Multi-directional radiation detector using photographic film

L K Junet, Z A Abdul Majid, A H Sapuan, I S Sayed and N F Pauzi
Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Kuantan, Pahang, 25200, Malaysia
E-mail: zafriazran@yahoo.com

Abstract: Ionising radiation has always been part of our surrounding and people are continuously exposed to it. Ionising radiation is harmful to human health, thus it is vital to monitor the radiation. To monitor radiation, there are three main points that should be observed cautiously, which are energy, quantity, and direction of the radiation sources. A three dimensional (3D) dosimeter is an example of a radiation detector that provide these three main points. This dosimeter is able to record the radiation dose distribution in 3D. Applying the concept of dose detection distribution, study has been done to design a multi-directional radiation detector of different filter thicknesses. This is obtained by designing a cylinder shaped aluminum filter with several layers of different thickness. Black and white photographic material is used as a radiation-sensitive material and a PVC material has been used as the enclosure. The device is then exposed to a radiation source with different exposure factors. For exposure factor 70 kVp, 16 mAs; the results have shown that optical density (OD) value at 135° is 1.86 higher compared with an OD value at 315° which is 0.71 as the 135° area received more radiation compare to 315° region. Furthermore, with an evidence of different angle of film give different value of OD shows that this device has a multidirectional ability. Materials used to develop this device are widely available in the market, thus reducing the cost of development and making it suitable for commercialisation.

1. Introduction
Ionising radiation has always been part of our surrounding and people are continuously exposed to it. This radiation is emitted by natural and/or man-made sources [1]. In the medical community, ionising radiation is used for two purposes; diagnosis and therapy [2]. As radiologic diagnosis provides greater accuracy for disease interpretation, the use of ionising radiation in medical application has rapidly increased [3].

Ionising radiation is an invisible form of energy that can cause harm to human health with cancer being the most popular effect [3,4]. In 1986, the reactor explosion in Chernobyl had caused a commotion regarding the effect of radiation to the human health. In the disaster, the explosion of radioactive substances and fire lasted for ten days and caused damage to the active zone of the reactor. This led to large quantities of radioactive particles being spread into the atmosphere, and the area was contaminated [5]. It was reported [6] that thyroid cancer cases had increased among the Chernobyl’s victims fourteen years after the accident.

To evaluate the radiological relevant doses received by the community and the potential impact of ionising radiation on human health, it is necessary to observe the radiation doses received [1]. For this reason, radiation monitoring devices or dosimeters is required. In order to monitor the radiation, there
are three main points that should be observed cautiously which are energy, quantity and direction of the radiation sources. A three dimensional (3D) dosimeter is an example of radiation detector that covers these three important aspects. This dosimeter is made of radiation sensitive materials (or chemicals) and is able to record the radiation dose distribution in 3D [7]. Applying the concept of dose detection distribution, study has been done to design a multi-directional radiation detector consisting of different filter thicknesses. Black and white photographic film is chosen to be used as a medium of radiation detector in this study.

Generally, photographic film has been used in photographic dosimeters such as film badges. This type of dosimeter is used for monitoring cumulative exposure of radiations such as X-rays and gamma rays [8] without showing the direction of the radiation sources. According to Dowsett, et al. [9] the major advantages of this dosimeter are that it provides a permanent record, able to distinguish different energies of photons and it can measure different types of ionising radiation. Photographic dosimeter makes use of film as a radiation-sensitive material. This film contains a special emulsion layer that can detect radiation and is later analysed to measure the doses [10]. Lalos [11] stated that for photographic dosimeter, the type of film used to detect radiation was basically similar to ordinary black and white photographic film. Furthermore, photographic films also contain a special emulsion layer and because of that, it can be used to detect ionising radiation [12]. Once the film is developed, exposed area forms an optical density (OD) in response to incident radiation. This OD represents the quantity of ionising radiation exposed to the film and it can be read using a densitometer. This type of film is most sensitive to ionising radiations that have energy of 50 keV and above [3].

To identify ionising radiations’ penetrating power, filters are used. With filtration it is possible to determine the different radiation energy. Filtration is the process of shaping the x-ray beam or eliminating the low energy photons by placing an absorbing material along the primary beam. This absorbing material also known as filter is a sheet of metal that is designed to selectively absorb photons from the ionising radiation [10]. Selecting proper filter material and thickness is important because different types of filter material and thickness may results in different film exposure [12] since each material has different atomic number. The higher the atomic number, the lesser the amount of radiation that can penetrate the material to be detected by the film. Aluminium which has atomic number of 13, was selected as the best material to be used as filter for this research.

2. Materials and methods

2.1. Materials

2.1.1 Construction of Multi-directional Radiation Detector. The multi-directional radiation detector consists of two main parts which are film casing and radiation sensitive material. The film casing is composed of polyvinyl chloride (PVC), aluminum middle rod and aluminum filters with several layers. A schematic diagram of the multi-directional radiation detector is shown in Figure 1. For radiation sensitive material, ILFORD DELTA 3200 Professional (HARMAN technology ltd, Cheshire, England) black and white photographic film was used. Aluminum middle rod is the innermost component, followed by photographic film with an effective area (area that receives ionising radiation) of 25mm, PVC enclosure and aluminum filter with several layers as the outermost component.

The detector is designed as a portable device with cylindrical shape particularly because this shape embraced similar surface on every angle. Thus, enlarging the surface for ionising radiation reaching the film. PVC was picked for the enclosure as it is a material opaque to ionising radiation; hence, there is no possibility for the film to fog up due to light.

