Reduction of Backscattered Radiation in Enclosure X-ray Radiography

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Abstract

Scattered radiation is the main source of radiation dose to radiation workers when working with x-ray radiography. When radiation from an industrial x-ray machine collides with the walls of an enclosure, some radiation is back-scattered back within the enclosure. The scattered radiation is due to, mainly, Compton interaction and fluorescence characteristics radiation following photoelectric interactions. The reduction of the backscattered radiation was accomplished by appropriate selection of a material to line the walls on which the primary radiation is incident and by designing a beam catcher that is capable of absorbing significant portion of the scattered radiation.

Backscattered radiation from commercially available materials was investigated. These materials include lead, concrete, aluminum and iron. The primary radiation from an x-ray machine was directed normally on the material and the backscattered radiation was measured by using sensitive ionization chamber. Measurements were made at different angles between incident and backscattered radiation and at several x-ray tube voltages ranged from 70 kVp to 110 kVp. It was found that iron produced the least amount of backscattered radiation that was about 50-60% of that of lead. On the other hand concrete and aluminum produced about 35% of that of lead. The significant reduction of scattered radiation by iron suggests that lead, which is currently used as a primary shield in most installations, should be located on walls from outside the enclosure and the walls should be lined from inside with iron.

A beam catcher panel was constructed of perpendicular parallel plates mounted on a planer base of the same material. Several panels made of iron and concrete were investigated. Backscattered radiations were measured at different x-ray tube applied voltages, different angles between incident and scattered radiation, different separation distances between the parallel plates, and different plate heights. The investigation suggests that it is possible to reduce backscattered radiation up to about 45% by using iron panel and up to about 30% using concrete panel.

1. Introduction

The aim of this work is to find out methods and means to reduce scattered radiation to a minimum in enclosure radiography. Scattered radiation is the main source of exposure to radiation workers in enclosure industrial radiography. Reduction of scattered radiation will reduce doses to workers and to general public as well.

In most industrial or medical x-ray rooms either concrete or lead is used for shielding and inner cladding of the room. Preliminary measurements indicate that lead backscatter large portion of incident radiation, increasing radiation doses to workers. Studies are needed on commercially available building materials radiation properties in order to select most appropriate materials that back-scatter least amount of radiation. Scattered radiation consists, mainly, of two components:

1. Compton scattering
2. Characteristic x-ray scattering

The Compton back-scattered x-ray energy E' is given by:

$$E' = \frac{EE_e}{E(1-Cos\vartheta)+E_e}$$

E = incident gamma energy

E_e = mass energy of electron (511 keV)

ϑ = Angle of scattering

The intensity of Compton scattered radiation depends on many factors that includes: attenuation coefficient, Compton cross section, thickness, and atomic number of the target material.

The intensity of characteristics x-rays emitted following incident radiation depends on type of material, energy and attenuation properties of the material to its own characteristics x-rays and on material thickness. Lead emits several high energy x-rays that reach close to about 85 keV. It, therefore, undergo less attenuation and self-absorption in the target material. Iron emits up to 6.4 keV.

As incident photon energy increases, more radiation is backscattered, because incident radiation can penetrate more inside the material and scattered (reflection) radiation can transport material easier in its way back to the detector. The relative intensity of mono-energetic backscattered radiation to incident radiation follows the relation: $\exp[-(\mu + \mu')t]$ where μ is the linear attenuation coefficient of incident radiation, μ' that of backscattered radiation and t is the penetration thickness. Incident radiation as well as backscattered radiation is not mono-energetic, the true relation will be a superposition of above equation over energy range.

In this work we studied scattered radiation from three commercially available materials that can be used for inner cladding of x-ray room enclosure in addition to lead. These are: iron, concrete and aluminum.

In addition to materials studies for back-scattered radiation, beam catchers were designed for further reduction of scattered radiation. Among different panel shapes, Parallel Plates Panel showed maximum reduction of radiation.

NCRP 49 gives the shielding requirements of scattered x-ray beams. Holynska [1] used low energy gamma and x-rays and observed that the intensity of scattered radiation increases with increasing grain size as observed in the case of sand and for samples containing heavy elements like iron and barium. Mcguire [2] calculated the barrier requirements for primary, secondary and scattered radiation at 100 kVp and compared the values to that of NCRP49. The values were less than that suggested by NCRP49. Simpkin [3] calculated the exact barrier thicknesses for primary as well as scattered and leakage radiations in an x-ray room containing multiple x-ray sources, for various operating potentials. The calculations were extension of the NCRP 49 formalism, which provides guidelines for single sources.

