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Safety Code 27
Requirements for Industrial X-ray Equipment Use and Installation

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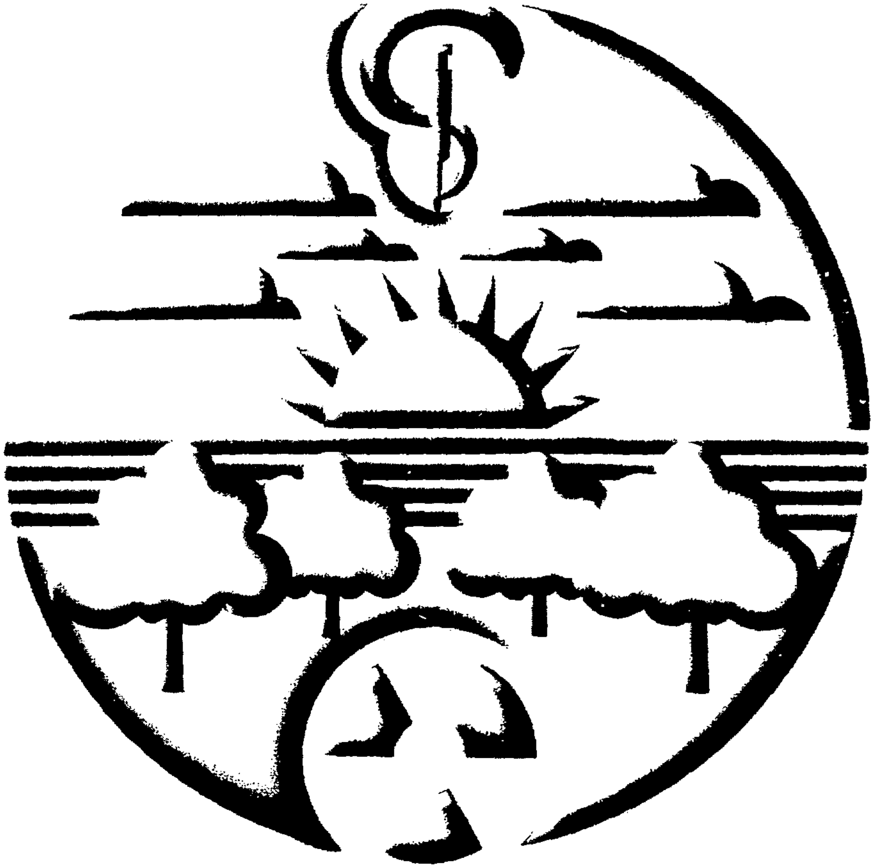

Canada

SAFETY CODE 27

REQUIREMENTS FOR INDUSTRIAL X-RAY EQUIPMENT:

USE AND INSTALLATION

Environmental Health Directorate

Health Protection Branch

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EXPLANATORY NOTES

This document is one in a series of Safety Codes prepared by the Bureau of Radiation and Medical Devices to set out requirements for the safe use of radiation-emitting devices.

The equipment installation guidelines and safety procedures detailed in this Code are primarily for the instruction and guidance of persons employed in Federal Government departments and agencies, as well as in all other installations covered by the Canada Labour Code. This Safety Code is also intended to assist other users of industrial X-ray equipment operating at energies up to 1 MeV, to select safe equipment, and to install and use it so that the radiation hazard to the operator and other persons in its vicinity is as low as reasonably achievable. It is advisable to consult the appropriate governmental agency when considering the installation of industrial X-ray equipment. Facilities under provincial jurisdiction will be subject to requirements specified by provincial statutes. Further information concerning the regulatory requirements of the individual provinces may be obtained by contacting the appropriate authority listed in Appendix VII.

This Code supersedes Safety Code RPB-SC-7, entitled "Requirements for Non-medical X-ray Equipment Use and Installation."

The words "must" and "should" in this Code have been chosen with purpose. The word "must" indicates a recommendation that is essential to meet the currently accepted standards of protection, while "should" indicates an advisory recommendation that is highly desirable, and which is to be implemented where feasible.

In a field where technology is advancing rapidly and unexpected and unique problems continually occur, this Code cannot deal with all possible situations. Blind adherence to rules cannot substitute for the exercise of sound judgment; consequently the recommendations may need to be modified in unusual circumstances, but only after consulting experts having recognized competence in radiation protection. To cover unforeseen situations this Code will be reviewed and revised periodically, and particular requirements may be reconsidered at any time. Interpretation or elaboration of any point can be obtained by contacting the Bureau of Radiation and Medical Devices, Health and Welfare Canada, Ottawa, Ontario, K1A 1C1.

This Code reflects the results of the work of many individuals. The final draft was prepared and compiled by H.P. Maharaj, and reviewed by the professional staff of the X-ray Section prior to publication.

Appreciation is expressed to all organizations, agencies and individuals whose comments and suggestions helped in the preparation of this Code.

1. INTRODUCTION

X-ray emitting equipment is widely used in industrial radiography, police and security investigations, and research applications. The ability of X-rays to penetrate materials in a non-destructive manner and provide information on the integrity or contents of a specimen has resulted in widespread and increasing use of X-ray emitting devices. Concomitant with this, the number of X-ray workers, X-ray equipment maintenance staff, and other personnel in the vicinity of X-ray equipment has been increasing steadily.

The effects of radiation on humans can be of two classes, somatic and genetic. Somatic effects manifest themselves in exposed individuals during their lifetime and may take the form of skin rashes, cataracts or cancer. Genetic effects are changes or mutations in the genetic material of the reproductive cells and may result in illness or deformity of future generations. Regardless of how small the dose of radiation, and in spite of lack of any evidence on humans, it is prudent to assume that the possibility exists that mutations giving rise to genetic defects may be produced. Hence it is necessary that X-ray equipment be selected, installed and used in a manner that protects personnel from unnecessary or excessive radiation exposure.

Facilities using radiation-emitting equipment must follow the system of dose limitation as recommended by the International Commission on Radiological Protection ICRP(2). On this basis, the recommended maximum permissible dose equivalent limits must not be exceeded (Appendix I). In addition, attempts must be made to keep the radiation exposure to persons as low as reasonably achievable, this objective being termed the ALARA principle.

2. PRINCIPAL AIM AND SCOPE OF THIS CODE

This Safety Code is concerned with the protection of all individuals who may be exposed to radiation emitted by X-ray equipment operating at energies up to 1 MeV as used in industrial radiograhy.

2.1 Principal Aim

The principal aim of this code is to present basic radiation safety information which, when followed, will provide adequate radiation protection of:

1. personnel operating and servicing X-ray equipment; and

2. other workers and the general public in the vicinity of areas where X-ray equipment is in operation.

2.2 Scope

To assist personnel in achieving these objectives, this Safety Code:

1. specifies general safety features of design, construction and functioning for X-ray equipment and facilities;

2. describes the responsibilities of the user, operator and maintenance personnel;

3. contains recommendations to ensure that the X-ray equipment is used and maintained in accordance with the ALARA principle; and

4. describes a program of personnel monitoring and radiation safety surveys.

3. RESPONSIBILITY AND PERSONNEL

The owner or manager is ultimately responsible for radiation safety of an Industrial X-ray facility. It is the responsibility of the owner or manager to ensure that the equipment provided for the responsible user and operators, and the facilities in which such equipment is installed and used, meet all applicable radiation safety standards.