The aluminum filter is comprised of four layers of different thicknesses; 0.75mm, 1.50mm, 2.25mm and 3.00mm. A schematic diagram of the aluminum filter is shown in Figure 2. The purpose of these layers of filter is to determine the radiation penetration energy and the quantity of radiation reaching the film. The purpose of aluminum middle rod is to prevent the ionising radiation from
reaching the film on more than one side which might lead to inaccurate result. Furthermore, the use of black and white photographic film as radiation sensitive material was due to its special emulsion layer that can be used to detect the ionising radiation [12].

2.2 Methods
This research was done in Diagnostic Imaging and Radiotherapy Department at International Islamic University Malaysia (IIUM), Kuantan, Pahang, Malaysia. Siemens POLYDOROS IT 80 x-ray machine was used as ionising radiation source. Before exposure, photographic film of 60mm in length was inserted in the space between PVC enclosure and aluminum middle rod. This step was done in a darkroom in order to avoid film’s fog that may cause imprecise result.

The detector was exposed to ionising radiation with fixed kilovoltage peak (kVp); 70 kVp and different milliampere-seconds (mAs). 70 kVp was chosen as the optimum parameter to detect the effect of different aluminium filter thicknesses in relation to ionising radiation exposure. During this procedure, only one area was exposed directly to ionising radiation which is approximately 45° to 225° from reference angle (0°) of the detector. The field size used was 8mm x 15mm. A schematic diagram of this procedure is shown in Figure 3. The purpose of this technique is to identify the differences in OD value between direct and indirect exposed region.

Figure 1. Schematic diagram of the radiation detector.
Figure 2. Schematic diagram of the thickness layers for aluminum filter.

Figure 3. Schematic diagram of multi-directional radiation detector exposed to ionising radiation.
Then, the film was processed using a procedure recommended by ILFORD [13,14]. The processed photographic film was divided into 17 horizontal segments of 3mm each and 5 vertical segments of 7mm each. The OD values were then taken at the center of each point. A densitometer (Hand Held Deluxe Digital Clamshell Densitometer ST07443) was used to measure the OD. The control OD value was measured on film that was totally unexposed to ionising radiation.

3. Results and discussions

Experimental results of this research are shown in Figure 4 and 5. The control OD value for this photographic film is 0.46.

Compared the control OD value and the results gathered for each exposure, there is significant increase in OD when photographic film is exposed to ionising radiation. For example, when a photographic film was exposed to 16 mAs (Figure 4) radiation with 3.00 mm aluminium filter thickness, the OD value for 0° (indirect exposed region) and 135° (direct exposed region) increased to 0.71 and 1.44 respectively from the control value of 0.46.

![Figure 4. OD values for different angle of radiation detector vs filter thickness for 16 mAs.](image)

![Figure 5. OD values for different angle of radiation detector vs filter thickness for 36 mAs.](image)

The black and white photographic film was chosen as radiation sensitive material, because as mentioned by Lalos [11], the film used in photographic dosimeters is essentially similar to ordinary black and white photographic film. Furthermore, according to Majid et al. [12] black and white photographic film also contains special emulsion layer and can be used to detect ionising radiation.
This special emulsion layer is composed of silver halide crystals that produce OD when exposed to ionising radiation [8]. The figures show the relationship between OD and filter thickness, proved that black and white photographic film can be used as a radiation-sensitive material. Additional advantages for using films as radiation-sensitive material are its ability to distinguish different photons' energy [9], provide permanent record [11] and cheap as it is a low cost material that is easily available [12].

Both figures show the relationship between OD values for angles of the multi-directional radiation detector with a given mAs. In this research the kVp value was kept constant at 70 kVp for each exposure but different values of mAs were used. This is because, as stated by Fauber [15], mAs controls the quantity of ionising radiation reaching the film.

For 0 mm filter, Figure 4 shows that OD value at 135° is 1.86 and Figure 5 shows OD value for 36 mAs at 135° is 2.16. These results show that OD value for 36 mAs is higher than 16 mAs. The higher the mAs value, the more ionising radiation reached the film, hence increased the OD value [9].

In this research, ionising radiation are detected based on filter thickness and angle of the multi-directional radiation detector. As referred in Figure 4, the same quantity of ionising radiation applied to the 90° region of the multi-directional radiation detector produces different OD values. This is because the radiation penetrates various filter thickness before reaching the film. For this region (90°) in Figure 4, OD values recorded are 1.71, 1.47, 1.43, 1.37 and 1.32 at 0mm, 0.75mm, 1.5mm, 2.25mm and 3.0mm filter thickness respectively. This shows that increase in filter thickness will decrease amount of ionising radiation reaching the film, hence decreasing the OD value. As mentioned by Majid et al. [12] different material thickness may produce different amount of radiation reaching the film. Thus, this can determine the different radiation energy.

The value of OD is not similar at every angle of multi-directional radiation detector. For example in Figure 4, for a 3.00 mm filter thickness the results shows OD value at 135° is 1.44 which is higher compared to OD value of 0.72 at 270°. This is because the area at 135° received more ionising radiation relative to 270° region; only one area was exposed directly to ionising radiation (direct exposed region). This technique was applied to identify the difference of OD value between the directly exposed region and indirectly exposed region. Results show difference in the OD values, hence this technique is practiced.

There is some limitations when using photographic film which are it cannot provide a real time dose information and very sensitive to high temperature [8]. High temperatures or excess humidity to photographic film will cause fog resulting in inaccurate exposure reading [3].

4. Conclusion
This study was found that this device has a multi-directional ability of detection of radiation from 0° to 360°, supported by evidence of different angles of film provide different values of OD. The results of penetration depend on the thickness of the aluminum filter as different thicknesses will affect ionising radiation penetration capability. Materials used to develop this device are widely available in the market, thus reducing the cost of development and making it suitable for commercialisation.

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