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Radiation Protection and Imaging Techniques

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Radiation Protection in Teletherapy

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The principal objective of radiation protection is to ensure that the dose received by any individual is as low as practicable and in any case, except for medically required doses to patients, does not exceeded the applicable maximum permissible value.

The objective can be achieved by one or a combination of the following methods:

-providing sufficient distance between the individual and the source or sources of radiation

-limiting the time of exposure

-interposing a protective barrier between the individual ant the source or sources of radiation.

Distance involves the inverse square relationship, the distance are determined by the position of persons relative to sources. It is usually assumed that the individual is at least 30 cm away from the barrier.

The time factor is determined by the period during which an individual is in the radiation field. Consequently it involves both the time when the sources is ON and the fraction of the ON time during which a person is in the radiation field.

In every medical application a protective barrier is required.

In fig 1 some of the physical factors used in determining the barrier requirements for beam sources are shown.

The source at A, surrounded by its protective housing, emits the beam of x or gamma radiation directed at the patient, M. This beam is attenuated somewhat as it passes through the patient; it is usually attenuated much more by the primary protective barrier before irradiating a person at position C, at a distance d_{pri} from the radiation source.

The leakage radiation from the protective housing and the radiation scattered by the patient are attenuated by secondary protective barrier before irradiating a person at position E, at a distance of d_{sec} from the source and the patient.

Radiation scattered from the primary protective barrier may also reach the position E. The radiation scattered from the patient is usually more significant than that scattered from the primary barrier.

Table 2, 3, 4 give suggested values of weekly workload W, use factor U, and occupancy factor T.

There are considerable variation in the shielding requirements for therapy installations due to the wide range of energies and different type of equipment used.

Induced radioactivity in the air and treatment room is negligible for installations operating at up to 10 MV.
Ozone production is negligible during x-ray or gamma-ray beam therapy. However some megavoltage equipment also permits electron beam therapy, which may results in significant ozone production.

Computation of Thickness of Primary Protective Barrier

The transmission factor B_{ux} for the useful beam can be determined by

$$B_{ux} = P\,(d_{pri})^2 / W\,U\,T$$

where d_{pri} is the distance between the source and the point of interest (m), P is the permissible weekly exposure (cGy), W is the weekly workload (Gy at 1 m), U is the use factor and T is the occupancy factors.
The curve showing the relation between B_{ux} and the required barrier thickness S_p is shown in fig. 2.

Computation of Secondary Protective Barrier

Secondary protective barrier shield againsts both leakage and scattered radiation.
It is necessary to evaluate the barrier thickness requirements for each separately.

Barrier against leakage radiation

The use factor U is equal to unit for leakage radiation.
A barrier having a transmission factor B_{lx} is required to reduce the weekly exposure to P. Thus

$$B_{lx} = 1000\,P\,(d_{sec})^2 / W\,T$$

if the leakage radiation is the 0.1 % of useful beam exposure rate at one meter from the source.

The thickness of barrier S_l to protect from leakage radiation at point of interest can be computed using B_{lx} together fig.3 and the table 5 of half-value layers and tenth-value layers.

The leakage barrier thickness S_l il computed by

S_l = N (HVL) or n (TVL)

where N and n are respectively the number of half-value layers and the number of tenth-value layers obtained from fig.3 and taken from table .5..

Barrier Against Scattered Radiation

Radiation scattered from an irradiated object has much lower exposure rate than the incident radiation and usually is of lower energy. The ratio a of the scattered to incident exposure is a function of energy and scattering angle. The numerical value for a field area of 400 cm^2 at the phantom surface is given in table .6.

It is usually assumed that the barrier penetrating capability of scattered photons is the same as that the useful beam.

The barrier thickness required to reduce the exposure to P is the one that corresponds to the value of K_{ux} on the pertinent attenuation curve, where

$$K_{ux} = (P / a W T) \; (d_{sca})^2 \; (d_{sec})^2 \; (400 / F)$$

where d_{sca} is the distance of the scatterer from the source (fig.4).

