Proceedings of the Eleventh EGS4 Users' Meeting in Japan, KEK Proceedings 2003-15, p.97-106

ESTIMATION OF THE EFFICACY OF PROTECTIVE COATS IN ABDOMINAL ANGIOGRAPHY

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Abstract

The risk of occupational exposure in abdominal angiography is reported to be high due not only to direct radiation, but also stray radiation from inspection tables, patients, the image intensifier, the beam limiting system (collimator), etc. The Japanese standard JISZ4831 prescribes protective coats of at least 0.25 mm lead equivalent and is the uniform thickness of lead equivalent. The most commonly used protective coats are 0.25, 0.35, or 0.5 mm in thickness. The weight of a typical protective coat is about 3 kg. While there are coats that weigh up to 6 kg, wearing such heavy coats becomes physically burdensome as inspection time increases. The trade-off between physical burden and protection was considered by measuring the X-ray intensity distribution and attenuation rate of stray radiation in each position assumed by the medical staff.

In the case of inspections performed at an x-ray tube voltage of 80 kV, it may be possible to reduce the weight of the lead rubber apron by about 33% because the lead thickness is reduced uniformly when shielding capability of a 0.25 mm thick Pb layer is accepted as the standard at 40 cm above the gonad position. The reduction in weight was feasible, even from a managerial perspective, because the increase in the dose rate is only about 0.01 mGy/min at 110 kV, whereas the intensity is about 1.5 times higher than at 80 kV.

1. Introduction

Medical personnel involved in abdominal angiography are exposed to not only direct radiation but also stray radiation from, e.g., inspection tables, patients, the image intensifier and beam limiting system (collimator). Their exposure is reported to reach dangerous levels as inspection time increases [1-3].

There are various methods of protection against radiation, such as the use of special protection equipment, controlling the inspection time and the distance from the radiation source. While radiation protection equipment will often include special components for eye and neck protection, the most basic and commonly used form of protection is the protective coat. The Japanese standard JISZ4831 prescribes protective coats of not less than 0.25 mm lead equivalent and uniform thickness of lead equivalent. Protective coats that are 0.25, 0.35, or 0.5 mm in thickness are the types most widely used among medical staffs. The weight of a typical protective coat is about 3 kg. Some protective coats weigh as much as 6 kg, however, these present a physical burden in extended inspections.

The present study investigates which positions necessitate protection from X-ray by analyzing the X-ray intensity distribution and the attenuation rate of the stray radiation at all the different positions assumed by the medical staff. The trade-off between burden and protection was considered, and the viability of the viability of using heavier coats was assessed.

2. Materials and Method

The Monte Carlo code used in this study was “Electron Gamma Shower version4 (EGS4, KEK-improved version)”. Low-Energy Photon-Scattering Expansion (LSCAT) was also used to calculate the stray radiation and the air kerma. The X-ray intensity and the air kerma were calculated with a PC/AT compatible computer (Windows), which could be compiled by Lahey Fortran. The angiography equipment is shown in Fig. 1. The total filtration thickness of aluminum was 2.5 mm.

2.1 Geometrical configuration used in the calculation of the x-ray distribution

The geometrical configuration used in calculating x-ray intensity is shown in Fig. 2. The x-ray tube focus was taken to be 0.0 cm. A point 30 cm away from the x-ray tube focus was translated horizontally to the origin. The detector was translated up and down from the origin to the measurement points in 10-cm increments. The phantom size 30 cm ×40 cm×20 cm, similar in size to the water phantom described in JISZ4915. The detector that the stray radiation penetrated corresponded to a 10 cm×10 cm×10 cm volume of air.

The configuration used in calculating the patient skin absorption dose is shown in Fig. 3. The volume of skin used for obtaining the skin absorption dose was 10 cm×10 cm×10 cm. The skin absorption dose was corrected for the dose absorbed by CsI.

The intensity distribution at each position assumed by the surgeon was calculated from the focal position (0.0 cm) up to 100 cm above the focal position with or without the phantom, and with or without the lead shield.
The distances were not measured from the floor in view of the differences between individual pieces of equipment.

2.2 Generation of X-ray photons

The distribution of X-ray photons was calculated using the equation of Birch and Marshall [4]. The number of X-ray photons generated per keV was 10^6. The X-ray tube voltage was successively adjusted to 50, 80, and 110 kV. Thus, the energies of the incident photons varied between 10 keV and the corresponding maximum energy (50, 80, or 110 keV). The ripple factor of the tube voltage was set to 0. The dimensions of the radiation field corresponded to the field size of the image intensifier.

