FACTORS AFFECTING PERCENTAGE BACKSCATTERED X-RADIATION

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ABSTRACT

The effect of the various parameters that are likely to affect the percentage backscattered radiation outside a wooden phantom were studied. It was found that the percentage backscatter increases with the increase of irradiated area, focal scatterer distance and the hardness of radiation used. For all radiation qualities investigated, the percentage backscatter shows a maximum at a backward distance from the scatterer 10 cm. Wide variations usually occur for soft radiations at small backward distances from the scatterer. The percentage backscatter distribution was found to deviate appreciably from the inverse square law within a range of 10%. It was also found that the value of percentage backscatter at one meter from the scatterer differs considerably from the generally accepted value 0.1% of the intensity of the primary beam at the scatterer (1).

INTRODUCTION

Backscattered radiations from objects exposed to primary X-ray beams comprise a possible source of radiation hazard to workers in radiological installations.

Detailed study of such radiations is essential for computing the most appropriate thicknesses of secondary protection barriers. The work of previous workers (2, 3. 4, 5, 6 and 7) in the field of radiation protection

(1) H. E. Johns, (1961). The Physics of Radiology, Page 635.

(2) H. E. Johns, J. W. Hunt and S. O. Fedoruk (1954). Brit. J. Radiol. 27, 443

(3) J. R. Greening (1954). Brit. J. Radiol. 27, 532.

(4) J. H. Martin and Ann Evans (1959). Brit. J. Radiol. 32, 7.

(5) Aaron. P. Sanders, C. W. Chin, K. W. Sharpe, Robert. J. Reeves and George. J. Baylin (1960). Radiology, 75, 595.

(6) J. H. Martin and Gwenda. M. Muller (1961). Brit. J. Radiol. 34, 227.

(7) C. K. Bomford and T. E. Burlin (1963). Brit. J. Radiol. 36, 436.

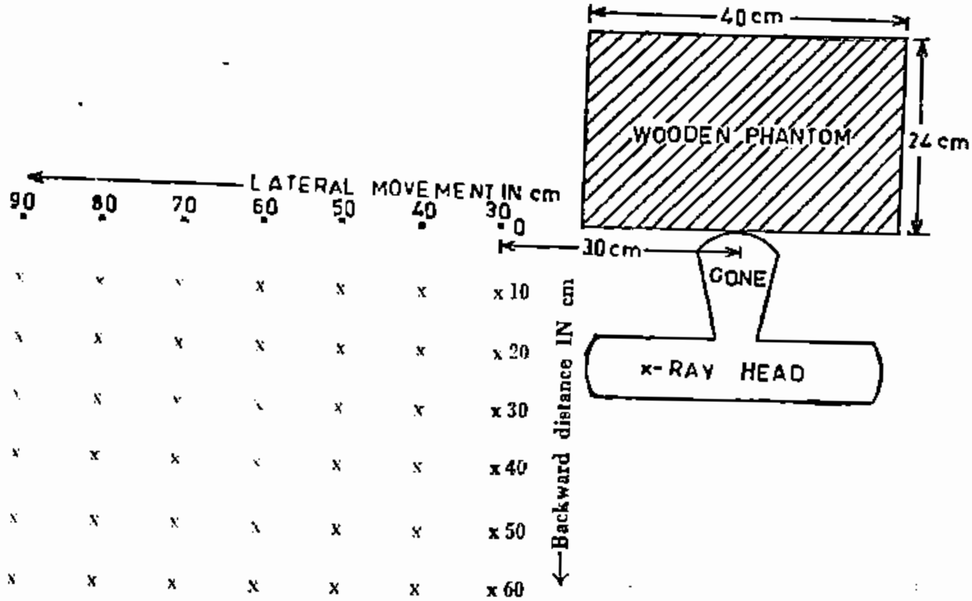


Fig. 1 — The arrangement used for measuring the backscatterd radiation at the places denoted by (X).

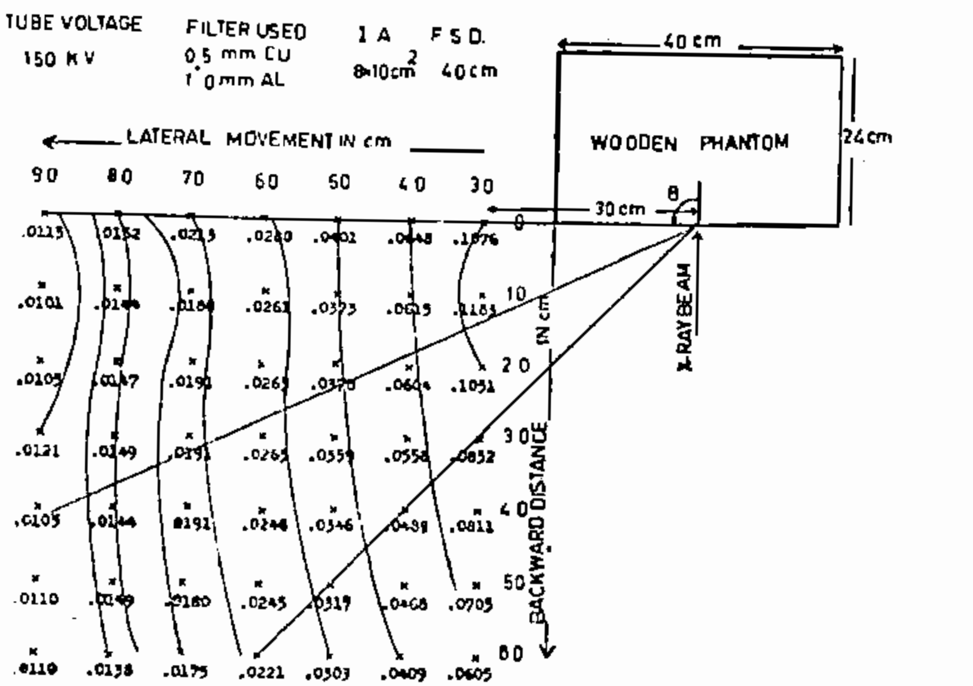


Fig. 2 — Show the different positions at which the percentage backscattered radiation was calculated and the isodose curves, for 150 Kv filtered by + 0.5 mm Cu / 1.0 mm Al

was mainly confined to assessment of percentage scattered radiation in specified directions.

