NCRP REPORT No. 33

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

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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:

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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

Contents

1. Introduction

1.1 Scope

This report, which supersedes parts of NCRP Reports 24 and 26 (NBS Handbooks 73 and 76) [1, 2][1], is concerned with protection against radiation emitted by medical x-ray equipment operating at energies up to 10 MeV and medical gamma-beam therapy equipment. It presents recommendations pertaining to equipment design, use, and operating conditions, and to radiation protection surveys and personnel monitoring. To be covered in separate reports are recommendations concerning structural shielding design and recommendations concerning dental x-ray and veterinary x-ray protection and brachytherapy sources.

This report includes sections for the specific guidance of (1) the physician and his associates, (2) the equipment designer and manufacturer, (3) the radiological physicist concerned with calibration procedures, equipment performance, and protection surveys and, (4) the radiological health inspector concerned with equipment inspection and survey measurements.

1.2 Purpose

The purpose of this report is to indicate the protection required in various circumstances and to describe one or more methods by which the required protection may be achieved. The recommendations are not meant to preclude alternative methods of achieving the radiation protection objectives. Since it is recognized that blind adherence to rules cannot substitute for the exercise of sound judgment, the recommendations of this report may well be modified in unusual circumstances upon the professional advice of experts with recognized competence in medical radiation protection. In an effort to ensure informed and judicious application of these recommendations, explanatory paragraphs designated *Comment* have been included, where appropriate, throughout this report.

This report contains design recommendations, some of which are new and some of which represent modifications of previous recommenda-

[1] Figures in brackets indicate the literature references listed in Section 8.

tions. Such new and modified recommendations are not intended to apply to equipment *designed* before the publication of this report. In general, such equipment may be regarded as acceptable from the standpoint of radiation safety if it meets the recommendations of NCRP Reports 24 and 26. In cases of doubt, however, qualified experts should be consulted about the appropriateness and the feasibility of modifying existing equipment to conform with the new or revised recommendations in question.

Terms used in this report are defined in Appendix A. Since, however, recommendations throughout this report are expressed in terms of "shall" and "should," these terms are defined here.

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

(2) *Should, is recommended, is advisable,* indicates an advisory recommendation that is to be applied when practicable.

2. General Considerations

2.1 Fundamental Objective

The fundamental objective of the medical use of radiation is to obtain optimum diagnostic information or therapeutic effect with minimum exposure of the patient, the radiological personnel concerned, and the general public. To achieve this objective in specific situations requires knowledge of the many technical factors and clinical considerations involved and an understanding of their relative importance.

The exposure of individuals can be greatly reduced by the correct application of technical methods. For patient exposure, however, the need for radiologic examination or treatment, the procedures to be employed, and the frequency of their repetition, can be determined only by the professional judgments of physicians and of other practitioners of the healing arts. Such judgment is developed through sound basic training, experience, and continued education and is difficult to control by rules and regulations. Therefore, this report is devoted principally to the technical aspects of minimizing unproductive radiation exposure of human beings.

2.2 Maximum Permissible Dose Equivalent (MPD)

Results of studies on the somatic and genetic effects of radiation are reviewed in other NCRP reports. These results have been utilized in developing recommendations for Maximum Permissible Doses by the National Council on Radiation Protection and Measurements (See NCRP Report No. 17) [3] and by the International Commission on Radiological Protection. The primary objective in establishing MPD values for occupational exposure is to keep the exposure of the radiation worker well below a level at which adverse effects are likely to be observed during his lifetime. Another objective is to minimize the incidence of genetic effects for the population as a whole. The occupational MPD for persons working in controlled areas is summarized

in Table 1, Appendix B. These values do not include any dose received by an individual as a patient or the dose from natural background radiation.

It must be emphasized that the risk to individuals exposed to the MPD is considered to be very small; however, risk increases gradually with the dose received. For this reason, it is desirable to keep radiation exposures as low as is practical with due consideration to medical objectives, feasibility, and efficiency of operation. For the same reason, small transient deviations in the exposure of an individual above the prescribed levels are unimportant except as an indication of inadequate protection practices. For administrative purposes, such a deviation should be regarded simply as a "technical overexposure" as distinct from "overexposure" since the term "overexposure" may have the connotation of injury.

2.3 Exposure of Individuals

2.3.1 *Exposure of Persons Other Than the Patient.* Reduction of radiation exposure to an individual from external sources of radiation may be achieved by any one or any combination of the following measures: (a) increasing the distance of the individual from the source, (b) reducing the duration of exposure and (c) using protective barriers between the individual and the source. For medical x-ray and gamma-ray equipment, shielding and distance are the factors most readily controlled. Protective shielding includes that incorporated into equipment; it may also consist of mobile or temporary devices used as the occasion demands, such as movable screens, or lead impregnated aprons and gloves; or it may comprise permanent protective barriers and structural shielding such as walls containing lead, concrete, or other materials in thicknesses sufficient to provide the required degree of attenuation. Structural shielding is an important part of installation planning and is covered in the forthcoming NCRP Report No. 34.

2.3.2 *Exposure of the Patient.* Techniques employed in radiography and radiation therapy should be those which achieve the desired objectives with minimum dose to the patient. Conflicting factors are often involved, depending upon the type of radiologic examination or condition to be treated. In such instances, compromise must be based on professional experience and judgment. For example, use of higher x-ray tube voltages and greater thicknesses of added filtration in radiography generally result in smaller doses to the patient for a given optical

density of the x-ray film. Under these conditions, however, the contrast of the radiographic image is reduced, resulting in a loss of information which may be critical in certain types of examination. As another example, the use of high speed films and intensifying screens reduces patient exposure, but an associated decrease in image definition may also reduce the value of the examination.

2.4 General Guidelines in the Clinical Use of Radiation

As a general principle, the exposure to the patient shall be kept to the practical minimum consistent with clinical objectives. To this end, the following recommendations are presented for the guidance of physicians and others responsible for the exposure of patients [4].

2.4.1 The useful beam *should* be limited to the smallest area practicable and consistent with the objectives of the radiological examination or treatment.

2.4.2 The voltage, filtration and source-skin distance (SSD) employed in medical radiological examinations *should* be as great as is practical and consistent with the diagnostic objectives of the study [5]. (For dental x-ray examinations, see NCRP Report No. 35).

2.4.3 Protection of the embryo or fetus during radiological examination or treatment of women known to be pregnant *should* be given special consideration.

> *Comment:* Ideally, abdominal radiological examination of a woman of childbearing age should be performed during the first few (approximately 10) days following the onset of menses to minimize the possibility of irradiation of an embryo. In practice, medical needs should be the primary factors in deciding the timing of the examination.

2.4.4 Suitable protective devices to shield the gonads of patients who are potentially procreative *should* be used when the examination or method of treatment may include the gonads in the useful beam, unless such devices interfere with the conditions or objectives of the examination or treatment.

2.4.5 Fluoroscopy *should not* be used as a substitute for radiography, but *should* be reserved for the study of dynamics or spatial relationships or for guidance in spot-film recording of critical details.

2.4.6 X-ray films, intensifying screens, and other image recording devices, *should* be as sensitive as is consistent with the requirements of the examination.

2.4.7 Film processing materials and techniques *should* be those recommended by the x-ray film manufacturer or those otherwise tested to ensure maximum information content of the developed x-ray film and, where practical, quality control methods *should* be employed to ensure optimum results.

3. X-ray Equipment

3.1 Fluoroscopic Equipment[2]

3.1.1 *Design Recommendations.*

(a) A diagnostic-type protective tube housing *shall* be used. (See definition in Appendix A) [6].

(b) The source-panel or source-tabletop distance *shall* be at least 12 inches (30 cm) and *should not* be less than 15 inches (38 cm). The source-skin distance of image intensifier equipment *should not* be less than 15 inches (38 cm).

Comment: The greater the source-tabletop distance, the lower is the entrance dose (and to a lesser extent, the integral dose) for a given screen luminance. Image unsharpness and image magnification also are reduced. However, other considerations place a practical upper limit on the source-tabletop distance. The heating load on the x-ray tube increases rapidly with distance because greater tube current is required to maintain constant screen luminance. For the same reason, it may be necessary to increase spot-film exposure time resulting in greater motion unsharpness. From the standpoint of radiation safety, it appears that the source-tabletop distance is not critical within rather broad limits. For conventional fluoroscopes, a distance of 15–18 inches seems to be a reasonable compromise between the conflicting factors involved [7].

(c) The total filtration permanently in the useful beam *shall* be at least 2.5 millimeters aluminum equivalent. When the tabletop or panel surface is interposed between the source and the patient, its aluminum equivalent may be included as part of the total filtration. (See comment under 3.2.2(a).)

