CLINICAL

THERAPEUTIC

RADIOLOGY

U. V. PORTMANN, M.D.
Editor

Head of Department of Therapeutic Radiology, Cleveland Clinic Foundation; Professor of Therapeutic Radiology, Bunts Educational Institute, Cleveland

CONTRIBUTORS

A. N. ARNESON, M.D.: Associate Professor, Clinical Radiology. Clinical Obstetrics and Gynecology, Washington University School of Medicine, St. Louis; Chief-of-Staff, Attending Gynecologist, Barnard Free Skin and Cancer Hospital, St. Louis.

BENJAMIN S. BARRINGER, M.D.: Surgeon Emeritus, Department of Urology, Memorial Hospital, New York.

JOHN V. BLADY, M.D.: Director, Tumor Clinic; Associate Professor of Surgery, Tumor Consultant to Department of Radiology, Temple University Medical School and Hospital, Philadelphia.

DONALD W. BORTZ, M.D.: Department of Medicine, Cleveland Clinic, Cleveland.

C. B. BRAESTRUP, B.S.: Senior Physicist, Department of Hospitals, New York; Associate Professor, New York University; Associate, Columbia University; Consultant, Atomic Energy Commission.

FRANZ BUSCHKE, M.D.: Associate Director, Tumor Institute of the Swedish Hospital, Seattle; Clinical Assistant Professor of Radiology, University of Washington Medical School, Consultant in Neoplastic Diseases U. S. Marine Hospital, Seattle.

GEORGE F. CAHILL, M.D.: Professor of Urology, College of Physicians and Surgeons, Columbia University; Director, Department of Urology, Columbia-Presbyterian Medical Center, New York.

J. W. J. CARPENDER, M.D.: Assistant Professor of Radiology, University of Chicago; Director, Irradiation Therapy, University of Chicago Clinics and Hospitals, Chicago.

R. M. CAULK, M.D.: Associate Radiologist and Medical Director, Cancer Detection Clinic and Tumor Clinic, Garfield Memorial Hospital, Washington, D. C.; Consultant, Radiation Therapy, U. S. Naval Hospital, Bethesda, Md.; Area Consultant, Radiation Therapy, U. S. Veterans Bureau, Washington, D. C.

RICHARD H. CHAMBERLAIN, M.D.: Assistant Professor of Radiology, University of Pennsylvania, School of Medicine and Graduate School of Medicine; Staff Radiologist, Hospital of the University of Pennsylvania, Philadelphia.

ANTHONY C. CIPOLLARO, M.D.: Professor and Director, Dermatology and Syphilology, New York Polyclinic Medical School and Hospital; Assistant Professor of Clinical Medicine (Dermatology), Cornell University Medical College, New York.

JAMES A. CORSCADEN, M.D.: Clinical Professor of Obstetrics and Gynecology Emeritus, Columbia University; Consulting Gynecologist, Sloane Hospital for Women; Nassau Hospital, Mineola; Englewood Hospital, Englewood, N. J.

WILLIAM E. COSTOLOW, M.D.: Los Angeles Tumor Institute, Los Angeles.

G. Marshall Crawford, M.D.: Instructor in Dermatology, Harvard Medical School; Dermatologist, Massachusetts General Hospital and Massachusetts Institute of Technology, Boston.

Samuel J. Crowe, M.D.: Department of Otolaryngology, Johns Hopkins University and Johns Hopkins Hospital, Baltimore.

Edwin C. Ernst, M.D.: Director, X-ray Department, President, Medical Staff, Barnard Free Skin and Cancer Hospital; Director, X-ray and Radium Department, DePaul Hospital, St. Louis; Consultant in Radiology, U. S. Marine Hospital.

Robert E. Fricke, M.D.: Consultant in Therapeutic Radiology, Mayo Clinic; Associate Professor of Radiology, Mayo Foundation; In charge of Department of Radiotherapy, Mayo Clinic, Rochester, Minn.

