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MEDICAL X-RAY AND GAMMA-RAY PROTECTION FOR ENERGIES UP TO 10 MeV

Equipment Design and Use

NCRP

National Council on Radiation Protection and Measurements

NCRP REPORT No. 33

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Equipment Design and Use

Recommedations of the
NATIONAL COUNCIL ON RADIATION PROTECTION
AND MEASUREMENTS

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Preface

This report of the National Council on Radiation Protection and Measurements, successor to the National Committee on Radiation Protection and Measurements, is concerned with radiation protection in connection with the medical use of x and gamma rays having energies up to 10 MeV. It represents in several respects a deviation from previous NCRP practice in dealing with the subject. In the past, the NCRP has treated comprehensively in one report the use of gamma-ray sources (NCRP Report No. 24, National Bureau of Standards Handbook 73) and in another report the use of x-ray sources (NCRP Report No. 26, National Bureau of Standards Handbook 76). Each of these reports dealt with equipment design and use as well as structural shielding. Now, however, the Council believes that a more useful treatment will result from consideration of design and operational problems in one report and structural shielding problems in another. This report is concerned primarily with the design and operational aspects of medical x-ray equipment and gamma-beam therapy equipment. The Council expects to publish soon other reports treating (1) structural shielding aspects of medical x- and gamma-ray installations up to 10 MeV (NCRP Report No. 34), (2) brachytherapy sources, (3) dental x-ray equipment and installations (NCRP Report No. 35), and (4) veterinary x-ray protection.

This report is intended to serve as a guide to good practice in medical radiation protection. While it provides basic standards for use in the preparation of regulatory protection codes, it is not specifically written for literal adoption as legal regulations.

This report contains a number of recommendations concerning the design and performance characteristics of medical radiation producing equipment and the manner in which it is used. The recommendations vary in importance and in applicability; some are particularly important for large busy installations but not for installations with very low work loads; some apply to all equipment of a given kind whereas others need not apply to equipment designed prior to publication of this report. In this regard, it is important to recognize that efficiency

and safety in the utilization of radiation equipment is influenced critically not only by its design characteristics but also by the manner of its use. For this reason, the Council believes that the risk involved in the judicious use of older equipment failing to meet the revised standards of this report is not necessarily so great as to justify the condemnation of thousands of otherwise satisfactory units.

Initial funds for publication of NCRP reports are being provided by the James Picker Foundation and for this the Council wishes to express its deep appreciation.

The present report was prepared by the Council's Scientific Committee 3 on Medical X- and Gamma-Ray Protection up to 10 MeV (Equipment Design and Use). Serving on the Committee during the preparation of this report were:

R. O. Gorson, *Chairman*

Working Group	*Advisory Group & Consultants*
J. Hale	C. B. Braestrup
F. R. Hendrickson	E. F. Focht
J. S. Krohmer	J. Haimson
R. R. Newell*	C. J. Karzmark
E. D. Trout	E. R. Miller
W. J. Tuddenham	J. M. Mozley
E. W. Webster	R. J. Nelsen
	S. W. Smith
	B. P. Sonnenblick
	M. H. Wittenborg
* Deceased	H. O. Wyckoff

The Council wishes to express its appreciation to the members of the Committee for the time and effort they devoted to the preparation of this report.

Lauriston S. Taylor
President, NCRP

Washington, D.C.
January 1, 1968

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Rem: The unit of dose equivalent. For radiation protection purposes in this report which covers only x and gamma radiation, the number of rems may be considered equal to the number of rads or the number of roentgens.

Roentgen (R): The special unit of exposure. It is the exposure required to produce in air 2.58×10^{-4} coulomb of ions of either sign per kilogram of air.

Scattered radiation: See radiation.

Sealed source: A radioactive source sealed in a container or having a bonded cover, in which the container or cover has sufficient mechanical strength to prevent contact with and dispersion of the radioactive material under the conditions of use and wear for which it was designed.

Secondary protective barrier: See protective barrier.

Shall: *Shall* indicates a recommendation that is necessary or essential to meet the currently accepted standards of protection.