The owner or manager may delegate this responsibility to staff. Such delegation or responsability may depend upon the size of the staff, and on the quantity and type of equipment owned and operated. In any event, at least one person must be designated to carry out the role described as follows:

3.1 Responsible User

For each facility, the owner or management must designate at least one person knowledgeable in radiation protection as the responsible user to undertake the responsibility for:

1. ensuring that operational procedures pertaining to radiation safety are reviewed periodically, and are implemented in such a manner that the radiation exposure to each worker is kept as low as reasonably achievable (ALARA principle). Any modifications to the equipment which may alter the exposure conditions must be assessed on this basis;

2. ensuring that all workers who operate, maintain or service industrial X-ray equipment (as well as other infrequent users of the equipment) have received adequate instructions (excerpts of material from this Safety Code may be used as a guide) in matters of radiation hazards and safety measures associated with the X-ray unit. A list of personnel qualified to operate the units should also be conspicuously posted at the location of each unit;

3. establishing controlled areas, including placement of appropriate radiation warning signs and/or devices;

4. reviewing and approving modifications to X-ray apparatus, including shielding and safety interlocks;

5. arranging for radiation safety inspections of X-ray equipment;

6. maintaining and/or establishing a system of personnel monitoring which may include responsibility for processing the dosimeters;

7. reviewing personnel monitoring data periodically, and investigating any inconsistencies which may be revealed. Should the cause(s) be due to improper radiographic procedures and/or work habits, remedial action must be instituted accordingly;

8. investigating all cases of radiation overexposure to personnel and taking remedial action, if necessary;

9. ensuring that all records of medical examinations of each person employed to operate or maintain the equipment are retained; the advice of the appropriate Statutory Authority must be sought regarding the period of retention;

10. ensuring that the facility complies with all applicable federal and/or provincial laws and regulations; and

11. ensuring that all survey meters under his authority are properly calibrated and maintained in good working condition.

3.2 Operators of X-ray Equipment

All operators of X-ray equipment must:

1. read and understand the contents of this Safety Code;

2. receive training and demonstrate to the satisfaction of the responsible user competence in the proper usage of the equipment and knowledge of potential radiation hazards;

3. keep radiation exposure to themselves and others as low as reasonably achievable;

4. wear personnel monitoring devices unless an exemption is granted by the responsible federal or provincial health authority (monitoring devices are discussed further in Section 7);

5. notify the responsible user of any known or suspected abnormal radiation exposure to themselves or others;

6. inform the responsible user of any radiation exposure history, if applicable;

7. ensure that no person is present inside the X-ray room or enclosure before activating the controls to produce X-rays; and

8. not permit any person to hold the specimen or film cassette while it is being exposed to X-rays.

3.3 Service and Maintenance Personnel

All personnel responsible for servicing or maintaining X-ray equipment must:

1. read and understand the contents of this Safety Code;

2. have adequate training to conduct the proper maintenance and repair services of the equipment, and understand the potential hazards associated with maintenance or service procedures carried out under conditions where X-rays are being generated by the equipment;

3. demonstrate to the responsible user competence, as described in paragraph 3.3.2, so that the servicing of the equipment will be carried out in a manner which minimizes any radiation hazard to themselves, to the operators, and to other individuals in the vicinity of the equipment;

4. wear personnel monitoring devices unless an exemption is granted by the responsible federal or provincial health authority;

5. report to the responsible user any anomalous situations which arise from maintenance or operation of the equipment; and

6. inform the responsible user of any radiation exposure history, if applicable.

NOTE: IT IS THE ULTIMATE RESPONSIBILITY OF ANY ONE OF THE RESPONSIBLE USER, OPERATOR, STUDENT, OPERATOR IN TRAINING, OR MAINTENANCE PERSONNEL TO TURN OFF THE EQUIPMENT AND REMOVE IT FROM SERVICE AS SOON AS ANY UNSAFE OPERATING CONDITION DEVELOPS OR THE POSSIBILITY OF AN UNSAFE OPERATING CONDITION OF THE EQUIPMENT EXISTS.

3.4 Students or Operators in Training

All students or operators in training must:

1. satisfy their instructor that they understand the contents of this safety code (or a similar radiation safety document) including a knowledge of possible radiation hazards associated with the operation of the equipment, and demonstrate in a practical manner their ability to operate the equipment properly;

2. work under the continuous observation and supervision of an X-ray operator in addition to the conditions outlined in paragraph 3.4.1;

3. wear personnel monitoring devices unless an exemption is granted by the responsible federal or provincial health authority; and

4. be assessed, for the purpose of radiation protection, in accordance with the maximum

permissible dose equivalent limit recommended for members of the public (Appendix I (4)).

3.5 Women Known to Be Pregnant

Upon confirmation of her pregnancy, a worker must:

1. inform both the employer and the responsible user of her pregnancy;

2. be informed by the responsible user of:

   a. the possible risks associated with radiation exposure to the fetus in the early stage of development (first trimester), and

   b. the exposure levels most likely to be encountered during the entire term of the pregnancy while performing the same job-related duties;

3. discuss with the employer and the responsible user possible options for lowering the occupational radiation exposures by a reassignment of duties and working areas; and

4. be informed by the employer should a reassignment as indicated in 3.5.3 prove unfeasible. The responsible user must ensure that under no circumstances can the applicable levels given in Appendix I (refer to paragraph 3) be exceeded should the employee continue performing the same job-related duties.

4. INSTALLATION REQUIREMENTS

4.1 Basic Principles of Radiation Protection

Radiation protection guidelines are established to protect humans. Unattended equipment isolated from people does not constitute a hazard. However, when equipment requires any form of human intervention, potential hazards will arise. Thus, for any operational X-ray facility, the overall hazards must be assessed using a combination of factors associated with equipment and humans.

According to the level of protection required, the areas surrounding an industrial X-ray machine fall into one of the following two categories:

a. Controlled - the area in which the occupational exposure of personnel is under the direct supervision of the responsible user. The radiation levels in controlled areas must not exceed the whole body dose equivalent limits for radiation workers as specified in Appendix I.

b. Noncontrolled - the space not satisfying the definition of controlled areas. The radiation levels in noncontrolled areas must not exceed the whole body dose equivalent limits for members of the public as specified in Appendix I.

In order to reduce the levels of radiation in areas occupied by persons, it is usually necessary to interpose barriers of lead, concrete, or some other material between the source of radiation and the persons. The thickness of such barriers may be calculated on the basis of distance, beam energy (or kVp), workload (W), use factor (U) and occupancy factor (T). Illustrative examples for controlled and noncontrolled areas are described in Appendix III.

4.2 General Recommendations

To protect personnel working in the vicinity of X-ray equipment, the following recommendations must be followed:

1. when planning a new installation, an area of comparatively low personnel occupancy should be selected for the location of X-ray equipment. In some cases, e.g. open area radiography, the unit should be used at times when there is a minimum number of personnel present;

2. warning signs of the type shown in Appendix V must be posted at all entrances to the controlled area(s); and

3. the final plans of the facility must be reviewed by the appropriate governmental agencies. (For facilities under the Federal jurisdiction this agency is the Bureau of Radiation and Medical Devices).

4.3 Additional Recommendations

4.3.1 Facilities with Stationary X-ray Equipment

In addition to the requirements of Sections 4.1 and 4.2, the following recommendations must be followed for stationary X-ray equipment:

1. stationary radiographic equipment must be installed in a shielded room or enclosure, which should be designed to be used solely for radiographic purposes. The floors, walls, ceilings and doors must contain sufficient shielding. Examples of calculations to determine the shielding requirements are given in Appendix IV. Care must be taken to ensure that all shielding, whether lead, concrete or other material, forms an unbroken barrier and is adequately supported;

2. the X-ray exposure control of the radiographic equipment must be operated from outside of the enclosure and located where the operator can effectively observe and prohibit any unauthorized entry of personnel into the enclosure;

3. reliable and effective door interlocks must be provided to terminate any exposure in progress if any door to the radiography room is opened accidentally. After such an interruption, it must not be possible to resume X-ray production from a location other than the control panel;

4. a visible warning signal must be provided both inside and outside of the enclosure to indicate when the X-ray beam is 'ON';

5. unless the operator has an unobstructed view of the entire room, a pre-exposure audible warning signal which lasts for 5 seconds must be provided both inside and outside of the enclosure and interlocked, so that X-rays are produced only after termination of the signal;

6. a suitable exit must be provided to enable any person shut in to vacate the radiography room without delay, or alternatively, a conspicuous "panic switch" to terminate the exposure and a reset button must be installed in the radiography room; and

7. if the panic switch is used to terminate the exposure, the reset button must be depressed or require an equivalent action before any further exposure can be made from the control panel.

