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Measurements of scattered radiation around an X-ray tube

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X線管周辺における散乱線の測定

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要　　旨

撮影時における患者や放射線技師への被曝線量およびそれに影響する因子を検討するために，種々の撮影条件下におけるX線管周辺の線量を測定した。散乱線による線量は，管電圧の増加および照射野の増大に伴い，指数関数的に増加した。また管電流や照射時間の増加に伴い，直線的に増加した。X線管周辺の線量分布は，方向によってほとんど変化はみられず等方性と考えられたが，X線管からの距離と地上からの高さによって，大きく変化した。すなわちX線管からの距離の増大に伴い線量は著明に減少し，距離の二乗に逆比例すると思われた。また距離が同じ場合には，地上からの高さ50cmから100cmの位置で線量は増加し，50cm以下および100cm以上の位置では減少した。放射線技師は，自己の施設のX線発生装置について，散乱線による線量分布などを熟知しておく必要があると思われた。

ABSTRACT

In order to evaluate the distribution of scattered radiation around an X-ray tube and the effects of exposure conditions on it, scattered radiation was repeatedly measured. Scattered radiation increased exponentially with increasing tube voltage and radiation field size, while it increased linearly with increasing tube current and exposure time. At 80KVp-100mA-0.05sec with a collimator full opened, $23.1 \pm 1.3 \mu R$ of scattered radiation per exposure was observed at the site of 100cm horizontally from the center of an X-ray focus and 150cm high from the ground in all directions. Significant difference between various directions was not observed. Scattered radiation decreased remarkably with increasing focus-to-detector distance and changed depending on the detector-to-ground distance. The maximum dose was observed at

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50 to 100cm high from the ground. At less than 50cm and more than 100cm high, the dose decreased gradually. It appears to be very important for the radiation protection to know the distribution of scattered radiation from an X-ray generator in one's institution.

KEY WORDS: scattered radiation
an X-ray tube
Survey meter
Radiation exposure
multiple vane collimator

INTRODUCTION

X-rays have been used widely in a variety of departments, since they were discovered by Roentgen in 1895. X-rays have some special properties 1): (1) the ability to penetrate organic matter; (2) the ability to produce a photographic effect on photosensitive film surfaces; and (3) the ability to produce a fluorescence in certain crystalline materials. Owing to the advantage of examining any substances without destruction, they have been used not only in the medical science but also in the technical engineering, archaeology and so on. The recent development of new diagnosing modalities as computed tomography (CT) and digital subtraction angiography (DSA) has led to a progressive increase in the number of radiographic examination. A majority of diseases seem to be in remarkable difficulties for being diagnosed without X-rays, though other modalities without using X-rays such as ultrasonography (US) and magnetic resornance imaging (MRI) have been developed. On the other hand, diagnostic radiology has disadvantages of harmful radiation exposure. Concern has always existed about radiation exposure reduction to patients and technologists. Though some reports 2)-6) about efforts to decrease radiation exposure were published, the report about the distribution of scattered radiation around an X-ray tube was not previously published. The purpose of this paper is to estimate the distribution of scattered radiation around an X-ray tube and the effects of exposure conditions on it.

MATERIALS AND METHODS

X-rays generator system

The apparatus has been used for the educational training in our department for past fifteen years. The X-ray apparatus, manufactured by Shimazu company (Kyoto), is consisted of an X-ray tube, a transformer and a controller. The X-ray tube and a transformer are equipped in a radiographic room, which is 550cm in length, 510cm in width and 340cm in height. The walls, ceiling and floor of this room are constructed of concrete. The X-ray tube can be easily moved along the rails suspended from the ceiling. During this study, the X-ray tube was constantly fixed at 184cm from the nearest wall, at 263cm from other wall, and at 150cm vertically from the ground ("h" in Fig 1.). It was at 190cm from the ceiling. The X-ray tube used herein is called "CIRCLEX 1/2 U1OCN-25" for general radiography. The rotating anode is consisted of tungsten target with an angle of 18 degrees. The heat-storage capacity of this X-ray tube is 80 KHU. The R5 type of collimator system is attached to the X-ray tube. The opening degree of a collimator can be adjusted by manual operation of dial-switches and radiation field can be varied steplessly in the rectangular shapes. With a collimator full opened, radiation field corresponds to 75cm＊75cm at 150cm vertically from the X-ray focus. The controller is equipped in a control room, which is shielded from the X-ray generator by concrete wall for the radiation protection. Exposure conditions such as tube voltage, current and exposure time can be controlled respectively by selector switches on the front panel of a controller.

