MEASUREMENT OF Ki USING IONIZATION CHAMBER AND GAFCHROMIC FILMS FOR MOBILE X-RAY MACHINE

By

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CERTIFICATE

This is to certify that dissertation entitled

"MEASUREMENT OF Ki USING IONIZATION CHAMBER AND GAFCHROMIC FILMS FOR MOBILE X-RAY MACHINE"

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TABLE OF CONTENT

LIST OF TABLES.

LIST OF FIGURES.

LIST OF ABBREVIATION.

Bi	Bismuth
C	Carbon
Cl	Chloride
Gy	Gray
H	Hydrogen
IC	ionization chamber
Ki	incident air kerma
kVp	kilovoltage peak
Li	Lithium
mAs	Miliampere-second
N	Nitrogen
NOD	Net Optical Density
O	Oxygen
PSDLs	Primary-standard dosimetry laboratories
SFD	shadow-free detector
SSDLs	Secondary-standard dosimetry laboratories
STP	standard temperature and pressure
TRS	Technical report series
Z_{eff}	Effective nuclear charge

ABSTRACT

The aim of this study is to determine the incident air kerma (Ki) for mobile unit x-ray by using ionization chamber and Gafchromic films based on TRS457. Examination of abdomen and chest had been chosen in this study. Exposure parameters that had been used was 83kVp/ 12.5 mAs, 85kVp/32.0 mAs and 85kVp/ 40mAs for abdomen examination, while for chest was 120kVp/ 5mAs, 125kVp/1.0 mAs and 125kVp/1.6mAs. The first objective was to study the dose response of the Gafchromic XR-QA2 and XR-RV3 films. The films irradiated with 70, 80, 90 and 100kVp for 20mAs. The films were scanned by using Epson 10000XL flatbed scanner after 24hours irradiation, to obtain the pixel value of the films. Then, the pixel value had to be changed to optical density to plot the linearly dose response graph. The study showed linear relationship for Gafchromic XR-QA2 film, but not for XR-RV3 films since the Gafchromic XR-RV3 films was fluoroscopic-guided favour. The study was preceded by obtaining of calibration curve for Gafchromic XR-QA2 films to get the dose from the films. The cross-checked dose obtained from IC and calibration curve used for the calculation for measurement of Ki. The result showed Ki for films was higher than IC due to the difference of sensitivity. Large variation was displayed in term of percentage difference (%) for abdomen was 34% to 108%, while for chest was 32% to 350%. The reasons why the large variation of percentage difference were due to the usage of parameter that contributed to out of range dose, properties of films and mishandling of the films. As a conclusion, the variation of percentage difference is not significantly different between IC and Gafchromic films if the dose in range applied in this study.

ABSTRAK

Tujuan kajian ini adalah untuk menentukan insiden kerma udara bagi mesin x-ray mudah alih menggunakan kebuk pengionan dan filem Gafchromic berdasarkan TRS457. Pemeriksaan abdomen dan dada dipilih dalam kajian ini. Parameter yang digunakan adalah 83kVp / 12.5 mAs, 85kVp / 32.0 mAs dan 85kVp / 40mAs untuk pemeriksaan abdomen, manakala dada adalah 120kVp / 5mAs, 125kVp / 1.0 mAs dan 125kVp / 1.6mAs. Objektif pertama adalah untuk mengkaji tindak balas dos terhadap Gafchromic XR-QA2 dan XR-RV3 filem. Filem didedah dengan 70, 80, 90 dan 100kVp untuk 20mAs. Filem diimbas dengan menggunakan Epson 10000XL pengimbas flatbed selepas 24 jam didedahkan, untuk mendapatkan nilai pixel. Nilai pixel ditukar kepada ketumpatan optik untuk membentuk graf linear dos. Kajian menunjukkan hubungan linear terhadap filem Gafchromic XR-QA2, tetapi tidak untuk XR-RV3 filem disebabkan filem Gafchromic XR-RV3 lebih sesuai untuk tujuan fluoroskopi. Keluk penentukuran Gafchromic filem XR-QA2 digunakan untuk mendapatkan dos dari filem yang telah didedahkan. Dos yang diperolehi daripada kebuk pengionan dan keluk penentukuran digunakan untuk pengiraan insiden kerma udara. Keputusan menunjukkan insiden kerma udara untuk filem adalah lebih tinggi daripada kebuk pengionan. Hal ini menunjukan filem lebih sensitif terhadap kebuk pengionan. Perbezaan besar bagi perbezaan peratusan (%) bagi abdomen adalah dalam julat 34% hingga 108%, manakala untuk dada adalah 32% hingga 350%. Sebab-sebab berlaku perbezaan peratusan yang sangat besar adalah disebabkan oleh penggunaan parameter yang menyumbang kepada daripada dos di luar julat, ciri-ciri filem dan pengendalian filem yang tidak betul. Kesimpulannya, perbezaan peratusan tidak jauh berbeza antara kebuk pengionan dan filem Gafchromic, jika dos dalam julat digunakan untuk kajian filem Gafchromic ini.

CHAPTER 1

INTRODUCTION

1.1 Background of the study.

1.1.1 Kerma and incident air kerma.

A basic dosimetric quantity involved in this study is kerma. The kerma, K is kinetic energy released per unit mass. It also defined as the sum of the initial kinetic energies of all charged ionising particles released by uncharged ionising particles (such as x-rays, gamma rays, fast neutrons) per unit mass of interacting medium. It is measured in joules per kilogram (J/kg) or Grays (Gy) in SI units. Application for specific dosimetric quantities for this study is incident air kerma.