(d) The equipment *shall* be so constructed that, under conditions of normal use, the entire cross section of the useful beam is attenuated by a primary protective barrier, permanently incorporated into the equipment. The exposure *shall* automatically terminate when the barrier is removed from the useful beam.

[2] Including image intensified fluoroscopic equipment.

(1) The lead equivalent of the barrier of conventional fluoroscopes *shall* be at least 1.5 millimeters for equipment capable of operating up to 100 kVp, at least 1.8 millimeters for equipment whose maximum operating potential is greater than 100 kVp and less than 125 kVp, and at least 2.0 millimeters for equipment whose maximum operating potential is 125 kVp or greater [8]. Special attention *shall* be paid to the shielding of image intensifiers so that neither the useful beam nor the scattered radiation from the intensifier itself or from the patient will produce significant radiation exposure to the operator or other personnel.

(2) A collimator *shall* be provided to restrict the size of the useful beam to less than the area of the barrier. The x-ray tube and collimating system *shall* be linked with the fluorescent screen assembly so that the useful beam at the fluorescent screen is confined within the barrier irrespective of the panel-screen distance. (See 3.1.2(d).) For image intensifiers, the useful beam *should* be centered on the input phosphor and during fluoroscopy or cine-recording, it *should not* exceed the diameter of the input phosphor. (Ideally, for spot film radiography with image intensifier equipment, the shutters *should* automatically open to the required field size before each exposure).

(3) Collimators, adjustable diaphragms and shutters *shall* provide the same degree of attenuation as is required of the tube housing.

(e) The fluoroscopic exposure switch *shall* be of the dead-man type. (See definition in Appendix A).

(f) Provision *shall* be made to intercept the scattered x rays from the undersurface of the tabletop and other structures under the table. In most cases, this may be accomplished either by a cone extending from the tube housing to the tabletop or by a shield around the fluoroscope understructure, or both. The cone *shall* provide the same degree of attenuation as is required of the tube housing, with the incident angle of the useful beam taken into consideration.

(g) A shielding device of at least 0.25 mm lead equivalent for covering the Bucky slot during fluoroscopy *should* be provided.

(h) A shield of at least 0.25 mm lead equivalent, such as overlapping protective drapes or hinged or sliding panels, *should* be provided to intercept scattered radiation which would otherwise reach the fluoroscopist and others near the machine.

(i) A cumulative timing device, activated by the fluoroscope exposure switch, *shall* be provided. It *shall* indicate the passage of a predetermined period of irradiation either by an audible signal or by

temporary interruption of the irradiation when the increment of exposure time exceeds a predetermined limit not exceeding five minutes.

Comment: While the timer does not ensure safe operation it is of value as a training device for physicians learning the techniques of fluoroscopy, and for the experienced fluoroscopist as a means for emphasizing the passage of time. The design should be such that the timer reset mechanism does not create a nuisance for the physician.

(j) Devices which indicate the x-ray tube potential and current *shall* be provided. On image intensified fluoroscopic equipment, such devices *should* be located in such a manner that the operator may monitor the tube potential and current during fluoroscopy. (See comment under 3.1.3(b).)

(k) Image intensification *shall* always be provided on mobile fluoroscopic equipment. It *shall* be impossible to operate mobile fluoroscopic equipment unless the useful beam is intercepted by the image intensifier. Inherent provisions *shall* be made so that the machine is not operated at source-skin distance of less than 12 inches (30 cm).

(l) Equipment to be operated in areas where explosive gases may be used *should* have the approval of Underwriters Laboratory for such use.[3]

3.1.2 *Performance Standards:* This section is primarily for the guidance of those concerned with evaluating the radiation safety characteristics of fluoroscopes. In general, equipment built according to the design recommendations of section 3.1.1 will meet the standards of performance outlined below.

(a) When the fluoroscope is operated at 80 kVp, the exposure rate measured in air at the position where the beam enters the patient *shall not* exceed 3.2 R/mA-min and *should not* exceed 2.1 R/mA-min. For other fluoroscopic tube potentials, the exposure per unit charge *shall not* exceed the values marked with an asterisk (*) in Table 2, Appendix B and *should not* exceed the values marked with a dagger sign (†). (See also 3.1.3(a) and (b).)

Comment: The tabletop exposure rate is probably the most important single index of equipment performance. If the measured values exceed the appropriate values, marked with an asterisk (*) in Table 2, the reasons should be investigated. Exposure rate measurements should also be made under the operating conditions normally used by the physician when such information is known.

[3] Information may be obtained from Underwriters Laboratory, 207 East Ohio Street, Chicago, Illinois 60611.

(See 3.1.3 (a) and (b)). With modern equipment, most fluoroscopy can be carried out with exposure rates of less than 5 R/min. If a fluoroscope meets the performance standards of this section but the fluoroscopist finds it necessary to operate the equipment routinely at exposure rates in excess of 5 R/min, it is advisable to check the efficiency of the fluorescent screen by comparing it with a new screen. It may be necessary to replace the screen, particularly in older equipment.

(b) If the amount of filtration in the fluoroscope is unknown, the half value layer of the useful beam *should* be measured. Recommendation 3.1.1(c) may be assumed to have been met if the half-value layer is not less than 2.4 mm of aluminum when the fluoroscopic tube is operated at 80 kVp. For other tube potentials, the measured half-value layers *should not* be less than the corresponding values specified by a dagger sign (†) in Table 3, Appendix B. (See Comment under 3.2.2 (a).)

(c) With the fluorescent screen 14 inches (35 cm) from the panel or tabletop, the exposure rate 2 inches (5 cm) beyond the viewing surface of the screen *shall not* exceed 30 mR/h for each R per minute at the tabletop with the screen in the useful beam without a patient and with the fluoroscope operating at the highest potential employed. (Note: When the operating conditions are known, Table 4 in Appendix B may be used as a guide for determining the expected exposure rate 2 inches (5 cm) beyond the viewing surface).

(d) When the adjustable diaphragm is opened to its fullest extent, an unilluminated margin *shall* exist at all edges of the fluorescent screen when the screen is 14 inches (35 cm) from the panel surface or tabletop, or at the fixed screen position in equipment such as an orthodiascope. In equipment used solely for image intensified fluoroscopy, the shutter *should* restrict the useful beam to the diameter of the input phosphor.

3.1.3 *Guidelines for the Fluoroscopist.*

(a) The exposure rate used in fluoroscopy *should* be as low as is consistent with the fluoroscopic requirements and *shall not* normally exceed 10 R/min (measured in air) at the position where the beam enters the patient. This recommendation applies to the use of image intensifier equipment (with or without television cameras) as well as conventional (direct viewing) fluoroscopes. (See Comment under 3.1.2(a).)

(b) The fluoroscopist *should* know the radiation characteristics of

his equipment. Therefore periodic measurements of table top or patient exposure rate *shall* be made. Patient exposure measurements are especially necessary on apparatus employing image intensifiers in which the intensifier brightness is automatically controlled and the x-ray factors in use are not readily ascertained. Such measurements necessitate the use of a phantom in the fluoroscopic beam.

Comment: Image intensifiers may significantly reduce both observation time and exposure rate when properly used, but do not inherently accomplish this reduction. In equipment with automatic brightness control, the tube potential and current may rise to high values without knowledge of the operator, particularly if the gain of the intensifier is diminished. It is important, therefore, for the operator to monitor tube current and potential on such equipment.

(c) The smallest practical field sizes and shortest exposure times *should* be employed. The possibilities of reducing dose by techniques utilizing high tube potential and low current *should* be considered.

(d) Fluoroscopy *should not* be used as a substitute for radiography but *should* be reserved for the study of dynamics or spatial relationships or for guidance in spot-film recording of critical details.

(e) Medical fluoroscopy *should* be performed only by or under the immediate supervision of physicians properly trained in fluoroscopic procedures.

(f) The fluoroscopist's eyes *should* be sufficiently dark-adapted for the visual task required before commencing fluoroscopy. Under no circumstances should he attempt to compensate for inadequate adaptation by increasing the exposure factors employed or by prolonging the fluoroscopic examination.

Comment: The perception of detail under conditions of scotopic vision requires retinal adaptation. The adaptation time necessary for the competent performance of a specific visual task depends upon the nature of the task itself, the pre-exposure luminance level and color, the conditions of adaptation, and a number of other physiologic factors. While wearing red goggles for 10 minutes will usually satisfy adaptation requirements in fluoroscopy, no specific adaptation period can be recommended for all situations [9]. Dark adaptation normally is not necessary when using image intensifiers.

(g) Extraneous light that interferes with the fluoroscopic examination *shall* be eliminated.