2.3 Calculation of the x-ray intensity

The distribution of the x-ray photons generated was factored into the calculation of stray radiation intensity distribution at each staff position. The calculated stray radiation was converted into kerma K by

$$K = \int [(\mu_{en}/\rho)_E \times E \times \Phi_E] dE$$

The mass energy absorption coefficient $(\mu_{en}/\rho)_E$ was calculated based on the photon attenuation coefficient data, and interpolated by a B-Spline curve between the calculated points at 1 keV increments. The parameters for the simulation were NCASES:10^6 for 1 keV, PCUT: 10 keV and ECUT: lower limit. The effective energy was calculated from the stray radiation spectrum at each operation staff position. The attenuation ratio of the stray radiation was calculated based on the difference between the lead thickness. The effect of the additional 0.1, 0.2, or 0.4 mm Cu filter were added to that of the fixed 2.5 mm Al filtration, and the intensities of the stray radiation were calculated from the focal position. These values were compared with the intensities where the doses absorbed by the CsI, which is the input fluorescent screen of the image intensifier, were equal to the intensities obtained without a filter. The protection capability of the coats was determined based on the results obtained.

3. Results

3.1 Intensity Distributions of the Stray (Scattered) Radiation

The intensity distributions of the stray (scattered) radiation are shown in Fig. 4. In the following discussion, (+) and (-) denote, respectively, the presence and absence of the item that they follow. For example, Phantom(-):Pb(-) is shorthand for “in the absence of a water phantom and lead shield”. In the case of Phantom(-):Pb(-), the intensity at 40 cm was low, and there was scattered radiation from the Image Intensifier. For Phantom(+):Pb(-), the intensity at 40 cm was large, and there was the small amount of scattered radiation from the Image Intensifier. For Phantom(+):Pb(+), the intensity at 40 cm was extremely low, and there was the small scattered radiation from the Image Intensifier. “Measurement” denotes the value measured by the survey meter. The calculated and measured values agreed almost exactly.

The stray radiation intensity distribution attained its maximum value at 130 degrees of the front-back direction with respect to the incidence direction when the phantom was present. The stray radiation decreased when the lead shielding was fixed in the table.

3.2 Stray (scattered) radiation spectra

The stray (scattered) radiation spectra obtained at the tube voltages of 50, 80, and 110 kV are shown in Fig. 5. The maximum intensities were observed 40 cm from the x-ray tube focus. The spectra were found to exhibit the same trends regardless of the tube voltage.

3.3 Attenuation ratio of the stray (scattered) radiation

The ratio by which the lead shield attenuated the radiation was calculated. The results are shown in Fig. 6. The attenuation ratio varied with distance from the x-ray tube focus. Above the x-ray tube focus, the quality of radiation rose slightly, while the intensity decreased.

3.4 Relationship between lead equivalence and attenuation ratio

The relationship between lead equivalence and attenuation ratio for the tube voltage of 80 kV is shown in Table 1. The attenuation ratio was normalized to a lead equivalence of 0.25 mm. The optimal shielding ability of lead was predominantly examined over the 30 to 50 cm range, where radiation of a slightly low quality but remarkable intensity was observed. Thus, the lead was not expected to enhance shielding ability at 100 cm. The results for the tube voltages of 50 kV and 110 kV are shown in Table 2.

3.5 Correction of the intensity for the dose absorbed by CsI

The attenuation ratio results were corrected for the dose absorbed by the input fluorescent screen (CsI) of the image intensifier. The corrected results are shown in Table 3. The dose absorbed by the patient’s skin did not show a significant decrease.

3.6 Ratio of the stray (scattered) radiation

The air kerma decreased at certain positions (10 cm, 40 cm, 70 cm), while increasing at others (100 cm) when the additional filter was fixed. The ratios of the air kerma are shown in Table 4.

3.7 Corrected relationship between lead equivalence and attenuation ratio

The ratio of the air kerma at locations where the medical staff may be found is shown in Table 5. The tube voltage was 80 kV. The air kerma in the head-cervix region, with the filter mounted, increased when corrected for the dose absorbed by CsI. The air kerma at all other positions decreased when corrected. The results for the tube voltages of 50 kV and 110 kV are shown in Table 6.