Milton Friedman, M.D.: Associate Professor and Associate Radiation Therapist, New York University, Bellevue Medical Center; Senior Consultant in Radiation Therapy, Veterans Administration; Consultant in Radiation Therapy, Walter Reed General Hospital; Attending Radiation Therapist, Hospital for Joint Diseases, New York.

Otto Glasser, Ph.D.: Professor of Biophysics, Cleveland Clinic Foundation, Cleveland.

Russell L. Haden, M.D.: Formerly Chief of Staff in Medicine, Cleveland Clinic Foundation, Cleveland.

Hugh F. Hare, M.D.: Chief Radiologist, Lahey Clinic; Assistant Roentgenologist, New England Baptist Hospital, Boston; Associate Roentgenologist, Peter Bent Brigham Hospital, Boston.

E. L. Harrington, Ph.D.: Head, Department of Physics, University of Saskatchewan; Superior of the Radon Plant of the Saskatchewan Cancer Commission.

William Harris, M.D.: Clinical Professor of Radiology, Columbia University; Chief of Radiotherapy and Tumor Clinics, Mount Sinai Hospital, Morrisania City Hospital, New York.

Robert A. Hays, M.D.: Assistant, Department of Therapeutic Radiology, Cleveland Clinic Foundation, Cleveland.

Paul S. Henshaw, Ph.D., LL.D.: Assistant Chief, Division of International Health, U. S. Public Health Service; Principal Radiobiologist, Manhattan Project, 1944–46; Co-leader, Atomic Bomb Casualty Commission to Japan, 1946; Chief, Fundamental Research Branch, GHQ, SCAP, Tokyo, Japan, 1947–49.

John W. Irvine, Jr., Ph.D.: Associate Professor of Chemistry, Massachusetts Institute of Technology.

Leon O. Jacobson, M.D.: Associate Professor of Medicine; Member, Institute of Radiobiology and Biophysics, University of Chicago, Chicago.

Harold W. Jacox, M.D.: Professor of Radiology, College of Physicians and Surgeons; Chief, Department of Radiotherapy, Radiological Service of the Presbyterian Hospital, New York.

Ira I. Kaplan, M.D.: Director, Radiation Therapy Department, Bellevue Hospital; Attending Radiation Therapist, Beth David Hospital; Consulting Radiation Therapist, French Hospital; Clinical Professor of Radiology, New York University Medical College, New York.

Roscoe J. Kennedy, M.D.: Head, Department of Ophthalmology, Cleveland Clinic Foundation; Professor of Ophthalmology, Frank E. Bunts Educational Institute, Cleveland.

H. Dabney Kerr, M.D.: Professor and Head of Radiology, College of Medicine, State University of Iowa, University Hospital, Iowa City, Ia.

Rudolph Kramer, M.D.: Otolaryngologist, Mt. Sinai Hospital, New York.

Eugene T. Leddy, M.D.: Associate Professor of Radiology, Mayo Foundation, University of Minnesota; Head, Section of Therapeutic Radiology, Mayo Clinic, Rochester, Minn.

Maurice Lenz, M.D.: Professor of Clinical Radiology, Columbia University; Consultant, Presbyterian Hospital, Manhattan Eye, Ear and Throat Hospital, Montefiore Hospital, New York.

T. Leucutia, M.D.: Director, Department of Therapeutic Radiology, Harper Hospital, Detroit; Assistant Professor of Radiology, Wayne University, Detroit.

Walter E. Loch, M.D.: Associate Professor of Laryngology and Otology, Johns Hopkins School of Medicine; Otolaryngologist, Johns Hopkins Hospital, Associate Otolaryngologist, Union Memorial Hospital, Baltimore.