Should: *Should* indicates an advisory recommendation that is to be applied when practicable.

Shutter: (1) In beam therapy equipment, a device, fixed to the x-ray or gamma-ray source housing to intercept the useful beam. (2) In diagnostic equipment, an adjustable device used to collimate the useful beam.

Source housing: See protective source housing.

Source-film distance (SFD): The distance measured along the central ray from the center of the front surface of the source (x-ray focal spot or sealed radioactive source) to the surface of the x-ray film.

Source-surface distance (Source-skin distance) (SSD): The distance measured along the central ray from the center of the front surface of the source (x-ray focal spot or sealed radioactive source) to the surface of the irradiated object.

Stray radiation: See radiation.

Survey: See radiation protective survey.

Therapeutic-type protective tube housing:

(a) For x-ray therapy equipment not capable of operating at 500 kVp or above, the following definition applies: An x-ray tube housing so constructed that the leakage radiation at a distance of one meter from the source does not exceed one roentgen in an hour when the tube is operated at its maximum rated continuous current for the maximum rated tube potential. (See 3.4.2 and 3.4.1 (a).)

(b) For x-ray therapy equipment capable of operating at 500 kVp or above, the following definition applies: An x-ray tube housing so constructed that the leakage radiation at a distance of one meter from the source does not exceed 0.1 per cent of the useful beam dose rate at one meter from the source, for any of its operating conditions.

(c) In either case, small areas of reduced protection are acceptable providing the average reading over any 100 cm^2 area at one meter distance from the source does not exceed the values given above.

Use factor (beam direction factor) (U): Fraction of the workload during which the useful beam is directed at the barrier under consideration.

Useful beam: See radiation.

User: Any individual who personally utilizes or manipulates a source of radiation.

Workload (W): The degree of use of an x-ray or gamma-ray source. For x-ray machines below 500 kVp, the workload is usually expressed in milliampere-minutes per week. For gamma-beam therapy sources and for x-ray equipment operating at 500 kVp or above, the workload is usually stated in terms of the weekly exposure of the useful beam at one meter from the source and is expressed in roentgens per week at one meter.

APPENDIX B

Tables

TABLE 1—*Maximum permissible dose equivalent values (MPD)*[a]

[The indicated values are for the limited scope of this report. See Addendum to NCRP Report No. 17 (NBS Handbook 59) issued April 15, 1958 for more complete information [3].]

	Average weekly dose[b]	Maximum 13-week dose	Maximum yearly dose	Maximum accumulated dose[c]
	rem[d]	*rem*[d]	*rem*[d]	*rem*[d]
Controlled Areas				
Whole body, gonads, blood-forming organs, lens of eye	0.1	3	—	5(N − 18)[e]
Skin of whole body	—	10[f]	30[f]	—
Hands and forearms, head, neck, feet and ankles	1.5	25	75	—
Non-controlled Areas	0.01	—	0.5	—

[a] Exposure of patients for medical and dental purposes is not included in the maximum permissible dose equivalent.

[b] For design purposes.

[c] When the previous occupational history of an individual is not definitely known, it shall be assumed that he has already received the full dose permitted by the formula 5(N − 18).

[d] The numerical value of the dose equivalent in rems may be assumed to be equal to the numerical value of the exposure in roentgens for the purposes of this report.

[e] N = Age in years and is greater than 18.

[f] Am. J. Roentgenology **84**, 152 (1960).

TABLE 2—*Effect of tube potential, distance and filtration on air exposure rate at panel of fluoroscopes*[a]

