Measurement of eye lens doses estimation in interventional radiology

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Abstract. International Commission of Radiological Protection (ICRP) Publication number 118 at 2012 recommends decreasing the Dose Limit Value of eye lens for workers from 150 mSv to 20 mSv in 1 year, and to not exceed 50 mSv in a certain year. This experiments is aimed to evaluate the value of eye lens radiation dose based on the effect of angles on the monitor in interventional radiology by using a head phantom as a simulation of the workers’ position with a height of 150 cm, 160 cm and installed thermoluminescent dosimeter (TLD) chips Hp (10) at 66 - 67 kV and 385 - 395 mA. The radiation lens dose value during 1 minute fluoroscopy irradiation results a mean of radiation dose value that ranges between 0.54 – 0.79 mSv and 0.52 - 0.70 mSv, during 4 minutes fluoroscopy irradiation ranges between 0.48 – 0.72 mSv and 0.55 - 0.75 mSv, and during 10 seconds cinefluorography ranges between 0.52 – 0.75 mSv and 0.48 - 0.66 mSv. The relationship between the linearity of fluoroscopy irradiation time and dose area product (DAP) obtained an equation of y = 0.0139x-0.0535 with a correlation coefficient R² = 0.9982. The relationship between the linearity of fluoroscopy irradiation time and Kinetic Energy Released per Mass unit (KERMA) obtained an equation of y = 0.0957x-0.0495 with a correlation coefficient R² = 0.9988.

1. Introduction
The effects of radiation and radiation protection measures are now a major concern, due to awareness of the long-term effects (life-time risk) both for patients, radiation workers and the general public around them. Interventional radiology workers should pay more attention to the radiation doses used during cardiology or interventional radiology [1, 2]. One of the effects of radiation that need to be considered is the effect of radiation received by radiation workers on the eye organ.

The eye lens is the part of the eye that is most sensitive to radiation, damage to the lens begins with the formation of turbidity points or loss of transparency of the lens fibers which can be detected after radiation exposure around 500 mGy, this damage is accumulative and can develop until blindness occurs due to
cataracts [3]. Recommends a reduction in the Dose Limit Value of the eye lens for radiation workers from 150 mSv to 20 mSv in one year and in one particular year not beyond 50 mSv [4, 5].

In interventional radiology actions, radiation workers have the potential to get higher radiation exposure because radiation workers work closer to patients and radiation sources, another factor causes radiation workers in interventional radiology can receive doses that exceed the threshold due to the high workload. Therefore it is necessary to monitor the radiation dose received by radiation workers using a dosimeter.

In this experiments using a head phantom as a simulation of the position of the radiation worker and installed thermoluminescent dosimeter (TLD) and will get the estimated value of the radiation dose received by the eye lens (mSv) from the influence of the direction of the monitor's position from several angles. So from the estimated radiation dose received by the radiation worker on the eye lens, it becomes a reference for optimizing radiation protection in interventional radiological measures.

2. Method

2.1 Measurement of the radiation lens of the eye lens using chips thermoluminescence dosimeter (TLD)

Retrieval of data in the interventional radiology room at Kraton Pekalongan Hospital began by placing the head phantom with TLD Hp chips installed (10) in a position that simulates radiation workers at the time of the action and placing a 20 cm thick solid water phantom on the patient's table to simulate the patient's position.

Next, install the thermoluminescent dosimeter (TLD) Hp (10) chips on the head phantom. Installation of TLD chips on the head phantom is mounted with an angle that varies as many as 7 corner positions at an angle of -45 °, -30 °, -15 °, 0 °, 15 °, 30 °, and 45 ° which have been previously marked by measuring the magnitude of the angle using a protractor, 150 cm and 160 cm phantom height and irradiating with fluoroscopy with time variations of 1 minute, 4 minutes, and cinefluorography for 10 seconds. Each variation will be replaced by a different TLD Hp (10) chip.