Barrier Against Stray Radiation

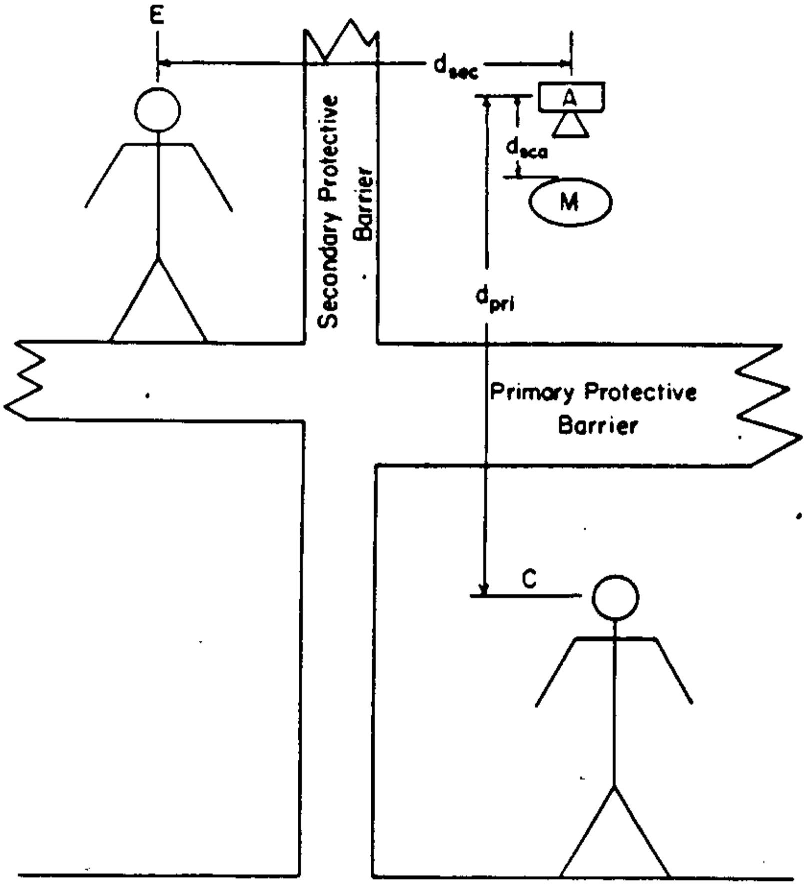
If the required barrier thickness for leakage and scattered radiations are found to be approximately the same, one HVL should be added to the larger one to obtain the required total secondary barrier thickness. If the two differ by at least one TVL, the ticker of the two will be adequate.

In table 7, 8, 9, 10 shielding requirements for barriers for tiptcal installations are given. The assumption use in calculating secondary barrier requirements are shown in table 11.

The radiation at all the energies is composed of photons produced by bremsstrahlung in the material which absorb the electron beam energy. In fact other radiation can be neglected completely unless the energy exceeds the threshold for neutron production. Threshold lie in the range 6-13 MeV for most material. Above this energy, giant-resonance neutron production must be considered, both as a form of promp radiation and as related to induced activity.

Previous shielding considerations are valid up to 10 MV with no neutron production by primary radiation. The planning of radiation shielding, in many Countries, must be performed by a Qualified Expert.

Data are taken from NCRP Report n.49



Elevation view of radiation room and its surroundings with indication of distances of interest for radiation shielding calculations. A is the radiation source, M the patient, and C and E positions that may be occupied by persons.

Fig 1

TABLE 2 – *Typical weekly workloads for busy installations*

Diagnostic	Daily Patient Load	Weekly workload (W) mA min		
		100 kV[a] or less	125 kV[a]	150 kV[a]
Admission Chest:				
(Miniature, with photo-timing grid)	100	100	–	–
Chest:				
(14 × 17: 3 films per patient, no grid)	60	150	–	–
Cystoscopy	8	600	–	–
Fluoroscopy including spot filming	24	1,500	600	300
Fluoroscopy without spot filming	24	1,000	400	200
Fluoroscopy with image intensification including spot filming	24	750	300	150
General Radiography	24	1,000	400	200
Special Procedures	8	700	280	140
Therapy		**Weekly workload (W)**		
Superficial (up to 150 kV[a])	32	3,000 mA min		
Orthovoltage (200–500 kV[a])	32	20,000 mA min		
Megavoltage (0.5 MV–10 MV)	50	100,000 R at a meter[b]		
Cesium				
50 cm *SSD*	16	8,000 R at a meter[b]		
50 cm *SSD*	32	15,000 R at a meter[b]		
60 cm *SSD*	32	24,000 R at a meter[b]		
Cobalt				
70 cm *SSD*	32	30,000 R at a meter[b]		
80 cm *SSD*	32	40,000 R at a meter[b]		
100 cm *SSD*	32	60,000 R at a meter[b]		

[a] Peak pulsating x-ray tube potential.

[b] R per week at a meter = R m^2 per week.

TABLE 3 – *Use factors for primary protective barriers*[a]

[To be used only if specific values for a given installation are not available.]

	Radiographic Installations	Therapy Installations
Floor	1	1
Walls	1/4	1/4
Ceiling	–[b]	–[c]

[a] The use factor for secondary protective barriers is usually 1.

[b] The shielding requirements for the ceiling of a radiographic installation are determined by the secondary barrier requirements rather than by the use factor which is generally extremely low.

[c] The use factor for the ceiling of a therapy installation depends on the type of equipment and techniques used, but usually is not more than 1/4.

TABLE 4—*Occupancy factors for non-occupationally[a] exposed persons[b]*

[For use as a guide in planning shielding where other occupancy data are not available.]

Full Occupancy (T = 1)
Work areas such as offices, laboratories, shops, wards, nurses' stations; living quarters; children's play areas; and occupied space in nearby buildings.
Partial Occupancy (T = 1/4)
Corridors, rest rooms, elevators using operators, unattended parking lots.
Occasional Occupancy (T = 1/16)[c]
Waiting rooms, toilets, stairways, unattended elevators, janitors' closets, outside areas used only for pedestrians or vehicular traffic.