(h) Special precautions, consistent with clinical needs, *should* be taken to minimize exposure of the gonads of potentially procreative pa-

tients and exposure of the embryo or fetus in patients known to be or suspected of being pregnant. (See 2.4.3 and 2.4.4).

(i) In cineradiography, special care *should* be taken to limit patient exposure when, as is often the case, tube currents and potentials employed are higher than those normally used in fluoroscopy. The exposure rates to which patients are normally subjected *shall* be determined periodically.

(j) Protective aprons of at least 0.25 mm lead equivalent *should* be worn in the fluoroscopy room by each person (except the patient) whose trunk is exposed to radiation fields of 5 mR/h or more.

> *Comment:* A busy fluoroscopist is unlikely to operate a fluoroscope more than five hours per week. Therefore, he would be unlikely to receive more than ¼ the maximum permissible dose to the trunk of the body if the scattered radiation level is less than 5 mR per hour. However, other sources of exposure also should be taken into account when deciding whether a protective apron is to be worn.

(k) The hand of the fluoroscopist *should not* be placed in the useful beam unless the beam is attenuated by the patient and a protective glove of at least 0.25 mm lead equivalent.

(l) Only persons whose presence is needed *should* be in the fluoroscopy room during x-ray exposures.

3.2 Fixed Radiographic Equipment

3.2.1 *Design Recommendations.*

(a) A diagnostic-type protective tube housing *shall* be used. (See definition in Appendix A) [6].

(b) Suitable devices (diaphragms, cones, adjustable collimators), capable of restricting the useful beam to the area of clinical interest *shall* be provided to define the beam and *shall* provide the same degree of attenuation as that required of the tube housing. Such devices *shall* be calibrated in terms of the size of the projected useful beam at specified source-film distances. (See 3.2.2(b).) For chest photofluorographic equipment, the collimator *shall* restrict the beam to dimensions no greater than those of the fluorographic screen.

(c) Radiographic equipment, particularly multipurpose machines, *should* be equipped with adjustable collimators containing light lo-

calizers that define the entire field. Rectangular collimators are usually preferable. Means *should* be provided to produce a visible indication of adequate collimation and alignment on the developed x-ray film. The field size indication on adjustable collimators *shall* be accurate to within one inch for a source-film distance of 72 inches. The light field *shall* be aligned with the x-ray field with the same degree of accuracy.

(d) The aluminum equivalent of the total filtration in the useful beam *shall* be not less than that shown in the following table: (See also Section 3.2.2(a). For dental radiography, see forthcoming NCRP Report No. 35.)

Operating kVp	Minimum Total Filter (Inherent plus added)
Below 50 kVp	0.5 mm aluminum
50–70 kVp	1.5 mm aluminum
Above 70 kVp	2.5 mm aluminum

(e) A device *shall* be provided which terminates the exposure at a preset time interval or exposure. The operator *should* be able to terminate the exposure at any time.

(f) The exposure switch, except for those used in conjunction with "spot-film" devices in fluoroscopy, *shall* be so arranged that it cannot be conveniently operated outside a shielded area.

(g) The control panel *shall* include a device (usually a milliammeter) to give positive indication of the production of x rays whenever the x-ray tube is energized.

(h) The control panel *shall* include devices (labelled control settings and/or meters) indicating the physical factors (such as kVp, mA, exposure time or whether timing is automatic) used for the exposure.

(i) Machines equipped with beryllium window x-ray tubes *shall* contain keyed filter interlock switches in the tube housing and suitable indication on the control panel of the added filter in the useful beam if the total filtration *permanently* in the useful beam is less than 0.5 mm aluminum equivalent. The total filtration permanently in the useful beam *shall* be clearly indicated on the tube housing.

> *Comment:* Beryllium window x-ray tubes with no added filtration emit low energy x rays at very high exposure rates. It is particularly important, therefore, that the operator be able to tell by a glance at the control panel how much added filter, if any, is present.

(j) Beryllium window x-ray tubes *should not* be used on multipurpose radiographic equipment.

(k) The aluminum equivalent of the tabletop when a cassette tray is used under the table top, or the aluminum equivalent of the front panel of the vertical cassette holder, *shall not* be more than 1 mm at 100 kVp.

(l) Equipment to be operated in areas where explosive gases may be used *should* have the approval of Underwriters Laboratory for such use.[3]

3.2.2 *Performance Standards.*

(a) If the filter in the machine is not accessible for examination and the total filtration is unknown, the half-value layer of the useful beam *should* be measured. Recommendation 3.2.1(d) may be assumed to have been met if the half-value layer is not less than 0.6 mm aluminum when the x-ray tube is operated at 49 kVp, or not less than 1.6 millimeters aluminum at 70 kVp, or not less than 2.6 millimeters aluminum at 90 kVp. For other tube potentials, the measured half-value layers *should not* be less than the corresponding values specified by an asterisk (*) in Table 3, Appendix B. (For dental radiography, see forthcoming NCRP Report No. 35.)

> *Comment:* The purpose of the filter is to absorb preferentially the lower energy (longer wavelength) portions of the x-ray spectrum which would otherwise be absorbed by the patient without significantly contributing to the information reaching the film. In general, the greater the amount of filtration, the greater the average energy of the x-ray beam, and the smaller the dose to the patient for a given exposure to the x-ray film. However, depending on kVp, the rate of dose reduction with increasing filtration diminishes rapidly and practical considerations place an upper limit on the amount of filtration that is reasonable in a given type of radiological examination. In practice, small changes in filter thickness are unimportant and for the great majority of x-ray examinations, one filter will suffice. Since relatively few examinations (such as mammography) are carried out below 50 kVp, most radiographic equipment should have 2 or more millimeters of added aluminum filtration securely fixed in the tube housing.

(b) The size of the x-ray beam projected by *fixed aperture* cones and collimators (except those used for stereoradiography) *should not* exceed the dimensions of the x-ray film by more than 2 inches for a source-film distance (SFD) of 72 inches or 1 inch for a source-film distance of 36 inches as illustrated in Figure 1.

(c) In general, modern diagnostic tube housings incorporate suf-

[3] Information may be obtained from Underwriters Laboratory, 207 East Ohio Street, Chicago, Illinois 60611.

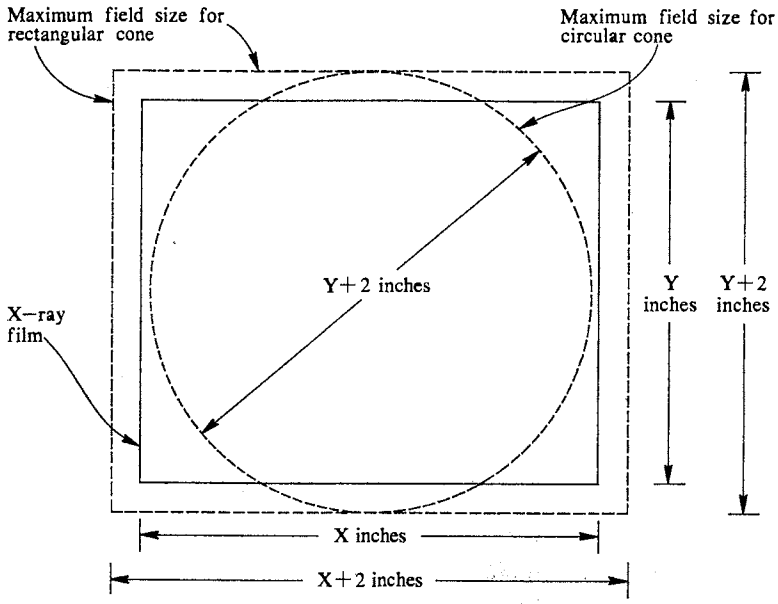

Fig. 1. Maximum beam size at 72 inch SFD.

ficient attenuating material to limit the leakage radiation to that permitted in the definition of a diagnostic-type protective tube housing (See Appendix A) and it usually is unnecessary to perform leakage tests in the field on modern x-ray machines. When in doubt, however, the following method for testing for leakage radiation is recommended: With the window of the housing blocked with at least 10 HVL of absorbing material (e.g., lead), the leakage radiation should be measured with the x-ray tube operating at its maximum voltage and at its maximum current for continuous operation at that voltage. When this method of testing is not practical, the test may be made at higher current, provided that careful consideration is given to the limitation of operating time imposed by the heat capacity of the tube or target as determined from the manufacturer's tube rating and cooling charts. Small areas of reduced protection are acceptable in evaluating the maximum exposure rate provided the average reading over 100 square centimeters at one meter distance does not exceed 100 mR per hour (normalized to maximum current for continuous operation).