Samir Abdul-Majid [4] studied the shielding property of marble using diagnostic x-ray of 60-120 kVp and found the attenuation properties of marble. Abdul-Majid [5&6] used a solar panel to measure primary and scattered beam intensities of an x-ray machine. The angular dependence of scattered radiation, using a phantom that simulated the upper part of the human body, was measured using the solar panel.

2. Materials and Methods

Experimental set-up consisted of an industrial x- ray machine and clinical x-ray machine, an ionization chamber dosimeter and holding systems for the material under study and for the ionization chamber.

Ionization Chamber

The ionization chamber used for the measurement of backscattered x-ray photons was a 600 cc (Model no. 2575C, NE Technology); its energy range is from 8 keV to 2 MeV, its sensitivity is 4.3 rad/nC and has a 99% efficiency at 250V. It was used with Farmer Dosimeter (type 2670A, NE Technology) which is a high quality electrometer. The detector is capable of measuring dose, dose rate, charge and current.

X-ray Machines

The industrial x-ray machine was type Radioflex 200-egs-2, with voltage range of 70 – 200 kVp. The clinical x-ray machine was made by Shimadzu Corporation. The machine has a rotating anode tube assembly (CIRCLEX U13) and has a tungsten faced molybdenum target that permits heavy duty loading. It has a voltage range from 40 kVp up to 150 kVp and operates at single phase full wave and three phase full wave.

Mobile Holders

Two mobile holder devices have been fabricated out of aluminum, one to hold the target material and the other to hold the ionization chamber. Aluminum was used to minimize interfering backscattered radiation. Both devices were fitted with a laser light sources for positioning the target materials with respect to the ionization chamber at suitable distances, angles and heights.

The ionization chamber was calibrated using a standard ^{137}Cs source of 120mCi. The back and sides of the chamber was shielded by a lead sheet to stop scattered radiation coming from sources other than the material under study. Care was taken that the x-ray tube, the material under study and the ion chamber were at the same horizontal level.

Beam Catchers

The beam catcher panel was designed putting into consideration the following points:

1. Its back-scattered to incident x-ray ratio is low.

2. Panel material is readily available at reasonable cost.

3. The material can easily be shaped and fabricated.

Iron and concrete satisfies these properties. Lead was excluded because it cannot be shaped easily to desired panel geometry and because of its high backscattered radiation.

The parallel plates laminated Panel, shown in Fig. 1. Incident primary beam can either hit surface A (strip thickness), or surface B, the distance between plates (strips). If the beam hit surface A, radiation will back-scatter in all directions, while if it hits surface B, most of it will be trapped. If scattered x-rays are unable to penetrate the parallel plates strips the fraction escapes will be □/□.

The base was chosen thick enough such that radiation scatters mainly from panel base and not from wall on which it was installed; this was called the saturation thickness. Iron scatters less radiation than the concrete wall behind it. Experimental measurement showed that the saturation thickness is not more than 4 mm in iron. This was the thickness taken for the base.

The standard x-ray beam cross sectional area is 20x20 cm. The panel dimension was 40x40 cm, 10 cm longer on each side. Larger panel does not affect the nature or results of this study as far as the panel area is larger than beam area.

Because of nature of concrete, we had limitations on the geometry and shape of the concrete panel. Panels with very large strip height can not be cast, and even when they are constructed, they can easily break down. The optimum concrete panels were built with strip height C of 5 cm and strip thickness A of 0.5 cm.

3. Results

Scattering from Different Materials

For materials at saturation thicknesses the backscattering properties were studied at a distance of one meter between x-ray machine target and material under investigation and one meter between the material and the dosimeter. At an angle of scattering of 160^o, the results are shown in Fig. 2. Clearly lead reflects the largest amount of radiation, while iron reflects the least amount. Accordingly, in order to have least amount of radiation to inside the room that may reach radiation workers, iron should be used to clad the surface on which the radiation is incident. Lead which is usually used as a primary shield should be put on the walls from outside, such that scattered radiation is stopped by the wall. Lead reflects about twice the amount of radiation compared to iron, while concrete and aluminum shows intermediate values of backscattered radiation.