4. Discussion

The Japanese standard JISZ4831 prescribes protective coats of at least 0.25 mm lead equivalent and of uniform quality. Medical staffs typically use protective coats having a thickness of 0.25, 0.35, or 0.5 mm. The weight of a typical protective coat is about 3 kg. One can find protective coats weighing up to 6 kg, however the physical burden of wearing these heavy coats increases considerably with inspection time. Analysis of a Monte Carlo simulation revealed that the reduction of the lead thickness would result in a 67% decrease in the weight of a lead rubber apron as a whole.

From the standpoint of radiation control, lowering the protective capability of protective coats is undesirable. On the other hand, any extra weight that is not needed adds unnecessarily to the manufacturing costs as well as to the physical burden associated with wearing the coats. The results of stray radiation analysis at all the different positions assumed by the medical staff will help streamline the design of protective coats, however, implementation of any weight reduction measures will have to take into account that the number of radiography examinations and exact laboratory procedures vary from one facility to another.

5. Conclusion

In the case of inspections performed at an x-ray tube voltage of 80 kV, it may be possible to reduce the weight of the lead rubber apron by about 33% because the lead thickness is reduced uniformly when shielding capability of a 0.25 mm thick Pb layer is accepted as the standard at 40 cm above the gonad position. The reduction in weight was feasible, even from a managerial perspective, because the increase in the dose rate is only about 0.01 mGy/min at 110 kV, whereas the intensity is about 1.5 times higher than at 80 kV. ICRP1990 stipulates that the benefits of protection intervention outweigh the cost of injury management and that the examination type, scale, and period be optimal. However, it is necessary to adjust the degree of weight reduction according to the annual inspection time and inspection conditions.

References

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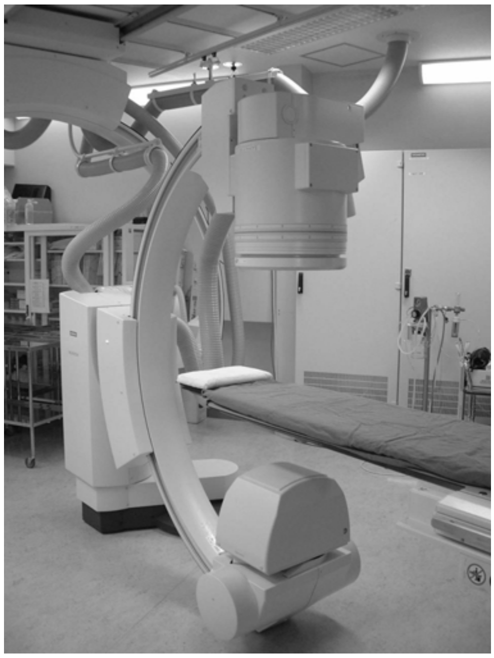

Fig. 1 : Photography of Angiography Equipment.