In view of the complexity and variety of the results obtained it was felt that so far, no conclusive results are yet available, and that further experimental work is still needed by theoreticians before they can establish a concrete solution of the general problem of backscatter.

The present investigation is taken up with a view of providing such experimental data concerning the various parameters that are likely to influence the percentage backscatter X-radiation outside the phantom relative to surface dose.

The main factors investigated are :

1.	Radiation quality ;	(H.V.L.)
2.	Irradiated area ;	(I.A.)
3.	Focal-scatterer distance ;	(F.S.D.)
4.	Lateral distance from the principal axis ;	(L.D.)
5.	Backward distance from the scatterer	(B.D.)

METHOD AND APPARATUS

For the results to be more comprehensive, the usual operating conditions of X-rays are chosen comprising :

i - Radiation qualities of half-value layers ranging from 0.1 to 1.6 mm Cu.

ii — Irradiated areas ranging from 24 to 300 cm^2.

iii — Focal-scatterer distances ranging from 30 to 75 cm.

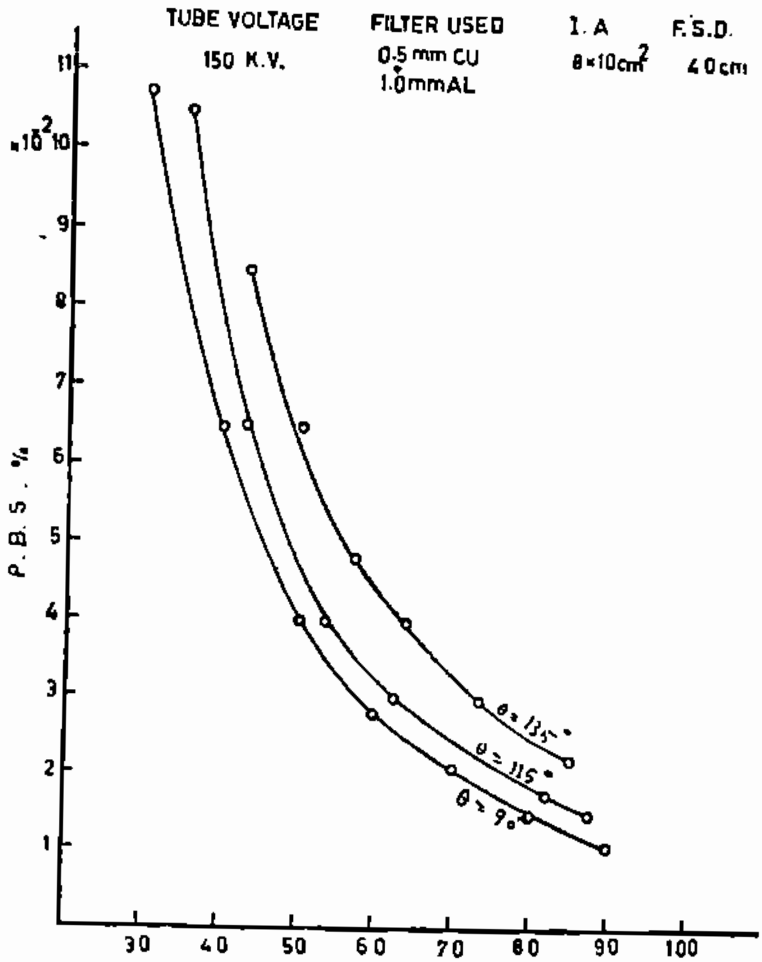
iv — Lateral distances from the principal axis ranging from 30 to 90 cm.

v — Backward distances from the scatterer ranging from 0 to 60 cm.

Measurements were carried out using rectangular fields and restricted to the plance containing the principal axis of the primary beam parallel to long side of the rectangular field. Figure (1) illustrates the set up used for measurements.

The backscattered radiation measurements were corrected for scattering from air and surroundings and expressed as percentage scatter Ds/Dp

(1) H. E. Johns (1961). The Physics of Radiology, Page 324.



DISTANCE IN cm

Fig. 3 — Relation between the percentage backscatter values and the distances from the centre of irradiated area at the selected angles (θ = 90°, 115° and 135°) for 150 Kv filtered by + 0.5 mm Cu / 1.0 mm Al

x 100, where Ds is the scattered dose at a certain position lateral to the phantom and Dp is the dose at a point on the axis of the useful beam at the surface of the phantom.

Leakage radiation from the tube housing under maximum operating conditions at the nearest point to X-ray head was found to be 0.093 mr/m ; a value which is relatively insignificant over the periods of exposures encountered in the measurements throughout this investigation.

The X-ray machine used for this investigation is a Philips 250 Kv — 25 mA, deep therapy unit. The phantom used is made of wooden cubes, of 8 cm side and density of 1.0 gm/c.c. The phantom has a cross-sectional area of 40 x 40 cm^2 and a thickness of 24 cm.

The dosemeter used is a Philips universal dosemeter with ionization and condenser chambers for measuring primary and scattered doses respectively.

RESULTS AND DISCUSSIONS

The results obtained for the scattered doses at the selected positions were corrected for scattering due to air and surroundings. These results — after correction — are given as percentage backscater relative to the dose at the center of the irradiated area on the surface of the phantom. Figure (2) shows a sample of the conditions at which the percentage back-scattered radiation was calculated. In the diagram each percentage is given at the corresponding position and isodose curves are then drawn.

The percentage backscatter values at various angles from the normal to the center of the irradiated area (as shown in the diagram) are deduced by drawing the lines making angles ($\theta = 90°$, 115° and 135°). The points of intersection of these lines with the isodose curves give the required values. These values and their distances from the center of the irradiated area are given in table (1).

Relations between the percentage backscatter values and the distances from the center of irradiated area at the selected angles ($\theta = 90°$, 115° and 135°) are given in figure (3). This figure is of exponential form and shows that percentage backscatter increases with the increase of angle θ . It is also clear that the percentage backscatter is minimum at angle $\theta = 90°$, i.e., tangential to the surface of irradiated area. This is in agreement with that obtained by Bomford and Burlin in 1963.