[a] The occupancy factor of occupationally exposed persons, in general, may be assumed to be one (see text, Section 2, for discussion).

[b] It is advantageous in shielding design to take into account that the occupancy factor in areas adjacent to the radiation room usually is zero for any space more than 2.1 m (7 feet) above the floor as the height of most individuals is less. It is possible, therefore, to reduce the thickness of the wall shielding above this height provided the radiation source is below 2.1 m (7 feet). In determining the shielding requirements for wall areas above 2.1 m (7 feet), consideration must be given to the protection of any persons occupying the floor above the areas adjacent to the radiation room. The wall areas over 2.1 m (7 feet) from the floor of the radiation room must also have sufficient shielding to adequately reduce the scattering from the ceiling of adjacent rooms toward occupants.

[c] It should be noted that the use of an occupancy factor of 1/16 may result in full-time exposures in non-controlled areas greater than 2 mR in any one hour or 100 mR in any seven consecutive days.

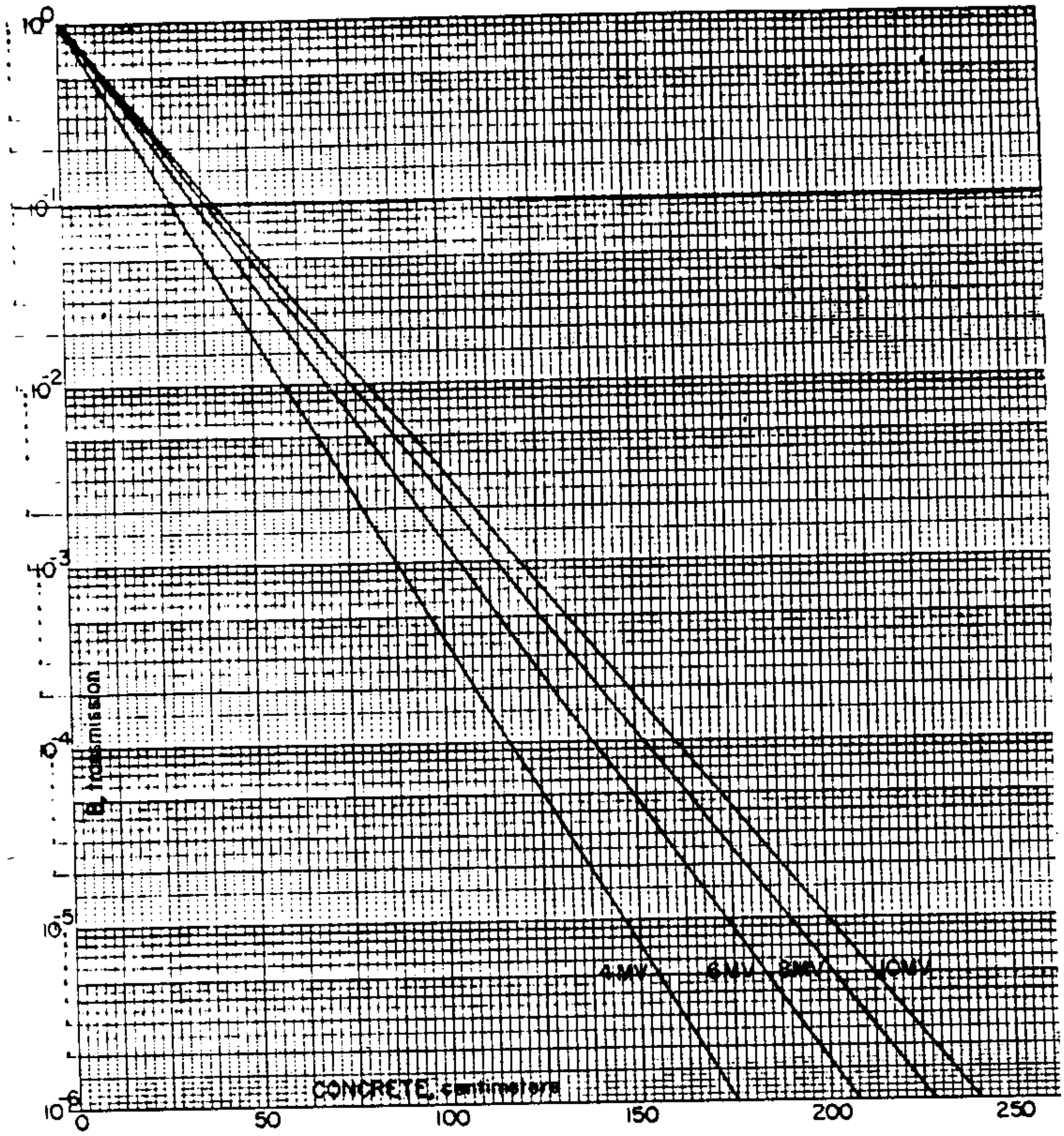
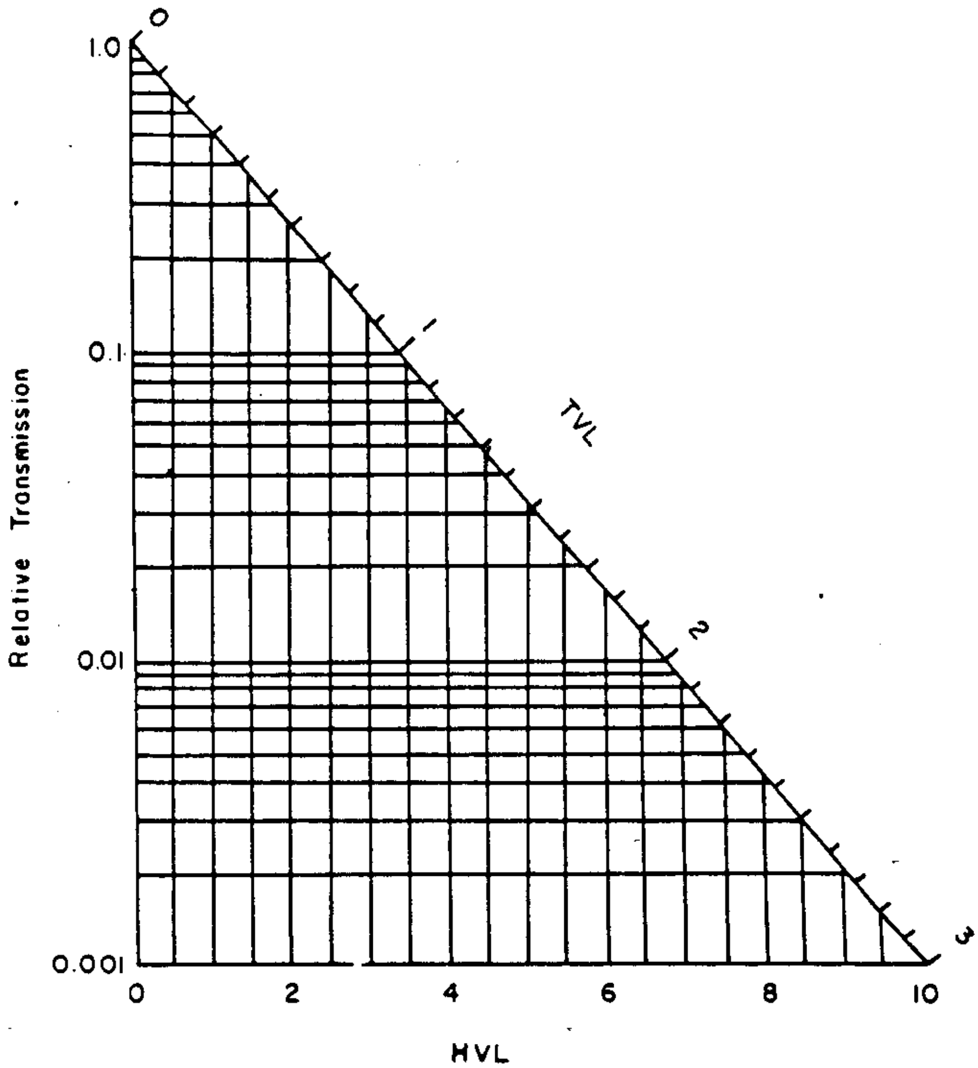