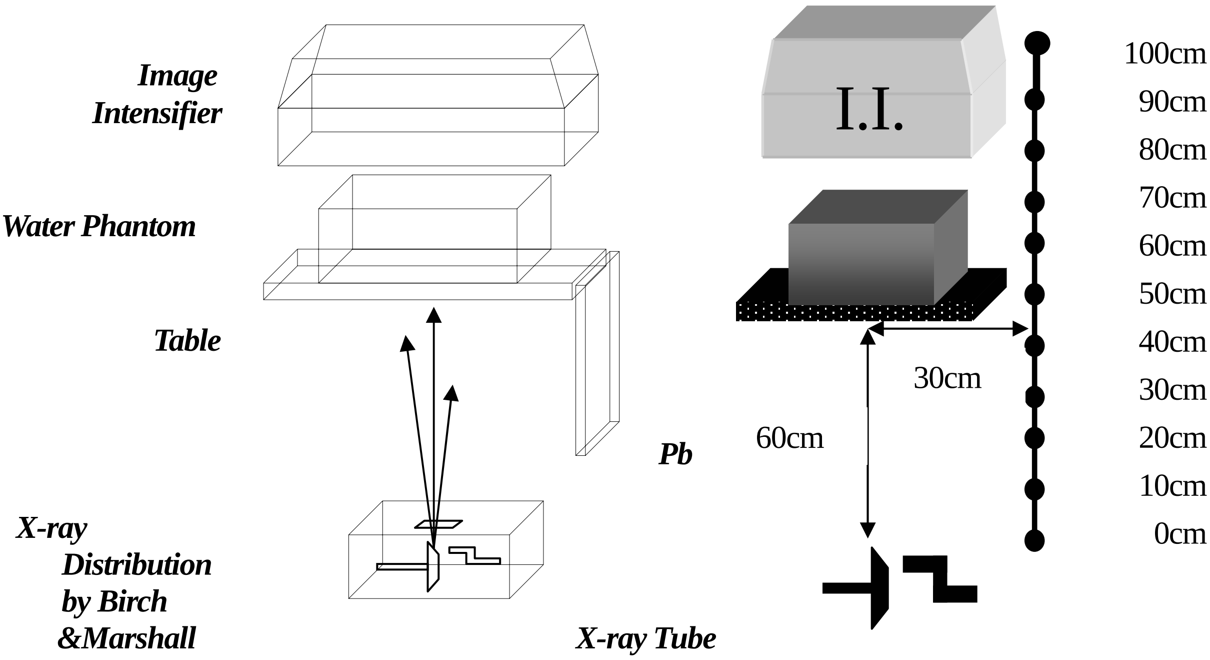

Fig. 2 : Geometry of the elements to calculate x-ray intensity

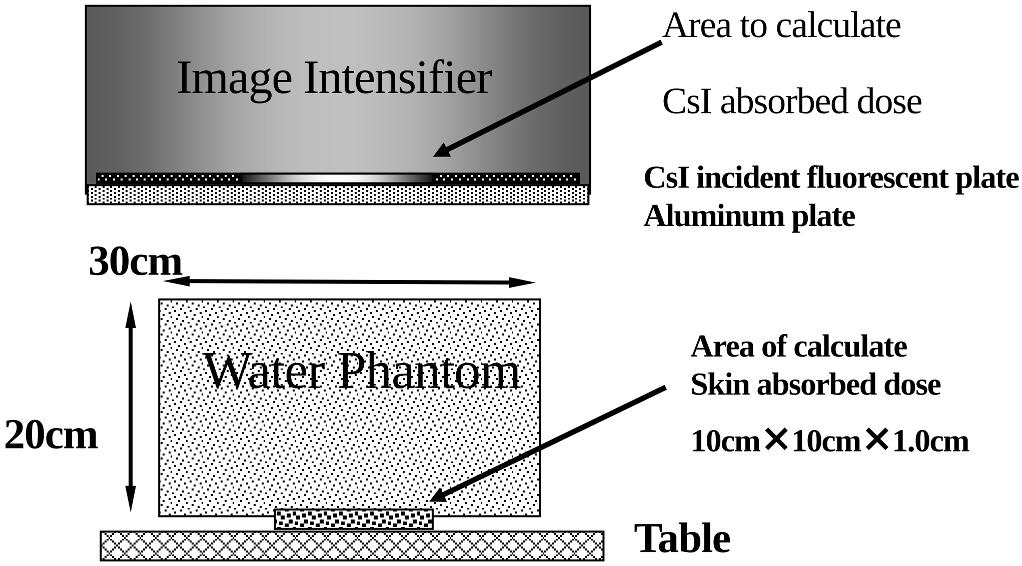

Fig. 3 : Geometry to calculate the patient skin absorbed dose and CsI absorbed dose.