Panel Beam Catchers

We have used different strip heights ranged from 2-10 cm and strip spacing also ranged from 2-10 cm. Large amount of data were collected; only typical values are shown in this work. Fig. 3 show backscattered x-ray exposure measured by ionization chamber at angle of 120^o for industrial x-ray machine exposure of 0.1s for iron panel whose strip spacing was 7 cm at different strip heights and at different x-ray machine operating voltages. Clearly the higher the applied voltage of the machine the higher is the exposure. The effect of increasing strip height is also very clear on reduction of backscattered radiation. As strip height increases, more scattered radiation is trapped in the panel. We found that 7 cm or 10 cm is a practical and economical strip height, although more strip height can trap more radiation.

Fig. 4 show scattered x-ray exposure at scattering angle of 140^o for 0.1s x-ray exposure time for 7 cm high iron panel strips at different panel strip spacing and different industrial x-ray machine operating voltages. The reduction in back-scattered radiation increase with reducing spacing between strips (increasing number of strips per unit length), but it increase significantly when strips were completely removed (infinite spacing, flat surface). At smaller scattering angle scattered radiation can be affected more clearly by change in strip spacing.

Fig. 5 show percentage reduction in scattered x-ray exposure at 140^o scattering angle for 0.1 s exposure time of 4 cm high iron panel strips at different panel strip spacing and different industrial x-ray machine operating voltage. The reduction is clearly high at smaller spacing between strips, particularly at higher machine applied voltage. At 110 kVp reduction is more than 40%.

Fig. 6 and Fig. 7 show back-scattered radiation capture properties of concrete parallel plate panels of 5 cm strip heights and 0.5 cm strip thickness at different strips spacing. As mentioned before concrete is less flexible than iron and only limited panel shapes can be made. Clearly back-scattered radiation increases with increase of spacing between strips. It is clear that iron panel can capture more radiation compared to concrete. On the other hand concrete panel can be designed to be part of the existing wall of the radiography enclosure.

4. Discussion and Conclusion

Reduction of backscattered radiation in industrial x-ray enclosure reduces doses to careless or unknowledgeable x-ray machine operators who do not care to stand behind secondary barrier. These types of operators usually less aware of radiation hazard, or their work load force them to complete work quickly.

One significant conclusion, when studying back-scattering properties of materials, is that lead, currently used in most x-ray rooms as primary shield, backscatter highest amount of radiation among material studied. This is confirmed by theoretical calculations by using Monte-Carlo MCNP method [7]. Lead primary radiation shield should be used from outside, not inside the room. If used from inside it can contribute significantly to back-scattered radiation. Iron, on the other hand, scatters least amount of radiation among materials studied. Lead characteristics x-rays energy reaches up to about 85 keV while that of iron is only 6.4 keV and at much lower intensity. Moreover, these high energy x-rays penetrate target materials much easier than lower energy x-rays of iron and able to escape to out side. Those of iron are self-absorbed by the target material itself.

Concrete of 4 cm saturation thickness can also be useful material if room walls were having this values thickness. In this case, no additional inner cladding is needed.

It can be concluded that flat sheets of iron or concrete can be useful inner cladding material. They backscatter least amount of radiation, commercially available and can be easily fabricated. Lead scatter large amount of radiation, expensive, difficult to fabricate and chemically poisonous.

Beam catcher panel prove to be very effective in backscattered radiation reduction. No beam catcher found in literature designed for reduction of back-scattered x-rays; this is the first time such a design is presented expected to be very useful for exposure reduction to radiation workers. The panel is inexpensive and can easily be manufactured. And if concrete is used it can be designed to be part of existing wall