Orville N. Meland, M.D.: Senior Staff, California Hospital, Los Angeles; Consultant, Therapeutic Radiology, Santa Fe Railway Hospital, Los Angeles; Former Senior Tumor Consultant, Veterans Administration, Sawtelle; Professor Emeritus, Therapeutic Radiology, College of Medical Evangelists, Los Angeles.

Ira T. Nathanson, M.D.: Assistant Professor of Surgery, Harvard Medical School; Associate Visiting Surgeon, Massachusetts General Hospital; Assistant Surgeon, Pondville Hospital, Walpole, Mass.

James F. Nolan, M.D.: Instructor in Obstetrics and Gynecology, University of Southern California; Associate Staff, California Hospital, Los Angeles; Associate Gynecologist, Los Angeles Tumor Institute; Courtesy Staff, St. Vincent's Hospital, Los Angeles.

Frederick W. O'Brien, M.D.: Radiologist, Cambridge City Hospital; Consultant to Tumor Clinic, Boston City Hospital; Emeritus Professor of Radiology, Tufts College Medical School, Medford, Mass.

Eugene P. Pendergrass, M.D.: Professor of Radiology, University of Pennsylvania, Philadelphia; Professor of Radiology, Graduate School of Medicine, University of Pennsylvania; Director of Department of Radiology, Hospital of the University of Pennsylvania; Director of Department of Radiology, Jeanes Hospital, Philadelphia.

U. V. Portmann, M.D.: Director of Therapeutic Radiology, Cleveland Clinic Foundation; Professor of Therapeutic Radiology, Bunts Educational Institute, Cleveland.

Douglas Quick, M.D.: Attending Surgeon, Doctors Hospital, New York; Visiting Consulting Surgeon, Roosevelt Hospital, New York; Consulting Surgeon, Midtown Hospital, New York; Consulting Surgeon, St. Luke's Hospital, Newburgh, N. Y.; Consulting Surgeon, Morristown Memorial Hospital, Morristown, N. J.

Juan A. del Regato, M.D.: Director, Penrose Cancer Hospital, Colorado Springs, Colo.

Ferdinand A. Salzman, M.D.: Associate Staff, Lahey Clinic, Boston.

Milford D. Schulz, M.D.: Radiologist, Massachusetts General Hospital; Consultant Radiologist, Massachusetts Eye and Ear Infirmary; Instructor, Harvard Medical School, Boston.

SIDNEY M. SILVERSTONE, M.D.: Associate Radiotherapist, Mount Sinai and Morrisania City Hospital, New York.

ARTHUR PURDY STOUT, M.D.: Professor of Surgery, Columbia University; Attending Pathologist, Presbyterian Hospital, New York.

HENRY A. TELOH, M.D.: Fellow in Pathology, Northwestern University Medical School and Passavant Memorial Hospital, Chicago.

JOHN G. TRUMP, M.D.: Associate Professor, Electrical Engineering, Massachusetts Institute of Technology; Consultant in Physics, Massachusetts General Hospital, Boston.

JOSEPHINE WELLS, M.D.: Instructor in Radiology, College of Physicians and Surgeons, Columbia University; Assistant Radiologist, Presbyterian Hospital, New York.

MARK C. WHEELOCK, M.D.: Associate Professor of Pathology, Northwestern University Medical School; Pathologist, Passavant Memorial Hospital, Chicago; Pathologist, Tumor Clinic, Northwestern University; Consulting Pathologist, Hines Veterans Hospital, Hines, Ill.

BERNARD P. WIDMAN, M.D.: Professor of Radiology, The Graduate School of Medicine, University of Pennsylvania; Chairman of Division of Radiology, The Graduate School of Medicine, University of Pennsylvania; Chief of Radiologic Departments, Philadelphia General Hospital and Fitzgerald Mercy Hospital, Philadelphia.

CONTENTS

1

RADIATION PROTECTION

C. B. BRAESTRUP, B.S., P.E.

THE NEED for protection against ionizing radiations has been recognized since the early days of radiology, when so many of the pioneers suffered painful and often fatal injuries from overexposure to the rays. As a result of extensive research and through the experiences of more than half a century it is possible today to use roentgen rays and radioactive materials with safety.