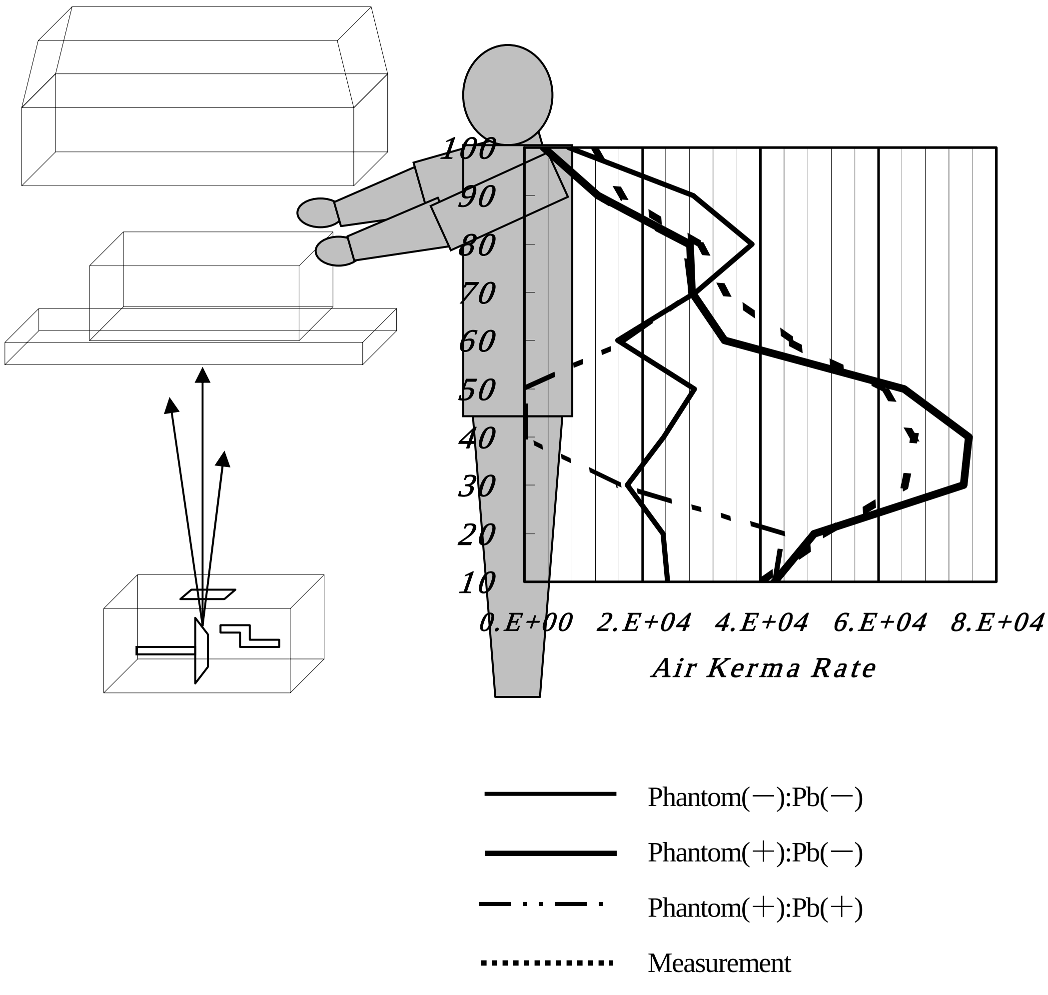

Fig. 4 : Intensity Distributions of the Stray (scattering) Radiation

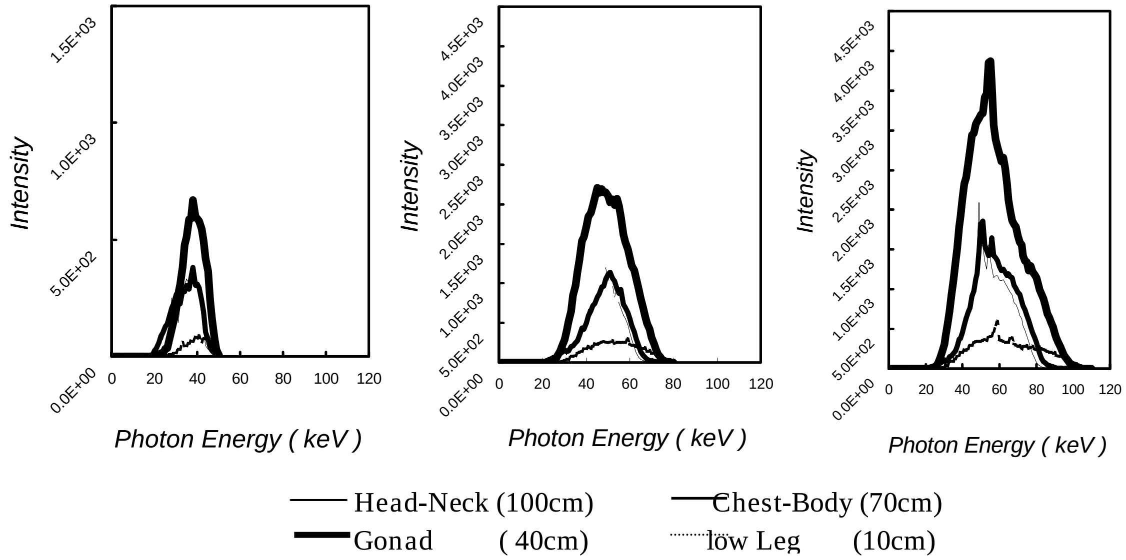

Fig. 5 : Stray(scattered) radiation spectra obtained at the tube voltages of 50, 80, and 110 kV