Fig. 7 Transmission through concrete, density 2.35 g cm^{-3} (147 lb ft^{-3}), of x rays produced at 4 to 10 MV. Based on NCRP Report No. 51 [27].



Relation between the transmission. B_{Lx} or B_{Ls}, and the number of half-value layers, N, or tenth-value layers, n.

Fig 3

Material	Range of Density[a]	Average Density[b]	
		g cm^{-3}	lb ft^{-3}
Barium sulfate (natural barite)	–	4.5	280
Barytes concrete	3.6 to 4.1	3.6	210
Brick, soft	1.4 to 1.9	1.65	103
hard	1.8 to 2.3	2.05	128
Earth, dry, packed	–	1.5	95
Ferrophosphorus aggregate concrete	6.0	4.8	300
Granite	2.6 to 2.7	2.65	165
Ilmenite aggregate concrete	4.4 to 4.7	3.85	240
Lead	–	11.36	709
Lead glass	–	3.27	205
Lead glass, high density	–	6.22	387
Limestone	2.1 to 2.8	2.46	153
Marble	2.6 to 2.86	2.7	170
Sand, dry, packed	1.6 to 1.9	–	100–120
Sand plaster	–	1.54	96
Concrete	2.25 to 2.4	2.35	147
Steel	–	7.8	489
Tile	1.6 to 2.5	1.9	118

[a] Density values for the concrete aggregates are given for the aggregate only.
[b] Density values are given for the concrete made from the specified aggregate.
Note: Concrete blocks and cinder blocks vary too much to be listed.
Reference: Mark's Mechanical Engineering Handbook, 5th ed. (McGraw-Hill, New York, 1941); excerpts from a table (pp. 522–523), Approximate Specific Gravity and Density.