4.3.2 Radiography in an Open Area

At times, it may be necessary to use a portable X-ray unit in an open area. In addition to the requirements of Sections 4.1 and 4.2, the following are necessary:

1. the X-ray tube must be operated from outside a designated controlled area whose perimeter is clearly indicated by conspicuous warning signs and barriers. The signs and barriers should be removed immediately upon completion of the radiographic procedures;

2. visible and audible warning signals, as described in paragraphs 4.3.1(4) and 4.3.1(5), must be installed in order to alert other personnel who may be in the designated controlled area;

3. survey meters must be used at all times to ensure that the exposure rate at the boundary of the designated controlled area does not exceed 2.5 milliroentgen per hour (or a dose equivalent rate of 0.025 mSv/h to the skin);

4. should radiographic operations within the designated controlled area require different orientations for either the primary beam or the temporary shield, the conditions specified in paragraph 4.3.2(3) must be satisfied in each separate case;

5. whenever practical, exposures should be performed at times when there is a minimum number of personnel present;

6. all set up procedures must be completed before the X-ray beam is switched on;

7. if the object being examined, or the X-ray tube, or the image receptor needs to be repositioned during radiography, the X-ray beam must be turned off before making the necessary changes; and

8. the primary X-ray beam must be directed towards adequately shielded or unoccupied areas.

4.3.3 Fluoroscopic Procedures

Facilities using fluoroscopy must comply with the requirements of Sections 4.1, 4.2, and as applicable, the requirements of Sections 4.3.1 and 4.3.2.

5. EQUIPMENT SPECIFICATIONS

5.1 X-Ray Unit

The X-ray unit must comply with the regulations pertaining to the standards of design, construction and functioning as promulgated under the Radiation Emitting Devices Act. As a minimum requirement where no applicable regulatory standard exists, the X-ray machine must incorporate the following safety features:

1. a warning sign on the external surface of the control panel that:

a. indicates that hazardous radiation emissions are produced when the X-ray machine is operating and prohibits unauthorized use, and

b. displays the X-radiation warning sign for X-ray machines as shown in Appendix V;

2. to prevent unauthorized use, a locking device that requires the insertion of a key before X-rays can be produced and where removal of the key terminates the production of X-rays;

3. a tube housing support that maintains the tube position without tipping, or excessive drift or vibration during the operation of the machine;

4. a control panel that includes:

   a. a power ON/OFF switch,

   b. an X-rays ON/OFF switch, or provision for a remote X-rays ON/OFF switch,

   c. separate warning lights to indicate when the machine is energized and when X-rays are being produced,

   d. a timer that controls the duration of the exposure, or an X-rays ON/OFF switch that requires continuous pressure by the operator to maintain X-ray production, and

   e. indicators that show the tube potential in kilovolts and X-ray tube current in milliamperes when the X-ray beam is ON; and

5. for portable X-ray machines, the connection of the X-rays "ON/OFF" switch to the control panel is such that for any setting of X-ray tube potential and current within the range of settings specified by the manufacturer and with the X-rays "ON/OFF" switch at its greatest possible

distance from the X-ray tube housing, the exposure rate from stray radiation at the position of the switch does not exceed 2.5 milliroentgen per hour (or a dose equivalent rate of 0.025 mSv/h to the skin).

6. MEANS TO REDUCE PERSONNEL EXPOSURE

6.1 General Recommendations

The following must be incorporated in all X-ray facilities:

1. radiation safety instructions, approved by the responsible user for the particular facility, must be conspicuously posted at the control panel and each radiation worker must read and understand these instructions to the satisfaction of the responsible user;

2. personnel must use protective devices as required;

3. set up procedures must be completed before the X-ray beam is switched "ON";

4. operators must at all times keep as far away as practicable from the primary X-ray beam. Under no circumstances must exposure of any person to the primary beam be allowed;

5. specimens and film cassettes must never be held by hand during an exposure;

6. the primary beam should be limited to the area being examined using cones or collimators where feasible;

7. the operator must be in immediate attendance at all times when the equipment is in operation;

8. when not in operation, the X-ray equipment must be secured in a manner which prevents its operation by unauthorized personnel;

9. alterations of safety devices such as the bypassing of interlocks or the removal of shielding must be specified and approved in writing by the responsible user, who also must post a notice near the X-ray tube housing and on the control panel so that other persons will know the existing status of the machine. The equipment must be restored to normal operation as soon as possible;

10. only trained and competent personnel, as described in paragraph 3.3.3 should be permitted to install, repair, or make other than routine modifications to the X-ray generating apparatus and tube housing assembly;

11. all safety devices (interlocks, collimators, warning lights, timers and shields) should be tested periodically to ensure their proper functioning. These tests should be conducted at least once per month for units in frequent use. In any event, there must be safety tests conducted prior to using the unit, and proper records should be documented and maintained;

12. written emergency procedures pertaining to radiation safety must be established for each facility by the responsible user and be posted in a conspicuous location near each X-ray machine. As a minimum, the procedures should include:

    a. the telephone numbers of

        1. the responsible user,

        2. a physician, and

        3. the appropriate provincial or federal radiation protection agency;

    b. instructions for notifying the responsible user and the appropriate radiation protection agency; and

c. instructions for arranging a medical examination being sure to notify the examining physician that exposure to X-rays has occurred.

6.2 Additional Recommendations for Fluoroscopy

In addition to the requirements of Section 6.1, the following recommendations apply to fluoroscopic procedures:

1. indirect viewing systems such as television monitors, mirrors, or viewing windows with an approved lead equivalent thickness must be used. Hand-held fluoroscopes must not be used;

2. when fluoroscopic examinations of the test object are required during radiography in an open area, provision should be made to achieve this from outside of the controlled area by remote control. If this is unfeasible, then the X-ray beam must be turned off before manual repositioning is undertaken.

7. RADIATION MONITORING

To minimize the probability of personnel overexposures, the responsible user or operator must assess the radiation fields in the immediate vicinity of the work area. The use of a survey meter is highly recommended and any necessary corrective measures must be taken before proceeding with the radiographic operations.

7.1 Personnel Monitoring

1. The evaluation of the need for personnel monitoring devices must include a combined assessment of potential radiation hazards associated with the X-ray equipment and the operational procedures.

2. If personnel monitoring devices are needed to monitor whole body exposures, such devices should be worn on the clothing, either at the waist or chest level.

3. If operational procedures indicate the possibility that organs such as the head, hands, or arms are likely to receive dose equivalents in excess of the limit recommended for the whole body, special extremity monitors must be worn in addition to the regular whole body monitors.

4. Personnel monitoring devices must be stored in a secure properly shielded location between periods of use.

5. Personnel monitoring data must be:

   a. retained as a permanent record,

   b. available for examination by authorized personnel and health officers, and

   c. posted in a convenient location so that each worker can review his/her exposure independently.

7.2 Radiation Protection Survey

1. The arrangements for radiation protection surveys are the responsibility of the responsible user.

2. A radiation protection survey of the X-ray equipment and facility, including all accessible adjacent areas of the controlled area, must be requested:

   a. at the time of installation of new X-ray equipment,

   b. after any major modification of the X-ray equipment, including installation, which could result in elevated levels of radiation emission e.g. new tube, modifications of the collimator, etc., and

   c. immediately upon any indication of elevated levels of X-ray emission having occurred during the normal operation of equipment.

It may be permissible in special cases, after consultation with the corresponding radiation protection authority, to operate the equipment for a limited period of time prior to the survey.