3.2.3 *Guidelines for the User.* (See also Section 2.4.)

(a) Particular care *should* be taken to limit the useful beam to the smallest area consistent with clinical requirements and to align accurately the x-ray beam with the patient and film. (See also 3.2.2(b).)

(b) Gonadal shielding *should* be used for the patient when appropriate, (see 2.4.4) but never as a substitute for adequate beam collimation and alignment.

(c) When a patient must be held in position for radiography, mechanical supporting or restraining devices *should* be used. If the patient must be held by an individual, that individual *shall* be protected with appropriate shielding devices such as protective gloves and apron and he *should* be so positioned that no part of his body will be struck by the useful beam and that his body is as far as possible from the edge of the useful beam.

(d) Only persons whose presence is necessary *shall* be in the radiographic room during exposure. All such persons *shall* be protected.

(e) The radiographer *shall* stand behind the barrier provided for his protection during radiographic exposures.

(f) Special care *shall* be taken to ensure adequate filtration in multipurpose machines.

> *Comment:* For soft tissue radiography such as mammography, operating potentials considerably below 50 kVp may be required. In performing such examinations on multipurpose machines, it is usually necessary to reduce the amount of filtration. It is important, however, that the appropriate filter be replaced before proceeding with exposures requiring normal filtration.

(g) Particular care *shall* be taken to ensure adequate filtration in any machine equipped with a beryllium window tube. Appropriate added filter is required to provide the filtration values recommended in section 3.2.1 (d). (See also 3.2.1 (i) and (j).)

3.3 Mobile Radiographic Equipment

3.3.1 *Design Recommendations.*

(a) Recommendations given in section 3.2.1 for fixed radiographic equipment are applicable to mobile equipment except for paragraphs (f) and (k).

(b) Inherent provisions *shall* be made so that the equipment is not operated at source-skin distances of less than 12 inches (30 cm).

(c) The exposure switch *shall* be so arranged that the operator can stand at least six feet from the patient, the x-ray tube, and the useful beam.

(d) If a mobile x-ray machine is used routinely in one location, it

should be considered a fixed installation. The shielding requirements for fixed installations apply (see forthcoming NCRP Report No. 34).

3.3.2 *Performance Standards.*

The performance standards of section 3.2.2 for fixed radiographic equipment are applicable to mobile equipment.

3.3.3 *Guidelines for the User.*

(a) Recommendations of section 3.2.3 for fixed radiographic units apply also to mobile equipment except for paragraphs (d) and (e).

(b) The operator *should* use the maximum source-skin distance (SSD) consistent with the conditions of the radiographic examination. Distances less than 12 inches (30 cm) *shall not* be used. Distances less than 15 inches (38 cm) *should not* be used.

(c) Mobile x-ray equipment *shall not* be used for fluoroscopy, unless it meets the requirements for mobile fluoroscopes (see 3.1.1 (k).)

(d) The operator *should* stand as far as possible from the patient, the tube, and the useful beam. He *should* wear a protective apron or stand behind a suitable shield.

(e) Mobile equipment *should* be used only for examinations where it is impractical to transfer patients to permanent radiographic installations.

(f) The responsible medical supervisor *should* assure himself that operators of mobile equipment understand the proper use and limitations of the equipment so as to avoid needless exposure of the patient, and other persons in the vicinity.

3.4 X-ray Therapy Equipment

3.4.1 *Design Recommendations.*

(a) A therapeutic-type protective tube housing *shall* be used. (See definition in Appendix A). Contact therapy machines *shall* meet the additional requirement that the leakage radiation at 2 inches (5 cm) from the surface of the housing not exceed 0.1 R/h.

(b) Permanent diaphragms or cones used for collimating the useful beam *shall* afford the same degree of attenuation as is required of the housing.

(c) Adjustable or removable beam-defining diaphragms or cones *shall* transmit not more than 5 percent of the useful beam as determined at the maximum tube potential and with maximum treatment filter.

(d) The filter system *shall* be so arranged as to minimize the possibility of error in filter selection and alignment. The filter slot *shall* be so constructed that the radiation escaping through it does not produce an exposure exceeding 1 R/h at one meter, or if the patient is likely to be exposed to radiation escaping from the slot, 30 R/h at 2 inches (5 cm) from the external opening. Each removable filter *shall* be marked with its thickness and material.

(e) A filter indication system *shall* be used on all therapy machines using changeable filters. It *shall* indicate, from the control panel, the presence or absence of any filter and it *shall* be designed to permit easy recognition of the filter in place.

(f) The x-ray tube *shall* be so mounted that it cannot turn or slide with respect to the housing aperture. A mark on the housing *should* show the location of the focal spot.

(g) Means *shall* be provided to immobilize the tube housing during stationary portal treatment.

(h) An easily discernible indicator which shows whether or not x rays are being produced *shall* be on the control panel.

(i) Beam monitoring devices *should* be fixed in the useful beam to indicate any error, due to incorrect filter, tube current, or tube potential, or to indicate any significant variation of field uniformity, unless the device introduces more filtration than is clinically acceptable.

Comment: A device to monitor the uniformity of the field is particularly important in linear accelerators.

(j) A suitable exposure control device (e.g. an automatic timer, exposure meter or dose meter) *shall* be provided to terminate the exposure after a preset time interval or preset exposure or dose limit. It *should* be designed to preserve its accumulated response in the event of equipment failure during patient treatment. If a timer is used, it *should* permit accurate presetting and determination of exposure times as short as 1 second. Means *shall* be provided for the operator to terminate the exposure at any time.

(k) Unless it is possible to bring the x-ray exposure rate to the prescribed value within 5 seconds after the x-ray "ON" switch is energized the tube housing on machines operating below 500 kVp *should* be fitted with an "ON-OFF" shutter operated from the control panel

and of lead equivalent not less than that of the tube housing. The "ON-OFF" positions of the shutter *shall* be indicated at the control panel.

(l) Mechanical and/or electrical stops *shall* be provided on x-ray machines capable of operating at 150 kVp or above to insure that the useful beam is oriented only toward primary barriers. (See NCRP Report No. 34 on Structural Shielding).

(m) Interlocks *shall* be provided for x-ray therapy equipment capable of operating above 150 kVp so that when any door to the treatment room is opened, either the machine will be shut off automatically or the radiation level within the room will be reduced to an average of not more than 2 mR/h and a maximum of 10 mR/h at a distance of one meter in any direction from the source. After such a shutoff or reduction in exposure rate, it *shall* be possible to restore the machine to full operation only from the control panel. (The 2 mR/h average shall be obtained from measurements as described in section 4.2.2(a).)

(n) The x-ray control circuit *should* be so designed that it is not possible to energize the x-ray tube to produce x rays without resetting the x-ray "ON" switch at the control panel. For machines not meeting this recommendation, see Section 3.4.3(g).

> *Comment:* The purpose of this recommendation is to prevent the accidental exposure that might result if x rays were produced by connecting the power line to the mains or by closing the primary disconnect switch.

(o) X-ray therapy machines *should* be provided with a locking device to prevent unauthorized use.

(p) When high energy x-ray therapy equipment is mounted isocentrically, the counterweight frequently serves also as a beam interceptor in order to reduce the structural shielding requirements. When a beam interceptor is provided, it *should* transmit not more than 0.1 percent of the useful beam under any operating condition. It *should* also reduce by the same factor the radiation scattered by the patient through an angle up to 30 degrees from the central ray. (See NCRP Report No. 34 on Structural Shielding.)

(q) When the relationship between the beam interceptor (when present) and the useful beam is not permanently fixed, mechanical or electrical stops *shall* be provided to ensure that the beam is oriented only toward primary barriers.

(r) An easily discernible or audible indicator which shows whether or not x rays are being produced *should* be provided in the treatment room for x-ray equipment capable of operating above 500 kVp. (Also see NCRP Report No. 34 for the need to provide emergency "cut-off" or "panic" buttons at appropriate places in the treatment room).

(s) Equipment to be operated in areas where explosive gases may be used *should* have the approval of Underwriters Laboratory for such use.[3]

(t) Special considerations *should* be given to the safety design of x-ray machines with electron beam extraction capability (e.g., to insure that the electron mode cannot be employed inadvertently when the x-ray mode is intended) [10].

Comment: As linear accelerators are capable of producing electron beam dose rates greater than 10,000 rads/sec at the treatment distance, extreme precautions must be taken in the therapeutic applications of electron beams generated by high energy electron accelerators.