TABLE 1

Tube voltage	Filter used	I.A.	F.S.D.
150 KV	0.5 mm Cu + 1.0 mm Al	8x10 cm^2	40 cm

θ = 90°		θ = 115°		θ = 135°	
Distance	P.B.S.	Distance	P.B.S.	Distance	P.B.S.
30	0.1076	35.5	0.1051	43.0	0.0852
40	0.0648	43.0	0.0648	50.0	0.0648
50	0.0401	53.5	0.0401	57.0	0.0483
60	0.0280	62.5	0.0303	64.0	0.0401
70	0.0213	75.0	0.0213	71.0	0.0317
80	0.0152	82.0	0.0175	73.5	0.0303
90	0.0113	87.5	0.0152	85.0	0.0221

Detailed discussion of the other factors that are likely to affect the percentage backscatter are given here below.

1. *Effect of Radiation Quality :*

Figure (4) — a, b, c and d — illustrates the effect of radiation quality on the percentage backscatter at different backward distances.

It is clear that in general the percentage backscatter is greater, the higher the radiation quality used within the range investigated. In all cases, variations with backward distance are maximum over a distance of 30 cm with a peak value at 10 cm depth. Throughout the backward distances up to 60 cm, it seems that highly significant differences in percentage backscatter values are mainly due to the radiation quality especially at small focal-scatterer distances and irradiated areas. These wide overall differences are seriously diminished by increasing the focal-scatterer distance as far as the 1.6 and 0.8 mm Cu half-value layer beams are concerned ; while for the softest quality used the overall differences still remain roughly the same.

2. *Effect of Irradiated Area :*

Figure (5) — a, b and c — illustrates the effect of irradiated area on the percentage backscatter at different backward distances for radiation qualities of half-value layers 0.12, 0.8 and 1.6 mm Cu respectively at a focal-scatterer distance 50 cm.

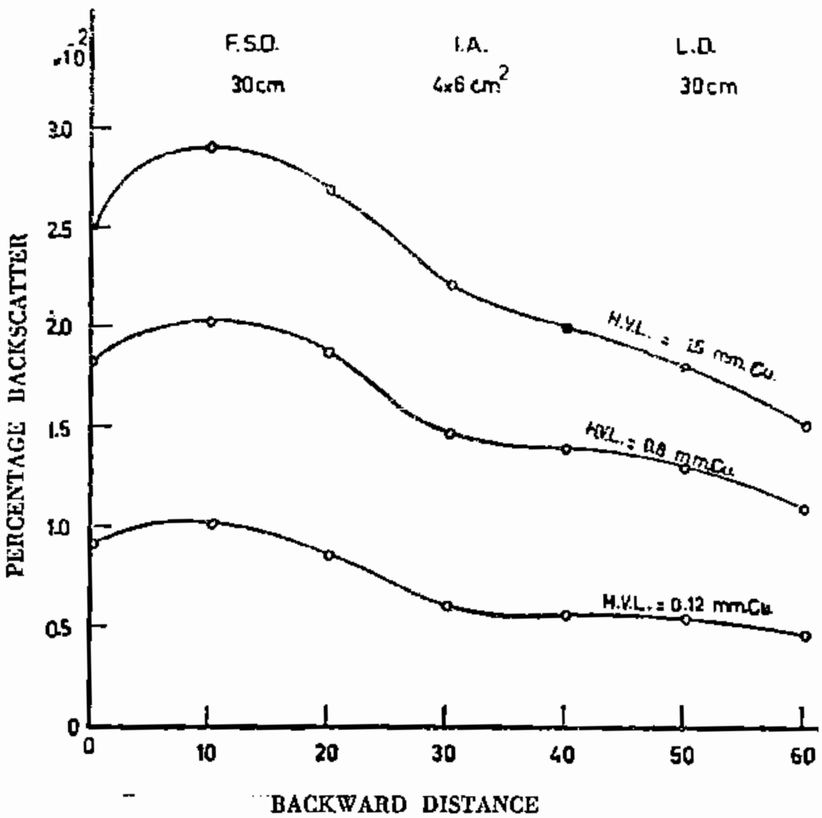


Fig. 4 (a) — The effect of radiation quality on percentage backscatter at different B. D. for focal scatterer distance 30 cm and irradiated area 4 X 6 cm^2.