3. Surveys should be performed on a periodic basis. The frequency of the surveys should be a function of the type of X-ray equipment, its use and workload. The responsible radiation protection authority should determine the required frequency of such surveys.

4. Radiation protection surveys must be performed by the Bureau of Radiation and Medical Devices (or the equivalent in a provincial agency for facilities that are under provincial jurisdiction). The responsible user of the X-ray installation should obtain and retain all copies of the surveys until such time as the unit is decommissioned.

5. A survey must include the inspection of all protective devices, particularly the operation of audible and visible warning indicators, interlocks, collimators, timers and shielding.

6. Measurements of radiation exposure rates must be carried out under conditions simulating the most adverse operating situations.

7. Lead aprons, gloves, other protective clothing and mobile lead screens must be inspected, by radiography if necessary, at least once per year to determine their condition. Any defects must be remedied as soon as possible.

8. At any installation where elevated exposure levels to workers have occurred during normal operation, the responsible user should forward all details of such overexposures to the corresponding radiation protection authority.

MAXIMUM PERMISSIBLE DOSE EQUIVALENT OF IONIZING RADIATION

For the purpose of radiation protection, individuals are divided into two main categories: those exposed to radiation in the course of their work (radiation workers) and non-radiation workers. Maximum permissible levels are given for both categories in the following table. These dose equivalent limits are based on the system of dose limitations as recommended by the International Commission on Radiological Protection (ICRP) and specified in ICRP Publication 26 (1977).

It must be noted that the maximum permissible dose equivalents for radiation workers apply only to exposures resulting directly from their occupation and do not include radiation exposures from medical diagnostic procedures and natural background radiation.

It should also be noted that the ICRP now believes it to be sufficient to set annual dose equivalent limits and does not recommend any further restrictions either on the instantaneous rate or on the rate at which the dose equivalent may be accumulated, except in the case of pregnant women. The former age-related formula limiting the dose equivalent at age N years to 50 (N-18) mSv is no longer advocated.

Maximum Permissible Dose Equivalent (Whole Body)

	Annual	
Radiation Workers	50 mSv	(5 rem)
Non-radiation Workers and Members of the Public	5 mSv	(0.5 rem)

1 sievert (Sv) is equivalent to 100 rem

Notes:

1. It is emphasized that any exposure may involve some degree of risk and although the levels recommended in this Appendix are maximum values, all doses should be kept as low as reasonably achievable and all unnecessary exposures should be avoided.

2. The ICRP no longer recommends discrimination in the dose limits between men and women of reproductive capacity.

3. When pregnancy has been diagnosed, the employer must ensure that for the remainder of the pregnancy the woman's working conditions are such that:

   a. the total integrated dose equivalent to the abdomen during the entire pregnancy does not exceed 10mSv, or

   b. 15mSv during the year of the pregnancy.

4. For trainee technicians, the dose equivalent limits should be the same as that for the general public.

5. The ICRP no longer recommends different limits for individual organs, except the lens of the eye. The ICRP believes that nonstochastic effects will be prevented by applying a dose-equivalent limit of 0.5Sv in a year to all tissues except the lens of the eye, for which a limit of 0.15Sv in a year is recommended.

CONDITIONS INDIRECTLY INFLUENCING OCCUPATIONAL EXPOSURE

In principle, fewer repeat radiographs imply lower occupational exposures. Hence, any innovations within existing facilities which will achieve this objective are encouraged.

For industrial radiography there are at least three fundamental requirements:

1. A properly designed X-ray unit which has already been described elsewhere in this Safety Code.
2. An effective means of image reception.
3. Radiographic images of adequate quality.

In some situations the combination of distances and shielding, and the use of advanced technology, may decrease the personnel exposure to levels lower than that of ambient background. In such cases, the number of retakes or direction of fluoroscopy is immaterial. The number of retakes may be reduced further by considering the factors listed below.

A. Darkroom and X-ray films

It is feasible, to incorporate one or more of the following factors into existing operations that would achieve the above objectives:

1. For darkrooms located in the vicinity of the X-ray unit, the walls, doors, ceilings and floors should be shielded in accordance with the requirements demanded by a noncontrolled area. Refer to paragraph (5) for film storage requirements.
2. The darkroom or enclosure must be light-tight. Typical entrance designs include a revolving capsule, double doors and a maze door. A warning light positioned outside the room to indicate when the room is in use may suffice in some situations.

3. Safelights should be positioned at the proper distance above the workbench with bulbs of suitable intensity and having filters appropriate for the films being used in accordance with the manufacturers' recommendations.

4. Where manual processors are used, it is advisable to maintain a well-organized layout of solutions, trays, timers, thermometers and film-handling accessories. The film manufacturer's instructions for storing, processing, and developing the films must be followed. For automatic processing units, the manufacturer's recommendations concerning solutions and cleaning procedures, etc., must be followed.

5. Unexposed films must be stored in a shielded area to reduce stray radiation levels reaching the film to less than approximately 1 mR exposure prior to use. The level of fog will increase on films that are loaded in cassettes containing intensifying screens.

B. Optimization of Exposure Techniques

This objective applies to all facilities. Factors which may be incorporated include one or more of the following:

1. Attempts should always be made to optimize the operating tube kilovoltage and tube current consistent with acceptable quality radiographs. Values higher than are necessary will increase exposure levels.

2. Limit the X-ray beam to a size commensurate with that of the image receptor by use of collimators. This will decrease the levels of scattered radiation.

3. If intensifying screens are used, the proper matching of film-screen spectral response should be exercised. Any mismatch will increase the exposure required for a given image quality.

APPENDIX III

GUIDES FOR SHIELDING X-RAY INSTALLATIONS

In order to determine the necessary shielding requirement for an X-ray installation, certain preliminary information must be obtained. In many situations lead and/or concrete are used to reduce radiation levels to the appropriate permissible values. Examples of typical shielding calculations are provided in Appendix IV.

Prior to any calculations the following information is required:

1. The minimum distance between the area to be shielded and the operational position of the X-ray tube.

2. Whether or not the area in question is designated as a controlled or noncontrolled area.

3. The occupancy factor (T) of the designated area. The occupancy factor is defined as the fraction of time an area is normally occupied while the beam is "ON" (Use Table 1 as a guide).

4. The classification of the barrier as primary or secondary. Barriers that attenuate the primary beam are classified as primary. A secondary barrier attenuates the stray (leakage and scattered) radiation.

5. The use factor (U) for the protective barriers. By definition, the use factor is the fraction of the operational time during which the useful beam will be/is directed at the barrier or area under consideration (Use Table 2 as a guide). The use factor for secondary barriers is always equal to 1.

6. The workload (W) of the X-ray unit. The workload is the product of the tube current (mA) and the operational "ON" time of the X-ray unit expressed in milliampere minutes per week.

7. The maximum and average operating tube potential, current and output.

TABLE 1

Occupancy Factors

The occupancy factors given in this table are for use as a guide in planning shielding requirements for facilities where actual occupancy factor data are not available.

T = 1 (Full occupancy)	Control booths, offices, corridors and waiting spaces large enough to hold desks, darkrooms, workrooms and shops, rest rooms and lounge rooms routinely used by occupationally-exposed personnel, living quarters, and occupied space in adjoining buildings.
T = 1/4 (Partial occupancy)	Corridors too narrow for desks, utility rooms, rest rooms and lounge rooms not used routinely by occupationally-exposed personnel, elevators using operators, unattended parking lots, dressing rooms.
T = 1/16 (Occasional occupancy)	Closets too small for future occupancy, toilets not used routinely by occupationally-exposed personnel, stairways, automatic elevators, sidewalks, streets.

TABLE 2

Use Factors for Primary Protective Barriers*

The use factors given in this table are for use as a guide in planning shielding requirements for facilities where actual use factor data are not available.