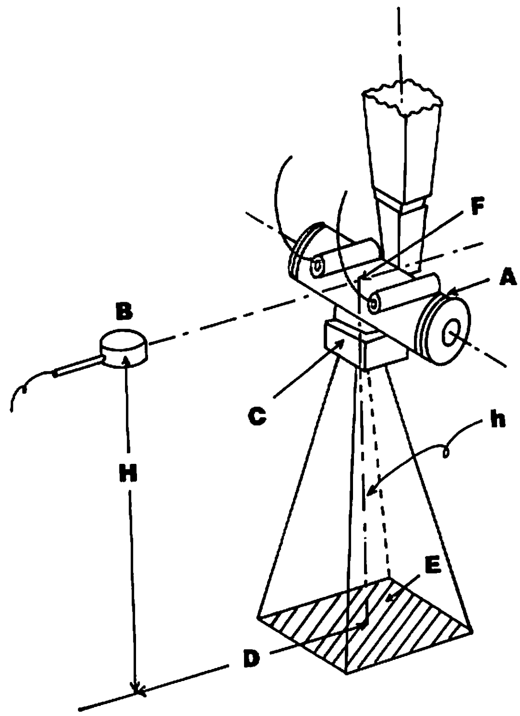

Fig 1. The outline of apparatus and parameters.
A: X-ray tube, B: detector, C: Collimator
D: Focus-to-detector distance (cm),
E: Field size, F: Focus,
H: Detector-to-ground distance (cm)
h: Focus-to-ground distance (=150cm)

A survey meter

The digital radiation survey meter (Model 660-5), manufactured by Victoreen company (USA), belongs to ionization-chamber type. In this instrument, two modes of operation can be chosen by a function switch; total exposure and rate of exposure. Total exposure mode was chosen herein to record total exposure per exposure. Manufacturer's specification describes that 0.001mR to 99.9mR of the scale reading is possible. In usual measurements, a detector was held at the same level as the X-ray focus: at 150cm vertically from the ground. In additional measurements, the level of a detector was changed ranging 4 to 200cm vertically from the ground.

Measurements

(1) The directional dependence of scattered radiation around an X-ray tube.

In order to evaluate the angular distribution of scattered radiation, measurements at 100cm horizontally from the center of focus were performed at intervals of 30 degrees circumferentially around the X-ray tube, with a collimator full opened.

(2) The effects of exposure conditions.

Since the significant difference between various directions was not observed in the previous measurement, following measurements were performed at the direction perpendicular to the axis of the X-rays tube. Standard measurements were performed under the conditions of 80KVp of tube voltage, 100mA of current, and 0.05sec of exposure time.

a) The effects of tube voltage and current

Tube voltage was changed ranging 60 to 150KVp with 10KVp interval at 0.05sec of exposure time and 25cm*25cm of radiation field, in case of 50, 100, and 200mA of current respectively.

b) The effect of exposure time

Exposure time was changed ranging 0.05 to 0.30sec with 0.05sec interval, and 0.40, 0.50, 0.80, and 1.0sec at 25cm*25cm of radiation field, in case of 50, 100, and 200mA of current at 80KVp of voltage and in case of 60, 100, and 120KVp of voltage at 100mA of current.

c) The effect of field size.

Radiation field was changed ranging 30cm*30cm to 75cm*75cm with 10cm*10cm interval and 25cm*25cm under the same condition as b).

(3) The effect of the location of a detector.

The detector-to-ground distance ("H" in Fig 1.) was changed ranging 4 to 200cm at 75cm*75cm of radiation field, in case of 80, 100, 120, 150, 200, and 250cm of focus-to-detector distance ("D" in Fig 1.).