The incident air kerma, Ki, is the kerma to air from an incident x-ray beam measured on the central beam axis at the position of the patient or phantom surface. Only the radiation incident on the patient or phantom and not the backscattered radiation is included (IAEA, 2007). Air kerma in free air is one of particular importance in the practical calibration of radiation protection instruments for photon measurement. According to IAEA safety report 16 "The quantity air kerma should be used for calibrating the reference photon radiation fields and reference instruments. Radiation protection monitoring instruments should be calibrated in terms of dose equivalent quantities (IAEA, 2000).

1.1.2 Chest and abdomen are most frequent examination in general radiology.

Chest radiology is the most frequently performed diagnostic x-ray examination. It is of value for solving a wide range of clinical problem. X-ray images of the chest provide important information for deciding upon further steps in the establishment of a diagnosis, treatment and follow-up procedure. Chest pain, shortness of breath and pneumonia are common presenting complaints about patients seeking medical care, especially through the emergency department. Therefore, it is not surprising that chest examination are by far the most commonly ordered examinations (Erkonen, 2010).

Another most common imaging study of the abdomen is referred to as KUB, it stands for kidney, ureter and bladder. It also is known as plain image of the abdomen. None of which is usually seen on a regular x-ray of abdomen, nevertheless the term remains widely used. This kind of imaging technique is usually done with patient supine (Mettler, 2005).

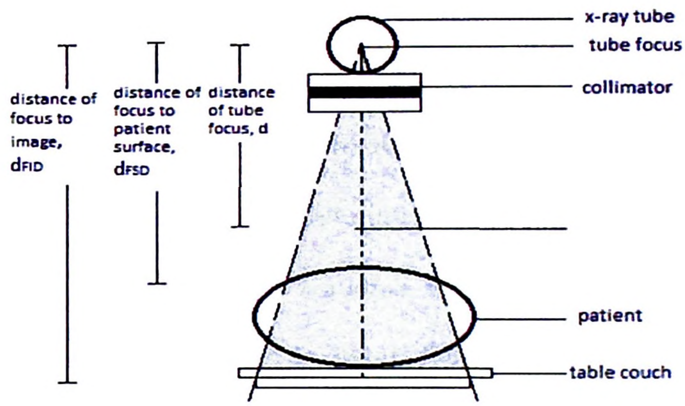


Figure 1.1 : Diagram of the measuring arrangement based on TRS457.

1.1.4 Properties of Gafchromic films.

Rampado (as cited in Butson et al,2013) found that Gafchromic radiochromics film has properties particularly suited for dosimetry in medical application. It possesses high spatial resolution, large surface area, and is easy to place under the patient, making it well-suited to measure skin dose during fluoroscopy (McCabe, 2011). These dosimeters are advantageous for their extreme ease of handling. They are relatively insensitive to visible light and thus offer a unique ease of handling and preparation for a film type product, as they can be used under normal room light. They undergo a colour change directly after irradiation and do not require chemical processing. Radiochromic dosimeters have a very high spatial resolution and generally a low-energy spectral sensitivity. A commercial flatbed scanner can be used to digitize the film and to determine the absorbed dose from the film colour using a proper calibration curve.

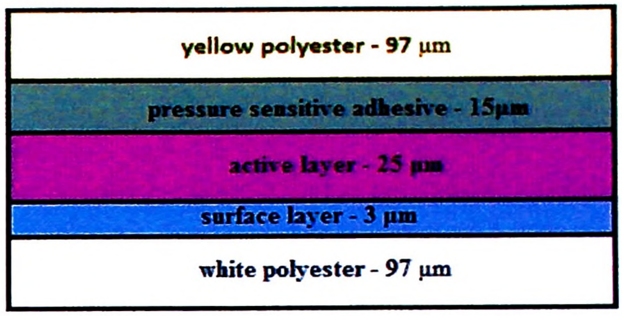


Figure 1.2 : Gafchromic XR-QA2 film.

One of the films that have been used in this study is Gafchromic XR-RV3 radiochromic film. XR-RV3 film is a reflective-type film consisting of five layers, including an opaque white backing. The five layers are composed primarily of carbon, hydrogen and oxygen. The active layer contains small quantities of sulphur (less than 4% by mass) and barium (less than 16% by mass) (McCabe, 2011).

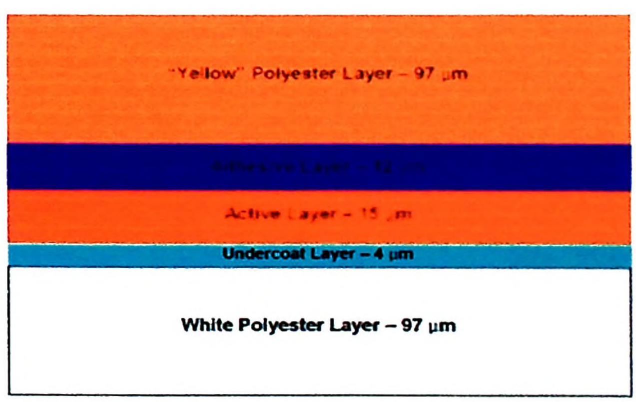


Figure 1.3. Gafchromic XR-RV3 film layer.