3.4.2 *Performance Standards.* Compliance with some of the design specifications recommended in Section 3.4.1 can be determined by visual inspection of the x-ray therapy equipment. Field testing for conformity with the remaining design recommendations generally is not necessary on modern equipment, particularly when manufacturers' test data are available on prototypes. In cases of doubt, however, appropriate measurements *shall* be made by or with the advice of a qualified expert responsible for calibrating x-ray therapy equipment. (See Section 5). With the following exception, no specific performance standards are suggested:

The leakage radiation through the x-ray tube housing for equipment operating below 500 kVp may be tested as follows: With the housing window and filter slots blocked with at least 10 half-value layers of absorbing material (e.g. lead), the exposure rate *should not* exceed 1 R/h at a distance of 1 meter from the source with the x-ray tube operating at its maximum potential and at its maximum current for continuous operation at that potential. Small areas of reduced shielding are acceptable providing the average reading over any 100 square centimeter area at one meter distance from the source does not exceed 1 R/h.

3.4.3 *Guidelines for the User.*

(a) An x-ray therapy machine *shall* be calibrated by a qualified expert before use for the treatment of patients. (See Section 5).

(b) X-ray therapy equipment capable of operating above 150 kVp *shall not* be operated routinely until the radiation safety of the instal-

[3] Information may be obtained from Underwriters Laboratory, 207 East Ohio Street, Chicago, Illinois 60611.

lation has been established by a protection survey. All x-ray therapy equipment *shall* be operated in conformance with recommendations of the protection survey. (See Section 6.)

(c) Both the control panel and the patient *should* be kept under observation during exposure.

(d) When a patient must be held in position for radiation therapy, mechanical supporting or restraining devices *should* be used. If the patient *must* be held by an individual, that individual *shall* be adequately protected and he *shall* be positioned so that no part of his body will be struck by the useful beam and so that his body is as far as possible from the edge of the useful beam. The exposure of any individual used for this purpose *shall* be monitored. (See Section 7.3.)

(e) With the above exception (3.4.3(d)), no person other than the patient *shall* be in the treatment room when the tube is operated at potentials exceeding 150 kVp. At operating potentials of 150 kVp or below, other persons may be in the treatment room for good reason but only if they are adequately protected and their radiation exposure is monitored.

(f) If the x-ray tube of a contact therapy machine is hand held during irradiation, the operator *shall* wear protective gloves and apron. When practical, a cap of at least 0.5 mm lead equivalent *should* cover the aperture window of the tube housing of such apparatus when the apparatus is not being used.

> *Comment:* Because of the exposure rate at the surface of the window of contact therapy and beryllium window machines may be more than 10,000 R per minute, extreme precautions are necessary to prevent accidental exposure to the useful beam.

(g) For x-ray therapy machines not meeting the recommendation of paragraph 3.4.1(n), the "ON-OFF" switch at the control *should* always be turned off first, then the primary switch (or wall plug disconnected). This sequence *should* never be reversed.

(h) Lead, lead rubber, lead foil, etc., used for limiting the field, *should not* transmit more than 5 per cent of the useful beam. (See Table 7, Appendix B.)

4. Gamma-Beam Therapy Equipment

4.1 Gamma-Beam Sealed Sources

4.1.1 *Sealed Source Capsules.* Sources used in gamma-beam therapy *shall* be sealed in capsules which are strongly resistant to breakage. Sources larger than a few curies have very high internal radiation intensities and are subject to decomposition of salts and minor contaminants, appreciable heat generation, and the potential production of gases, with a buildup of pressure within the source container. Such sources *should* be sealed in a welded capsule which is contained in a second welded container.

4.1.2 *Leakage Testing of Sealed Sources by Manufacturer.* After the source is loaded into the inner welded capsule, the capsule *shall* be scrubbed clean of contaminating radioactivity. It *shall not* be placed into the second container until tests reveal no significant leakage. A recommended test is to scrub the dry container with a filter-paper sponge and to assay the removable radioactivity. After welding of the second container, the container *should* again be checked for contamination. Upon completion of the source assembly, the assembly *shall* be checked by the manufacturer for contamination. (See 4.2.2(c) for leakage testing by user.)

4.1.3 *Replacement of Gamma-Beam Sealed Sources.* Contamination tests of the source assembly housing *shall* be conducted whenever a gamma-beam source is replaced. Any removable contamination *shall* be removed prior to insertion of the new source.

Should the radiation survey of the source assembly housing reveal contamination, the used source *shall not* be reused until it has been definitely determined that the source is not leaking. Such a determination may require that the source be inspected in an appropriate hot cell.

4.2 Gamma-Beam Equipment

4.2.1 *Design Recommendations.*

(a) *Protective Source Housing: Beam "OFF" Position.* The housing *shall* be so constructed that at 1 meter from the source, the maximum and the average exposure rates do not exceed 10 mR/h and 2 mR/h, respectively, when the beam control mechanism is in the "OFF" position. (See Section 4.2.2(a).) In the design of the housing, consideration *should* also be given to reducing the surface exposure rate for small diameter housings.

(b) *Protective Source Housing: Beam "ON" Position.* The leakage radiation measured at one meter from the source *shall not* exceed 0.1 per cent of the useful beam exposure rate at that distance when the beam control mechanism is in the "ON" position, except for the portion of the housing which includes the collimator zone. (See Section 4.2.2(b).) A reduction of the leakage radiation below this limit may result in more economical secondary protective barriers for the radiation room. This limit, however, does not apply to source housings where the leakage radiation at one meter is less than 1 R/h, nor does it apply to apparatus used exclusively for whole-body irradiation.

(c) *Beam Defining Apparatus.* The beam-defining apparatus comprising the collimator zone *shall* be constructed to attenuate the useful beam so that the transmitted exposure rate is not more than 5 per cent of the unattenuated beam. (See Section 4.2.2(b).) Auxiliary beam-defining devices need not meet this requirement.

(d) *Beam Control Mechanism.* The beam-control mechanism *shall* meet the following specifications:

1. In the "ON" position, the source and beam-collimating device *shall* be accurately aligned.
2. The mechanism *shall* be capable of acting in any orientation of the housing.
3. The mechanism *shall* be so constructed that in an emergency it can be returned manually to the "OFF" position with a minimum exposure to personnel.
4. The moving parts *shall* be so constructed that it is highly improbable that the apparatus will fail to return to the "OFF" position at the end of the preset exposure time.
5. There *shall* be on the housing and on the control panel a warning device that plainly indicates whether the beam is "ON" or "OFF".

6. The control panel *shall* be provided with a timer that automatically terminates the exposure after a preset time.

7. The beam-control mechanism *shall* be so designed as to return automatically to the "OFF" position in the event of any breakdown or interruption of the activating force and *shall* stay in the "OFF" position until reactivated from the control panel.

8. When the door to the treatment room is opened, the beam control mechanism *shall* automatically and rapidly return to the "OFF" position where it *shall* remain until the door is again closed and the machine is manually reactivated from the control panel.

9. It *shall not* be possible to switch the beam-control mechanism to the "ON" position from inside the treatment room.

(e) *Lock.* The equipment *shall* be provided with a locking device to prevent unauthorized use.

(f) *Beam Interceptor.* With gamma-beam equipment utilizing an isocentric mounting the counterweight is frequently designed to serve also as a beam interceptor in order to reduce the structural shielding requirements. When a beam interceptor is provided it *should* transmit not more than 0.1 per cent of the useful beam. It *should* also reduce by the same factor the radiation scattered by the patient through an angle of up to 30 degrees from the central ray. (See NCRP Report No. 34 on Structural Shielding.)

(g) *Beam Orientation.* A beam interceptor is considered a primary barrier. When a beam interceptor is not present or when the relationship between the useful beam and the beam interceptor is not permanently fixed, mechanical or electrical stops *shall* be provided to ensure that the beam is oriented only toward primary barriers.

(h) *Resistance of Source-Housing to Fire.* The source housing *should* be so constructed that the integrity of the shield is preserved in case of fire. The source capsule *shall* be constructed so as to minimize the probability of escape of radioactive material contained within it.

4.2.2 *Performance Standards.* Compliance with some of the design specifications recommended in Section 4.2.1 can be checked by visual inspection of the gamma-beam apparatus. Field testing for conformance with other sections may not be necessary if the manufacturers' test data are available on exact prototypes. In case of doubt, however, appropriate measurements *shall* be made by or with the advice of a qualified expert. (See Section 5.) The following performance standards *should* be used when indicated:

(a) *Leakage Radiation: Beam "OFF" Position.* The leakage radiation through the source housing with the beam in the "OFF" position (see Section 4.2.1(a)) *shall* be measured with a suitable calibrated instrument. An acceptable method for obtaining the average exposure

at 1 meter from the source is to take measurements on the surface of the sphere 1 meter in radius centered on the source. Measurement points may be located as follows: The initial 6 of 14 primary points are defined by the poles of the sphere and 4 equally spaced points on its equator. The remaining 8 primary points are located at the centers of the spherical triangles formed by connecting the initial 6 points. An additional 12 secondary points are defined by points midway between the 6 initial primary points. The average of readings determined at these 26 points *shall not* exceed 2 mR/h and no point *shall* exceed 10 mR/h. Small areas of reduced protection, however, are acceptable in evaluating the maximum exposure rate providing the average over 100 square centimeters at one meter from the source does not exceed 10 mR/hour. For field survey procedures after the installation of a teletherapy apparatus or after a replacement of the source in an existing installation, measurements at the 14 primary points are sufficient.