However, even at present, adequate radiation safeguards are not universally employed. In many cases this is due to a false sense of security caused by lack of early and obvious physiologic changes associated with the overexposure to radiation. Too often the hazards are minimized by such reasoning as: "nothing has happened to me and I have been exposed to the rays for years," because it is not realized that many years elapse between the termination of the exposure and manifestation of radiation damage.

The main objective in providing protection against radiation is to reduce stray radiation to such a low value that it has no known harmful effects on the body. As this level has been progressively reduced the expense of protection has steadily risen and has now reached a point where it is an important factor in the construction cost of any radiotherapy department. Too often lack of understanding of underlying principles of protection has caused inadequate shielding and needless expense. It is the purpose of this chapter, therefore, to show how radiation hazards may be reduced most effectively at a minimal cost. Detailed recommendations are provided in the various protection codes, and this discussion serves, therefore, primarily to supplement these and to emphasize points most frequently overlooked.

PERMISSIBLE EXPOSURE

According to the recommendations of the National Protection Committee, the maximum permissible exposure to roentgen or gamma radiation from external sources is 0.3 r (300 milliroentgens) per week, measured in air. That is, it is considered safe to expose the whole body weekly to this dose for a period of many years. Obviously, irradiation of only a small part of the body, such as the fingers, is less harmful than "total body" irradiation and a dose of 1.0 r per week is considered permissible for the hands. However, no other part of the body is excepted from the maximal permissible exposure of 0.3 r/week, nor is any distinction made for differences in penetration of rays.

In roentgen therapy there is seldom difficulty, aside from economic considerations, in complying with the regulations. When employing radioactive materials, however, the problem is more difficult, as the radiation is emitted continuously and it may be necessary to be close to the source during its preparation and while applying it to patients.

It should be realized that it is impossible to eliminate exposure to ionizing radiations entirely; cosmic rays and the presence of radioactive elements in the earth, atmosphere, and common building materials give a "background" dosage rate of about 0.01 mr/hr.

ROENTGEN THERAPY

Roentgen rays produced at potentials anywhere from a few kilovolts to several million volts are employed therapeutically at the present time, and generators operating at many megavolts may be used in the not too distant future. There is, therefore, a wide variation in protective requirements for different types of therapeutic installations. However, the aim is the same for all, that is: (1) to limit the dose at all accessible locations outside the treatment room to the maximal permissible weekly value of 0.3 r; (2) to minimize, as much as practical, the total body exposure of patients except for the therapeutic dose.

Protection requirements may be considered from three different aspects: equipment, structural shielding, and operating procedures.

EQUIPMENT

Protective materials may be applied most economically close to the x-ray tube as the area to be shielded varies approximately as the square of the target distance. There is, therefore, a definite saving in using a *protective tube housing*,* which practically limits the beam to the fractional part actually needed for therapeutic purposes. With this type of tube housing it is still necessary to protect against the useful therapeutic beam, the small amount of direct radiation passing through the shielding of the tube housing, and the secondary radiation emitted by any object exposed to radiation.

As the dosage rate of the useful beam is generally of the order of 500 to 1000 r/hr at 1 meter, corresponding to 33 to 66 r/min. at 50 cm., a protective tube housing affords also a high degree of protection to patients as the "total body" radiation is less than 0.2 per cent of the therapeutic dose. It is usually not practical to provide this degree of shielding in cones or other removable collimating systems, and a dosage rate of 10 r/hr at 1 meter is considered adequate as only a limited area around the therapeutic field on the patient will be exposed to the higher dose.

Where materials, such as lead rubber and lead foil, are used to limit the field on the patient, they should have a sufficient lead equivalent to reduce incident radiation to less than 3 per cent. The thicknesses required are shown in Table I.