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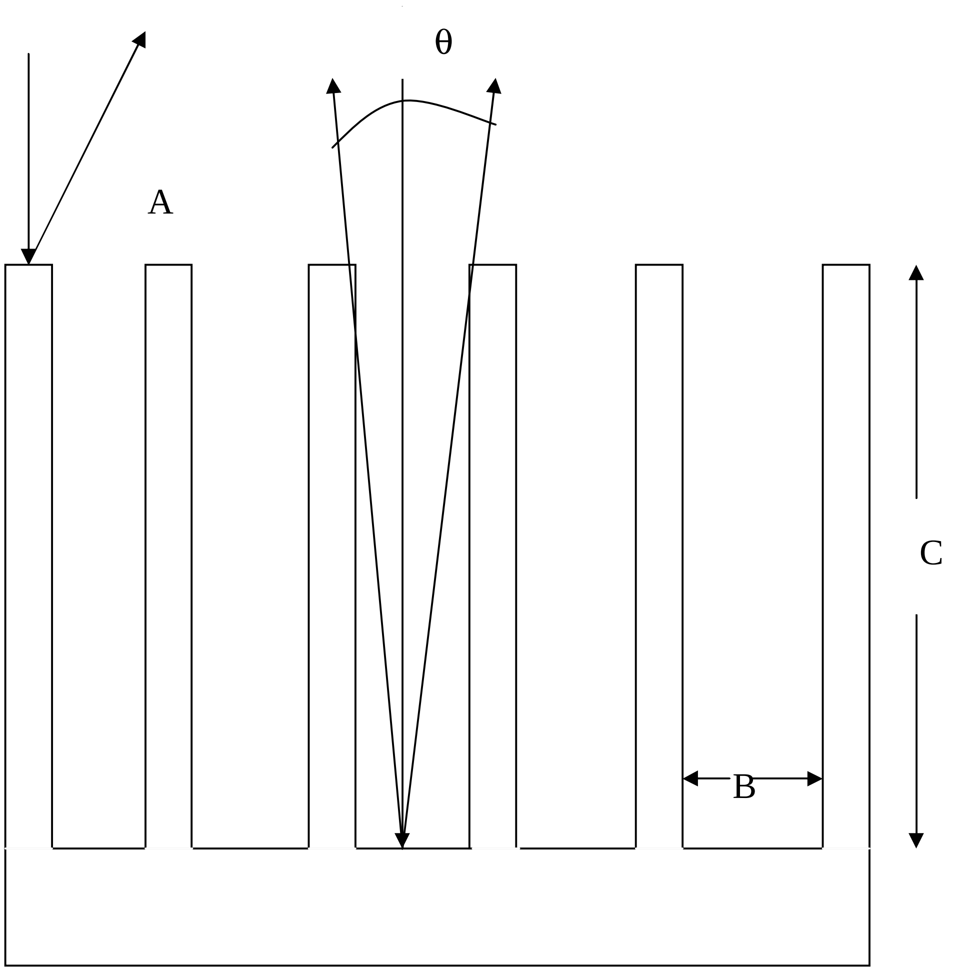
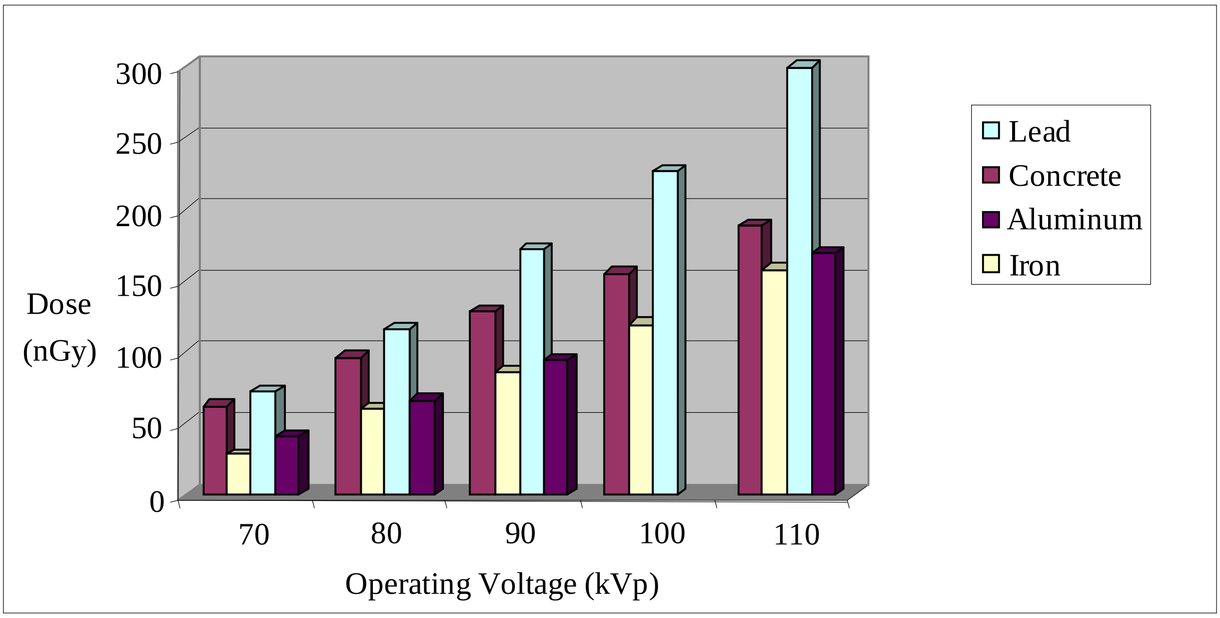