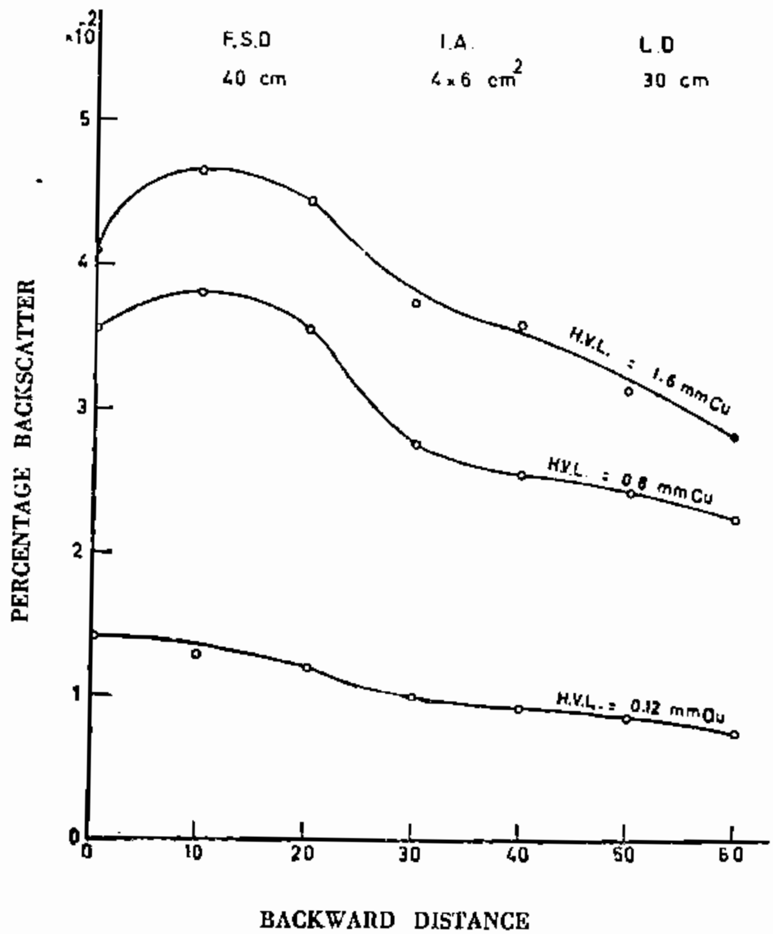
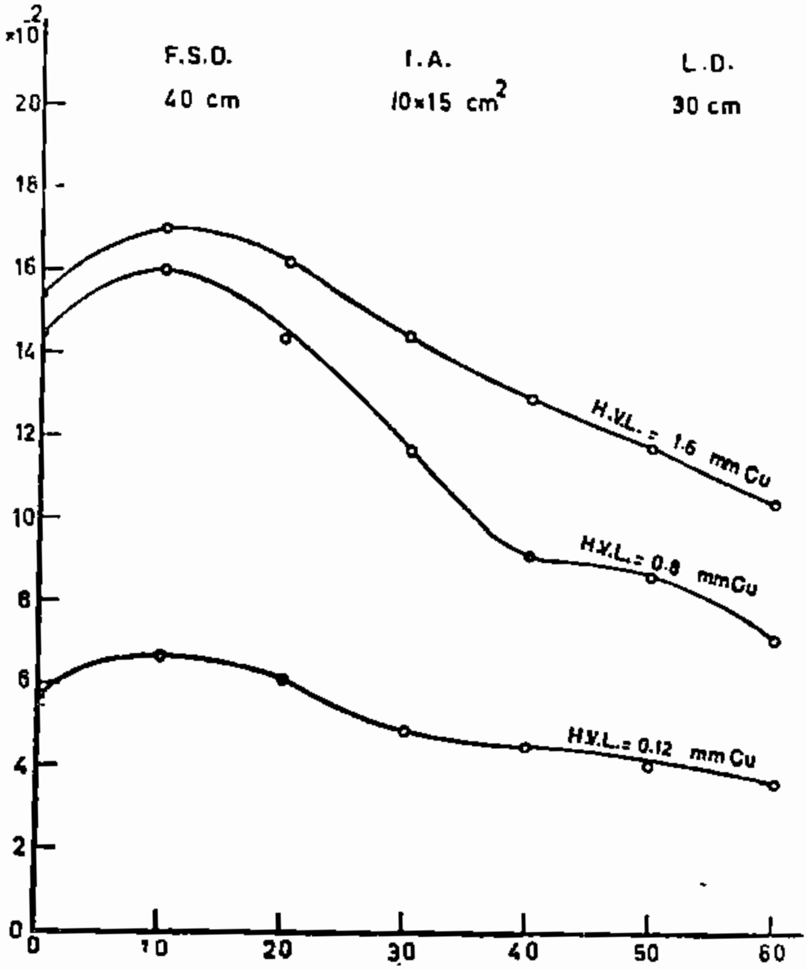


Fig. 4 (b) — The effect of radiation quality on percentage backscatter at different B. D. for focal scatterer distance 40 cm and irradiated area 4 X 6 cm².



BACKWARD DISTANCE

Fig. 4 (c) — The effect of radiation quality on percentage backscatter at different B. D. for focal scatterer distance 40 cm and irradiated area 10 X 15 cm².

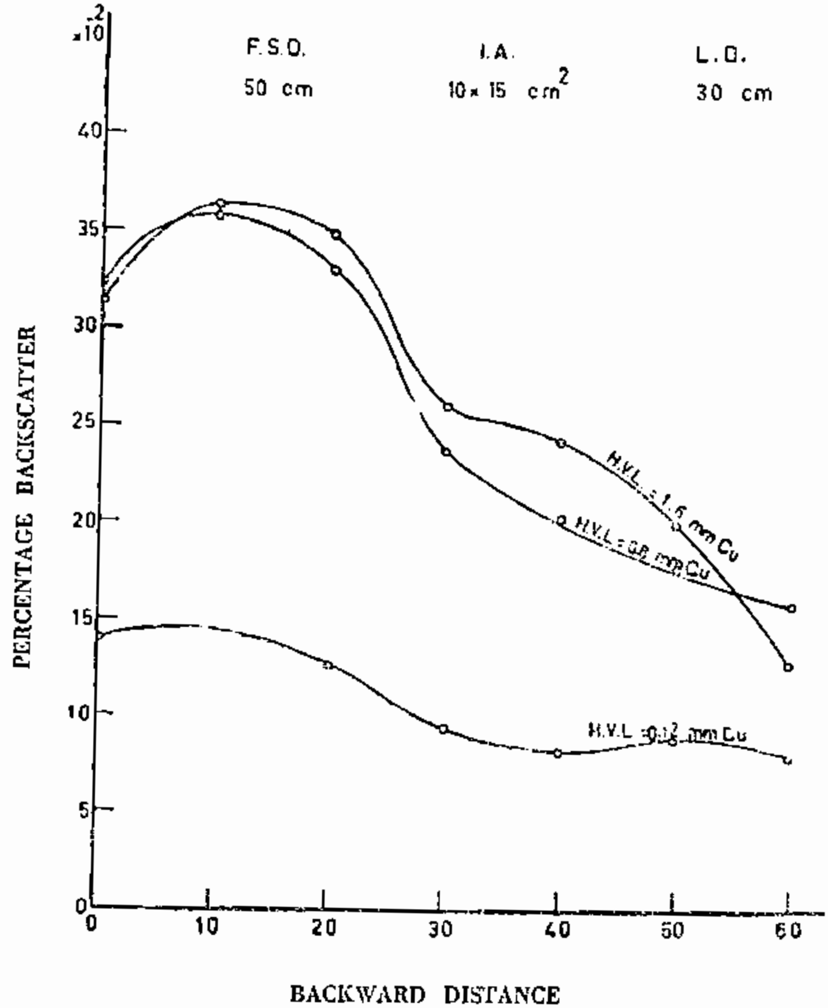
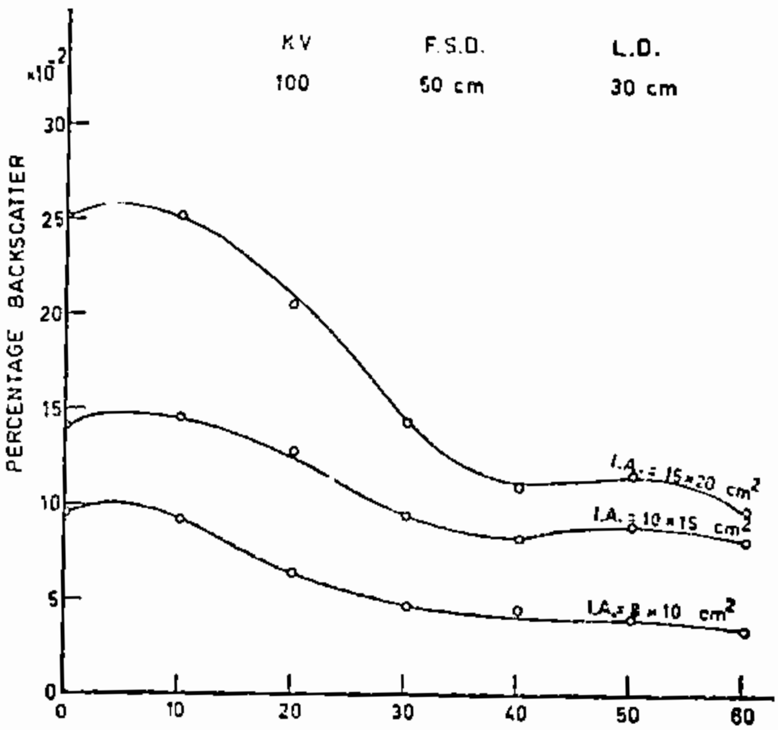