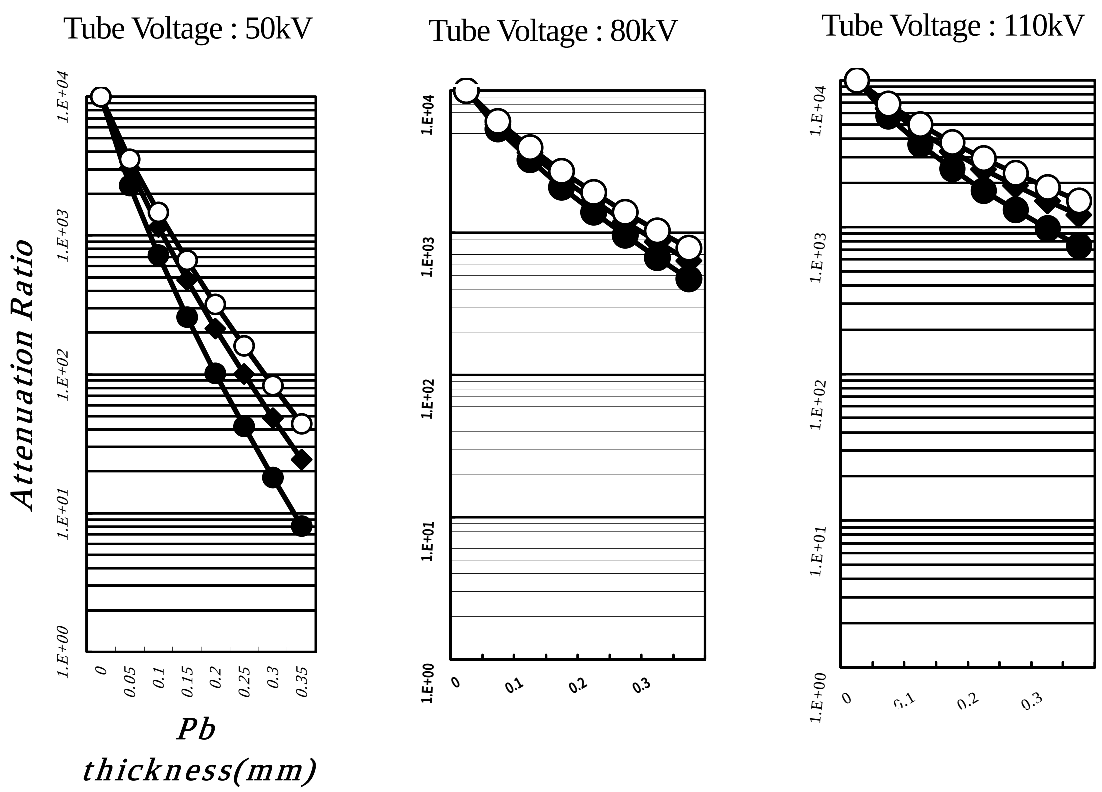

Fig. 6 : Ratios by which the lead shield attenuated the radiation was calculated

Table 1 : Relationship between lead equivalence and attenuation ratio for the tube voltage of 80 kV

		Ratio of Stray Radiation (80kV)		
Lead Thickness(mm)	Ratio of Lead Weight	40cm (Gonad)	70cm (Chest-Body)	100cm (Head-Neck)
0.05	0.2	5.64	3.45	**1.02**
0.1	0.4	3.41	2.18	0.67
0.15	0.6	2.19	1.45	0.46
0.20	0.8	1.46	**1.00**	0.32
0.25	**1.0**	1.00	0.71	0.24
0.3	1.2	0.70	0.52	0.17
0.35	1.4	0.50	0.38	0.13

Table 2 : Relationship between lead equivalence and attenuation ratio for the tube voltages of 50 kV and 110kV

		Ratio of Stray Radiation(50kV)		
Pb	Ratio	40cm	70cm	100cm
0.05	0.20	2.63	1.42	**0.44**
0.10	0.40	0.82	0.53	0.18
0.15	0.60	0.30	0.22	0.08
0.20	0.80	0.12	**0.09**	0.04
0.25	**1.00**	**0.04**	0.05	0.02
0.30	1.20	0.02	0.02	0.01
0.35	1.40	0.01	0.01	0.004