1.1.4 Basic principle of ionization detector.

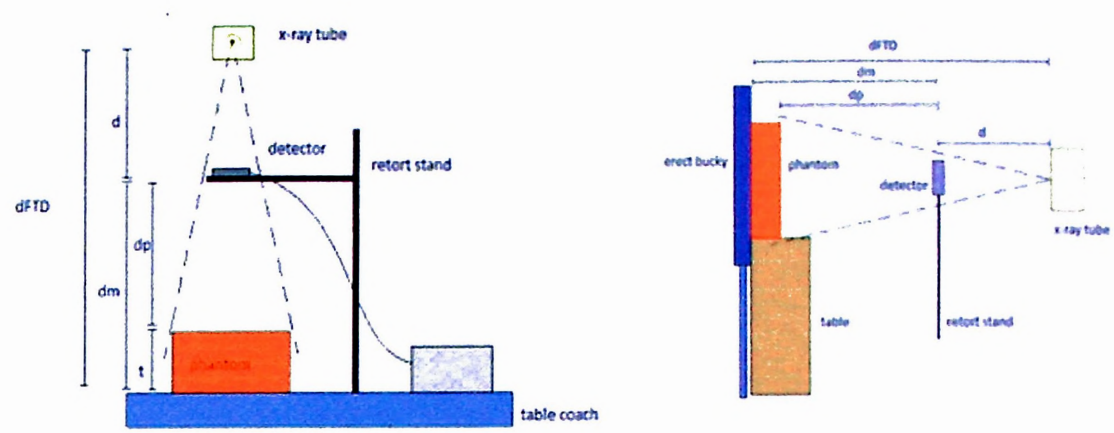
The first class detectors are the gas ionization detectors. These include ionization chambers, Geiger-Mueller (G-M) counters, and proportional counters. Each detector has a chamber, which consists of a container with a fixed volume of a gas and two electrodes, which act as the collectors of ions created in the container when ionizing radiation strikes it. The chamber, sometimes called a probe, isolates the gas between the two electrodes. The gas molecules are ionized by incoming particulate or photon beams and produce positive and negative ions. These pairs of ions are referred to as ion pairs. The negative ions travel to the positive electrode while the positive ions travel to the negative electrode. The higher the voltage of the electrodes, the faster the ion move. This current of moving ions, the ionization current indicates the ionization rate in the ionization chamber. The voltage to the electrodes can be supplied by a battery or, in a linear accelerator system, by a stable high-voltage system. This voltage is called the polarization voltage because in essence the electrodes polarize the chamber, collecting charges of opposite sign at opposite electrodes (Stanton & Stinson,1996).

1.1.5 Single-phase generator x-ray machine.

Barthez (as cited in Seibert, 1997) the different components of an x-ray system are the x-ray tube and generator. The main purpose of the generator is to produce a single-direction, high-voltage current between the anode and the cathode, allowing the electrons to be accelerated, eventually, strike the anode and produce x-ray. A control panel allows the operator to adjust tube current, voltage and exposure time accordingly. The quality of the generator depends mainly on the accuracy of kVp setting, reproducibility, and variation in potential difference during exposure called the ripple factor. Different types of generators for x-ray units are available among which single-phase (SP), three-phase (TP), power storage, constant potential and high-frequency (HF) generators are most common. Even though, single-phase generator has been replaced progressively by higher performance generators like three-phase and high frequency generators, they are still inexpensive and easy to install.

1.1.6 Free in air ionization chamber.

Since the free in air ionization chamber is primary standard for radiation measurement, accuracy better than 1% is required. Although it is a simple instrument in principle, great care is required to achieve such precision and a number of corrections have to be applied to the raw data. For example, a correction must be made if the air in the chamber is not at STP. Due to first principle, ion pairs are created because x-ray photons interact with air molecules. If the air pressure increase above normal atmospheric pressure, the number of molecules will increase, the number of interaction will increase and reading will be artificially high. Changes in temperature may be considered similarly. The essential properties that are chosen as the basis for radiation measurement are must be accurate, very sensitive to produce a large response for the small amount of radiation energy, reproducible, measurement should be independent of intensity (law of reciprocity) and reliable at all radiation energies. Since there are no properties of ionizing radiation satisfy all requirements perfectly, ionization in the air comes closest and has been internationally accepted as the basis for radiation dosimetric (Dendy & Heaton, 1999).



(a) (b)

Figure 1.4: Set up for (a) supine position and (b) erect position.

Table 1.1 : The label of the set up figure.

Label	Explanation
dFTD	Distance of tube to phantom
Dm	Distance of detector to table
Dp	Distance of detector to phantom
D	Distance of tube to detector
T	Thickness of phantom

1.2 Aim

To determine the incident air kerma (Ki) for abdomen and chest examination using OPTIMA XR200 mobile x-ray machine based on TRS 457 protocol.

1.3 Objective

1. To study the dose response of the Gafchromic XR-QA2 and XR-RV3 films.

2. To determine the measurement of incident air kerma by using mobile x-ray machine (OPTIMA XR200) for abdomen and chest examination.

3. To compare the measurement of incident air kerma by using ionization chamber and Gafchromic films.

1.4 Significant of study.

Incident air kerma is one of important particular aspect in determination of absorbed dose and measurement of radiation protection instrument. Incident air kerma is free in air measurement as it is free from backscatter and stroked by primary photon. This study was done since there is lack brief study in this particular quantity.

CHAPTER 2

LITERATURE REVIEW.

2.1 Air kerma is used as direct measured in diagnostic radiology.

Meghzifene (2010) found that a particular problem has been the use of 'absorbed dose' in situations where this quantity is inappropriate and cannot easily be measured because of a lack of secondary electron equilibrium. In view of the complex nature of the absorbed dose to air, all PSDLs have developed and maintain primary standards for the quantity air kerma and calibrations of dosimeters for use in diagnostic radiology at PSDLs and SSDLs are provided in terms of air kerma. Both ICRU and IAEA therefore, recommend that air kerma is used as the basis of all directly measured application specific quantities in diagnostic radiology. The realization of the unit of air kerma in low and medium energy x-ray beams is accomplished at PSDLs by using free air chambers. Plane parallel and cylindrical types of different designs are use as reference or transfer standards. Comparison of air kerma standards for low and medium energy x-rays from BIPM and PSDLs have been conducted and the results are generally within ± 5%.