U = 1 (Full use)	Floors of radiation rooms, other walls, doors or ceiling areas routinely exposed to the primary beam.
U = 1/4 (Partial use)	Doors and wall areas of radiation rooms not routinely exposed to the primary beam.
U = 1/16 (Occasional use)	Ceiling areas of radiation rooms not routinely exposed to the primary beam.

***Note:** The use factor for secondary protective barriers is always equal to 1.

SHIELDING CALCULATIONS

The thickness of shielding required may be calculated using the formulae given below. This method requires a knowledge of the workload W, in mA-min. per week, the use factor U, the occupancy factor T, and the distance d, in metres, from the X-ray target to the occupied area.

The method involves:

1. computation of an average value for the exposure per unit workload at unit distance, K, (in R/mA-min. at 1m); and

2. the use of appropriate attenuation curves shown in Figures 1-3.

The following examples demonstrate the above procedures.

Example 1: **Calculation of a primary protective barrier**

Determine the thickness of a primary barrier required to protect a controlled area 3 metres from the target of a 150 kVp unit having a weekly workload of 2000 mA-min. The wall has a use factor of 1 and the occupancy factor of the area beyond the wall is 1.

Solution:

The following equation is applicable:

$$K = \frac{Pd_p^2}{WUT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where P = maximum permissible weekly exposure rate expressed in R/week. For controlled areas $P \doteq 0.1$ R/week; for noncontrolled areas $P = 0.01$ R/week.

d_p = distance in metres from the target to the primary barrier.

W = workload in mA-min/week.

U = use factor.

T = occupancy factor.

K = exposure per unit workload at unit distance, in R/mA-min at 1 metre.

For this case:

$P = 0.1$R/week

$d_p = 3.0$ m

$W = 2000$ mA-min/week

$U = 1$

$T = 1$

Using equation (1): $$K = \frac{0.1 \times (3)^2}{2000 \times 1 \times 1} = \frac{0.9}{2000}$$

$$= 0.00045 \text{ or } 4.5 \times 10^{-4}$$

Using the 150 kVp curves of Figures 1 and 3, the minimum barrier thickness required is 2.3 mm of lead or 20.5 cm of concrete respectively. The standard thicknesses of commercially-available lead sheets are given in Table 5.

2. Secondary Protective Barriers

Secondary protective barriers are required to provide shielding against both leakage and scattered radiation. Since these two types of radiation are of different qualities, it is necessary to determine the barrier thickness requirements for each separately. If the computed barrier thicknesses for leakage and scatter radiations are about the same, one half-value layer should be added to the larger one to obtain the total secondary barrier thickness. If the computed thicknesses for leakage and scattering conditions differ by at least three half-value layers, the larger of the two will be adequate.

Example 2:1 **Calculations of a protective barrier against leakage radiation**

Determine the thickness of barrier required to protect a controlled area 2 metres from the housing of a 200 kVp unit having a weekly workoad of 2000 mA-min. Assume that the maximum leakage from the tube housing is 0.1 R/h, the tube operates at 5 mA and the area in question has an occupancy factor of 1.

Solution:

To determine the barrier thinkness required to protect against leakage radiation, it is necessary to calculate the transmission factor B required to reduce the weekly exposure to P. For a tube housing, where the maximum leakage from the housing is 0.1 roentgen in an hour, the transmission factor is given by the following formula:

$$B = \frac{600\, I\, P d_s^2}{WT} \quad \ldots\ldots\ldots\ldots (2)$$

where: P = maximum permissible weekly exposure, rate expressed in R/week.
For controlled areas P = 0.1 R/week; for noncontrolled areas P = 0.01 R/week.

d_s = distance in metres from the tube housing to the secondary barrier.

I = tube current in milliamperes.

W = workload in mA-min/week.

T= occupancy factor.

Calculate transmission factor B, and use Figure 4 to determine the barrier thickness, as a number of half-value layers (HVLs), N, or tenth-value layers, (TVLs), n.

The required barrier thickness in mm of lead or cm of concrete can then be obtained from Table 3, for the appropriate energy.

For this case:

$P = 0.1$ R/week
$d_s = 2.0$m
$W = 2000$ mA-min/week
$T = 1$
$I = 5$ mA

Using Equation (2)

$$B = \frac{600 \times 5 \times 0.1 \times 2^2}{2000 \times 1}$$

$$= 0.6$$

From Figure 4, a transmission factor of 0.6 corresponds to 0.23 TVL's or 0.7 HVL's. From Table 3, the HVL for 200 kVp is 0.52 mm lead or 2.5 cm concrete. Thus the minimum barrier thickness required for protection against leakage radiation is either:

(i) (0.7 x 0.52) = 0.36 mm lead
(ii) (0.7 x 2.5) = 1.75 cm concrete

Example 2:2 **Calculations of a protective barrier for scattered radiation**

Determine the minimum thickness required to effectively shield a controlled area from scattered radiation. Use the data as given in example 2:1 above. The projected field size on the scattering media is 75 cm x 75 cm. The distance from the scattering media to the controlled area is 4 meters. The scattering angle as measured from the central axis of the beam is 135°.

Solution:

Scattered radiation has a much lower exposure rate than that of the primary beam and is usually of lower energy. However, for X-ray machines operating below 500 kVp, it is usually assumed that the scattered X-rays have the same barrier penetrating capability as the primary beam. For X-rays generated at kVp's less than 500 kVp, the value for K can be determined from the formula:

$$K = \frac{400\, P d_{ts}^{2}\, D^{2}}{aWTF} \quad \text{..............(3)}$$

where: K = exposure per unit workload at 1 metre, expressed in R per mA-min at 1 m.

P = maximum permissible exposure rate, expressed in R/week. For controlled areas $P = 0.1$ R/week. For noncontrolled areas, $P = 0.01$ R/week.

d_{ts} = distance in metres from the target to the scattered.

D = distance in metres from the scatterer to the secondary barrier.

a = ratio of scattered to incident exposure (Tabulated in Table 4).

W = workload in mA-min/week.

T = occupancy factor.

F = field area in cm^2.

Calculate K using equation (3) above, and use Figures 2 and 3 to determine the thickness of lead and concrete respectively for the appropriate energy.

For this case:

P = 0.1 R/week
d_{ts} = 2.0 m
D = 4.0 m
a = .0028
W = 2000 mA-min/week
T = 1
F = 5625 cm^2

Upon substitution in equation (3) above

$$K = \frac{400 \times 0.1 \times 2^2 \times 4^2}{.0028 \times 2000 \times 1 \times 5625}$$

$$= 8.1 \times 10^{-2}$$

From Figure 2, the minimum barrier thickness corresponds to ~ 0.7 mm lead (Pb) and Figure 3 corresponds to 7.5 cm of concrete.

Example 2.3 **Calculation of the total secondary barrier thickness**

Using the results from examples 2:1 and 2:2 for leakage and scattered radiation respectively, calculate the total secondary barrier thickness.

Solution:

If the barrier thickness for leakage and for scattered radiation differ by at least 3 HVLs, the thicker of them will be adequate. If they differ by less than 3 HVLs, 1 HVL should be added to the thicker one to obtain the required total secondary barrier thickness.

Thus: a. For lead (Pb):

Thickness of Pb for leakage radiation, t_1 = 0.36 mmPb
Thickness of Pb for scattered radiation, t_s = 0.70 mmPb

1 HVL for 200 kv (from Table 3) = 0.52 mmPb

$$\therefore \quad \frac{ts - t_1}{3(HVL)} = \frac{0.7 - .36}{3(.52)} = \frac{.34}{1.56} = .22 < 1.0$$

∴ One HVL should be added to the thicker value i.e. (0.7 + .52) = 1.22 mm of lead (Pb) is the total thickness required to adequately shield secondary radiation.

b. For Concrete:

Thickness of Concrete for leakage radiation,
$t_l = 1.75$ cm

Thickness of Concrete for scattered radiation,
$t_s = 7.5$ cm

1 HVL for 200 kv (From Table 3) = 2.5 cm of concrete.

$$\therefore \quad \frac{t_s - t_l}{3(HVL)} = \frac{7.5 - 1.75}{3(2.5)} = \frac{5.75}{7.5} = .77 < 1.0$$

$\therefore$ One HVL should be added to the thicker value i.e. (7.5 + 2.5) = 10.0 cm of concrete is the total thickness required to adequately shield secondary radiation.