		Ratio of Stray Radiation(110kV)		
Pb	Ratio	40cm	70cm	100cm
0.05	0.20	5.50	4.33	**1.46**
0.10	0.40	3.51	3.02	1.07
0.15	0.60	2.41	2.12	0.81
0.20	0.80	1.72	**1.67**	0.62
0.25	**1.00**	**1.26**	1.30	0.49
0.30	1.20	0.94	1.02	0.57
0.35	1.40	0.72	0.81	0.32

Table 3 : Correction for CsI absorbed Dose

Filter	110k	80kV	50kV
	1.00	1.00	1.00
0.1mmCu	0.82	0.77	0.61
0.2mmCu	0.69	0.60	0.39
0.4mmCu	0.51	0.40	0.17

Correction Factors

1.00	1.00	1.00
1.13	1.18	1.40
1.26	1.38	2.00
1.58	1.91	4.14

–	1.00	1.00	1.00
0.1mmCu	0.92	0.90	0.85
0.2mmCu	0.87	0.83	0.78
0.4mmCu	0.80	0.76	0.71

Table 4 Intensity distributions of the stray (scattered) radiation

Head-Neck	110k	80k	50k
Filter(--)	1.00	1.00	1.00
0.1mmCu	1.03	1.05	1.12
0.2mmCu	1.04	1.01	1.20
0.4mmCu	1.02	1.06	1.24

Chest-Body	110k	80k	50k
Filter(--)	1.00	1.00	1.00
0.1mmCu	0.95	0.89	0.57
0.2mmCu	0.93	0.83	0.40
0.4mmCu	0.92	0.82	0.22

Gonad	110k	80k	50k
Filter (--)	1.00	1.00	1.00
0.1mmCu	1.00	0.99	0.95
0.2mmCu	0.99	0.97	0.94
0.4mmCu	0.99	0.97	0.92

Low Leg	110k	80k	50k
Filter(--)	1.00	1.00	1.00
0.1mmCu	0.95	0.89	0.71
0.2mmCu	0.93	0.84	0.57
0.4mmCu	0.92	0.83	0.53

Table 5 : Relationship between lead equivalence and attenuation ratio for the tube voltage of 80 kV with the correction to the CsI absorbed dose, adding the filter of 0.1 mmCu.

		Ratio of Stray Radiation (80kV)		
Lead Thickness (mm)	Ratio of Lead Weight	**40cm** (Gonad)	**70cm** (Chest-Body)	**100cm** (Head-Neck)
0.05	0.2	5.58	3.14	1.08(*1.02*)
0.10	0.4	3.37	1.98	0.71
0.15	0.6	2.17	1.32	**0.49**
0.2	**0.8**	**1.45**	**0.91**(*1.00*)	**0.34**
0.25	**1.0**	**0.99**	**0.65**(*0.71*)	**0.25**(*0.24*)
0.30	**1.2**	**0.69**	**0.47**	**0.18**
0.35	**1.4**	**0.50**	**0.35**	**0.14**

Table 6 : Relationship between lead equivalence and attenuation ratio for the tube voltages of 50 kV and 110kV with the correction to the CsI absorbed dose, adding the filter of 0.1 mmCu.

		Ratio of Stray Radiation (50kV)		
Pb	Ratio	40cm	70cm	100cm
0.05	0.2	2.50	0.77	0.46
0.1	0.4	0.78	0.29	0.19
0.15	0.6	0.29	0.12	0.08
0.2	0.8	0.11	**0.05**	**0.04**
0.25	**1.0**	**0.04**	**0.03**	**0.02**
0.3	**1.2**	**0.02**	**0.01**	**0.01**
0.35	**1.4**	**0.01**	**0.005**	**0.002**

		Ratio of Stray Radiation (110kV)		
Pb	Ratio	40cm	70cm	100cm
0.05	**0.2**	**5.50**	**4.11**	**1.50**
0.1	**0.4**	**3.51**	**2.87**	**1.10**
0.15	**0.6**	**2.41**	**2.10**	**0.83**
0.2	**0.8**	**1.72**	**1.59**	**0.64**
0.25	**1.0**	**1.26**	**1.23**	**0.52**
0.3	**1.2**	**0.94**	**0.97**	**0.59**
0.35	**1.4**	0.72	**0.77**	**0.33**