Fig. 4 (d) — The effect of radiation quality on percentage backscatter at different B. D. for focal scatterer distance 50 cm and irradiated area 10 X 15 cm².



BACKWARD DISTANCE

Fig. 5 (a) — The effect of irradiated area on the percentage backscatter at different B. D. for radiation quality of half layer 0.12 m m Cu. at focal scatterer distance 50 cm.

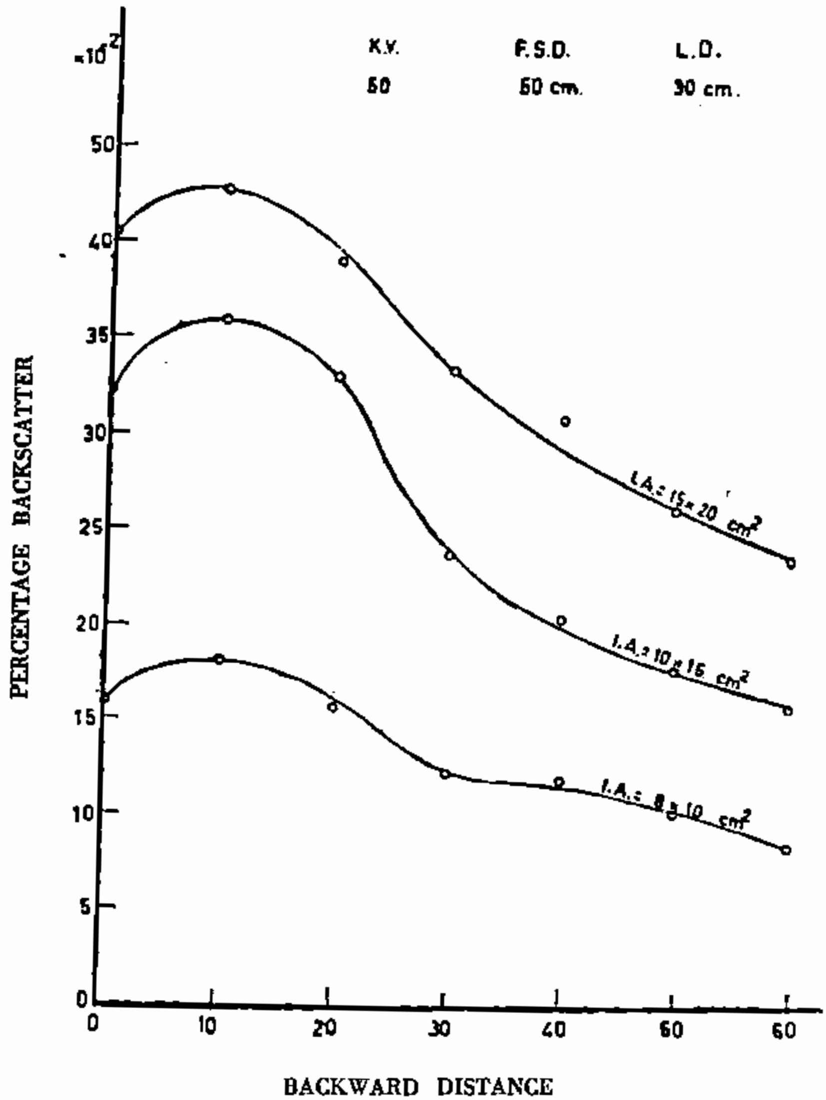


Fig. 5 (b) — The effect of irradiated area on the percentage backscatter at different B. D. for radiation quality of half layer 0.8 m m Cu. at focal scatterer distance 50 cm.