2.2 Properties of radiation detector.

There are three general properties of the radiation detector, which are pulse mode, current mode and mean square voltage mode. Pulse mode is one of the most commonly used for the radiation detector, where the detector is designed to record each individual quantum of radiation that interacts with it. The measurement of the dose is one of application area of detectors. Measurements can be divided into two categories, which are absolute and relative. Absolute determination of dose, also known as reference dosimetry. The aim of this dosimetry is to produce accurate and consistent values relative to primary standards. Measurements are performed under controlled reference conditions, which are chosen to ensure transient electron equilibrium, stable and reproducible measurement conditions (Seco et al., 2014).

2.3 Film response of XR-RV3.

According to Bradley et al, XR-RV3 radiochromic film response to a given air kerma shows dependence on beam quality and film orientation. Calibration curves showed a strong dependence on film orientation (white side versus orange side facing the x-ray source) and kVp and small dependence on patient-equivalent backscattering.

2.4 Determination of characteristics of film in range of kilovoltage energy.

According to Rampado (2010), the dosimetric characteristics of Gafchromic XR-QA films were determined experimentally for kilovoltage radiation energies. Film samples were exposed to six different x-ray beams with energies and filtration over all the range of values used in diagnostic radiology, from very low effective energies (mammography unit) to relatively higher voltage and filtrations (CT x-ray beams). Film sample color change was analysed by a commercial flat-bed scanner, after a study of the uniformity and repeatability properties, considering variations in a quantity proportional to the ratio between the pixel value of unexposed films and the pixel value of exposed films. The Gafchromc radiochromic film model XR-QA2 contain 25-micron thick active layer, it has the sensitivity to doses ranging from 0.1 to 20cGy and to energies ranging from 20 to 200keV. Percentage of elemental composition in the sensitive layer for XR-QA2 film by atomic are 56.2 for H, 1.0 for Li, 27.6 for C, 1.6 for N, 11.7 for O, 0.1 for Cl, 1.7 for Bi and Zeff for XR-QA2 film is 55.2 (Devic, 2016)

Additionally, the films remained undisturbed for 24hours before beginning of the readout process to allow the chemical in the layer reach stability, so that the appropriate pixel value can be obtained. The storage of the film must be ensured by placing the film in the envelop in order to minimize the exposure to the light, before and after irradiation and scanning (Butson et al., 2002). XR-QA2 is differed from XR-QA film as the sensitive layer of XR-QA2 consist of Bi2O3 as a substance to boost the photo-electric effect at low energies. The addition of bismuth decreased the otherwise significant energy dependent response of XR film models (Devic et al, 2016).

2.5 Factors affecting the pixel value of films.

According to Baptista (2013), an appropriate radiochromic film should respond uniformly throughout its surface after exposure to a uniform radiation field. The evaluation of radiochromic films may be carried out, for example, by measuring color intensities in film-based digitized images. Fluctuations in colour intensity may be caused by many different factors such as an optical structure of film's active layer, the defect in the structure of the film, scratches and external agents, such as dust. The use of high spatial resolution during film scanning should also increase microscopic uniformity. Since the average is strongly influenced by extreme values, the use of other statistical tools, for which this problem becomes inconspicuous, optimizes the application of higher spatial resolution as well as reduces standard deviations.

There is a necessary for the first responders to monitor their radiation exposure instantly. It is of interest to find a dosimeter that can be used across a wide range of radiation qualities. The dosimeter should be conveniently handle as it must have characteristics such as light in weight, portable, easy to use with minimal training and affordable. An instantaneous reading of exposure in the appropriate dose range is desirable, so that timely and appropriate action can be taken regarding the rescue operation and prevent overexposure. Radiochromic film has been found to be used as the radiation detector for emergency responders (Butson, 2003).

2.6 Measurement of NOD.

The Gafchromic films develop automatically due to radiation- induced polymerisation reactions within its sensitive layer. Due to the detection of ionizing radiation, the yellow color of Gafchromic films will be change into brown and the intensity of the color depends on quantities of the radiation strike on the surface of the film. The change in NOD can be measured with densitometers, film scanners or spectrophotometers. The changes of the radiochromic film color quantitatively after being digitized using flatbed-type document scanner. There are several advantages of using these film : high spatial resolution, capture peak dose from overlapping projections, large surface area, easy to place under the patient, self-developing and insensitive to visible light (McCabe, 2011).

2.7 Calibration curve acquirement.

According to Soliman (2013), the radiochromic film calibration curve was obtained by exposing the films free in the air as recommended by the film's manufacturer. Films were placed on the patient table and irradiated free in air using the under-couch configuration exactly as in the clinical set-up. Once the calibration process was established and dose data were cross-checked, the radiochromic films were used in vivo and placed over the examination table, and under the patient's body, the irradiated films captured all the radiation fields used during the procedure in size and in value.

CHAPTER 3

METHODOLOGY

For the measurement of incident air kerma in general radiography, the chest and abdomen phantom was centred in the beam at the d_p according to clinical set up which were 100 cm for abdomen and 180 cm for chest examination, with the beam size adjusted to the phantom edge. The exposure parameters (based on previous study) chosen should be those used clinically for postero-anterior (PA) for chest and antero-posterior (AP) for abdomen. A detector of diagnostic dosimeter was positioned at the sufficient distance, 240mm (according to TRS457) to avoid backscatter. The incident air kerma was calculated from the measurement at detector position using the inverse square law. The measured data and exposure parameters were recorded.