TABLE I

APPROXIMATE LEAD EQUIVALENTS REQUIRED TO REDUCE THE THERAPEUTIC BEAM TO 3 PER CENT

100 kv.	*150 kv.*	*200 kv.*	*250 kv.*
mm.	*mm.*	*mm.*	*mm.*
0.6	1.0	1.5	2.2

Roentgen-ray Emission from Valve Tubes. During the useful part of the voltage wave, roentgen rays are emitted by the anode of the valve tube; but normally the

* "Protective tube housings are those in which the direct radiation (radiation coming through the tube housing) is reduced to 1 r per hour at a distance of 1 meter from the tube target when the tube is operating continuously at its maximum rated current for the maximum rated voltage" (*National Bureau of Standards Handbook, 1949*).

voltage across the valve is small, less than 1 kv., and the rays, therefore, too soft to penetrate the glass envelope of the valve. However, if the valve filament current is too low, the voltage drop may be considerable, resulting in the production of more penetrating radiation. Furthermore, during the suppressed part of the wave, when the voltage across the valve is high, penetrating rays may be produced by cold emission and gas in the tube. It is necessary, therefore, to provide shielding against radiation produced by valves unless these are oil-immersed or located distantly from occupied areas. Generally, 0.25 mm. lead equivalent is sufficient for 100 kv. and 1.0 mm. for 200 kv.

Location of Therapy Rooms

The cost of structural shielding may be reduced materially by locating the treatment room distant from habitually occupied regions, taking advantage of the inverse square law. As the useful beam is most frequently directed toward the floor, considerable saving may be gained by avoiding occupancy directly below the treatment room. This is particularly true for high voltage installations. Further economy may be obtained by restricting the orientation of the beam to the floor and outside walls and by using corner rooms, where possible. However, even outside walls and especially windows may require radiation barriers if close to occupied regions. This is illustrated in Table II, where the distance required to reduce the dosage rate to 6.25 mr per hour is shown for various conditions.

TABLE II

Distance from Tube Target at Which the Dosage Rate of the Useful Beam is 6.25 Milliroentgens per Hour

Tube Current Milliampere	*100 kv. Feet*	*150 kv. Feet*	*200 kv. Feet*	*250 kv. Feet*
5	289	295	342	401
10	335	351	404	472
15	364	388	444	515
20	387	410	473	548
25	404	433	496	575

Note: This table is based on reduction in dosage rate by both distance and air absorption, but by no other means.

The control of the roentgen-ray generator should be located outside the treatment room if voltages above 100 kv. are used. Even below this voltage movable lead floor screens do not offer as satisfactory protection as fixed barriers; there is always some scattering around the screen and frequently it is not placed to give the most effective protection to the operator.

Structural Shielding

The factor by which the useful beam has to be attenuated is usually of the order of 100,000 to 200,000 and the reduction, therefore, cannot be accomplished by distance only. Further attenuation must be obtained by interposing radiation barriers between the x-ray tube and the persons to be protected. Lead is preferred for this purpose up to voltages of about 400 kv., although, other materials, such as concrete, may be used to advantage where they serve also for structural purposes, as in the ceiling and floor. At higher voltages concrete is used almost exclusively, except where it is necessary to reduce the weight and space of the barrier.

The protective requirements of the barrier will depend upon the type of radiation to which it is exposed, that is, whether it is the useful beam or scattered and direct radiation only. Other factors affecting the thickness of the barrier are x-ray tube voltage, milliamperage, cumulative exposure time, the angle at which the beam strikes the barrier, and the distance from the tube target to the persons to be protected.

Primary Protective Barriers. Barriers exposed to the useful beam are called *primary protective barriers* and their thickness may be determined directly from Table III. For hospital and other busy therapy departments it is generally assumed that the equipment is operating at its maximum rating for forty-eight hours a week which makes the permissible dosage rate 6.25 mr/hr; actually, the cumulative exposure time is considerably less, owing to intervals between treatments and prevailing shorter working hours.