Fig. 1 Parallel plates laminated panel



Dose (nGy)
300
250
200
150
100
50
0
70
80
90
100
110
Operating Voltage (kVp)
Lead
Concrete
Aluminum
Iron

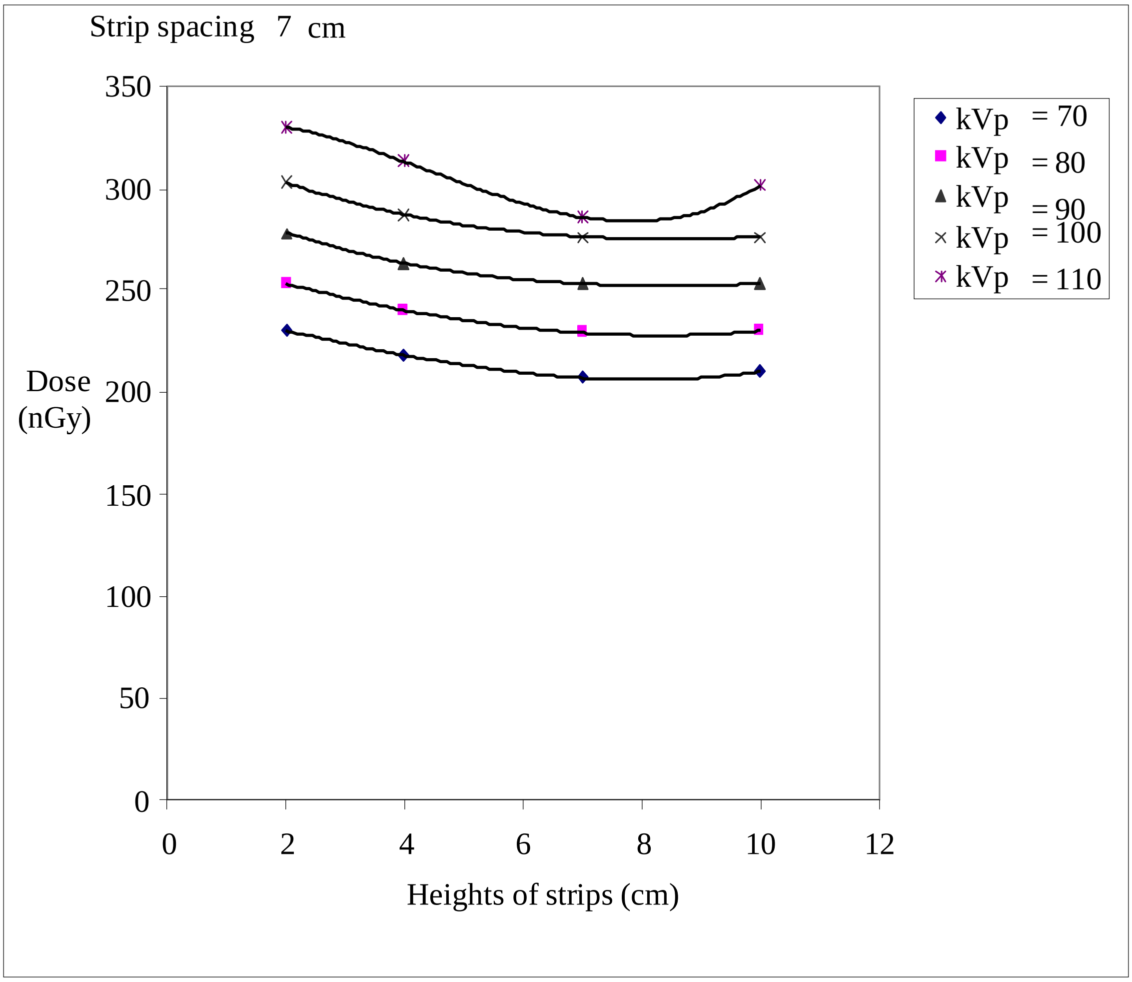


Fig. 3. Scattered x-ray doses in nGy at 120 degrees with incident beam for 0.1s exposure of 7 cm spacing iron panel strips vs different strip heights at different industrial x-ray machine operating voltages.