Mean value of at least three measurements was used as the result.

RESULTS

1) The directional dependence of scattered radiation around an X-ray tube.

At 80KVp-100mA-0.05sec, 23±1.3μR (micro-Roentgen) of dose were observed in all directions around the X-ray tube. Significant difference was not observed between various directions.

2) The effect of tube voltage (Fig 2)

The dose increased with increasing tube voltage. Specially in high current regions, it increased exponentially with voltage.

3) The effect of tube current (Fig 3)

The linear relationship was observed between tube current and dose.

4) The effect of exposure time (Fig 4)

The linear relationship was observed between exposure time and dose.

5) The effect of field size (Fig 5).

The dose increased exponentially with increasing field size in case of various exposure conditions.

6) The effect of the location of a detector.

The dose decreased remarkably with increasing focus-to-detector distance (Fig 6).

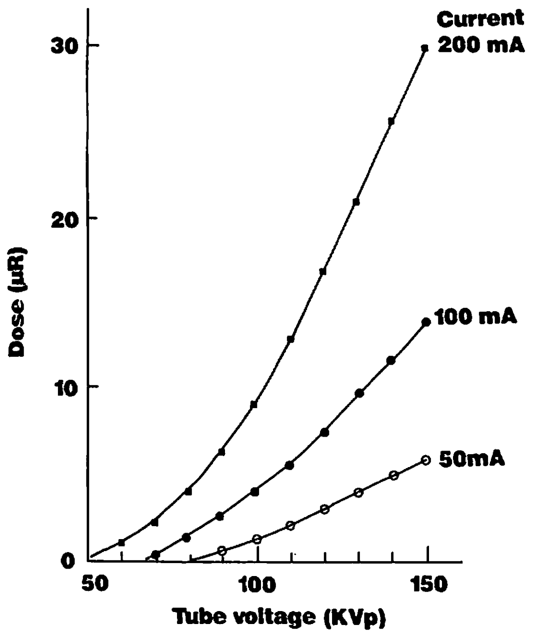

Fig 2: The relation between tube voltage and dose. Exposure time: 0.05sec, Field size: 25*25 cm^2, H: 150cm, D: 100cm

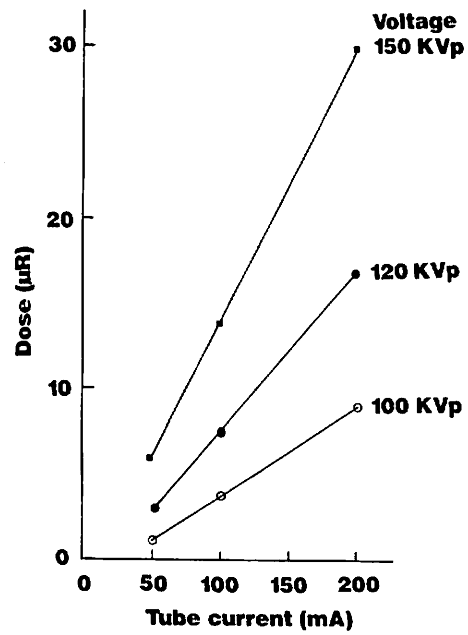

Fig 3: The relation between tube current and dose. Exposure time: 0.05sec, Field size: 25*25 cm^2, H: 150cm, D: 100cm

The dose depended on detector-to-ground distance (Fig 7). The maximum dose was observed at 50cm to 100cm high. The dose decreased gradually at less than 50cm and more than 100cm high.