TABLE III

THICKNESS REQUIRED FOR PRIMARY PROTECTIVE BARRIERS FOR OPERATION AT 5 MILLIAMPERES AND AT THE DISTANCE AND KILOVOLTAGE INDICATED

Target Distance Feet	*100 kv.* Lead mm.	*100 kv.* Concrete in.	*150 kv.* Lead mm.	*150 kv.* Concrete in.	*200 kv.* Lead mm.	*200 kv.* Concrete in.	*250 kv.* Lead mm.	*250 kv.* Concrete in.
4	2.7	6.5	3.4	10.7	5.3	14.0	9.5	17.2
5	2.6	6.2	3.3	10.4	5.0	13.2	9.0	16.3
6	2.4	5.7	3.1	9.8	4.8	12.7	8.6	15.6
8	2.2	5.2	2.9	9.1	4.4	11.7	7.9	14.4
10	2.1	5.0	2.7	8.5	4.1	10.8	7.4	13.5
15	1.8	4.3	2.4	7.6	3.6	9.5	6.5	11.8
20	1.6	3.8	2.2	6.9	3.2	8.5	5.8	10.6
30	1.3	3.1	1.9	6.0	2.7	7.2	4.8	8.7
40	1.1	2.6	1.6	5.0	2.4	6.3	4.2	7.6

The thicknesses given above apply for a tube current of 5 ma. only. For other values of current *add* the thicknesses listed below to those obtained from the table above.

Milliamperes	*100 kv.* Lead mm.	*100 kv.* Concrete in.	*150 kv.* Lead mm.	*150 kv.* Concrete in.	*200 kv.* Lead mm.	*200 kv.* Concrete in.	*250 kv.* Lead mm.	*250 kv.* Concrete in.
10	0.2	0.7	0.3	1.0	0.4	1.2	0.8	1.5
15	0.3	1.1	0.4	1.5	0.7	1.9	1.2	2.3
20	0.4	1.4	0.5	1.9	0.9	2.4	1.5	3.0
25	0.5	1 6	0.6	2.2	1 0	2.8	1.8	3.2

Notes: (1) These thicknesses are sufficient to reduce the dosage rate of the useful beam to 6.25 mr per hr under the indicated conditions. 6.25 mr/hr corresponds to 0.3 r/week for 48 hr of weekly exposure. (2) Density of concrete 2.47 gm./cm.^{3}

Unless orientation of the useful beam is restricted, primary protective barriers are generally provided in the entire floor and all the inside walls up to a height of 7 feet. Where the location of the x-ray tube is fixed, it is possible to limit primary shielding in the floor to the area actually exposed to the useful beam, plus a border strip 1 foot wide. This saving is not recommended where there is a possibility of later changes in location of the tube stand. Primary protection is usually not necessary in the ceiling as the required secondary protective barriers are adequate to permit occasional therapy with the useful beam directed upward. As previously mentioned, even outside walls and especially windows may require shielding. This is particularly true where the treatment room faces a narrow court in a residential building.

Scattered Radiation

A frequent cause of inadequate protection is insufficient shielding against scattered rays emitted by the patient, the floor and walls, or other irradiated objects. The dosage rate and quality of scattered radiation vary with the size of field, angle of scattering, and nature of the scattering object. Furthermore, the intensity depends also on the dosage rate of the incident beam and the distance from the scattering object. With so many variables it is not possible to calculate accurately protection requirements for scattered radiation, and only certain approximations can be made. For the usual therapeutic conditions, the 90° scattered radiation at a distance of 1 meter from the center of the field varies from less than 1 per cent of the incident dosage rate at 100 kv. to less than 0.1 per cent at 1 mv. At the higher voltages consideration should also be given to the lower penetration of the scattered radiation produced by the Compton effect.*

This is illustrated in Table IV where it will be seen that at 1 mv. and 2 mv. the change in wave length is very significant.