3.1 Choice of dosimetric quantities.

The principle quantities to be measured for use in general radiography are incident air kerma, entrance air kerma and air kerma product. For phantom, the incident air kerma is measured. Since the study involved of the usage of a phantom, so the incident air kerma is taken into account instead of entrance air kerma and air kerma product.

3.2 Phantom as a simulation of patient.

Incident air kerma was measured for standard phantom utilizing x-ray exposure parameter for the average size adult patient. The methodology was described for two common imaging parts which were chest and abdomen. The recommended phantom for determination of incident air kerma was the Center of Devices and Radiological Health (CDRH) chest and abdomen phantom. Since this phantom was not available, the anthropomorphic was used instead for both chest and abdominal examination. As cited in ICRP (1975), the phantom is 73.5 kg in weight and 173 cm in height. The phantom contained bone equivalents in the form of human skeleton surrounded by soft tissues. The phantom composed of transverse slices with 2.5 cm thickness each.

Figure 3.1: Anthropomorphic phantom.

3.3 Free-in-air film calibration.

An entire sheet of film was cut into 5cm x 5cm. The films were numbered and marked so that they could be placed on the scanner bed to match their positions and orientations in the original sheet. Before and after the exposures, the calibration films were stored in an envelope, environmentally controlled room. Free-in-air indicates that the calibration films were placed at certain sufficience distance to avoid backscatter radiation, and then it will be exposed to the primary x-ray beam with negligible x-ray scatter. The exposures were made with one orange side of the film, which is the surface of the films that contain active material that act as detector facing the x-ray source. The exposure parameters that had been used for abdomen were 83kVp for 10, 20, 30 mAs and for energy 85kVp, the mAs that we used were 10, 30 and 50. For chest, we used 120kVp for 3.2, 5 and 8, while for 125kVp, 1.0, 2.0 and 3.2 mAs were used. After 24 hours post- irradiation, for the scanning purpose, each film was placed down in the center of the scanner bed. To minimize the potential film orientation issues that could be caused by the manner in which the active layer of the film, the calibration pieces were rotated so that the numbered orientation mark was consistently aligned.

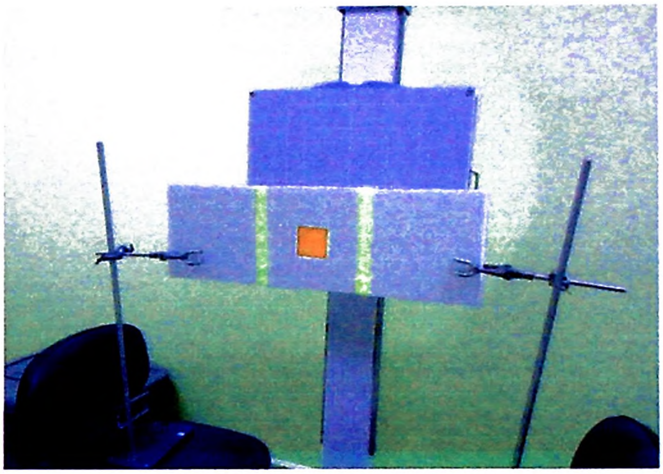


Figure 3.2: Position of film during measurement of film calibration for chest examination.

3.4 Incident air kerma measurement.

The procedure for measurement of incident air kerma shown in **Figure 1.4.** The x-ray equipment was set up according to the normal adult patient for PA chest by selecting the chosen exposure such as 120kVp/ 5.0mAs, 125kVp/ 1.0mAs and 125kVp/ 1.6mAs. The phantom was in erect position according to clinical procedure arrangement, then the IC was placed posteriorly to the phantom in sufficient distance for chest examination. The distance of source to the detector for chest was 156 cm, while the detector to phantom was 24cm. The IC was placed within 24 cm away from the phantom surface to avoid backscatter radiation. It should be placed as close to the central axis to minimize the influence of anode-heel effect. The IC was exposed and the dosimeter reading was recorded. The exposures were repeated for three times to get the average. The steps were repeated by replacing the IC with Gafchromic XR-QA2 films.

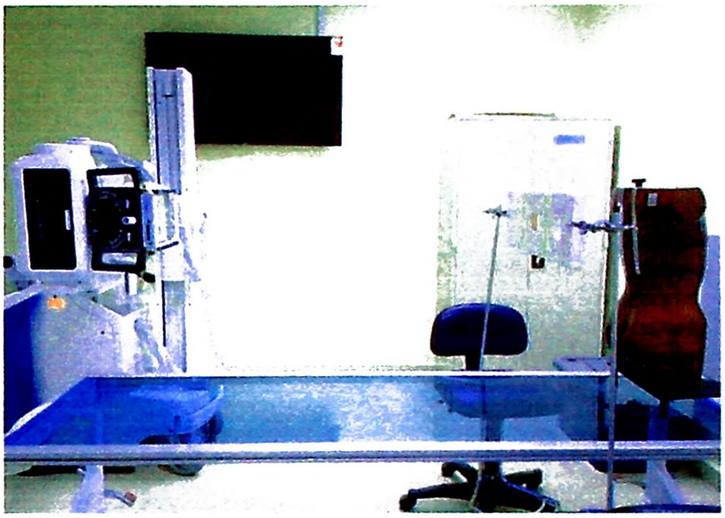


Figure 3.3: Set up for chest examination.

After that, the set up was adjusted to the abdominal examination arrangement by positioning the phantom in supine and the detector was placed above the phantom surface within 24 cm. The distance between source to IC was 56cm. The exposure parameters that had been used for abdomen examination were 83kVp/ 12.5mAs, 85kVp/ 32mAs and 85kVp/ 40mAs. Every exposure parameter was repeated for three times to get the average reading.