TABLE 5 – *Half-value and tenth-value layers*

Approximate values obtained at high attenuation for the indicated peak voltage values under broad-beam conditions; with low attenuation these values will be significantly less.

Peak Voltage (kV)	Attenuation Material: Lead (mm)		Concrete (cm)		Iron (cm)	
	HVL	*TVL*	*HVL*	*TVL*	*HVL*	*TVL*
50	0.06	0.17	0.43	1.5		
70	0.17	0.52	0.84	2.8		
100	0.27	0.88	1.6	5.3		
125	0.28	0.93	2.0	6.6		
150	0.30	0.99	2.24	7.4		
200	0.52	1.7	2.5	8.4		
250	0.88	2.9	2.8	9.4		
300	1.47	4.8	3.1	10.4		
400	2.5	8.3	3.3	10.9		
500	3.6	11.9	3.6	11.7		
1,000	7.9	26	4.4	14.7		
2,000	12.5	42	6.4	21		
3,000	14.5	48.5	7.4	24.5		
4,000	16	53	8.8	29.2	2.7	9.1
6,000	16.9	56	10.4	34.5	3.0	9.9
8,000	16.9	56	11.4	37.8	3.1	10.3
10,000	16.6	55	11.9	39.6	3.2	10.5
Cesium-137	6.5	21.6	4.8	15.7	1.6	5.3
Cobalt-60	12	40	6.2	20.6	2.1	6.9
Radium	16.6	55	6.9	23.4	2.2	7.4

TABLE 6 -*Ratio, a, of scattered to incident exposure*[a]

Source	Scattering Angle (from Central Ray)					
	30	45	60	90	120	135
X Rays						
50 kV[b]	0.0005	0.0002	0.00025	0.00035	0.0008	0.0010
70 kV[b]	0.00065	0.00035	0.00035	0.0005	0.0010	0.0013
100 kV[b]	0.0015	0.0012	0.0012	0.0013	0.0020	0.0022
125 kV[b]	0.0018	0.0015	0.0015	0.0015	0.0023	0.0025
150 kV[b]	0.0020	0.0016	0.0016	0.0016	0.0024	0.0026
200 kV[b]	0.0024	0.0020	0.0019	0.0019	0.0027	0.0028
250 kV[b]	0.0025	0.0021	0.0019	0.0019	0.0027	0.0028
300 kV[b]	0.0026	0.0022	0.0020	0.0019	0.0026	0.0028
4 MV[c]	—	0.0027	—	—	—	—
6 MV[d]	0.007	0.0018	0.0011	0.0006	—	0.0004
Gamma Rays						
^{137}Cs[e]	0.0065	0.0050	0.0041	0.0028	—	0.0019
^{60}Co[f]	0.0060	0.0036	0.0023	0.0009	—	0.0006

[a] Scattered radiation measured at one meter from phantom when field area is 400 cm^2 at the phantom surface; incident exposure measured at center of field one meter from the source but without phantom.

[b] From Trout and Kelley (Radiology 104, 161 (1972)). Average scatter for beam centered and beam at edge of typical patient cross-section phantom. Peak pulsating x-ray tube potential.

[c] From Greene and Massey (Brit. J. Radiology 34, 389 (1961)), cylindrical phantom.

[d] From Karzmark and Capone (Brit. J. Radiology 41, 222 (1968)), cylindrical phantom.

[e] Interpolated from Frantz and Wyckoff (Radiology 73, 263 (1959)), these data were obtained from a slab placed obliquely to the central ray. A cylindrical phantom should give smaller values.

[f] From Mooney and Braestrup (AEC Report NYO 2165 (1967)), modified for F = 400 $cm.^2$