DISCUSSION

At the collimator full opened, 23.1±1.3μR of total exposure per exposure was observed at 100cm horizontally from the center of focus. Significant difference was not observed in all directions. Thus, scattered radiation may be regarded approximately as isotropic. In spite of the recommendation of the International Commission on Radiation Units and Measurements (ICRU), SI units was not employed herein because the detector indicated mR units in place of SI units. Conversion of the survey meter reading to

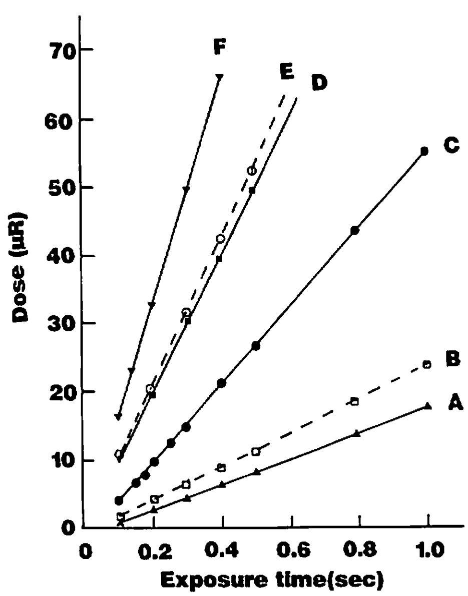

Fig 4: The relation between exposure time and dose. field size: 25*25cm^2, H: 150, D: 100cm
A: 60KVp-100mA, B: 80KVp-50mA,
C: 80KVp-100mA, D: 100KVp-100mA,
E: 80KVp-200mA, F: 120KVp-100mA

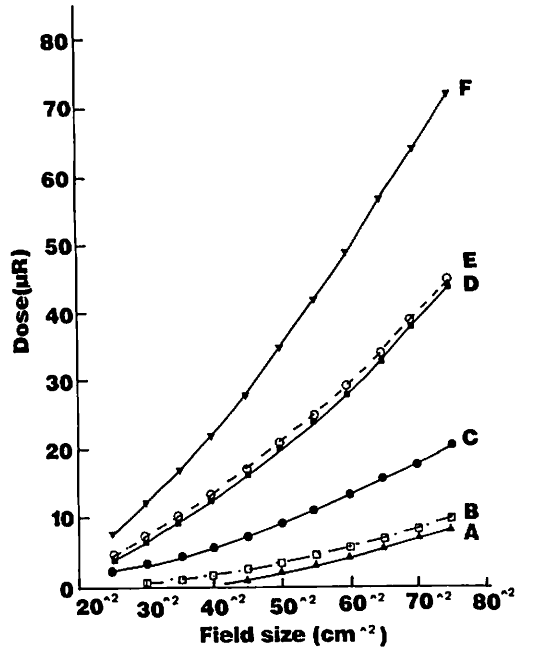

Fig 5: The relation between field size and dose.
Exposure time: 0.05sec, H: 150cm, D: 100cm
A: 60KVp-100mA, B: 80KVp-50mA,
C: 80KVp-100mA, D: 100KVp-100mA,
E: 80KVp-200mA, F: 120KVp-100mA

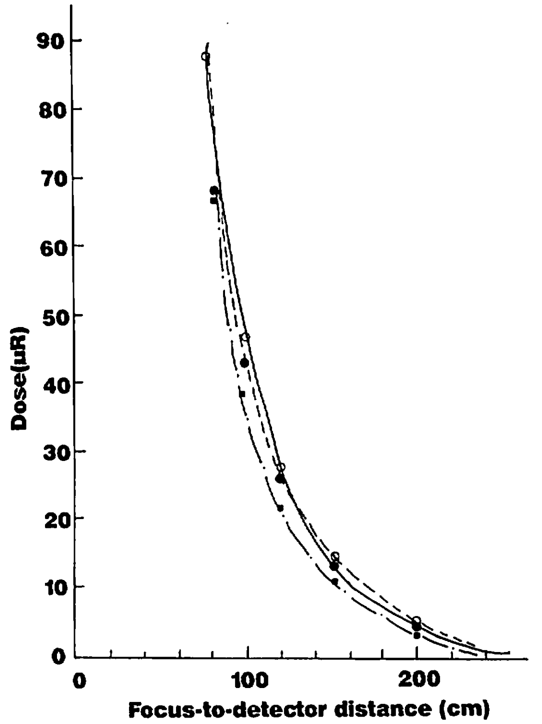

Fig 6: The relation between focus-to-detector distance and dose.
80KVp-100mA-0.05sec, Field size: 75*75cm^2
●; H: 20cm, ○; H: 60cm, ■; H: 100cm.