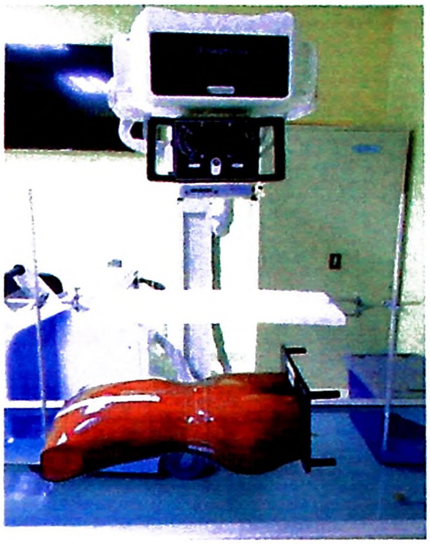


Figure 3.4: Set up for abdominal examination.

3.5 Irradiation source by mobile x-ray unit.

Irradiation was carried out by using GE OPTIMA XR200 MAX mobile x-ray machine. The x-ray machine has maximum kilovoltage, which is 125kV while the maximum milliampere is 300mA.

Figure 3.5: GE OPTIMA XR200 MAX

3.6 Pixel value determination.

Through out this study, the XR-QA2 and XR-RV3 films were used as radiation dosimeter with lot number 02201501 for XR-QA2 films and A03281101A for XR-RV3. So, the equipment that we used to obtain the pixel value in order to get the reading for the absorbed dose was a flatbed scanner, to be specific Epson Expression 10000XL. The films were scanned by using the flatbed scanner with similar orientations for each of the film since different orientation will give different pixel value (McCabe, 2011). The size of the scanner was 65.6 cm x 45.8 cm x 18.5 cm, weight was 15 kg. The set up for the scanner was in landscape format so that the lid was not being opened at the small side but on the long side. The scanner had a maximum density of 3.8 and optical resolution 2400 x 4800 pi. The special feature for the scanner is auto-focus (Patrick, n.d).

Figure 3.6: Flatbed scanner used for pixel value determination.

3.7 Dose determination by using ionization chamber.

In order to get the dose for each of exposure parameter, the IC that connected to the electrometer were used. Dose from IC will be used to cross-check with NOD in order to get the calibration curve. NOD can be calculated by using equation 3.1 from pixel value that obtained from flatbed scanner,

$$\mathrm{Log}_{10}\frac{\mathrm{PV\ unexposed}}{\mathrm{PV\ exposed}} \qquad \textbf{Equation 3.1}$$

Figure 3.7: SFD ionization chamber.

Figure 3.8 : Electrometer model UNIDOS E, Physikalisch-Technische Werkstatten (PTW)

3.8 Incident air kerma calculation.

The inverse square law was used to calculate the incident air kerma from air kerma at the position of the dosimeter for exposure of standard patient with PA chest thickness 225 mm or AP abdomen thickness of 230 mm.

$$\text{Inverse square law equation} = \left(\frac{(dFTD - dm)}{(dFTD - t)}\right)^2 \qquad \textbf{Equation 3.2}$$

The air kerma K(d) was calculated at the measurement point (at a distance, d, from the X-ray focus) from the mean value of dosimeter readings, M is shown in Equation 2. In this equation, k_{TP} is the correction factor for temperature and pressure, N_{KQ} is the dosimeter calibration coefficient and k_Q is the factor which corrects for differences in the response of the dosimeter at the calibration quality, Q_0 and at the quality Q, of the clinical X-ray beam (IAEA, 2007)

$$K(d) = MNK,QokQk_{TP} \qquad \textbf{Equation 3.3}$$

The correction factor, k_{TP} is unity for dosimeters with IC. For dosimeters with IC, it is given by Equation 3.

$$K_{TP}=((273.2+T)/(273.2+To))(Po/P) \qquad \textbf{Equation 3.4}$$

The quantities T and P are the temperatures and pressures (in °C and kPa) recorded during the measurement and T_o and P_o are their reference values for which $N_{K,Qo}$ is provided. The incident air kerma, Ki is calculated based on Equation 4. D_{FTD} is measured tube focus to phantom support distance in 19entimetres and dm and tp are distance from table top to the reference point of the chamber at the measurement position and the thickness of a standard chest or abdomen phantom (IAEA, 2007)

$$Ki = K\ (d)\ ((d_{FTD} - dm)/(d_{FTD} - t))2 \qquad \textbf{Equation 3.5}$$

After Ki were obtained, the percentage different between IC and films were calculated. This calculation was done due to determine how much different between IC and films. The formula for percentage difference is as below:

$$\text{Percentage difference (\%)} = \frac{\text{Ki from film} - \text{Ki from IC}}{\text{Ki from IC}} \times 100\% \qquad \textbf{Equation 3.6}$$

CHAPTER 4 : RESULTS

4.1 Result for dose response of Gafchromic film.

Table 4.1: Result XR-QA2 and XR-RV3 films study.