TABLE IV

Minimum Wave Length and Equivalent Voltage of Roentgen Rays Scattered at Various Angles

Useful Beam		Scattered Radiation			
		45°	*90°*	*135°*	*180°*
Kv. max.	*λ min. Å*	*Kv. max.*	*Kv. max.*	*Kv. max.*	*Kv. max.*
100	0.1235	95	84	75	72
150	0.0824	124	116	100	94
200	0.0618	180	144	120	112
250	0.0494	219	168	136	126
400	0.0309	326	224	171	156
1000	0.0123	638	338	230	203
2000	0.0062	930	406	260	226

Special precautions should be taken to prevent scattering under lead-lined doors and barriers where the floor is not lead-lined. This may best be accomplished by providing the door frame with an 18-in. wide lead saddle and by extending the wall lead barrier into the floor or by covering the floor with an 18-in. wide strip of lead at the wall. It may sometimes be necessary to provide shielding in the entire floor, even though there is no occupancy below, to prevent scattering under the lead-lined walls. Even nearby buildings may cause "back scatter" into occupied regions near the treatment room, necessitating shielding of the treatment room windows.

Direct Radiation

Direct radiation from a protective tube housing does not exceed 1 r/hr at 1 meter and its quality may be assumed to be equal to that of the useful beam. The protective requirements of a barrier exposed only to direct radiation may, therefore readily be calculated. To reduce this radiation to 6.25 mr/hr by the inverse square law would require a distance of 12.6 meters, or more than is usually practical. For instance, people on the floor directly above the treatment room may well be within a target distance of 2 meters, therefore requiring shielding in the

* $\Delta\lambda = 0.024\ (1\text{-}\cos\theta)$ where $\Delta\lambda$ is the change in wave length in angstroms and θ the angle of scattering.

ceiling sufficient to reduce the radiation by a factor of 40. Typical protection requirements are shown in Fig. 1 and Table V.

Operating Procedures

Modern equipment and ample structural protection are not sufficient to eliminate radiation hazards. Of equal importance are proper operating procedures. This is particularly true in view of the high dosage rates available.

To guard against filter errors, equipment may be provided with a radiation monitor which indicates any abnormal dosage rate. Omission of filter is, of course, particularly serious where the inherent filtration is low and it is advisable, therefore, to have as much fixed filtration as possible.

TABLE V

Typical Lead Protection Requirements
for a 16 x 18 ft. corner therapy room with 240 ma-hr
exposure per week at indicated voltages

	Floor	*Ceiling*	*Walls*			
			N	E	S	W
Type of Wall			Inside	Inside	Outside	Outside
Type of Protection Barrier	Primary	Secondary	Primary	Secondary	Primary	Primary
Target Distance to Nearest Occupied Region	10 ft.	6 ft.	8 ft.	6 ft.	40 ft.	400 ft.
100 kvp.	(c)	(c)	2.2(0)	1.0(0)	1.1	0
150 kvp.	0.8+(c)	(c)	2.9(1.0)	1.3(1.0)	1.6	0
200 kvp.	2.3+(c)	0.25+(c)	4.4(1.5)	2.4(1.5)	2.4(0)	0
250 kvp.	5.0+(c)	1.2+(c)	7.9(3.0)	3.8(3.0)	4.2(0)	0

Notes
(a) The thickness of lead is shown in mm.
(b) Where two numbers are indicated, the first refers to the thickness of the lead up to a height of 7 ft., and the second, in parentheses, to the thickness of lead above 7 ft. to ceiling.
(c) 6 in. concrete floor (density 2.47 gm./cm.^{3}).
(d) All doors and lead glass windows shall have the same lead equivalent as that required of the walls in which they are located.
(e) Indicated protection permits 240 ma-hr a week useful beam exposure of any of the primary protection barriers. For most therapy installations this is unlikely, except for the floor.
(f) Maximum permissible dose 0.3 r per week.

