experiment outcomes showed that QTF sensors might be used as inexpensive, simple, and sensitive radiation detectors (7).

The work "Reduced Graphene Oxide/Polymethyl Methacrylate (rGO/PMMA) Nanocomposite for Real-Time Gamma Radiation Detection" was carried out by Feizi et al. in 2019. To detect the rate at which gamma radiation is administered, new three-dimensional (3D) radiation sensors were created by synthesising and fabricating reduced graphene oxide (rGO) nanoflakes in a polymethyl methacrylate matrix as the sensing material. A thorough examination of the synthesised reduced graphene oxide through the use of Fourier-transform infrared spectroscopy (FTIR), high-resolution transmission electron microscopy (HRTEM), atomic force microscopy (AFM), field emission scanning electron microscopy (FE-SEM), X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), thermal gravimetric analysis (TGA), and other techniques is provided. One method used to make a composite of reduced graphene oxide and polymethyl methacrylate was dispersing reduced graphene oxide nanoflakes in the polymer matrix with the use of a methylene chloride solvent. The primary components of the gamma sensor are two glass electrodes coated in silver to form a conducting cell and a polymethyl methacrylate/reduced graphene oxide (rGO/PMMA) nanocomposite, which serves as the sensing material. Investigations are conducted into the nanocomposite's real-time dose rate information, including sensitivity and linearity in response to dose rate. Gamma sensors based on rGO/PMMA exhibit superior performance compared to graphene oxide (GO) dosimeters when operating at a standard bias voltage. In the 50–130 mGy/min range, the response to dose rate is linear, and the sensor array may be used for gamma radiation application dosimetry in diagnostic tasks (8).

In 2021, Alodhayb et al. carried out a paper named "Metal Oxide-Based Micromechanical Sensors for Sensitive Gamma Radiation Detection." The purpose of this work was to evaluate the possibility of employing silicon microcantilevers and wafers to detect gamma-ray radiation by using TiO<sub>2</sub> thin

films as a sensing layer. The samples were subjected to gamma rays generated by <sup>60</sup>Co at varying dosages, which varied from 0 kGy to 40 kGy. XRD spectrum, SEM, SE, and AFM were used to examine the optical characteristics of silicon covered by TiO<sub>2</sub> at 200°C ALD grown and 100 nm thickness both before and after irradiation. The X-ray diffraction optical tests demonstrated that the irradiation of our film changed it from a nanocrystalline combination of rutile and anatase phases to anatase; this change manifested as ( $\Delta f$ ) in AFM, while the sensors' response to dosages between 0 and 20 KGy was highly sensitive and linear. The Cauchy model was used to match the findings of the spectroscopic ellipsometry experiments, which revealed the same linearity change in the thickness, roughness, and optical constants with irradiation doses. In the second experiment, gamma radiation was applied to gold-coated quartz tuning forks (QTFs), and we saw a discernible change in QTFs as the gamma dosage increased. Our results show that both techniques are excellent candidates for dosimetry applications (9).

A research project named "A Doped-Polymer-Based Porous Silicon Photonic Crystal Sensor for the Detection of Gamma-Ray Radiation" was conducted by Sayed et al. in 2023. In order to detect gamma radiation, one-dimensional faulty photonic crystals were theoretically investigated in this study. The unit cells of the one-dimensional photonic crystals (1D PhCs) under consideration consist of two layers made of porous silicon that are infused with a polyvinyl alcohol polymer doped with dyes that have variable porosities, namely crystal violet (CV) and carbol fuchsin (CF). In the centre of the planned 1D PhCs, a single layer of doped polymer is included to promote the localization of a unique resonant frequency across the photonic band gap.

### Types of radiation dosimetry

The degree of radiation exposure is measured by a dosimeter-radiometer. Typically, dosimeters record a dosage, such as the equivalent dose in sieverts (Sv) or the absorbed dose in greys (Gy) (10–12).

There are two types of dosimeters in terms of recording the radiation dose received: passive (delayed) dosimeters and active (operational) dosimeters.

- **Passive dosimeters:** Both the film badge and the thermoluminescent dosimeter (TLD) are frequently used passive dosimeters. An induced signal from radiation is produced by a passive dosimeter and is retained within the apparatus. After that, the dosimeter is processed, and the results are examined.
- **Active dosimeters:** An electronic personal dosimeter (EPD) or other active dosimeter can provide you with a real-time exposure value. A real-

time, direct measurement of the measured dosage or dose rate is shown by an active dosimeter, which also generates a radiation-induced signal. In order to enhance one another, passive and active dosimeters



are frequently used in tandem.