(*b*) *Leakage Radiation: Beam "ON" Position.* The leakage radiation through the source housing with the beam in the "ON" position may be measured as follows: If the beam-defining apparatus has movable diaphragms, they *should* be closed as far as possible. If the movable diaphragms do not completely block the useful beam aperture, or if the beam-defining device does not have movable diaphragms, the entire collimating zone *should* then be covered with lead or other suitable material providing attenuation equal to that of the adjacent wall of the housing while making this measurement. (See Section 4.2.1 (b).) This measurement is not required on each source housing if results of measurements on an exact prototype are available.

(c) *Leakage of Radioactive Material.* The gamma-beam apparatus *shall* be tested for possible leakage of radioactive material from the source after installation and at intervals not exceeding six months. An acceptable method of testing for source leakage is to wipe (with moistened cotton swabs or filter paper) accessible surfaces of the housing port and collimator with the beam in the "OFF" position and to assay these wipes for transferred contamination. If the amount of transferred activity exceeds 0.05 microcurie, action *shall* be taken to prevent spread of contamination and appropriate authorities shall be notified.

(d) *Alignment of Source and Beam-Collimating Device.* The symmetry of the radiation field about the central axis of the useful beam *should* be measured. This may be accomplished by the judicious exposure of x-ray films to the useful beam with the beam collimating device opened to its fullest extent, or by using any of a variety of small dosimeters distributed across the field. (See also 5.2.3 and 5.2.4.)

4.2.3 *Guidelines for the User.*

(a) Paragraphs (c) and (h) of Section 3.4.3 concerning the use of x-ray therapy equipment apply.

(b) The gamma-beam appartus *shall* be calibrated by a qualified expert before use for the treatment of patients. (See Section 5.)

(c) The gamma-beam therapy installation *shall not* be operated routinely until the radiation safety has been established by a radiation protection survey. The apparatus *shall* be operated in conformance with recommendations of the protection survey. (See Section 6.) A resurvey *should* be carried out each time the apparatus is reloaded with a new source.

(d) Emergency procedures to be followed in the event of failure of the beam control mechanism *shall* be established and posted at the control panel. (See Appendix C for a sample emergency procedure).

(e) When a patient must be held in position for radiation therapy, mechanical supporting or restraining devices *should* be used. If the patient *must* be held by an individual, that individual *shall* be adequately protected and he *shall* be positioned so that no part of his body will be struck by the useful beam and so that his body is as far as possible from the edge of the useful beam. The exposure of any individual used for this purpose *shall* be monitored. (See Section 7.3.)

(f) With the above exception (4.3.3(e)), no person other than the patient *shall* be in the treatment room while the source is in the "ON" position.

5. Therapy Equipment Calibration Guides

This section is primarily for the guidance of physicians practicing radiation therapy and of those concerned with the calibration of x-ray and gamma-beam therapy equipment.

5.1 General

The exposure rate or dose rate of the useful beam and the geometry of the useful beam *shall* be known with reasonable certainty at all times during operation of the radiation therapy apparatus for medical purposes [11].

5.2 Calibration

A calibration of the therapy apparatus *shall* be performed by or under the direct supervision of a qualified expert (See definition, Appendix A) before the apparatus is first used for medical purposes. The calibration *should* include at least the following determinations:

5.2.1 The exposure rate or dose rate for the range in field sizes used and for each radiation quality and for each treatment distance used for radiation therapy.

5.2.2 The radiation quality (e.g. half-value layer when appropriate or effective energy) for every combination of kVp and filter used for radiation therapy.

5.2.3 The congruence between the radiation field and the field indicated by the localizing device when localizing devices are used for radiation therapy.

5.2.4 The uniformity of the radiation field and its dependence upon the direction of the useful beam.

5.3 Recalibration

The user *should* make or *should* have made appropriate determinations as described in 5.2 in the following circumstances:

5.3.1 Whenever the beam monitor or other meter related to exposure rate or dose rate shows a continued, significant change[4] in its normal reading. (See paragraph 3.4.1 (i).)

5.3.2 Following major mechanical or electrical alterations of the radiation source, its housing, power supply or controls, or following replacement of the radiation source, or following reinstallation of the apparatus in a new location.

5.3.3 At least once in every calendar year except that recalibrations are not required so long as spot checks, as defined below, indicate no significant change[4] in the exposure rate or dose rate.

5.4 Spot Check Measurement

A spot check measurement consists of determining the exposure rate or dose rate or a quantity related in a known manner to these entities for one typical set of operating conditions. Spot checks *should* be made periodically (for x-ray therapy equipment, at least once a month or after every 50 operating hours, whichever is the longer time interval). A log *shall* be kept of all spot check measurements.

[4] The percentage change in dose rate necessary to be considered significant is a matter of judgment and depends upon the circumstances.

6. Radiation Protection Surveys

This section is primarily for the guidance of the user, the radiation protection supervisor (see Section 7.2), and those responsible for conducting radiation protection surveys. For further information, see the forthcoming NCRP Report on Instrumentation and Monitoring Methods for Radiation Protection.

6.1 General Survey Procedures

6.1.1 As used in this report, *radiation protection survey* means an evaluation of potential radiation exposure incident to the use of medical x-ray and gamma-beam equipment under specified conditions. When appropriate, such evaluation includes inspection of the equipment, an examination of its location with reference to controlled and noncontrolled areas in the immediate environment, and measurements of exposure levels in the environment arising from operation of the equipment.

6.1.2 A radiation protection survey of all new installations and existing installations not previously surveyed *shall* be made by, or under the direction of, a qualified expert. A resurvey *shall* be made after every change in equipment, workload, or operating conditions which might *significantly* increase the probability of persons receiving more than the MPD. If, as a result of a radiation survey, supplementary shielding is installed, another survey *should* be made in order to confirm the adequacy of the shielding after the modification.

> *Comment:* The qualified expert may be anyone, including the user himself, who has the training and experience in radiation protection as applied to medical installations of the type involved to: (1) make the necessary radiation measurements, (2) evaluate their significance, and (3) institute the corrective measures called for by the evaluation. See definition of qualified expert in Appendix A.

6.1.3 In evaluating the results of the survey, account *shall* be taken of actual operating conditions, including workload, use factor, occu-

pancy factor, and attenuation of the useful beam provided by patients and objects permanently in the path of the useful beam.

6.1.4 Whenever, in the opinion of the qualified expert, there is a reasonable probability that a person in a given controlled or noncontrolled area may receive more than 10 mR in any week, then *one or more* of the following courses of action (whichever may be appropriate) *should* be taken to demonstrate or to ensure that no person is likely to receive more than the applicable MPD:

(a) Make cumulative radiation measurements in the area of interest over appropriate time periods, or make dose rate measurements and apply appropriate workload, use, and occupancy factors to calculate the cumulative dose to occupants in the area;

(b) Use personnel monitoring to estimate the exposures received by occupants of the area; (see 7.3);

(c) Add supplementary shielding to the protective barriers to ensure conformity with NCRP protective barrier recommendations; (see NCRP Report No. 34);

(d) Impose restrictions on the use of the equipment (workload or use factor);

(e) Impose restrictions on the occupancy of the area, if controlled.

6.1.5 Exposure or dose measurements to evaluate the adequacy of secondary barriers for x-ray or gamma-beam therapy equipment *should* be made with a phantom intercepting the useful beam and with the largest field size used clinically.

6.1.6 All interlocks, "ON-OFF" beam control mechanisms, safety and warning devices on radiation therapy installations *should* be checked and appropriately serviced at least once in every six-month period.

6.1.7 "Radiation Area" warning signs *should* be posted in any accessible area wherein a person, if he were continuously present, could receive an exposure in excess of 5 mR in any one hour. "High Radiation Area" warning signs *shall* be posted in any accessible area wherein a person could receive an exposure of 100 mR in any one hour were he continuously present. Exceptions to the posting requirement of "High Radiation Area" signs are permitted in locations visible to patients when such signs may be a source of apprehension, provided personnel occupying the areas are otherwise informed of the radiation levels to which they may be exposed and entrance to the area is strictly controlled.