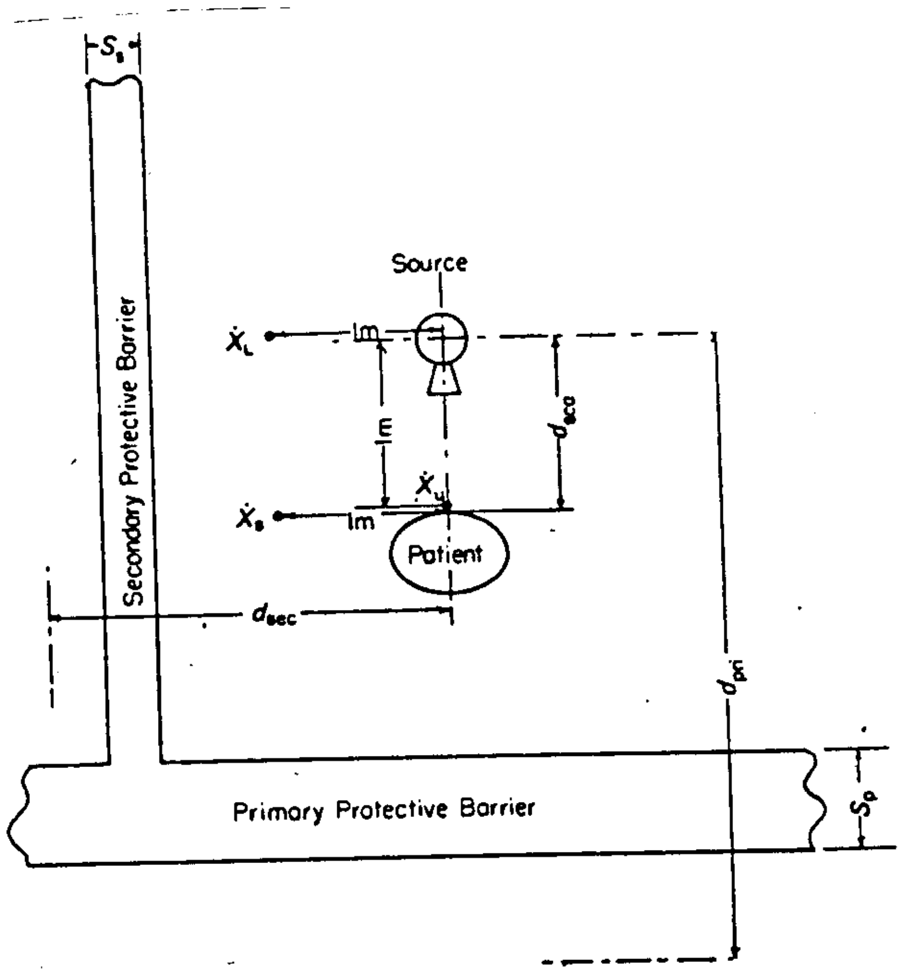


Fig 4 Geometry used in deriving equations for computing thickness of primary protective behavior, S_p, and of secondary protective barrier, S_s.

TABLE 7 – *Minimum shielding requirements for 200 kV[a] therapy installations*

WUT[b] in mA min		Distance in meters from source to occupied area											
40,000		1.5	2.1	3.0	4.2	6.1	8.4	12.2					
20,000			1.5	2.1	3.0	4.2	6.1	8.4	12.2				
10,000				1.5	2.1	3.0	4.2	6.1	8.4	12.2			
5,000					1.5	2.1	3.0	4.2	6.1	8.4	12.2		
2,500						1.5	2.1	3.0	4.2	6.1	8.4	12.2	
1,250							1.5	2.1	3.0	4.2	6.1	8.4	12.2
625								1.5	2.1	3.0	4.2	6.1	8.4
Type of Area	**Material**	**Primary protective barrier thickness[c]**											
Controlled	Lead, mm[d]	6.6	6.1	5.5	5.0	4.5	4.0	3.6	3.1	2.7	2.3	1.9	1.6
Noncontrolled	Lead, mm[d]	8.4	7.6	7.2	6.8	6.2	5.8	5.2	4.7	4.2	3.7	3.2	2.8
Controlled	Concrete, cm[e]	43.5	40.5	37.5	35	32.5	29.5	27	24.5	21.5	19.5	17	14.5
Noncontrolled	Concrete, cm[e]	52	50	46.5	44	41.5	39	36	33.5	30.5	28	25.5	23
		Secondary protective barrier thickness[c]											
Controlled	Lead, mm[d]	4.25	3.7	3.2	2.7	2.15	1.7	1.4	1.15	0.9	0.75	0.6	0.05
Noncontrolled	Lead, mm[d]	6.0	5.45	4.95	4.4	3.9	3.4	2.85	2.35	1.8	1.5	1.25	1.0
Controlled	Concrete, cm[e]	27	24.5	22	19.5	17	14	11.5	9.5	7	5	3.5	0.5
Noncontrolled	Concrete, cm[e]	35.5	33	30.5	28	25.5	23	20	17.5	15	12.5	10	8

[a] Peak pulsating x-ray tube potential.

[b] W – weekly workload in mA min, U – use factor, T – occupancy factor.

[c] Constant potential requires about 20 percent larger thicknesses of lead and about 10 percent larger thicknesses of concrete than those given here for pulsating potential.

[d] See Table 26 for conversion of thickness in millimeters to inches or to surface density.

[e] Thickness based on concrete density 2,35 g cm^{-3} (147 lb ft^{-3}).