**Fig. 1:** A schematic of an active dosimeter

In order to determine the effective dosage, dosimeters need to be worn on the front of the torso, facing the radioactive source, and in a position that corresponds to the exposure, usually between the waist and the neck. In order to denote the dosage to the "whole body," dosimeters are often worn across the chest or torso, outside of garments. To quantify equal dosages for these tissues, dosimeters can also be worn on the extremities or next to the eyes (13 and 14).

**Film badge dosimeters:**

Film badges, also known as film badge dosimeters, are compact, portable instruments used to track the total amount of radiation exposure from ionising radiation. The working concept is the same as that of X-ray images. There are two components to the badge: a holder and photographic film. Because the photographic film is delicate, it needs to be taken out and processed once a month.

The film gets blacker the more radiation it is exposed to. Doses up to roughly 10 Gy can be assessed since the blackening of the film is linear with dosage.

**TLDs:**

Thermoluminescent dosimeters (TLDs) are a type of passive radiation dosimeter that detects the amount of ionising radiation by measuring the amount of visible light that is released when a sensitive crystal inside the detector is heated.

The TLD reader monitors light intensity, which is a function of radiation exposure. Professor Farrington Daniels of the University of Wisconsin–Madison created TLDs in 1954. TLD dosimeters can be used in scenarios where real-time data is not required, but accurate cumulative dose monitoring records are needed to compare with outdoor measurements or determine whether long-term health impacts could be a possibility.

**Electronic Personal Dosimeters (EPDs):**

An electronic personal dosimeter is a contemporary form of dosimeter that can continuously display the cumulative dosage and current dose rate. It can also alert the wearer when either the cumulative dose or a designated dose rate is exceeded. When a wearer's residence time is restricted by dosage restrictions, such as in high-dose zones, EPDs are particularly helpful. The detected dosage or dose rate may be directly read out of an EPD in real time. In addition to main dosimeters, electronic dosimeters can be used as supplemental dosimeters. In order to supplement one another, passive dosimeters and electronic personal dosimeters are frequently used in tandem (15–20).

**MOSFET dosimeters**

A compact, portable gadget called a MOSFET dosimeter is used to measure and directly read the rate of radiation exposure. The concept of operation is similar to that of semiconductor detectors since it is based on the MOSFET transistor, or metal-oxide-semiconductor field-effect transistor. These days, radiation treatment radiation beams are dosed clinically using MOSFET dosimeters. Their primary benefit stems from their compact size, measuring less than 4 mm<sup>2</sup>. Due to its instantaneous reading, MOSFET dosimeters frequently replace TLD dosimeters in radiation treatment dosimetry (21).

**Quartz fiber dosimeters:**

A quartz fibre dosimeter, also known as a self-indicating pocket dosimeter (SIPD), is a pen-shaped instrument that calculates the total amount of ionising radiation it has been exposed to, often throughout a single workday..

**Self-developing photochemical card:** The self-developing photochemical card is a rapid color-developing emergency dosimeter the size of a credit card. Its purpose is to reduce anxiety and fear by tracking exposure during a radiation incident and triaging medical care.

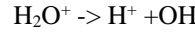
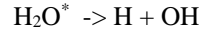
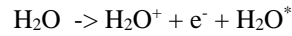
**DISs:**

Using an electronic reader unit, the direct-ion storage dosimeter (DIS) is an electronic dosimeter that provides instantaneous dosage information for both Hp (10) and Hp

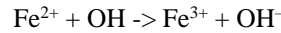
(0.07) at the workplace. An ion chamber and a non-volatile electronic charge storage device form the basis of the DIS dosimeter. An analogue memory cell housed in a tiny, gas-filled ionisation chamber powers the DIS dosimeter. Ionisations in the gas and the chamber wall are brought on by incident radiation, and the charge is retained for later reading. By connecting to an electronic reader device, the DIS dosimeter is read at the user's location (22-26).

**Chemical dosimeters:**

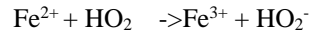
An accurate assessment of the absorbed dose can be achieved by measuring the chemical change that may result from the energy absorbed by ionisation radiation. There have been hundreds of suggested chemical dosimetry systems, but very few have been implemented outside of the main laboratories. One of the most important dosimetry systems (ferrous sulfate or the Fricke dosimeter) was proposed by Fricke and Morse. In this system, consisting of a ferrous sulfate solution in dilute air-saturated sulfuric acid, Fe<sup>2+</sup> ions are oxidized to Fe<sup>3+</sup> ions by radiation, with a well-researched and well-known mechanism. At least 96% of the dosimeter solution usually consists of water; therefore, the rays mainly collide with water, leading to the ionization or excitation of water molecules to the extent of breaking the H-OH bond:



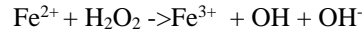
Hydroxyl radical (OH) can oxidize a Fe<sup>2+</sup> ion to a Fe<sup>3+</sup> ion:



Also, hydrogen atoms combine with dissolved oxygen (DO) and create hydroperoxyl radical (HO<sub>2</sub>), which in turn oxidizes more Fe<sup>2+</sup> ions to Fe<sup>3+</sup> ions.