6.1.8 If the design and/or approved use of the installation depends upon restrictions on the use factor of any primary barrier, it *should* be determined that these restrictions are actually observed.

6.1.9 When personnel monitoring is required, an evaluation of the

techniques used *should* be made by the qualified expert. (See Section 7.3.)

6.1.10 The qualified expert *shall* report his findings in writing, including recommendations for any required corrective measures. The report *should* indicate if a further survey is necessary after corrections have been made.

6.2 Surveys of Radiation Equipment

Surveys to evaluate the radiation safety characteristics of x-ray machines and gamma-beam therapy equipment *should* be performed when necessary according to the judgment of the qualified expert and the recommendations of Sections 3.1.2, 3.2.2, 3.3.2, 3.4.2, and 4.2.2.

7. Working Conditions

7.1 General

7.1.1 The *owner* (see definition in Appendix A) is responsible for radiation safety. He is responsible for assuring that radiation sources under his jurisdiction are used only by persons competent to use them. He is responsible for providing the instruction of personnel in safe operating procedures and for promulgating rules for radiation safety.
7.1.2 Deliberate exposure of an individual to the useful beam for training or demonstration purposes *shall not* be permitted unless there is also a medical (or dental) indication for the exposure and the exposure is prescribed by a physician (or dentist).

7.2 Radiation Protection Supervisor

7.2.1 A radiation protection supervisor (who may be the user himself) *shall* be designated for every installation to assume the responsibilities outlined below and to advise on the establishment of safe working conditions according to the recommendations of this report and in compliance with all pertinent federal, state, and local regulations. He *should* be familiar with the basic principles of radiation protection in order to properly discharge his responsibilities, although for details he may consult with appropriate qualified experts for advice.
7.2.2 Among the specific responsibilities of the radiation protection supervisor or his deputy are the following:

(a) To establish and supervise operating procedures and to review them periodically to assure their conformity with the recommendations of this report.

(b) To instruct personnel in proper radiation protection practices.

(c) To conduct or have conducted radiation surveys and source leak tests where indicated (Section 6 and 4.2.2 (c)) and to keep records of such surveys and tests, including summaries of corrective measures recommended and/or instituted.

(d) To assure that personnel monitoring devices are used where

indicated (Section 7.3) and that records are kept of the results of such monitoring.

(e) To assure that interlock switches and warning signals are functioning and that signs are properly located.

(f) To investigate each known or suspected case of excessive or abnormal exposure to determine the cause and to take steps to prevent its recurrence. (See 7.3.3.)

7.3 Personnel Monitoring

Personnel monitoring is valuable for checking the adequacy of the radiation safety program. It can be useful in disclosing inadequate or improper radiation protection practices, and potentially serious radiation exposure situations.

Personnel monitoring may be of value also in documenting occupational exposure if proper consideration is given to the limitations of the monitoring system [12]. Accordingly, the following recommendations are made:

7.3.1 Personnel monitoring *shall* be performed in controlled areas for each occupationally exposed individual for whom there is a reasonable possibility of receiving a dose exceeding one-fourth the applicable MPD. (See Table 1, Appendix B.)

7.3.2 A qualified expert *should* be consulted on establishing and evaluating the personnel monitoring system. When feasible, the system *should* be tested periodically.

7.3.3 All reported cases of apparently high exposures *shall* be investigated by the radiation protection supervisor and his findings and conclusions *should* be made a part of the personnel monitoring record.

7.3.4 Devices worn for the monitoring of occupational exposure *shall not* be worn by the individual when he is exposed as a patient for medical or dental reasons.

7.3.5 Monitoring devices used to estimate whole body exposure normally *should* be worn on the chest or abdomen. When a protective apron is worn (e.g., during fluoroscopy), particular care *should* be taken in choosing the location of the monitoring device and in interpreting its reading. Devices worn on the inside of the apron will not normally provide a reliable indication of the radiation environment outside of the apron. Devices worn on the outside of the apron usually will provide only an upper limit for the estimation of the exposure of parts of the body covered by the apron. Accordingly, a qualified

expert *should* be consulted in situations where the interpretation of the reading is highly dependent upon the conditions under which the monitoring device is used. (For further information on the use of personnel monitoring devices, see the forthcoming NCRP Report on Instrumentation and Monitoring Methods for Radiation Protection.)

7.3.6 Blood counts *shall not* be used for personnel monitoring [13].

7.4 Medical Examination

7.4.1 A preplacement medical examination is recommended to establish baseline values for the radiation worker and to reveal any physical condition that later might otherwise be attributed to radiation exposure. It *should* include medical history, radiation exposure history, physical examination, and, at the discretion of the physician in charge, a complete blood count.

7.4.2 Whenever it is known or suspected that a person has received a dose substantially in excess of the MPD, the individual *should* be referred at once to a competent medical authority.

7.5 Vacations

7.5.1 Vacations *shall not* be used as a substitute for adequate protection against exposure to radiation.

8. References[5]

1. National Committee on Radiation Protection and Measurements, *Medical X-Ray Protection up to Three Million Volts,* NCRP Report No. 26 (National Bureau of Standards Handbook 76, Washington, D.C., 1961)
2. National Committee on Radiation Protection and Measurements, *Protection Against Radiations from Sealed Gamma Sources,* NCRP Report No. 24 (National Bureau of Standards Handbook 73, Washington, D.C., 1960)
3. National Committee on Radiation Protection and Measurements, *Permissible Dose from External Sources of Ionizing Radiation,* NCRP Report No. 17 (National Bureau of Standards Handbook 59, Washington, D.C., 1954)
4. World Health Organization, *Public Health and the Medical Use of Ionizing Radiation,* World Health Organization Technical Report Series No. 306 (World Health Organization, Geneva, 1965) (Obtainable for $1.00 from Columbia University Press, International Documents Service, 2960 Broadway, New York, N.Y. 10027)
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APPENDIX A

Definitions

Absorbed dose: The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The special unit of absorbed dose is the rad. One rad equals 100 ergs per gram.

Activity: The number of nuclear disintegrations occurring in a given quantity of material per unit time. See curie.

Aluminum equivalent: The thickness of aluminum affording the same attenuation, under specified conditions, as the material in question.

Added filter: See filter.

Attenuation: The reduction of exposure rate upon passage of radiation through matter.

Barrier: See protective barrier.

Brachytherapy: A method of radiation therapy in which an encapsulated source is utilized to deliver gamma or beta radiation at a distance up to a few centimeters either by surface, intracavitary or interstitial application.

Collimator zone: That portion of the source housing of a gamma-beam apparatus which includes the beam defining mechanism.

Constant potential: In radiological practice, this term is applied to a unidirectional potential (or voltage) which has little, or no, periodic variation. The periodic component is called the ripple potential (or ripple voltage).

Contact therapy apparatus: X-ray therapy apparatus designed for very short treatment distances (SSD of 5 cm or less) usually employing tube potentials in the range of 20 to 50 kVp.

Contamination. (radioactive): A radioactive substance dispersed in materials or places where it is undesirable.

Controlled area: A defined area in which the occupational exposure of personnel to radiation is under the supervision of the Radiation Protection Supervisor. (See 7.2.)

Curie (Ci): (1) The special unit of activity equal to 3.7×10^{10} disintegrations per second. (2) By popular usage, the quantity of any radioactive material having an activity of one curie.

Dead-man switch: A switch so constructed that a circuit closing contact can be maintained only by continuous pressure on the switch.

Diagnostic-type protective tube housing: An x-ray tube housing so constructed that the leakage radiation measured at a distance of 1 meter from the source does not exceed 100 mR in 1 hour when the tube is operated at its maximum continuous rated current for the maximum rated tube potential. (See Section 3.2.2 (c) for a method of testing leakage radiation.)

Dose Equivalent (DE): A quantity used for radiation protection purposes that expresses on a common scale for all radiations the irradiation incurred by exposed persons. It is defined as the product of the absorbed dose in rads and certain modifying factors. The unit of dose equivalent is the rem. (For radiation

protection purposes in this report, the dose equivalent in rems may be considered numerically equivalent to the absorbed dose in rads and the exposure in roentgens).

Exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all of the ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air divided by the mass of the air in the volume element. The special unit of exposure is the roentgen. (For radiation protection purposes in this report, the number of roentgens may be considered to be numerically equivalent to the number of rads or rems).

Filter; filtration: Material in the useful beam which usually absorbs preferentially the less penetrating radiation.

Inherent filter: the filter permanently in the useful beam; it includes the window of the x-ray tube and any permanent tube or source enclosure.

Added filter: Filter added to the inherent filtration.

Total filter: The sum of the inherent and added filters.