Figure 1. Attenuation in lead of X-rays produced by potentials of 50 to 200 kVp(5)

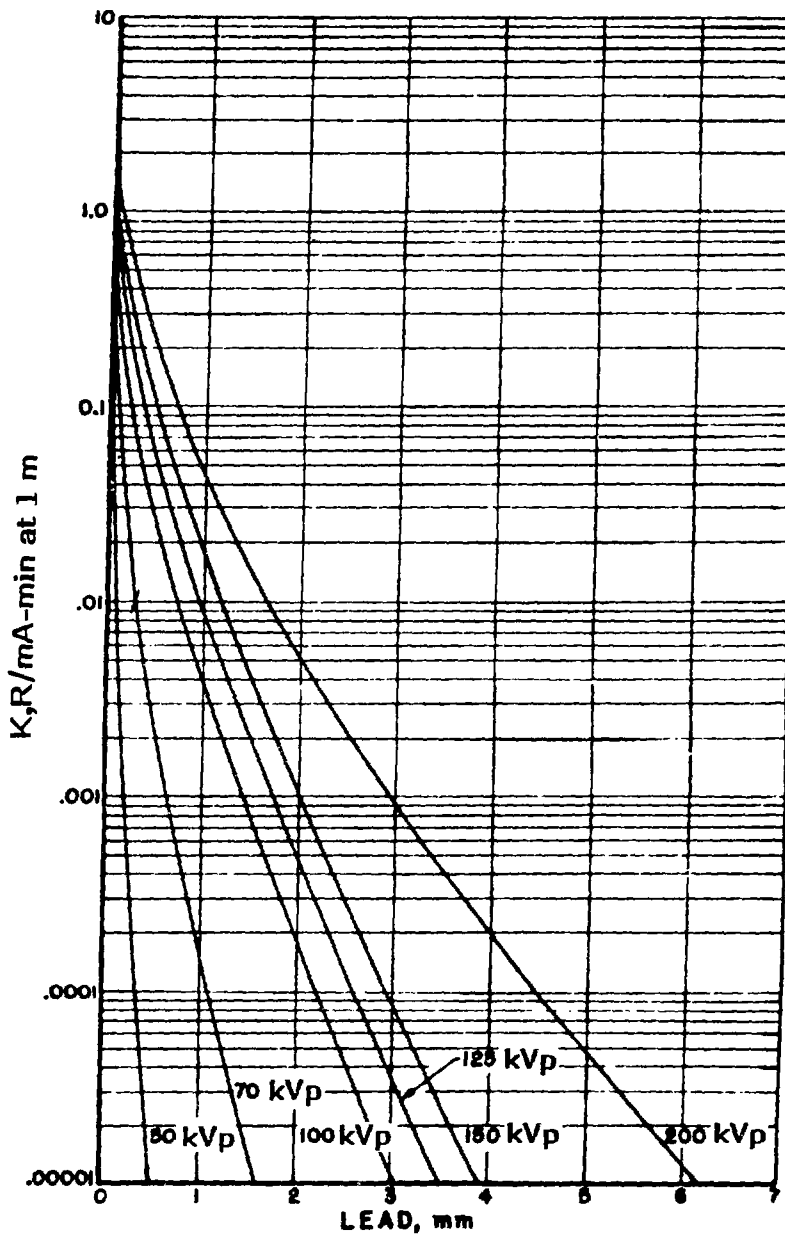


Figure 2. Attenuation in lead of X-rays produced by potentials of 250 to 400 kVp(5)

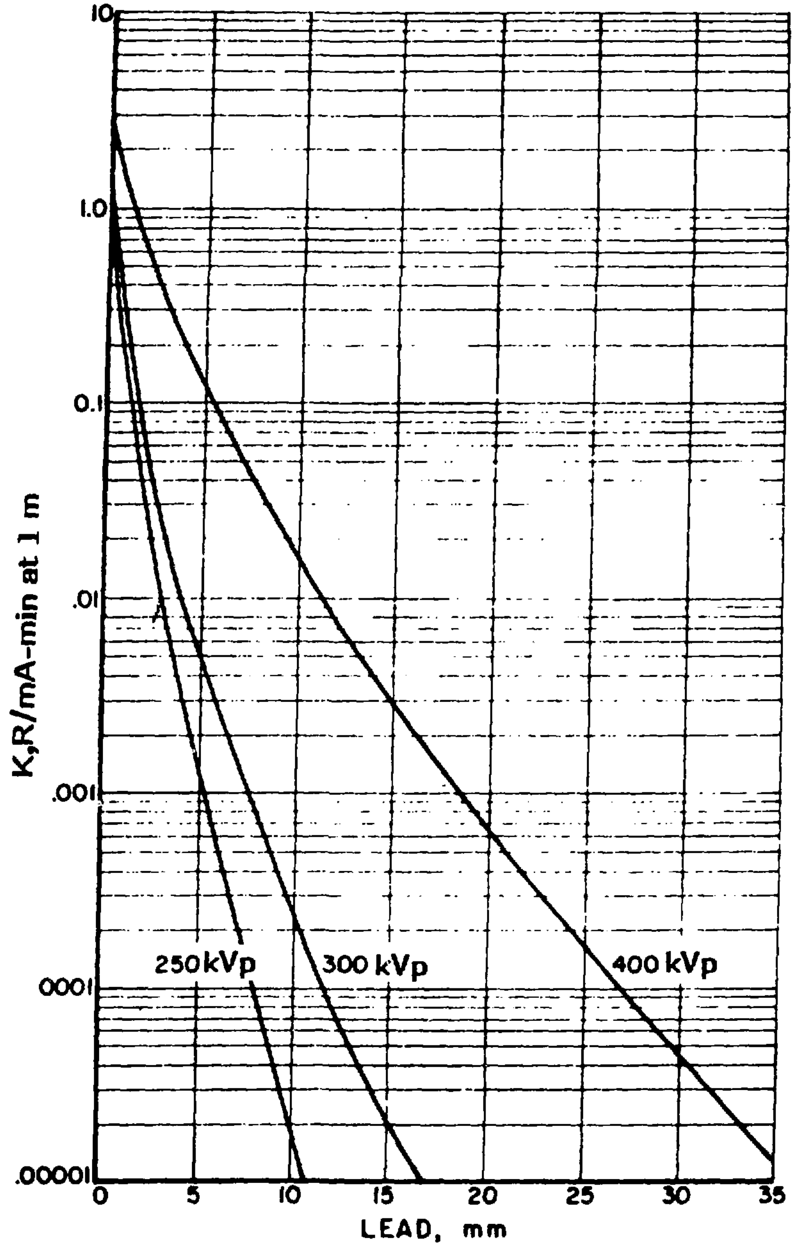


Figure 3. Attenuation in concrete of X-rays produced by potentials of 50 to 300 kVp(6)