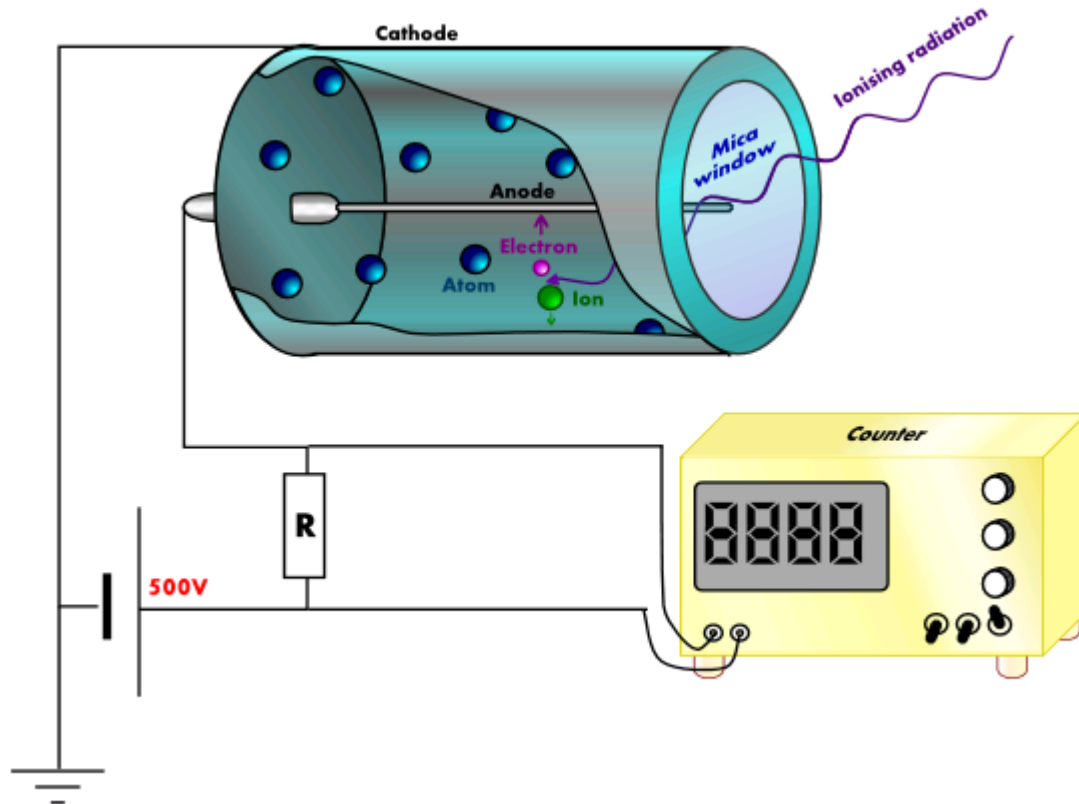


The resulting ion forms hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) with the H<sup>+</sup> ions in the solution, leading to more Fe<sup>3+</sup> ions.



Radiation chemical yield is a measurement. Chemical dosimeters define G(x) in the context of dosimetry. In dosimetry, this amount is comparable to the inverse of the average energy needed to produce an ion pair using an ionisation chamber. G(X) is defined as the quotient of the mean energy (E) given to the irradiated matter (27–30) and the quantity n(X) of a substance of a specified entity (X) created, destroyed, or modified by radiation.

If the yield of Fe<sup>3+</sup> ions is known, the absorbed energy can be calculated using G(x) by measuring the number of moles.



**Fig. 2:** A schematic of a chemical dosimeter

**Conclusion**

Knowledge of radiation in different treatment stages and the radiation dose received by employees in health centers

require the use of detectors, dosimeters, and different biodosimetry methods. Several detectors, such as Geiger-Muller, thermoluminescence, and scintillation, each of which is based on specific physical principles, are currently used to detect ionizing radiation. Although the long history of using each of the above methods has caused the measurement errors to be reduced to an acceptable level (including the strengths of the above methods), limitations such as energy range, dose range, and the type of ionizing radiation that can be measured, human, instrumental, and environmental errors are among the weaknesses of the above methods. Hence, finding newer solutions for detection and ionizing radiation dosimetry is still an important research topic.

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