Potential kVp	Source to panel distance		Equivalent total aluminum filtration				
			1 mm	2 mm	2.5 mm	3 mm	4 mm
	cm	inches	Roentgens per milliampere minute				
70	30	12	5.3	2.7	2.2*	1 8	1 3
	38	15	3.5	1.7	1.4†	1.2	0.8
	46	18	2.4	1.2	1.0	0.8	0.6
80	30	12	7.0	3.9	3.2*	2.6	2 0
	38	15	4.6	2.5	2.1†	1.7	1.3
	46	18	3.2	1.8	1.4	1.2	0.9
90	30	12	9.0	5.2	4.3*	3.6	2.8
	38	15	5.8	3.3	2.8†	2.3	1.8
	46	18	4.0	2.3	1.9	1.6	1.2
100	30	12	11.0	6.6	5.5*	4.7	3.7
	38	15	7.0	4.2	3.5†	3.0	2.3
	46	18	4.9	2.9	2.5	2.1	1.6
110	30	12	13.1	8.0	6.8*	5.9	4.6
	38	15	8.4	5.1	4.4†	3.8	3.0
	46	18	5.8	3.5	3.0	2.6	2.0
120	30	12	14.7	9.3	8.0*	7.0	5.5
	38	15	9.5	6.0	5.1†	4.5	3.6
	46	18	6.5	4.1	3.6	3.1	2.5
130	38	15	—	6.8	5.9†	5.2	4.2
	46	18	—	4.7	4.1	3.6	2 9
140	38	15	—	7.6	6.6†	5.9	4.8
	46	18	—	5.3	4.6	4.1	3.3
150	38	15	—	8.5	7.5†	6.7	5.4
	46	18	—	5.8	5.2	4.6	3.7

[a] Typical exposure rates produced by equipment with medium length cables, derived from references [8] and [14] by interpolation and extrapolation. Filtration includes that of the tabletop and the x-ray tube with its inherent and added filter. As used above, panel means either panel or tabletop.

*† See Section 3.1.2 (a).

TABLE 3—*Half-value layers as a function of filtration and tube potential for diagnostic units*[a]

Total Filtration mm Al	Peak Potential (kVp)									
	30	40	50	60	70	80	90	100	110	120
	Typical half-value-layers in millimeters of aluminum									
0.5	0.36*	0.47*	0.58	0.67	0.76	0.84	0.92	1.00	1.08	1.16
1.0	0.55	0.78	0.95	1.08	1.21	1.33	1.46	1.58	1.70	1.82
1.5	0.78	1.04	1.25*	1.42*	1.59*	1.75	1.90	2.08	2.25	2.42
2.0	0.92	1.22	1.49	1.70	1.90	2.10	2.28	2.48	2.70	2.90
2.5	1.02	1.38	1.69	1.95	2.16	2.37*†	2.58*†	2.82*†	3.06*†	3.30*†
3.0	—	1.49	1.87	2.16	2.40	2.62	2.86	3.12	3.38	3.65
3.5	—	1.58	2.00	2.34	2.60	2.86	3.12	3.40	3.68	3.95

[a] For full-wave rectified potential. Derived from reference [14] by interpolation and extrapolation.
* Recommended minimum HVL for radiographic units. See Section 3.2.2 (a).
† Recommended minimum HVL for fluoroscopes. See Section 3.1.2 (b).

TABLE 4—*Exposure rate through fluoroscopic screen without patient*[a]

Total Filtration: 3 mm aluminum equivalent
Table top to Screen distance: 14 inches
Screen to Chamber distance: 2 inches
Medium length High Tension Cables

X-ray Tube Potential kVp	Source to table top distance		Lead Equivalent of Screen Protective Barrier[b]		
			1.5 mm	1.8 mm	2.0 mm
	inches	cm	Typical Exposure Rate: mR/h per R/min at Tabletop		
80	12	30	10	4.5	2.5
	15	38	13	6	3.5
	18	46	15	7	4
90	12	30	12	6	3.5
	15	38	16	7 5	4.5
	18	46	19	9	5.5
100	12	30	15	7	4.5
	15	38	20	9	5.5
	18	46	23	11	7
110	12	30	19	9	5.5
	15	38	24	12	7
	18	46	29	14	8.5
120	12	30	23	11	7
	15	38	30	14	9
	18	46	35	17	10
130	15	38	35	17	10
	18	46	42	20	12
140	15	38	41	19	12
	18	46	49	23	14
150	15	38	46	20	12
	18	46	55	24	15

[a] Adapted from reference [8] by interpolation and extrapolation. Actual exposure rate values may differ from the typical values given above by ±15% depending upon length of high tension cables.

[b] See Section 3.1.1 (d) and 3.1.2 (c).