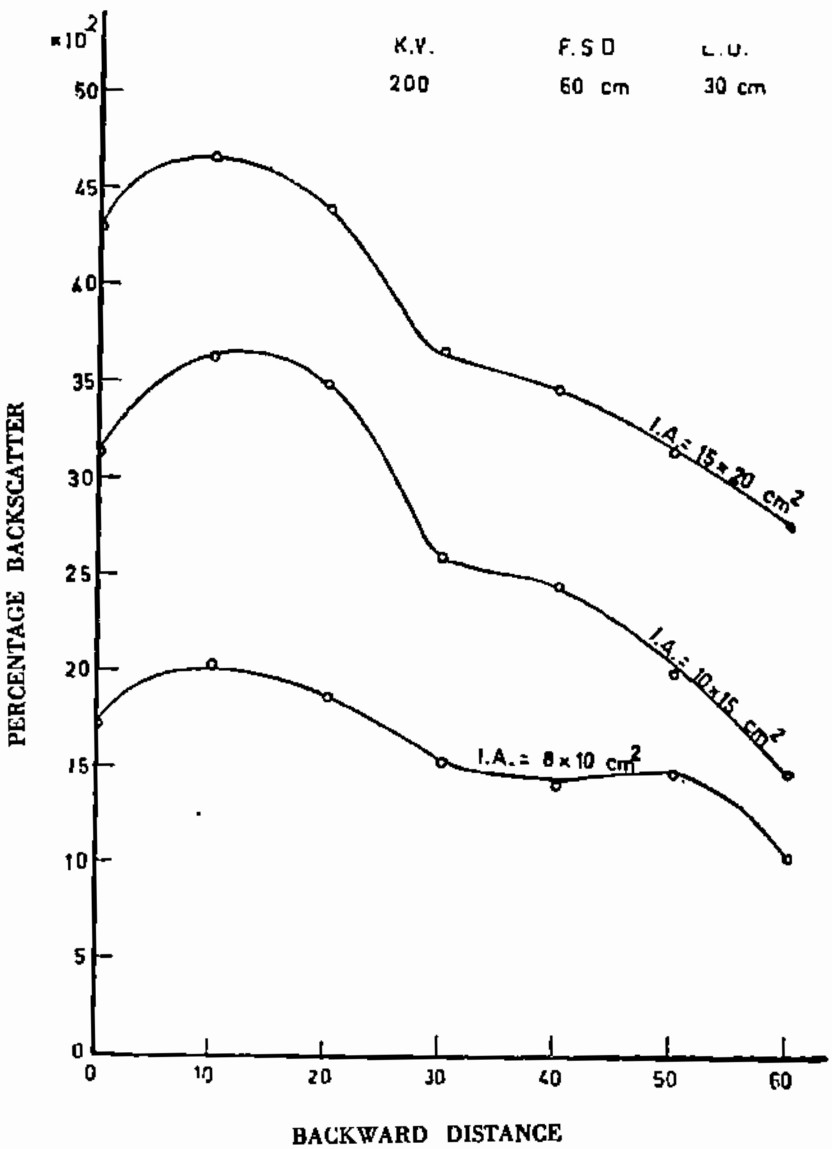


Fig. 5 (c) — The effect of irradiated area on the percentage backscatter at different B, D, for radiation quality of half layer 1.6 m m Cu. at focal scatterer distance 50 cm.

TABLE 2

Focal-scatterer distance (F.S.D.) = 50 cm

Lateral distance (L.D.) = 30 cm

Case A / B

I. A. cm^2	Ratio of P.B.S. at different backward distances						
	0	10	20	30	40	50	60
8 x 10	1.08	1.13	1.19	1.27	1.21	1.48	1.25
10 x 15	0.97	1.01	1.06	1.02	1.21	1.13	0.95
15 x 20	1.06	1.09	1.13	1.37	1.12	1.20	1.17

Case A / C

I. A. cm^2	Ratio of P.B.S. at different backward distances						
	0	10	20	30	40	50	60
8 x 10	2.29	2.86	2.86	3.32	3.13	3.61	3.16
10 x 15	2.23	2.50	2.73	2.77	2.98	2.25	1.85
15 x 20	1.59	1.85	2.15	2.58	3.15	2.73	2.83

It is clear from the accompanying graphs that in all cases the level of the backscatter is higher the bigger the irradiated area. Table (2) summarises the ratios of percentage backscatter at different backward distances. As the half-value layer alone is a crude specification of radiation quality ; ratios of percentage backscatter were found to fit roughly the empirical formula ;

$$\text{Ratio of percentage backscatter} = \sqrt{\frac{\text{Ratio of Kv} + \text{Ratio of H.V.L.}}{2}}$$

According to the suggested formula the ratio for the case represented by A/B is equal to 1.29 and for the case represented by A/C is equal to 2.76, where A denotes the P.B.S. at 200 Kv filtered by 1.0 mm Cu + 1.0 mm Al (H.V.L. = 1.60 mm Cu), B denotes the P.B.S. at 150 Kv filtered by 0.5 mm Cu + 1.0 mm Al (H.V.L. = 0.80 mm Cu) and C denotes the P.B.S. at 100 Kv filtered by 1.0 mm Al (H.V.L. = 0.12 mm Cu).

It is to be noted from table (2) that the ratios of percentage backscatter did comprise irradiation areas of ratios 1 : 2 : 4 approximately.

3. *Effect of Focal-scatterer Distance :*

Figure (6) illustrates a sample of the effect of focal-scatterer distance on the percentage backscatter at different backward distances for radiation quality of half-value layer 0.12 mm Cu.

It is clear that the percentage backscatter generally increases with the increase of focal-scatterer distance. This may be attributed to the fact that the depth dose, within a scattering volume, increases with the increase of the focal-scatterer distance giving rise to an increase in the percentage scattered outside the phantom.

It is also evident that wide variations of percentage backscatter are observed for large focal-scatterer distances especially at small backward distances up to 30 cm.

4. *Effect of Lateral Distance :*

Figure (7) illustrates a sample of the percentage backscatter at different backward distances for a radiation quality of half-value layer 0.8 mm Cu ; keeping other factors constant.

It is clear that for all radiation qualities used the level of percentage backscatter is higher the nearer we get to the scatterer surface (30 cm lateral distance from the principal axis) with a maximum at a backward distance of 10 cm. The further we get away from the side of the scatterer even with a relatively small distance of 10 cm (case of 40 cm lateral distance) the percentage backscatter values are brought down to half their original values for small backward distances up to 20 cm. Beyond 60 cm lateral distance, however, the percentage backscatter variations with backward distance are so small for all the radiation qualities investigated.

5. *Effect of Backward Distance :*

Figure (8) illustrates a sample of the relation between percentage backscatter and lateral distance at different backward distances (planes) for a radiation quality of half-value layer 1.6 mm Cu.