In the experiments the value of the dose area of the product (DAP) and the value of KERMA (Kinetic Energy Released in Mass), obtained from the results of irradiation with the fluoroscopy method for 1 minute and 4 minutes and each irradiation was performed seven times, using solid water phantom with a thickness of 20 cm and a field size of 20 cm x 20 cm placed on the patient's table, with a source image distance (SID) of 87 cm and Focus Distance (FD) 25 cm with Automatic Exposure Control (AEC) operating voltage measured 66 kV and current 384.57 – 387 mA.

2.2 Data acquisition

Figure 1 layout position of the phantom

Figure 2 layout position of the TLD system
The results of receiving the radiation dose received for each TLD chips package is the average of the results of receiving the dose of two TLD Hp chips (10) contained in each TLD chips package and taking into account the TLD calibration factor (FK) against X-rays. Data from TLD chip readings mounted on the head phantom will be acquired and evaluated to obtain the value of the radiation dose received by the radiation lens of the worker's eye. This measurement also obtained the value of the dose area product (DAP), the value of KERMA (Kinetic Energy Released in Mass), and the value of the KERMA Rate so that from the data obtained we can then evaluate.

2.3 Analysis of data
Data from the reading of the thermoluminescent dosimeter (TLD) chips will obtain the value of the eye lens radiation dose received by the radiation worker. Next will be a mapping of the value of the eye lens radiation dose to the effect of the angle, the estimated value of the eye lens radiation dose from the effect of the exposure time on fluoroscopy mode and cinefluorography mode and the estimated value of the eye lens radiation dose from the influence of the height of the phantom position.

The value of the radiation dose of the eye lens obtained from reading TLD Hp chips (10) is an equivalent dose, and analyzing the effect of the angle, duration of irradiation and altitude on the radiation dose received by the eye lens of the radiation worker in interventional radiology by referring to BAPETEN regulatory in Indonesia for threshold dose values the limit on the eye lens is 20mSv per year.

Analyzing the relationship between fluoroscopy irradiation time with measured dose area product (DAP) and analyzing the relationship of irradiation time with measured Kinetic Energy Released in Mass (KERMA) values [6].

3. Results and discussion

3.1 Dose Area Product Value (DAP)
DAP values obtained from measurement results with 1 minute irradiation time, 4 minutes fluoroscopy mode and 10 seconds cinefluorography obtained mean values in table 1

| Time              | 1-minute fluoroscopy | 4 minutes fluoroscopy | 10 seconds cinefluorography |
|-------------------|----------------------|-----------------------|-----------------------------|
| DAP               | 0.78 Gycm$^2$        | 3.30 Gycm$^2$         | 1.26 Gycm$^2$              |

Based on table 1, the average value of DAP at 1 minute fluoroscopy is smaller than the DAP value at 10 seconds cinefluorography. The basic reason for the large value of DAP when sine, because the examination requires several times recording good quality images.) Normal fluoroscopy conditions usually the radiation exposure required to reach the image amplifier is 30 µR per seconds and when cinefluorography is needed around 20 µR per frame, at 30 fps there is a 20-fold increase in dose [7].

In this experiment the DAP value obtained was 0.013 Gycm$^2$ per second on fluoroscopy and on cinefluorography 0.126 Gycm$^2$ per second. The DAP value obtained shows that there is an increase in the dose value up to 10 times because the device is set with cinefluorography 15 fps (frame per second). The relationship between DAP linearity and exposure time with fluoroscopy mode is shown in Figure 3.
Figure 3 Linearity relationship between fluoroscopy irradiation time with dose area product (DAP)

Figure 3 shows that the linear increase between fluoroscopy time and the increase in DAP values, the equation is obtained

\[ y = 0.0139x - 0.0535 \]

Correlation coefficient value \( R^2 = 0.9988 \). From the results of equation (1), it can be used to estimate the DAP value on examinations in interventional radiology. For example, the action requires fluoroscopy irradiation time of 15 minutes or 900 seconds so that the DAP value that will be obtained from equation (1) is 12.46 Gycm\(^2\)

DAP values measured and calculated using equation (1) are shown in Figure 3.