Half-value layer (HVL): Thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces the exposure rate by one-half.

Inherent filtration: See filter.

Installaton: Radiation sources, with associated equipment, and the space in which located.

Interlock: A device for precluding access to a high radiation area by automatically reducing the exposure rate upon entry by personnel.

Kilovolt (kV): A unit of electrical potential difference equal to 1000 volts.

Kilovolt constant potential (kVcp): The potential difference in kilovolts of a constant potential generator.

Kilovolt peak (kVp): The crest value in kilovolts of the potential difference of a pulsating potential generator. When only one-half of the wave is used, the value refers to the useful half of the cycle.

Lead equivalent: The thickness of lead affording the same attenuation, under specified conditions, as the material in question.

Leakage radiation: See radiation.

Maximum permissible dose equivalent (MPD): For radiation protection purposes, the maximum dose equivalent that a person or specified parts thereof shall be allowed to receive in a stated period of time. (See Section 2.2 and Table 1, Appendix B). For radiation protection purposes in this report, the dose equivalent in rems may be considered numerically equal to the absorbed dose in rads and the exposure in roentgens.

Million electron volts (MeV): Energy equal to that acquired by a particle with one electronic charge in passing through a potential difference of one million volts (one MV).

Milliroentgen (mR): One-thousandth of a roentgen.

Monitor, personnel: See personnel monitor.

Multipurpose machine: An x-ray machine designed or used for radiographic examinations of more than one part of the body, or one designed or used for both diagnosis and therapy.

Noncontrolled area: Any space not meeting the definition of a controlled area.

Occupancy factor (T): The factor by which the workload should be multiplied to correct for the degree of occupancy of the area in question while the source is "ON".

Occupied area: An area that is or may be occupied by persons.

Owner: A person, organization, or institution having title to or administrative control over one or more installations or sources of radiation.

Panel, fluoroscopic: Surface of a vertical fluoroscope analogous to the tabletop of a tilting table fluoroscope.

Personnel monitor: An appropriately sensitive device used to estimate the radiation exposure to an individual.

Phantom: As used in this report for radiation protection purposes, a tissue-equivalent object used to simulate the absorption and scatter characteristics of the patient's body.

Primary beam: See useful beam.

Primary protective barrier: See protective barrier.

Protective apron: Apron made of radiation absorbing materials, used to reduce radiation exposure.

Protective barrier: A barrier of radiation absorbing material(s) used to reduce radiation exposure.

Primary protective barrier: A barrier sufficient to attenuate the useful beam to the required degree.

Secondary protective barrier: A barrier sufficient to attenuate the stray radiation to the required degree.

Protective glove: Glove made of radiation absorbing materials used to reduce radiation exposure.

Protective source housing: An enclosure, for a gamma-beam therapy source, so constructed that the leakage radiation does not exceed specified limits with the source in the "ON" and "OFF" positions. See 4.2.1 (a) and (b).

Qualified expert: With reference to *radiation protection,* a person having the knowledge and training to measure ionizing radiation, to evaluate safety techniques, and to advise regarding radiation protection needs (for example, persons certified in this field by the American Board of Radiology, or the American Board of Health Physics, or those having equivalent qualifications). With reference to the *calibration of radiation therapy equipment,* a person having in addition to the above qualifications, training and experience in the clinical applications of radiation physics to radiation therapy (for example, persons certified in Radiological Physics or X-ray and Radium Physics by the American Board of Radiology, or those having equivalent qualifications).

Rad: The special unit of absorbed dose equal to 100 ergs per gram.

Radiation (Ionizing): Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter.

Leakage radiation: All radiation coming from within the source housing except the useful beam. (Note: leakage radiation includes the portion of the radiation coming directly from the source and not absorbed by the source housing as well as the scattered radiation produced within the source housing).

Scattered radiation: Radiation that, during passage through matter, has been deviated in direction. (It may also have been modified by a decrease in energy).

Stray radiation: The sum of leakage and scattered radiation.

Useful beam: Radiation which passes through the window, aperture, cone or other collimating device of the source housing. Sometimes called "primary beam".

Radiation protection supervisor: The person directly responsible for radiation protection. (See Section 7.2.)

Radiation protection survey: An evaluation of the radiation safety in and around an installation. (See Section 6.)

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).

TABLE 5—*Scattered radiation exposure rate at side of fluoroscopy table*[a]

Phantom: 100 lb Sack of flour
15 inch source-panel distance
10 × 10 cm field at tabletop
Phantom edge 6 inches from side of table

Peak Potential kVp	Exposure Rate in mR per mA-hour	
	No screen drape	With screen drape[b]
80	300	4.5
90	400	8.0
100	650	17.5
110	850	32
120	1050	42
130	1330	60
140	1550	77
150	1750	98

[a] After J. S. Krohmer (unpublished).
[b] 0.3 mm lead equivalent.

TABLE 6—*Average exposure rates produced by diagnostic x-ray equipment*[a]

Distance from Source to Point of Measurement		Tube potential						
		50 kVp	60 kVp	70 kVp	80 kVp	90 kVp	100 kVp	125 kVp
in	cm	Roentgens per 100 milliampere seconds						
12	30	1.8	2.8	4.2	5.8	8.0	9.8	15.2
18	46	0.8	1.3	1.8	2.5	3.4	4.2	6.7
24	61	0.4	0.7	1.1	1.4	1.9	2.3	3.8
39	100	0.2	0.3	0.4	0.5	0.7	0.9	1.4
54	137	0.1	0.1	0.2	0.3	0.4	0.5	0.7
72	183	0.1	0.1	0.1	0.2	0.2	0.3	0.4

[a] Measured in air with total filtration equivalent to 2.5 mm aluminum.

TABLE 7—*Thickness of lead required to reduce useful beam to 5 per cent*[a]

Beam Quality		Required Lead Thickness millimeters
Potential	Half Value Layer millimeters	
60 kVp	1.2 Al	0.10
100 kVp	1.0 Al	0.16
100 kVp	2.0 Al	0.25
100 kVp	3.0 Al	0.35
140 kVp	0.5 Cu	0.7
200 kVp	1.0 Cu	1.0
250 kVp	3.0 Cu	1.7
400 kVp	4.0 Cu	2.3
1000 kVp	3.2 Pb	20.5
2000 kVp	6.0 Pb	43.0
2000 kVcp	14.5 Pb	63.0
3000 kVcp	16.2 Pb	70.0
6000 kV	17.0 Pb	74.0
8000 kV	15.5 Pb	67.0
Cobalt 60	10.4 Pb	47.0

[a] Approximate values for broad beams. Transmission data for brass, steel and other material for potentials up to 2000 kVp may be found in reference [15]. Measurements on 1000 kVp and 2000 kVp made with resonant-type therapy units. Data for 6000 kV taken from reference [16], for a linear accelerator. Data for 2000 kVcp, 3000 kVcp, and 8000 kV derived by interpolation from graph presented in reference [17]. The third column refers to lead or to the required equivalent lead thickness of lead-containing materials (e.g. lead rubber, lead glass, etc.).

APPENDIX C

Example of Emergency Procedures for Failure of Gamma-Beam Control Mechanism

The emergency procedure to be used in case of failure of the gamma-beam control mechanism depends on the individual installation. The following is an example.

Emergency Procedure in Case Beam Control Fails

If the light signals indicate that the beam control mechanism has failed to terminate the exposure at the end of the preset time (for example if the red light stays on and/or the green signal does not light up) the source may still be in the "ON" position. The following steps are to be carried out in a calm manner.

FOR THE RADIATION THERAPY TECHNICIAN

1. Open the door to the treatment room.
2. If the patient is ambulatory direct him to get off the table and leave the room.
3. If the patient is not ambulatory:
   Enter the treatment room but avoid exposure to the useful beam.
   Pull the treatment table as far away from the useful beam as possible.
   Transfer the patient to a stretcher and remove him from the room.
4. Close the door.
5. Turn off the main switch at the control panel.
6. Notify the radiation therapist and radiation protection supervisor at once.

FOR THE RADIATION PROTECTION SUPERVISOR

1. Secure a portable survey meter. Check to see that the meter is functioning properly.
2. Turn the power on and open the door a few inches.
3. Stand behind the door and insert the survey meter into the door opening to test whether in fact the source is still in the "ON" position.
4. If the source is still "ON" enter the room and manually turn the source "OFF" as per manufacturer's instructions. Avoid intercepting the useful beam with any part of your body.
5. Adjust the limiting diaphragms to the smallest field size.
6. Close the door to the treatment room. Turn off the power. Lock the control panel. Post a sign warning people not to enter.
7. Notify the equipment manufacturer's representative.