TABLE 8 —*Minimum lead shielding requirements for cobalt-60 therapy installations for controlled areas*[a]

WUT[b] in R at 1 meter	Distance in meters from source to occupied area										
120,000	1.5	3.0	4.2	6.1	8.4	12.2					
60,000		1.5	3.0	4.2	6.1	8.4	12.2				
30,000			1.5	3.0	4.2	6.1	8.4	12.2			
15,000				1.5	3.0	4.2	6.1	8.4	12.2		
7,500					1.5	3.0	4.2	6.1	8.4	12.2	
3,750						1.5	3.0	4.2	6.1	8.4	12.2
1,875							1.5	3.0	4.2	6.1	8.4
950								1.5	3.0	4.2	6.1
475									1.5	3.0	4.2
240										1.5	3.0
120											1.5

Type of Protective Barrier	Approx. *HVL* cm of lead	Approx. *TVL* cm of lead	Thickness of lead in centimeters										
			23.5	22	21	20	18.5	17.5	16	15	14	12.5	11.5
Primary	1.2	4.0											
Secondary Leakage[c]			11.5	10	9	8	6.5	5.5	4	3	1.5	0.5	0
0.1 percent	1.2	4.0	10	9	8	6.5	5.5	4	3	1.5	0.5	0	0
0.05 percent	1.2	4.0											
Scatter[d]			14	13	12	11	10	9	8	7	6	4.5	3.5
30°	1.0	3.35	10.5	9.5	9	8	7.5	6.5	5.5	5	4	3.5	2.5
45°	0.87	2.9	8.5	8	7	6.5	5.5	5	4.5	3.5	3	2.5	1.5
60°	0.74	2.45	5	4.5	4	3.5	3	2.5	2.5	2	1.5	1	0.5
90°	0.44	1.45	2	2	1.5	1.5	1	1	1	0.5	0.5	0.5	0.5
120°	0.20	0.65											

[a] For a weekly design level of 100 mR; add one tenth-value layer *(TVL)* for noncontrolled areas, to reduce to 10 mR.

[b] *W*—weekly workload in R at 1 m, U—use factor, T—occupancy factor.

[c] Refers to leakage radiation from source housing when source in "ON" condition; may be ignored if less than 2.5 mR per h at 1 m.

[d] For large field (20 cm diameter) and a source to skin distance of 40 to 60 cm. This includes scattering from the collimator and from the phantom.

TABLE ¢ —*Minimum shielding requirements for 4 MV therapy installations for controlled areas*[a]

WUT[b] in R at 1 meter			Distance in meters from source to occupied area									
160,000			1.5	2.1	3.0	4.2	6.1	8.4	12.2	17		
80,000				1.5	2.1	3.0	4.2	6.1	8.4	12.2	17	
40,000					1.5	2.1	3.0	4.2	6.1	8.4	12.2	17
20,000						1.5	2.1	3.0	4.2	6.1	8.4	12.2
10,000							1.5	2.1	3.0	4.2	6.1	8.4
5,000								1.5	2.1	3.0	4.2	6.1
2,500									1.5	2.1	3.0	4.2
Type of Protective Barrier	**Material**	***TVL* cm**	**Thickness of barrier in cm**									
Primary	Concrete[c]	29.2	171	162	153	144	136	127	118	109	101	92
Primary	Lead	5.3	31	29.5	28	26.5	24.5	23	21.5	19.5	18	16.5
Primary	Iron[e]	9.1	53.5	50.5	48	45	42.5	39.5	37	34	31.5	28.5
Leakage[d] 0.1 percent	Concrete[c]	29.2	83	75	66	57	48	39	31	22	13	4
Leakage[d] 0.1 percent	Lead	5.3	15	13.5	12	11.5	10	8.5	7	5.5	4	2.5

[a] For a weekly design level of 100 mR; add one tenth-value layer *(TVL)* for noncontrolled areas to reduce to 10 mR.

[b] *W*—weekly workload in R at 1 m, U—use factor, T—occupancy factor.

[c] Thickness based on concrete density of 2.35 g cm^{-3} (147 lb ft^{-3}).

[d] Shielding for leakage radiation from tube housing.

[e] Thickness based on iron density of 7.8 g cm^{-3} (488 lb ft^{-3}).

TABLE 10—*Minimum shielding requirements for 10 MV therapy installations for controlled areas*[a]

WUT[b] in R at 1 meter		Distance in meters from source to occupied area									
160,000		1.5	2.1	3.0	4.2	6.1	8.4	12.2	17		
80,000			1.5	2.1	3.0	4.2	6.1	8.4	12.2	17	
40,000				1.5	2.1	3.0	4.2	6.1	8.4	12.2	17
20,000					1.5	2.1	3.0	4.2	6.1	8.4	12.2
10,000						1.5	2.1	3.0	4.2	6.1	8.4
5,000							1.5	2.1	3.0	4.2	6.1
2,500								1.5	2.1	3.0	4.2
Type of Protective Barrier	**Material**	**Thickness of barrier in cm**									
Primary	Concrete[c]	234	222	210	198	186	174	162	150	138	126
Primary	Lead	32.5	30.5	29	27.5	25.5	24	22.5	20.5	19	17.5
Primary	Iron[e]	61.5	58.5	55.5	52	49	46	42.5	39.5	36	33
Leakage[d] 0.1 percent	Concrete[c]	114	102	90	77.5	66	53.5	42	29.5	17.5	6
Leakage[d] 0.1 percent	Lead	15.5	14	12.5	11	9.5	7.5	6	4	2.5	1
Leakage[d] 0.1 percent	Iron[e]	30	26.5	23.5	20.5	17.5	14	11	7.5	4.5	1.5

[a] For a weekly design level of 100 mR; add one tenth-value layer *(TVL)* for noncontrolled areas to reduce to 10 mR (see Table 27).