Exposure parameter (kVp/mAs)	Number of exposure	IC reading (mGy)	NOD for XR-QA2 films.	NOD for XR-RV3 films.
70/20	1	3.36	0.035	0.021
	2	5.97	0.038	0.020
	3	8.96	0.068	0.005
	4	11.99	0.074	0.008
	5	15.12	0.098	0.005
80/20	1	4.02	0.052	0.021
	2	8.04	0.057	0.020
	3	12.02	0.083	0.019
	4	16.01	0.095	0.018
	5	19.99	0.121	0.020
90/20	1	5.13	0.055	0.020
	2	10.40	0.094	0.019
	3	15.34	0.096	0.017
	4	20.73	0.129	0.017
	5	25.96	0.140	0.018
100/20	1	6.49	0.048	0.027
	2	13.09	0.076	0.022
	3	19.51	0.115	0.018
	4	26.04	0.127	0.020
	5	32.23	0.141	0.021

Table 4.1 showed the reading of IC and NOD for both Gafchromic films that had been irradiated with 70, 80, 90, 100 and 120 kVp with 20 mAs. The reading of IC in unit of nC. NOD was calculated by using the equation 3.1. This data was needed to plot dose response curve.

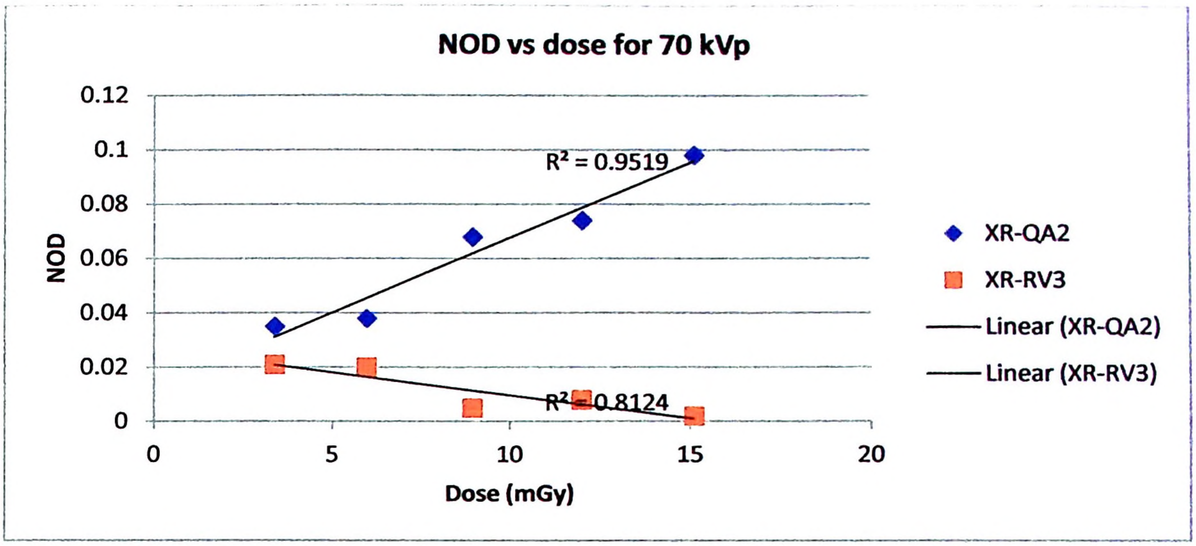


Figure 4.1 : Graph of NOD versus dose for 70kVp/ 20mAs.

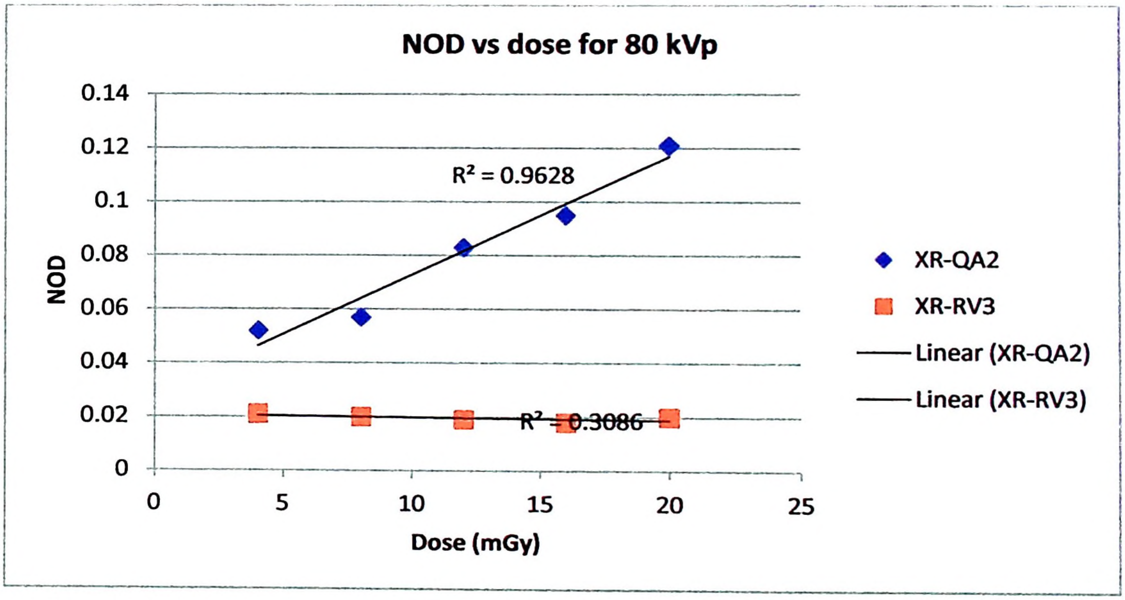


Figure 4.2 : Graph of NOD versus dose for 80kVp/ 20mAs.