Structural shielding is obviously of little value if the door to the x-ray room is left open; hence technicians should be instructed to see that the treatment room doors are closed and that only the patient is inside before starting the treatment. Doors may be provided with electrical interlocks which permit exposure only with the doors closed.

Only relatives or nonradiologic personnel should be allowed to hold babies or other patients during treatment. In any case such people should be adequately shielded against the useful beam and if necessary wear lead rubber apron and gloves.

Where the lack of complete structural shielding limits orientation of the useful beam, such restrictions should be carefully carried out. When it is necessary to treat with the beam horizontally it should preferably be directed toward areas not habitually occupied. It is occasionally necessary to direct the beam against barriers which do not offer primary protection; a record should be kept of such exposures. In any case it is good practice to record the total monthly or yearly exposure hours. Such data have proved valuable in cases of unjustified legal claims of insufficient protection.

REQUIREMENTS OF SPECIAL TYPES OF ROENTGEN THERAPY INSTALLATIONS

Grenz rays are extremely soft roentgen rays produced at voltages below 15 kv. Owing to the low penetration, no structural shielding is required other than ordinary walls or partitions; nor is protection for the operator or other persons in the same room required, unless these are exposed to the useful beam, or are closer than 3 feet to the patient or other significant sources of scattered radiation. It should, however, be pointed out that Grenz rays are roentgen rays and may cause

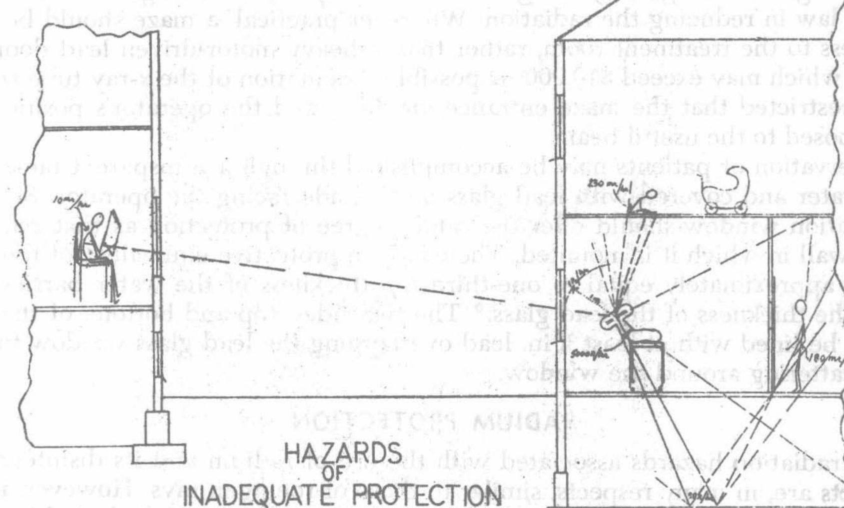

FIG. 1.

essentially the same type of damage as the more penetrating rays, although the injuries are limited to superficial tissue.

Contact therapy refers to short-distance irradiation of accessible lesions with 40 to 50 kv. roentgen rays. Because of the short target contact distance, less than 2 cm., the dosage rate at contact is extremely high, 10,000 to 20,000 r per minute, necessitating rigid safeguards to avoid accidental exposures to the intense useful beam. If the tube is held by hand during irradiation, special shielding must be provided against the scattered radiation (Braestrup and Blatz).

Unless the tube housing is provided with a radiation shield, or the cumulative weekly exposure is limited to three minutes, it is necessary for the operator, when holding the tube, to wear lead rubber gloves and apron. The face and other parts of the operator's body are, of course, still exposed to scattered radiation, and irradiation with hand-held tubes should, therefore, be limited as much as possible. Accidental contact with the tube window during exposure has already caused skin