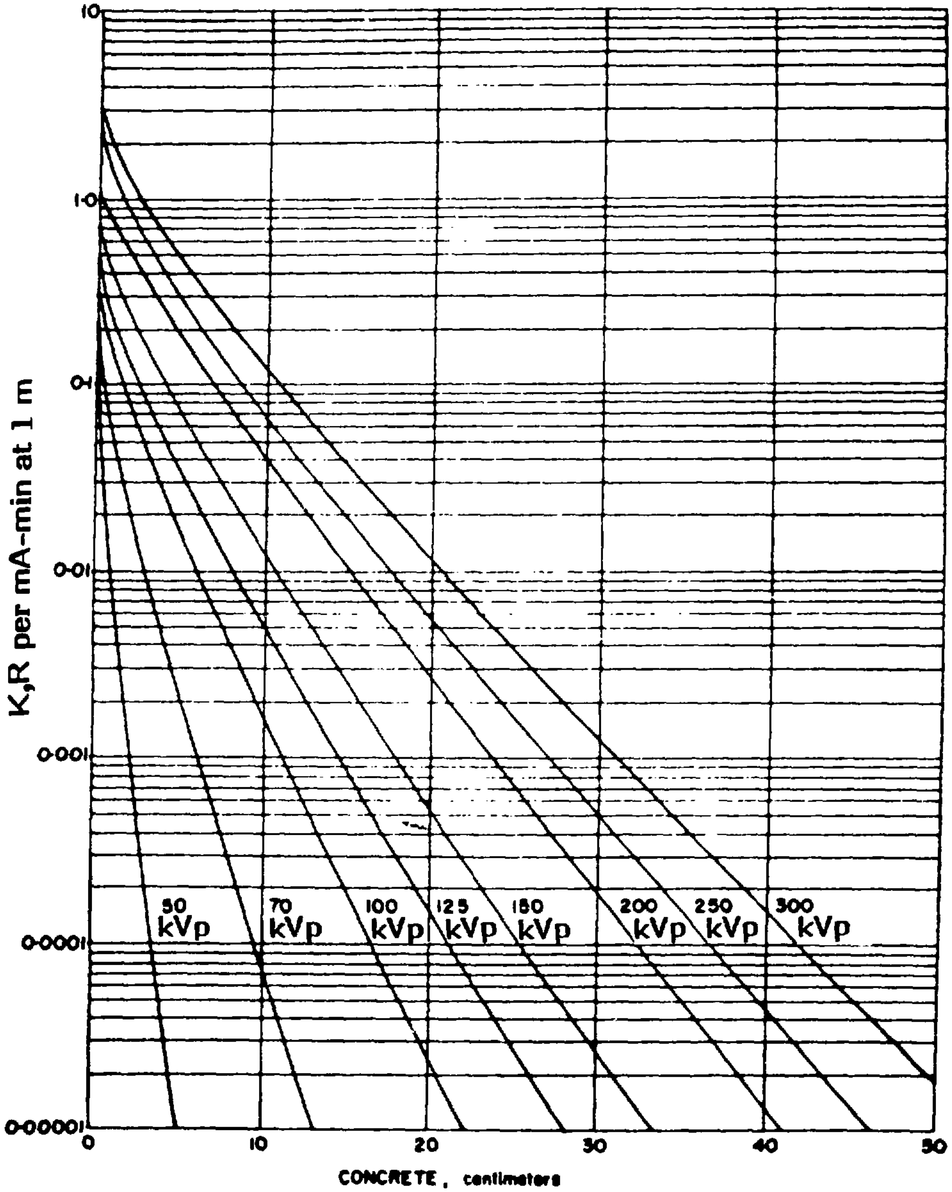


Figure 4. Relation between transmission factor B and the number of half-value layers, N, or tenth-value layers, n(3)

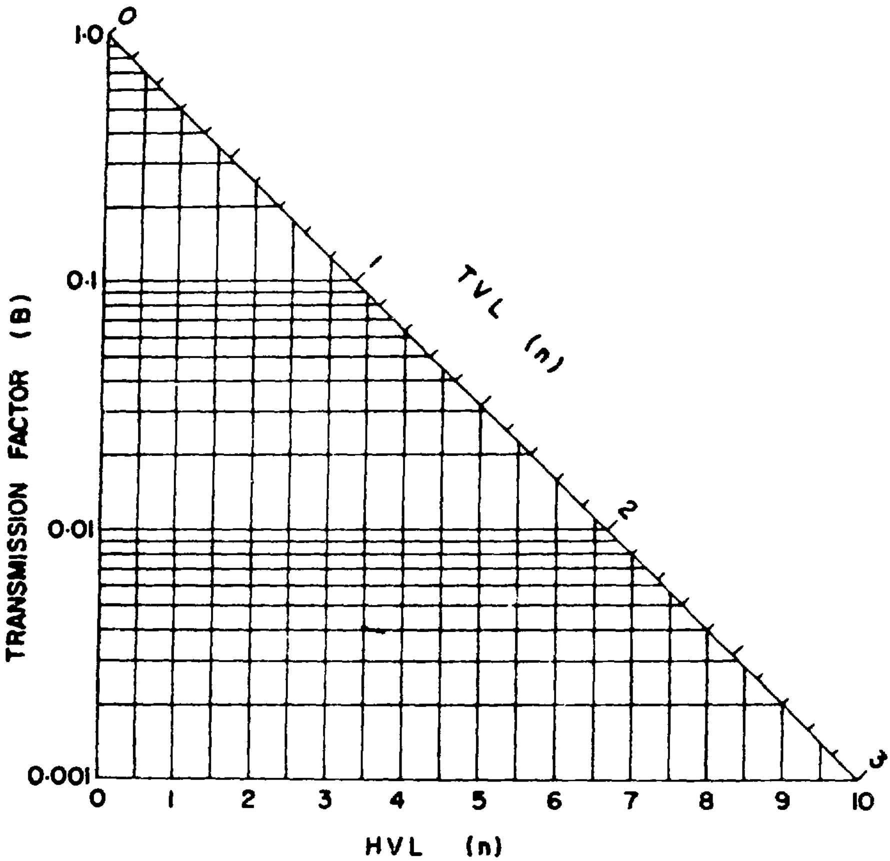


Table 3

Half-value Layers and Tenth-value Layers For Heavily Filtered X-radiation Under Broad-beam Conditions

Tube Potential	Attenuation Material			
	Lead (mm)		Concrete (cm)	
kVp	HVL	TVL	HVL	TVL
50	0.06	0.17	0.43	1.5
70	0.17	0.52	0.84	2.8
85	0.22	0.73	1.25	4.5
100	0.27	0.88	1.6	5.3
125	0.28	0.93	2.0	6.6
150	0.30	0.99	2.24	7.4
200	0.52	1.7	2.5	8.4
250	0.88	2.9	2.8	9.4
300	1.47	4.8	3.1	10.4

Table 4

Ratio, a, of Scattered to Incident Exposure

Type Potential kVp	Scattering Angle (From Central Axis of Beam)					
	30°	45°	60°	90°	120°	135°
50	0.0005	0.0002	0.00025	0.00035	0.0008	0.0010
70	0.00065	0.00035	0.00035	0.0005	0.0010	0.0013
85	0.0012	0.0007	0.0007	0.0009	0.0015	0.0017
100	0.0015	0.0012	0.0012	0.0013	0.0020	0.0022
125	0.0018	0.0015	0.0015	0.0015	0.0023	0.0025
150	0.0020	0.0016	0.0016	0.0016	0.0024	0.0026
200	0.0024	0.0020	0.0019	0.0019	0.0027	0.0028
250	0.0025	0.0021	0.0019	0.0019	0.0027	0.0028
300	0.0026	0.0022	0.0020	0.0019	0.0026	0.0028

Table 5

Commercial Lead Sheets

Thickness		Weight in Pounds for a 1 Square Foot Section	
Inches	Millimeter Equivalent	Nominal Weight	Actual Weight
1/64	0.40	1	0.92
3/128	0.60	1-1/2	1.38
1/32	0.79	2	1.85
5/128	1.00	2-1/2	2.31
3/64	1.19	3	2.76
7/128	1.39	3-2/3	3.22
-	1.50	-	3.48
1/16	1.58	4	3.69
5/64	1.98	5	4.60
3/32	2.38	6	5.53
-	2.5	-	5.80
-	3.0	-	6.98
1/8	3.18	8	7.38
5/32	3.97	10	9.22
3/16	4.76	12	11.06
7/32	5.55	14	12.9
1/4	6.35	16	14.75
1/3	8.47	20	19.66
2/5	10.76	24	23.60
1/2	12.70	30	29.50
2/3	16.93	40	39.33
1	25.40	60	59.00

Notes:

1. The density of commercially rolled lead is 11.36 g/cm^3.
2. The commercial tolerances are ± 0.005 inches for lead up to 7/128 and ± 1/32 for heavier sheets.
3. The total cost of installation is frequently more expensive for lead sheets less than 1/32" thick than for thicker sheets.