It is clear that all curves are generally of an exponential form. No systematic arrangement among the backscatter radiation levels at successive planes could be traced for the various qualities investigated. This is due to the combination of both attenuation and scattering in a complicated manner that makes the identification of the separate effects practically impossible.

It is clear that the backscatter component is greater at a lower plane (10 cm backward distance) than that at a plane parallel to scatterer

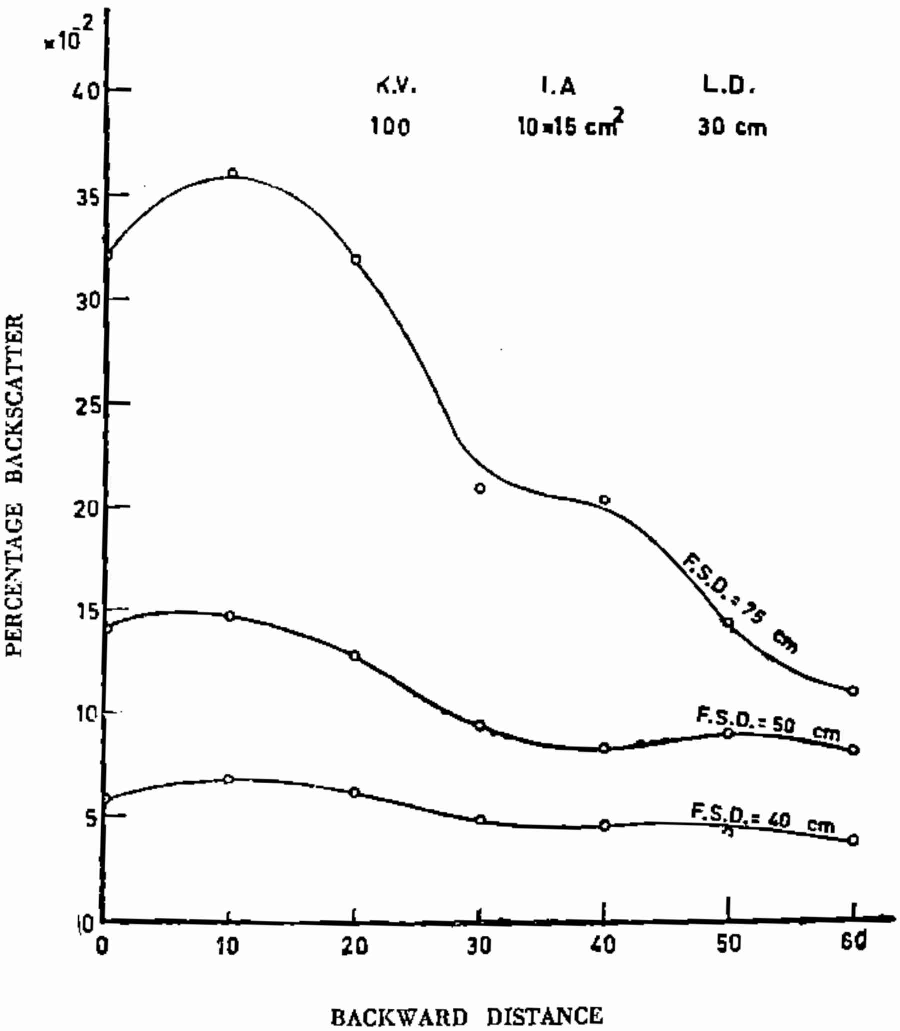


Fig. 6 — The effect of focal scatterer distance on the percentage backscatter at different B. D. for radiation quality of half value layer 0.12 mm Cu. at lateral distance 30 cm.