Figure 4 Comparison graph of the calculation results and measurement of fluoroscopy irradiation time against the DAP value

Based on Figure 4, it can be seen a comparison between the value of the measurement results with the calculated values based on equation (1), the graph shows the value of a small difference. And produces an error value of 0.16 - 4.35%, and a comparison chart of the DAP value from the influence of the fluoroscopy exposure time.

3.2 KERMA (Kinetic Energy Released in Mass) Value
Based on table 2 the average value of KERMA at 1 minute fluoroscopy is smaller than the value of KERMA at 10 seconds cinefluorography. The same reason with the DAP value of the value of KERMA when sine, because the examination requires several times a recording of good quality images so that the dose of energy per unit mass at the time of cinefluorography is greater and gives a large exposure to the patient.

Table 2 Average values of KERMA from measurements

| Time                        | 1-minute fluoroscopy | 4 minutes fluoroscopy | 10 seconds cinefluorography |
|-----------------------------|----------------------|-----------------------|-----------------------------|
| KERMA                       | 5.69 mGy             | 22.93 mGy             | 11.48 mGy                   |

In this experiments the value of KERMA obtained by 0.0948 mGy per second on fluoroscopy and on cinefluorography 1.148 mGy per second. The KERMA value obtained shows that there is an increase in the dose value up to 10 times because the device is set with cinefluorography 15 fps. The average measured KERMA rate is 0.094 mGy/s. Correlation between KERMA linearity and irradiation time, with fluoroscopy mode 1 minute and 4 minutes 14 data obtained and shown in Figure 5.

Figure 5 Linearity relationship between fluoroscopy exposure time with KERMA

From the graph, fluoroscopy time has a linear relationship to the increase in the value of KERMA, then get the equation

\[ y = 0.0957x - 0.0495 \]

Correlation coefficient value \( R^2 = 0.9988 \). From the results of equation (2), it can be used to estimate the value of KERMA (mGy) on examination in interventional radiology. The KERMA value measured and calculated using equation (2) produces an error value of 0.30 - 4.75% and the graph of the KERMA value of the influence of fluoroscopy time is shown in Figure 6.
Figure 6 Comparative graph of the calculation results and measurement of fluoroscopy irradiation time against KERMA (mGy) values

3.3 Measurement Value of Radiation Lens of the Eye lens with TLD Hp chips (10)
Workers' doses must be declared as effective doses and as equivalent doses for the eye lens, feet, and hands. Radiation dose value on the lens of the radiation worker's eye in the interventional radiology room is obtained by simulating a phantom as high as 160 cm placed in the position of the working radiation worker, to represent the height of the radiation worker as high as 160 cm, in this experiments the radiation dose value read from TLD Hp (10) with a variety of angles and irradiation times [8, 9].

Radiation dose values received by the eye lens on the phantom with a height of 150 cm and 1 minute fluoroscopy irradiation time produce radiation dose values of 0.54 – 0.79 mSv mSv, with the influence of voltage values 66 - 67 kV and current values 380 - 395 mA, values the highest radiation dose in the TLD A4 position is at an angle of 0°. The relationship between the angle and the value of the received radiation dose is shown in the following graph:

Figure 7 The relationship between radiation dose received by the eye lens with angular variation at 150 cm height with 1-minute fluoroscopy

Radiation dose values received by the eye lens on the phantom with a height of 150 cm and a fluoroscopy 4 minute irradiation time produce a radiation dose value of sebesar 0.48 – 0.72 mSv, with the influence of a voltage value of 66 - 67 kV and a current value of 380 - 395 mA, the value of the highest radiation dose
is in the TLD A7 position at an angle of 45°. The relationship between the angle and the value of the dose received is shown in the following graph:

![Figure 8](image_url)  
**Figure 8** The relationship between radiation dose received by the eye lens with angular variation at 150 cm height with 4-minute fluoroscopy

The radiation dose value received by the eye lens on the phantom with a height of 150 cm and the irradiation time of 10 seconds cinefluorography results in a radiation dose value of 0.52 – 0.75 mSv, with the effect of a voltage value of 66 - 67 kV and a current value of 380 - 395 mA, a value of the highest radiation dose in the A2 TLD position is 30° angle. The relationship between the angle and the value of the dose received is shown by the following graph:

