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Radiation Protection in Veterinary Medicine

Recommended Safety Procedures for Installation and Use of Veterinary X-Ray Equipment

Safety Code 28

Canada

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Environmental Health Directorate
Health Protection Branch

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Explanatory Notes

This document is one of 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 equipment. Included in this code are sections for the specific guidance of the veterinarian, the operator and the health physicist concerned with safety procedures, equipment performance and protection surveys.

The safety procedures, equipment and installation guidelines detailed in this code are primarily for the instruction and guidance of persons employed in Federal Public Service departments and agencies, as well as those under the jurisdiction of the Canada Labour Code. Facilities under provincial jurisdiction may be subject to requirements specified under provincial statutes. The authorities listed in Appendix IV should be contacted for details of the regulatory requirements of individual provinces.

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 should be implemented where applicable.

In a field in which technology is advancing rapidly and where unexpected and unique problems continually occur, the code cannot cover all possible situations. Blind adherence to rules cannot substitute for the exercise of sound judgement. Recommendations may be modified in unusual circumstances but only upon the advice of experts with recognized competence in radiation protection. This code will be reviewed and revised periodically, and a particular requirement may be reconsidered at any time if it becomes necessary to cover an unforeseen situation. Interpretation or elaboration on any point can be obtained by contacting the Bureau of Radiation and Medical Devices, Department of National Health and Welfare, Ottawa, Ontario K1A 1C1.

This code reflects the results of the work of many individuals. It was prepared and compiled by Mr. C. Lavoie and reviewed by the professional staff of the X-Ray Section, Bureau of Radiation and Medical Devices.

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

1. Introduction

Diagnostic radiology is an essential part of present-day veterinary practice. The need for radiation protection exists because occupational exposure to ionizing radiation can result in deleterious effects that may manifest themselves not only in exposed individuals but in their descendants as well. These are respectively called somatic and genetic effects. Somatic effects are characterized by observable changes occurring in the body organs of the exposed individual. These changes may appear from within a few hours to many years later, depending on the amount and duration of exposure of the individual. In veterinary medicine, the possibility that anyone may be exposed to enough radiation to create somatic effect is extremely remote. Genetic effects are more a cause for concern at the lower doses used in veterinary radiology. Although the radiation doses may be small and appear to cause no observable damage, the probability of chromosomal damage in the germ cells, with the consequence of mutations, does exist. These mutations may give rise to genetic defects and therefore make these doses significant when applied to a large number of individuals.

There are two main aspects of the problem to be considered. First, personnel working with X-ray equipment *must* be protected from excessive exposure to radiation during their work. Secondly, personnel in the vicinity of veterinary X-ray facilities and the general public require adequate protection.

2. Principal Aims and Scope of the Code

This safety code is concerned with the protection of all individuals who may be exposed to radiation emitted by X-ray equipment used in the practice of veterinary radiology.

2.1 Principal Aims

The principal aims of this code are:

1. to provide radiation safety information for the protection of personnel operating or servicing X-ray equipment; and
2. to provide radiation safety information for the protection of 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. sets out the relative responsibilities of the owner, responsible user, operator and other personnel;
2. provides information for designing shielding and determining its effectiveness and adequacy in attenuating primary and stray radiation, and
3. presents recommendations for minimizing irradiation to the operators and ensuring that veterinary X-ray equipment is used in a safe manner.

3. Responsibility and Personnel

3.1 Responsibility

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

The owner may delegate this responsibility to staff. How this responsibility is delegated will depend upon the number of staff members and on the amount of X-ray equipment owned. In any event, one or more persons *must* be designated to carry out the roles described below.

3.2 Responsible User

There *must* be at least one person designated as the responsible user (veterinarian, animal health technologist, registered radiology technician) to undertake responsibility for:

1. ensuring that the equipment is maintained properly and functions correctly and that maintenance is performed by competent personnel;
2. ensuring that the equipment is used correctly and only by competent personnel;
3. establishing safe operating procedures for the equipment and ensuring that operating staff are adequately instructed in them;
4. prescribing rules of radiation safety and ensuring that staff are made aware of them;
5. ensuring that radiation levels outside controlled areas are below the permissible limits of Appendix I;
6. ensuring that the facility complies with all applicable regulatory requirements;
7. establishing safe working conditions according to the recommendations of this safety code and the statutory requirements of federal or provincial legislation where applicable;

8. carrying out routine checks of equipment and facility safety features;
9. keeping records of radiation surveys, including summaries of corrective measures recommended or instituted;
10. declaring which personnel are occupationally exposed persons: these persons are either routinely participating in radiological procedures or are likely to receive a radiation dose in excess of 1/20th of the permissible dose equivalent limits specified in Appendix I;
11. organizing participation, where necessary, in a personnel radiation monitoring service such as that provided by the Bureau of Radiation and Medical Devices, Department of National Health and Welfare, Ottawa, Ontario K1A 1C1;
12. ensuring that all occupationally exposed persons wear personal dosimeters during radiological procedures or when occupational exposures are likely;
13. keeping records of occupational exposures received by personnel;
14. investigating each known or suspected case of excessive or abnormal occupational exposure to determine the cause and to take remedial steps to prevent its recurrence;
15. ensuring that all safety devices recommended by this code are in good condition;
16. ensuring that appropriate warning signs are properly located, and
17. ensuring that operators understand the contents of this code.