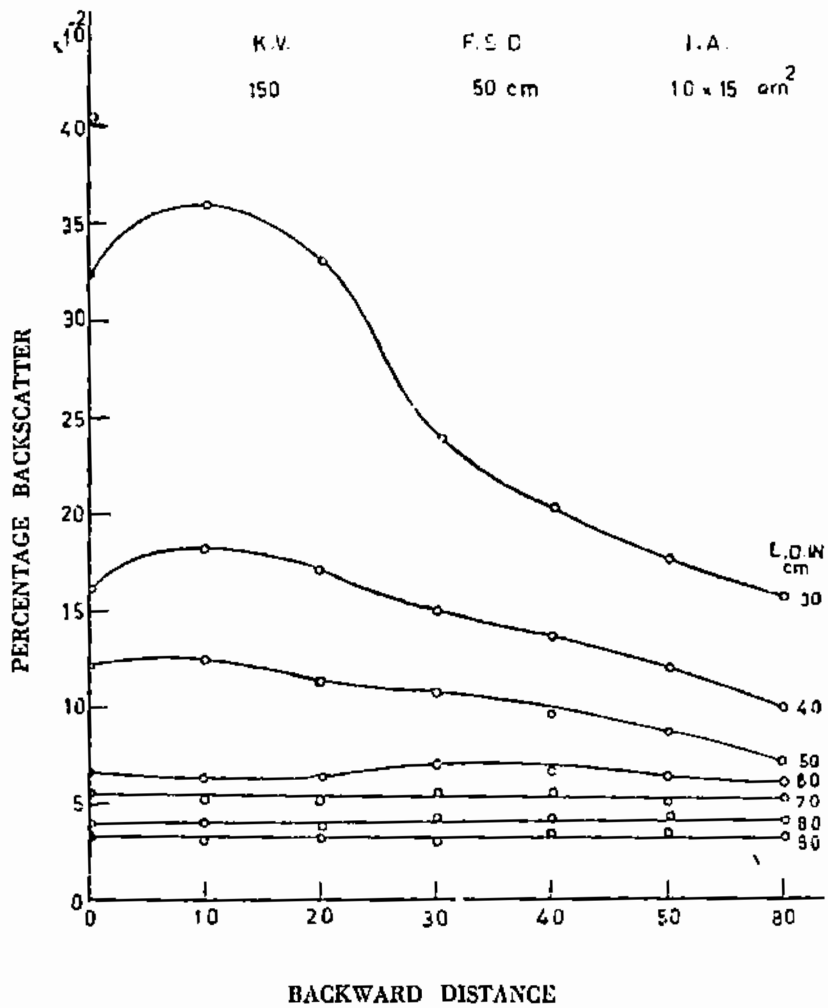
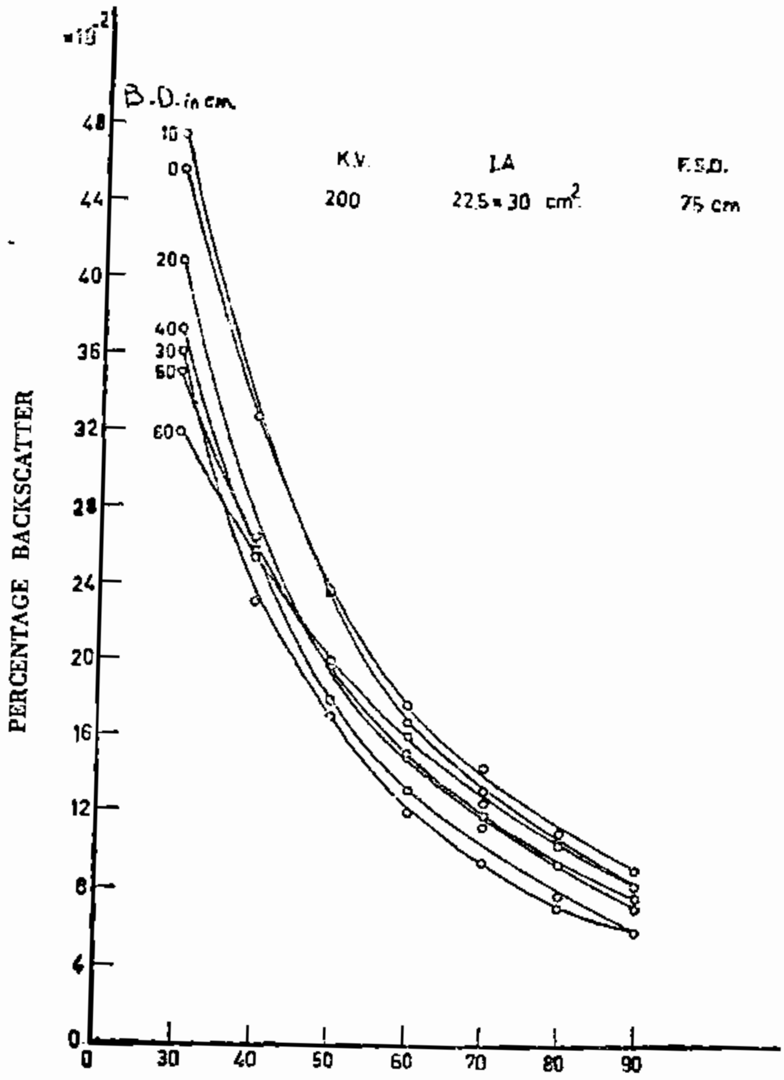


Fig. 7 — The effect of lateral distance on the percentage backscatter at different B. D. for radiation quality of half value layer 0.8 m m Cu.



LATERAL DISTANCE IN cm.

Fig. 8 — Relation between percentage backscatter and lateral distance at different B. D. for radiation quality of half value layer 1.6 m m Cu.

surface (zero cm backward distance) at a lateral distance of 30 cm. This effect is further increased the softer the original radiation quality becomes. Beyond the 30 cm lateral distance irregularities show themselves up in virtue of the numerous other factors involved in the process.

6. *Percentage Deviation from Inverse Square Law :*

It has been illustrated that beyond 50 cm lateral distance the percentage backscatter values suffer slight variations with backward distance. Mean values of percentage backscatter (M) were obtained at lateral distances 50, 60, 70, 80 and 90 cm respectively. The ratios of these mean values at the first two successive planes were denoted by M_1/M_2 ; while the inverse ratio of the corresponding lateral distances were denoted by D_2/D_1. The percentage deviation of the ratio M_1/M_2 from the inverse square law was calculated using the formula :

$$\frac{M_1/M_2 - (D_2/D_1)^2}{(D_2/D_1)^2} \times 100$$

Table (3) summarises the percentage deviations under all operating conditions of focal scatterer distances and irradiated areas for a radiation quality of half-value layer 1.6 mm Cu.

TABLE 3

200 KV. Filiter 1.0 mm Cu + 1.0 mm Al H.V.L. = 1.6 mm Cu.

F.S.D. (in cm)	I.A. (in cm^2)	Percentage Deviation from Inverse Squqare Law I %	II %	III %	IV %
30	4 x 6	— 1.39	— 2.94	+ 2.29	——
40	4 x 6	+ 2.08	+ 2.21	+ 4.58	— 7.08
	8 x 10	— 3.47	— 2.94	— 1.53	— 3.15
	10 x 15	—10.41	——	+ 3.82	— 2.36
50	8 x 10	0.00	— 2.21	— 3.05	—10.23
	10 x 15	— 0.69	— 6.62	+ 3.82	— 3.94
	15 x 20	— 7.63	+ 4.41	— 7.63	+ 5.51
75	12 x 15	+ 2.78	+ 1.47	0.00	— 3.94
	15 x 22.5	+ 6.94	+ 0.74	+ 4.58	— 1.57
	22.5 x 30	— 6.94	— 4.41	— 4.58	— 0.79

In view of the wide scatter of tabulated values, it is concluded that the percentage deviations of backscatter from the inverse square law vary within a range of 10 %.

The columns denoted by I, II, III and IV were calculated according to the corresponding formulae :

$$I = \frac{M_2/M_3 - (D_3/D_2)^2}{(D_3/D_2)^2} \times 100 \quad ; \quad II = \frac{M_1/M_2 - (D_2/D_1)^2}{(D_2/D_1)^2} \times 100$$

$$III = \frac{M_3/M_4 - (D_4/D_3)^2}{(D_4/D_3)^2} \times 100 \quad ; \quad IV = \frac{M_4/M_5 - (D_5/D_4)^2}{(D_5/D_4)^2} \times 100$$

It can be seen from the results that the percentage backscatter varies widely according to the radiation quality used. In all cases it is very much different from the generally accepted value at 1.0 meter from the scatterer which is taken as 0.1% of the intensity of the primary beam at the scatterer.