APPENDIX V

X-RAY WARNING SIGN

The X-ray warning signs referred to in Sections 4.2 and 5.0 of this Code is a sign that:

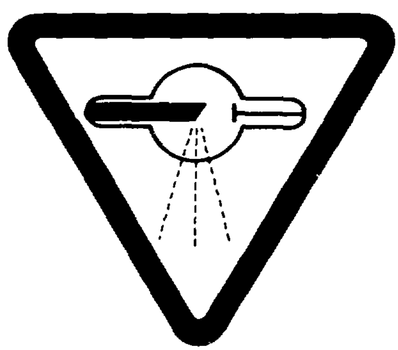
a. is shown in two contrasting colours;

b. is clearly visible and identifiable from a distance of 1 metre;

c. has no outer dimensions less than 2 centimetres;

d. bears the words "CAUTION, X-RAYS" and "ATTENTION, RAYONS X"; and

e. is designed in accordance with the following diagram:



APPENDIX VI

REQUIREMENTS FOR SURVEY METERS

Detailed in this Appendix are some of the more important criteria which must be considered when selecting or using a survey meter. This Safety Code cannot give a rigorous specification for such meters, as it is impossible to cover all applications in one generalized description. In general, the following points must be considered:

1. Shape and Size of the Chamber

   To avoid underestimation of the true exposure rate, the cross-sectional area of the sensitive volume of the detector should not be greater than the cross-sectional area of the radiation beam which is to be measured.

2. Accuracy

   For routine survey work the meter is sufficiently accurate if the readings can be translated into measurements which are accurate to ±20%.

3. Energy Response

   The energy response should be flat to within ±20% over all the energies which are to be measured.

4. Range

   Ideally, there should be multiple ranges available on the meter to provide greater flexibility. For instruments designed to indicate exposure rates, the ranges should cover the domain between 0.25 mR/h and 100 R/h. Similarly, for instruments that indicate the readings in dose equivalent units, the domain should span rates of 1 μSv/h to 1.0 Sv/h.

5. Response Time

   The response time (the time required for the survey meter to indicate 90% of the final reading) must be short enough for an accurate measurement of the exposure rate to be made.

6. Miscellaneous Characteristics

The following should be considered when choosing a meter:

a. "Fold-back" must not occur under any circumstances. When the instrument is exposed to a dose-rate or dose in excess of its calibrated range, the meter must show an off-scale deflection or, with a digital display, show an overload condition.

b. The portability of the instrument. For radiography or survey work it is essential that it can be conveniently carried about.

c. Range switching should be simple and easy to understand.

d. For survey work in areas where radio frequency (RF) fields are present, the survey meter must not be sensitive to the ambient RF fields.

APPENDIX VII

PROVINCIAL AGENCIES RESPONSIBLE FOR RADIATION SAFETY

ALBERTA

Director
Radiation Health Branch
Occupational Health and Safety Division
4th Floor
10709 Jasper Avenue
EDMONTON, Alberta
T5J 3N3
(403) 427-2691

BRITISH COLUMBIA

Director
Radiation Protection Service
B.C. Ministry of Health
200-307 West Broadway
VANCOUVER, British Columbia
V5Y 1P9
(604) 660-6633

MANITOBA

Head
Physics Department
Radiation Protection Section
Manitoba Cancer Treatment and Research Foundation
100 Olivia Street
WINNIPEG, Manitoba
R3E 0V9
(204) 787-2211

NEW BRUNSWICK

Radiation Protection Officer
New Brunswick Department of Health
P.O. Box 6000
348 King Street
FREDERICTON, New Brunswick
E38 5H1
(506) 453-2067

NEWFOUNDLAND

Radiation Protection Officer
Division of Occupational Health and Safety
Department of Labour and Manpower
Beothuck Building, Crosbie Place
ST. JOHN'S, Newfoundland
A1C 5T7
(709) 737-2644

NORTHWEST TERRITORIES

Head
Occupational Health Section
Safety Division
Department of Justice and Public Services
Government of the Northwest Territories
YELLOWKNIFE, Northwest Territories
X1A 2L1
(403) 873-7468

NOVA SCOTIA

Radiation Health Officer
Department of Health
7th Floor, Joseph Howe Building
P.O. Box 488
HALIFAX, Nova Scotia
B3J 2R8
(902) 424-4077

ONTARIO

Supervisor X-ray Safety
Radiation Protection Service
Special Studies and Services Branch
Ontario Ministry of Labour
8th Floor, 400 University Avenue
TORONTO, Ontario
M7A 1T7
(416) 965-8178

PRINCE EDWARD ISLAND

Manager
Radiology Department
Queen Elizabeth Hospital
CHARLOTTETOWN, Prince Edward Island
C1A 8T4
(902) 566-6295

QUÉBEC

Chef
Ministère de l'environnement du Québec
5199, rue Sherbrooke Est
Suite 3860
Montréal (Québec)
H1T 3X9
(514) 873-3636

SASKATCHEWAN

Head
Radiation Protection Service
Occupational Health and Safety Branch
Department of Labour
1150 Rose Street
REGINA, Saskatchewan
S4P 3V7
(306) 565-4486

YUKON TERRITORY

Director of Health Services
Government of the Yukon Territory
P.O. Box 2703
WHITEHORSE, Yukon
Y1A 2C6
(403) 667-5202

RADIATION MEASUREMENT UNITS - INTERNATIONAL SYSTEM (SI)

Exposure

The COULOMB/KILOGRAM (C/kg) replaces the ROENTGEN (R) as the unit of exposure. The relationship between the two units is as follows:

1 C/k ~ 3876 R	1 R ~ 258 µC/kg
1 mC/kg ~ 3876 mR	1 mR ~ 258nC/kg

(Note: m = milli = 10^{-3}; µ = micro = 10^{-6}; n = nano = 10^{-9})

Absorbed Dose

The GRAY (Gy) replaces the RAD (rad) as the unit of absorbed dose. The relationship between the two units is as follows:

1 Gy = 100 rad	1 rem = 10 mGy
1 mGy = 100 mrad	1 mrad = 10 µGy

Dose Equivalent

The SIEVERT (Sv) replaces the REM (rem) as the unit of DOSE EQUIVALENT. The relationship between the two units is as follows:

1 Sv = 100 rem	1 rem = 10 mSv
1 mSv = 100 mrem	1 mrem = 10 µSv

BIBLIOGRAPHY

Further details on the topics covered in this Safety Code may be obtained from the references listed below.

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2. "Recommendations of the International Commission on Radiological Protection", ICRP Publication 26, Annals of the ICRP, Volume 1, No. 3, (1977).

3. "Structural Shielding Design and Evaluation for Medical Use of X-rays and Gamma Rays of Energies up to 10 Mev", National Council on Radiation Protection and Measurements, NCRP Report No. 49, (1976).

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5. "Safety Standard for Non-medical X-ray and Sealed Gamma Ray Sources", NBS Handbook 93, Washington D.C., U.S. Government Printing Office, (1964).

6. "Safety Code - 20A - X-ray Equipment in Medical Diagnosis, Part A: Recommended Safety Procedures for Installation and Use", 80-EHD-65, Health and Welfare Canada, (1981).