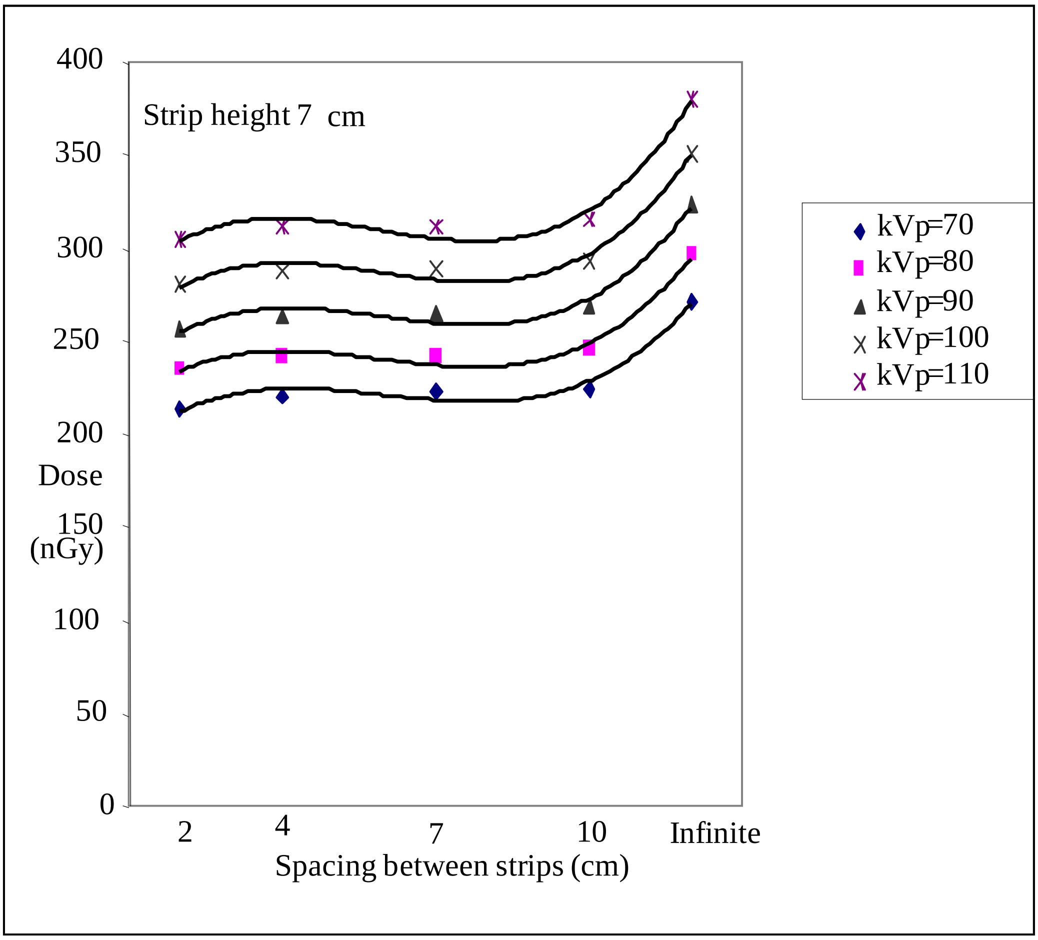


Fig. 4. Scattered x-ray doses in nGy at 140 degrees with incident beam for 0.1s exposure of 7 cm high iron panel strips vs panel strip spacing at different industrial x-ray machine operating voltages.