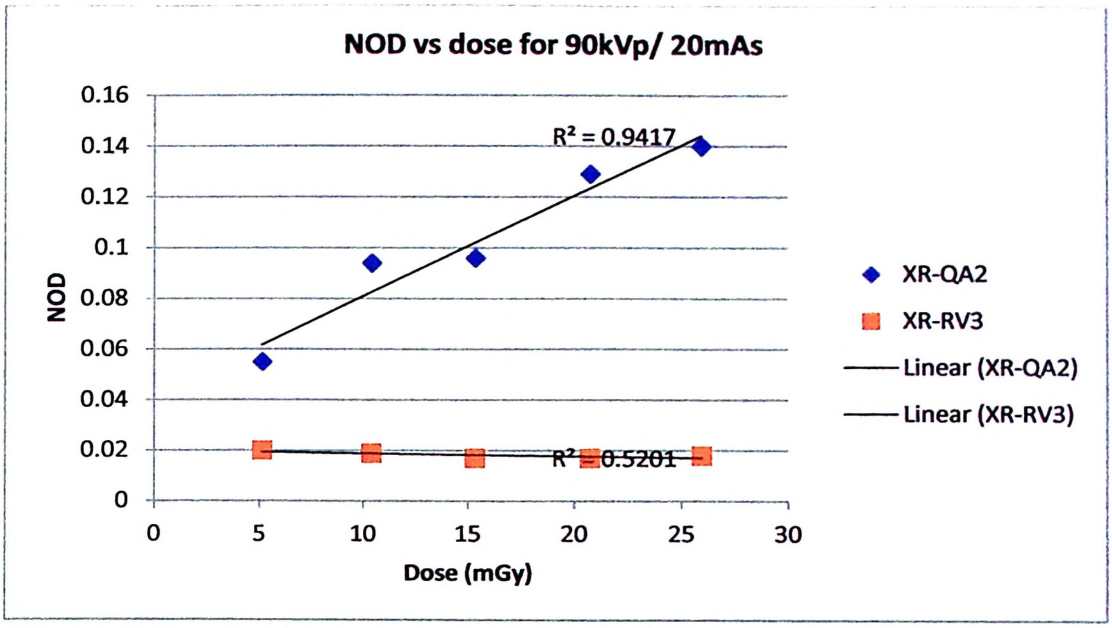


Figure 4.3 : Graph of NOD versus dose for 90kVp/ 20mAs.

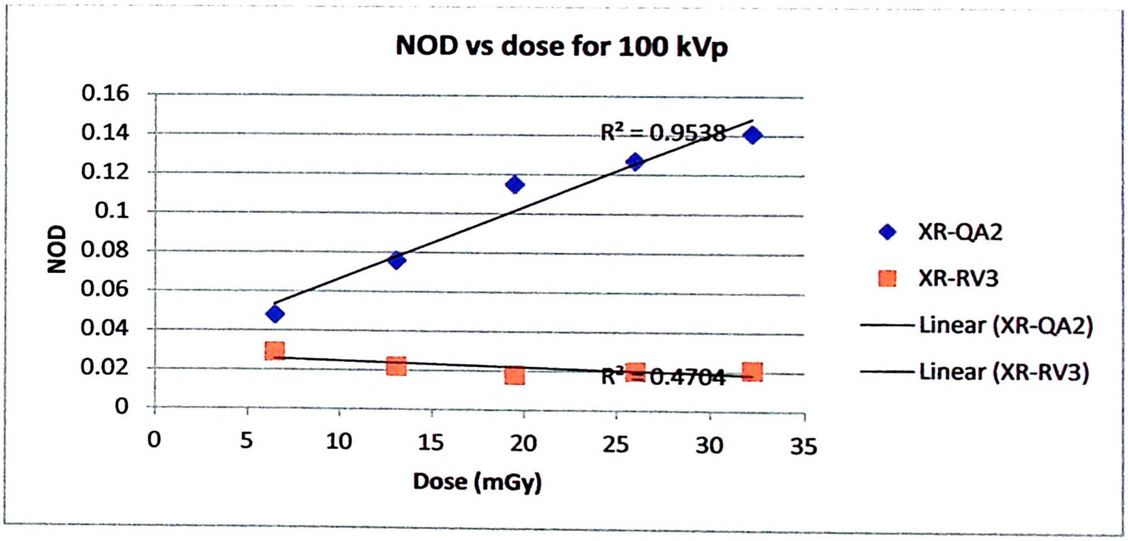


Figure 4.4 : Graph of NOD versus dose for 100kVp/ 20mAs.

Figure 4.1 to Figure 4.4 showed the relationship between dose and NOD for energy 70, 80, 90 and 100kVp. For XR-QA2 films, the NOD is increase directly proportional to the dose for all energy since the R^2 value approaching 1.0, while the graphs for XR-RV3 films the NOD is decreased linearly, slightly flat to the dose.

4.2 Calibration of XR-QA2 film.

Table 4.2 : Result of the calibration XR-QA2 film in Ki calculation for abdomen.

Abdomen			
kVp	mAs	Ki (mGy)	NOD
83	10	0.72	0.017
	20	1.45	0.020
	30	2.32	0.028
85	10	0.77	0.012
	32	2.45	0.025
	50	3.83	0.040

Table 4.2 showed the value of Ki and NOD for abdomen examination. This data was used to plot calibration curve for energy 83kVp and 85kVp. The calibration curve was used to obtain the dose from value of NOD.

Table 4.3 : Result of the calibration XR-QA2 film in Ki calculation for chest.

Chest			
kVp	mAs	Ki (mGy)	NOD
120	3.2	0.11	0.009
	5.0	0.18	0.013
	8.0	0.26	0.014
125	1.0	0.03	0.006
	3.2	0.11	0.014
	5.0	0.18	0.017

Table 4.3 showed the value of Ki and NOD for chest examination. This data was used to plot calibration curve for energy 120kVp and 125kVp. The calibration curve was used to obtain the dose from value of NOD.