![Figure 9](image_url)  
**Figure 9** The relationship of radiation dose received by the eye to the influence of the angle at a height of 160 cm and 10 seconds cinefluorography

Radiation dose values received by the eye lens on the phantom with a height of 160 cm and 1 minute fluoroscopy irradiation time produce radiation dose values of 0.52 - 0.70 mSv, with the influence of voltage values 66 - 67 kV and current values 380 - 395 mA, values the highest radiation dose in the TLD A3 position is at an angle of -15°. The relationship between the angle and the value of the received radiation dose is shown in the following graph:
Figure 10 The relationship between radiation dose received by the eye lens with angular variation at 160 cm height with 1-minute fluoroscopy

Radiation dose values received by the eye lens on the phantom with a height of 160 cm and a fluoroscopy 4 minute irradiation time produce a radiation dose value of 0.55 - 0.75 mSv, with the influence of a voltage value of 66 - 67 kV and a current value of 380 - 395 mA, the value of the highest radiation dose is in the TLD A2 position at an angle of -30°. The relationship between the angle and the value of the dose received is shown in the following graph:

Figure 11 The relationship of radiation dose received by the eye to the influence of the angle at a height of 160 cm and 4 minutes fluoroscopy

The radiation dose value received by the eye lens on the phantom with a height of 160 cm and the irradiation time of 10 seconds cinefluorography results in a radiation dose value of 0.48 - 0.66 mSv, with the effect of a voltage value of 66 - 67 kV and a current value of 380 - 395 mA, a value of the highest radiation dose in the A2 TLD position is -30° angle. The relationship between the angle and the value of the dose received is shown by the following graph:
The measurement of the dose received by radiation workers using a precise and accurate luminescence dosimeter on radiation workers is very important. Because the dosimeter's position on the dose received by the radiation worker from the angle of radiation exposure can have an effect on the dose received by the radiation worker. The radiation angle is an important factor and is very necessary to evaluate the dose correctly. The dosimeter position for X-ray exposure reference is 0°, ±30°, ±60°, and the angle criteria are according to -29%, and +67% (±60°) [10].

The type of action in interventional radiology requires different times. To calculate the estimated dose limit value of radiation workers we can assume the average value of time used in each action is 10 minutes fluoroscopy, then it can be estimated the equivalent dose value required in the radiation work glasses is 5.2 - 7.0 mSv per action. If a radiation worker with a workload of 50-100 actions per year, the value of the radiation dose received is 260-700 mSv per year. This radiation dose has exceeded the recommended dose limit value [11, 12].

4. Conclusions
Radiation dose values with an average of 1 minute fluoroscopy in the range 0.52 - 0.70 mSv, 4 minutes fluoroscopy 0.55 - 0.75 mSv, and 10 seconds cinefluorography 0.48 - 0.66 mSv. The influence of the angle at a height of 150 cm, at 1 minute irradiation time with the highest dose of the eye lens radiation dose at an angle of 0° which is 0.79 mSv, at 4 minutes fluoroscopy the highest value of the lens eye dose at the angle of 45° that is 0.72 mSv, at 10 seconds cinefluorography the highest dose of the eye lens dose is at an angle of 30° which is 0.75 mSv. The influence of the angle at a height of 160cm, at 1 minute irradiation time with the highest dose of the eye lens radiation dose at an angle of -15° which is 0.70 mSv, at 4 minutes fluoroscopy the highest value of the lens eye dose at the angle of -30° that is 0.75 mSv, at 10 seconds cinefluorography the highest dose of the eye lens dose is at an angle of -30° which is 0.66 mSv. The linear relationship between fluoroscopy irradiation time and the increase in DAP (Gycm²), we get the equation y = 0.0139x - 0.0535 with the correlation coefficient R² = 0.9982, and the error value is 0.16 - 4.35%. The linear relationship between fluoroscopy irradiation time and the increase in the value of KERMA (mGy), the equation y = 0.0957x - 0.0495 with the correlation coefficient R² = 0.9988, and error values 0.30 - 4.75%.

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