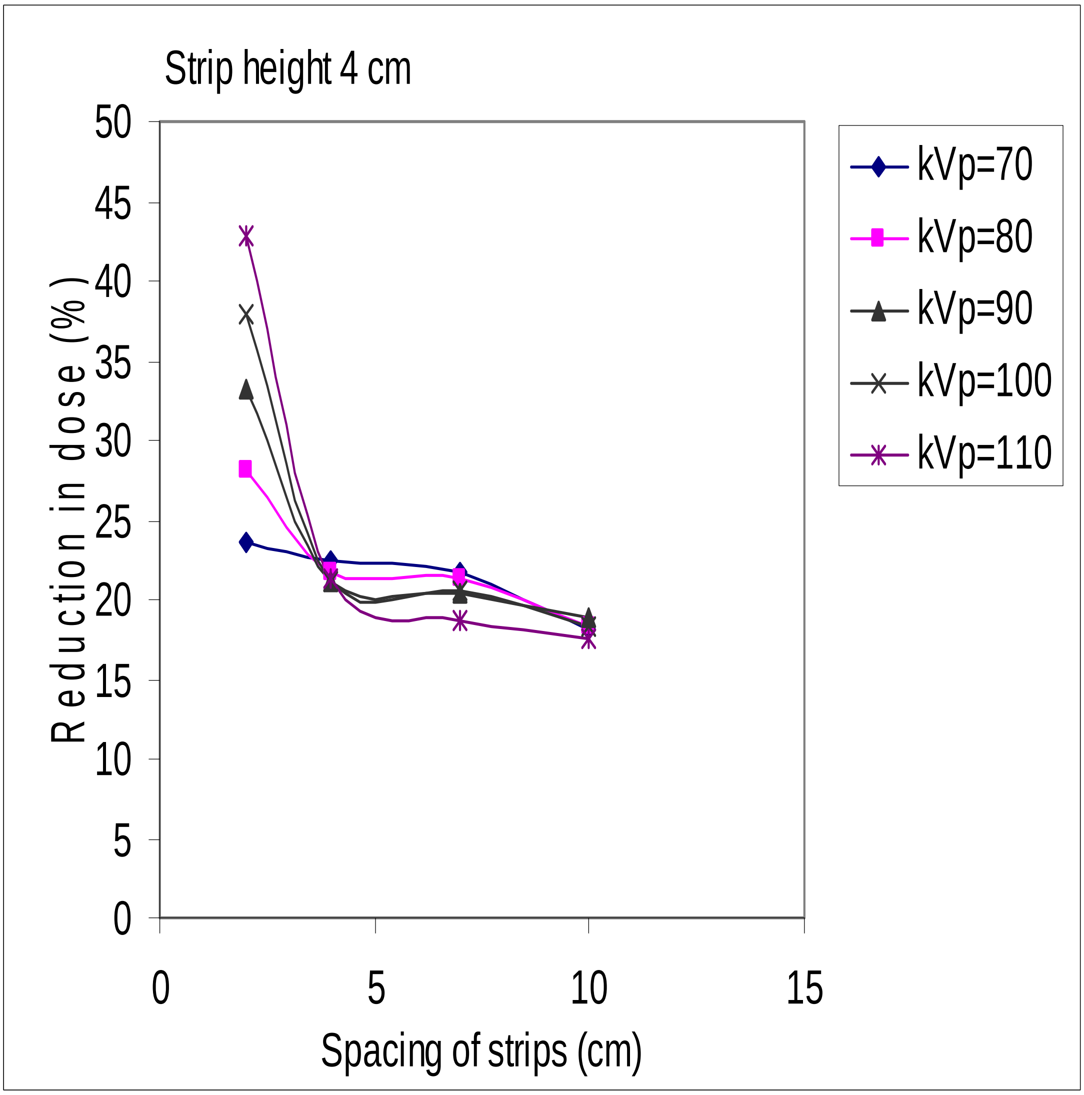


Fig. 5. Percentage reduction in scattered x-ray doses in nGy at 140 degrees with incident beam for 0.1 s exposure time, of 4 cm high iron panel strips vs panel strip spacing at different industrial x-ray machine operating voltage.