[b] *W*—weekly workload in R at 1 m, U—use factor, T—occupancy factor.

[c] Thickness based on concrete density of 2.35 g cm^{-3} (147 lb ft^{-3}).

[d] Shielding for leakage radiation from tube housing.

[e] Thickness based on iron density of 7.8 g cm^{-3} (488 lb ft^{-3}).

TABLE 11 –*Assumptions used in calculating secondary barrier requirements, Appendix C, Tables 5-24*

Installations	I[a]	a[b]	d_{sca}[c]	F[d]
100kV[e] diagnostic fluoroscopic	5	0.0013	0.45	400
125kV[e] diagnostic fluoroscopic	4	0.0015	0.45	400
150kV[e] diagnostic fluoroscopic	3.3	0.0016	0.45	400
100kV[e] diagnostic radiographic	5	0.0013	0.8	1000[f]
125kV[e] diagnostic radiographic	4	0.0015	0.8	1000[f]
150kV[e] diagnostic radiographic	3.3	0.0016	0.8	1000[f]
50kV[e] x-ray therapy	10	0.00035	0.25	400
100kV[e] x-ray therapy	5	0.0013	0.25	400
150kV[e] x-ray therapy	5	0.0016	0.5	400
200kV[e] x-ray therapy	20	0.0019	0.5	400
250kV[e] x-ray therapy	20	0.0019	0.5	400
300kV[e] x-ray therapy	20	0.0019	0.5	400
1000kV[e] x-ray therapy	–[g]	0.001	1	400
2000kV[e] x-ray therapy	–[g]	0.001	1	400
3000kV[e] x-ray therapy	–[g]	0.001	1	400
4000kV[e] x-ray therapy	–[g]	–	–	–
6000kV[e] x-ray therapy	–[g]	0.006	1	400
8000kV[e] x-ray therapy	–[g]	–	–	–
10000kV[e] x-ray therapy	–[g]	–	–	–
^{137}Cs teletherapy	–[g]	0.0028	0.5	400
^{60}Co teletherapy	–[g]	0.0009	0.5	400

[a] I is the maximum rated continuous tube current in milliamperes at the tube potential listed.

[b] a is the ratio of scattered to incident exposure at 1 meter (see Table B-2).

[c] d_{sca} is the distance in meters from the radiation source to the scatterer.

[d] F is the field area at the scatterer in cm^2.

[e] Peak pulsating x-ray tube potential.

[f] Based on 36 × 43 cm (14 × 17 inch) field at 1 meter.

[g] Source housing leakage 0.1 percent of useful beam exposure rate.

TABLE —*Quantities used*[a] *in calculations of barrier thickness*

Quantity[b]	Symbol	Units
Weekly design exposure rate[c]	P	R
Weekly workload:		
X-ray equipment with current meter	W	mA min[d]
Megavoltage and gamma sources	W	R at 1 m[e]
Use factor	U	–
Occupancy factor	T	–
Distance from radiation source:		
To person to be protected	d_{pri}, d_{sec}	m
To scatterer	d_{sca}	m
Field area	F	cm^2
Normalized output	$\dot{X}_n$	R per mA min at 1 m
Exposure rate at 1 meter from the source of the:		
Useful beam	$\dot{X}_u$	R per min
Leakage radiation	$\dot{X}_L$	R per min
Exposure rate at 1 meter from the scatter for:		
Scattered radiation	$\dot{X}_s$	R per min at 1 m
Quotient of exposure at unit distance and workload	K_{ux}	R per mA min at 1 m
Transmission factor for:		
Useful beam:		
x rays	B_{ux}	–
gamma rays	$B_{u\gamma}$	–
Leakage radiation:		
x rays	B_{Lx}	–
gamma rays	$B_{L\gamma}$	–
Scattered radiation:		
x rays	B_{sx}	–
gamma rays	$B_{s\gamma}$	–
Leakage of source housing	L	R per h at 1 m
Exposure	X_u, X_L, X_s	R
Tube current	I	mA
Weekly beam ON-time	t	min
Barrier thickness:		
Primary	S_p	mm (lead) cm (concrete)
Secondary	S_s	mm (lead) cm (concrete)
Half value layer	HVL	mm or cm
Tenth value layer	TVL	mm or cm

[a] It is assumed that the acceleration potential is known for x-ray sources and that the energy is known for gamma-ray sources.

[b] See definitions in Appendix A.

[c] As this report deals with x and gamma radiation only, the number of roentgens may be considered equal to the number of rems (see Table 1 in Appendix C).

[d] This unit is used for x rays produced by potentials below 4 MV, and for higher potentials when the equipment has a target-current meter.

[e] This unit is used for all gamma-ray sources and for x rays produced by potentials of 4 to 10 MV, when the equipment does not have a target-current meter.