SI units was not conveniently accomplished. When a substance exists during the passage of radiation, radiation is deviated in different directions. Consequently, scattered radiation occurs. On the other hand, when primary electrons from a filament collide against target, secondary electrons arise from the target. The collison of

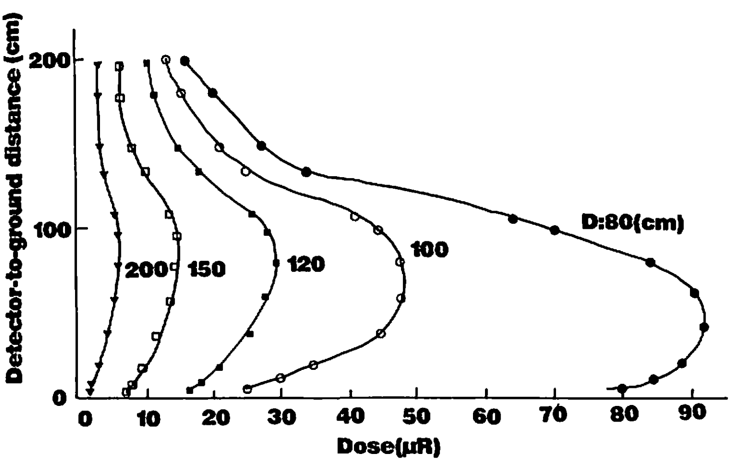

Fig 7: The relation between detector-to-ground distance and dose.
80KVp-100mA-0.05sec, Field size: 75*75cm^2

secondary electrons against target causes off-focus X-rays. Scattered radiation and off-focus X-rays deteriorate the image quality of radiography and make patient exposure increase. In order to reduce these undesirable X-rays and to increase the contrast of radiographic image, an X-ray apparatus is usually equipped with beam limiting devices. It is consisted of multiple vane collimators with optical field system. Optical field system is usuful in deciding desirable radiation field. The useful beam of radiation generated from an X-ray tube proceeds straightly toward X-ray image reception area through a collimator.

In this study, concrete floor is directly bombarded by X-rays. Therefore, most of scattered radiation are probably those originating from concrete floor. The X-ray tube was at 184cm horizontally from the nearest wall. Scattered radiation from the concrete wall seems to be very small amounts. Furthermore, small amount of leakage radiation, defined as the radiation which escapes through a protective shield, may be included in the results. However, even if it is included, leakage radiation is imagined to be far less than scattered radiation because observed dose decreased remarkably with decreasing field size.

Scattered radiation was prominently influenced by exposure conditions. Standard measurements were performed at 80KVp-100mA-0.05sec. These values were derived from the condition of conventional chest radiography, while 75KVp-200mA-0.2sec from abdominal radiography. The exposure conditions should be selected to provide for proper density in radiography according to patient size, his positioning and so on. The dose increased exponentially with increasing voltage and increased linearly with increasing current and exposure time. The effects of current and exposure time were not so prominent as voltage. The dose increased exponentially with increasing field size, specially in high voltage regions. The selection of appropriate radiation field is very useful not only in reducing patient exposure, but also in improving the image quality of radiography. However, excessive limitation of radiation field miss the image of objects from the image reception area. Therefore, careful attention should be paid to select appropriate radiation field. The dose decreased prominently with increasing focus-to-detector distance. The results agreed with our knowledge that the dose is proportional to the reciprocal of the square of distance. It is more valuable for the radiation protection, to keep a distance from an X-ray tube as possible as one can. As shown in Fig 7, the dose depended on the detector-to-ground distance and the maximum dose was observed at 50 to 100cm high from the ground. At less than 50cm and more than 100cm high, the dose decreased gradually.

In conclusion, radiologic technologists can't avoid occupational exposure as far as they use X-rays generator. However, they can reduce it by taking into consideration of radiation protection. It serves to limit radiation exposure to know about scattered radiation from an X-ray generator in one's institution.

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