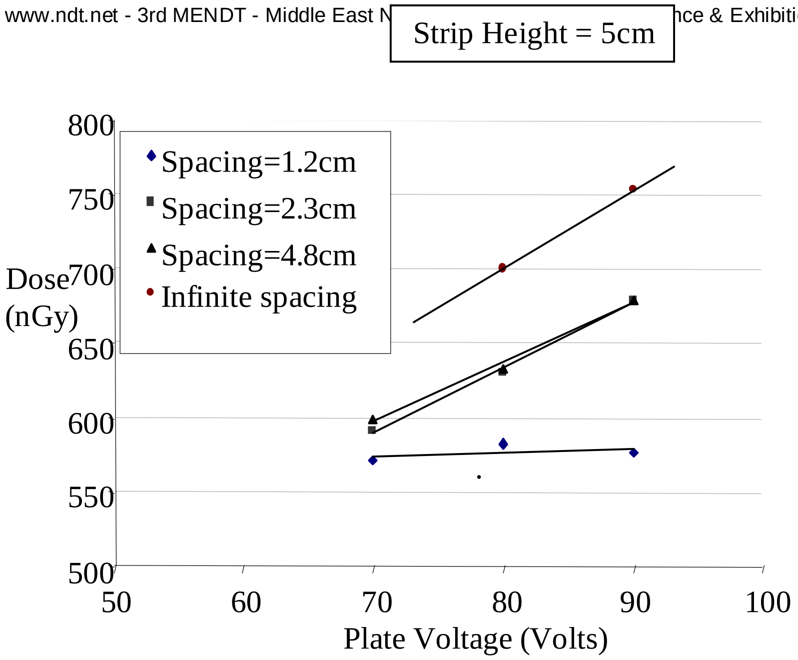


Fig. 6. Scattered x-ray doses in nGy at 140 degrees with incident beam for 0.1 s exposure of 5 cm high concrete panel strips vs industrial x-ray machine applied voltages at different panel strip spacing.

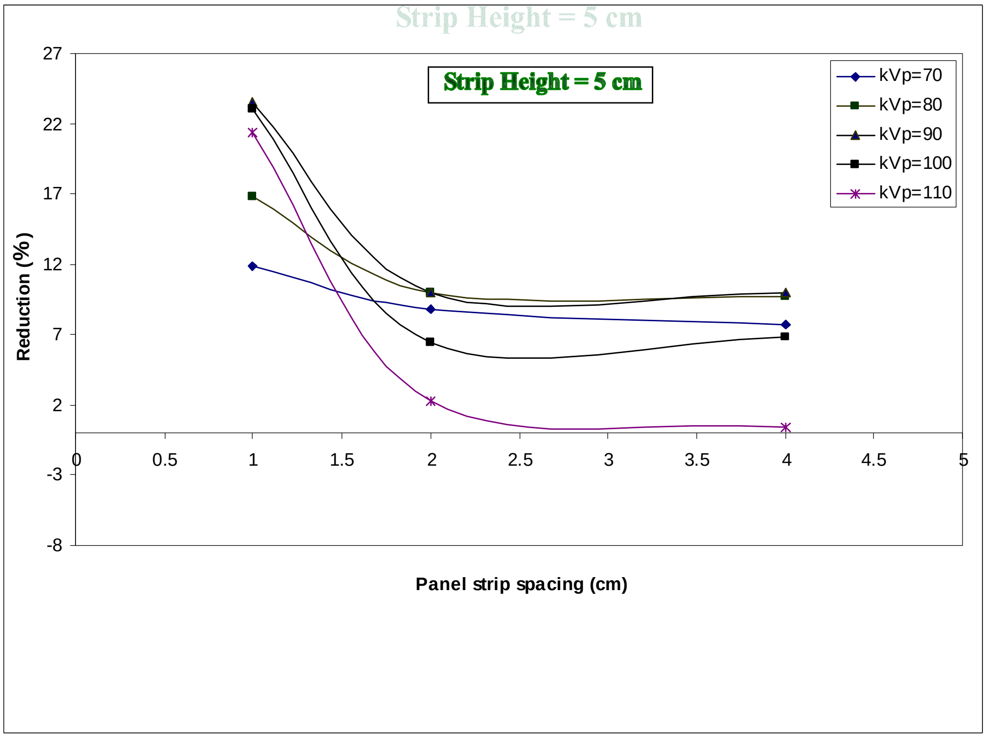


Fig. 7. Percentage reduction in scattered x-ray doses at 140 degrees with incident beam, for 0.1 s exposure time, of 5 cm high concrete panel strips, versus panel strip spacing at different industrial x-ray machine operating voltages.