3.3 X-Ray Equipment Operators

All operators *must*:

1. be aware of the contents of this safety code;
2. be aware of the radiation hazards associated with their work and of their duty to protect themselves and others, and
3. have a thorough understanding of their professions, of safe working methods and of special techniques.

A female operator *should* be encouraged to notify her employer if she believes herself pregnant. Appropriate steps may then be taken to ensure that her work duties during the remainder of the pregnancy are compatible with the permissible dose equivalent limits, as set out in Appendix I.

3.4 Students or Operators-in-Training

All students, operators-in-training and personnel not experienced in the use of X-ray equipment *must* work only under the direct supervision of a qualified operator. Dose equivalent limits for students and operators-in-training *should not* be greater than the limits set for members of the public.

4. Building and Installation Requirements

4.1 Design Criteria

In the planning of any veterinary X-ray facility, account *must* be taken of the expected maximum workload of the equipment, use factors of the barriers and occupancy factors for areas adjacent to the facility. Allowance *should* be made for possible future changes in any of these parameters, such as increased operating X-ray tube voltage and workload or an increase in the degree of occupancy of surrounding areas.

It is particularly advantageous to make visual inspections during construction of a new facility to ensure compliance with specifications and to identify faulty material or workmanship. Deficiencies can be remedied more economically at this stage than later. Such inspections *should* verify the thickness and density of all barriers, including lead sheets, concrete walls and shielding glass used in viewing windows.

Certain basic principles *must* be observed when determining the shielding requirements for a room used routinely for veterinary radiological procedures.

1. The radiation levels in controlled areas that are routinely occupied by radiation workers only *must* be such that no radiation worker is occupationally exposed to more than 20 mSv per year.
2. The radiation levels in uncontrolled areas *must* be such that no person can receive more than 1 mSv per year.

In general, radiation levels close to the X-ray equipment are such that the above limits are exceeded even at very low workloads. Reductions in radiation intensity can be accomplished by interposing physical barriers or increasing the distance between the sources of radiation and the persons to be protected.

The shielding required to reduce radiation levels to acceptable values may be determined on the basis of distance, nominal X-ray tube voltage, and workload. To ensure that the radiation levels are always below acceptable limits, the maximum expected workload *should* be used.

4.2 General Recommendations

The procedures described below *must* be followed to protect personnel working with or in the vicinity of X-ray equipment.

1. The radiation beam must *always* be directed toward adequately shielded or unoccupied areas.
2. The radiation beam and scattered radiation *should* be attenuated as closely as possible to the source.
3. Where necessary, the floors, walls, ceilings and doors *must* be built with materials providing adequate radiation protection to workers.
4. The shielding *should* be constructed to form an unbroken barrier. Care *should* be taken in the use of shielding materials, especially lead, which *must* be adequately supported to prevent "creeping".
5. When necessary, a control booth *must* be provided for the protection of the operator. The control booth and its viewing window *must* have shielding properties such that no operator is exposed to more than 20 mSv per year. Mobile protective barriers are not considered adequate as a control booth except for facilities requiring no shielding at 1 metre from source, or where 1/20 of permissible dose equivalent limits are not likely to be exceeded at 1 metre.
6. The control booth *should* be located, whenever possible, such that the radiation has to be scattered at least twice before entering the booth. In facilities where the radiation beam may be directed toward the booth the shielding of the booth must be that of a primary barrier.
7. The control booth *should* be positioned so that during an irradiation no one can enter the radiographic room without the knowledge of the operator.
8. Warning signs *must* be posted on all entrance doors of radiographic room. The warning signs *must* incorporate the X-radiation warning symbol and *should* incorporate the words "Unauthorized Entry Prohibited."
9. The final plans for the facility *must* be reviewed by the appropriate responsible government agencies before construction. For facilities under federal jurisdiction; the responsible agency is the Bureau of Radiation and Medical Devices of the Department of National Health and Welfare. For facilities under provincial jurisdiction the responsible agencies are listed in Appendix IV. The thickness of the shielding and the materials used *must* be indicated on the plans. The plans *must* also show the positions of

all windows, doors, pipes and louvres that may affect the protection requirements. Adjacent rooms as well as rooms above and below *must* also be noted.

10. Mobile X-ray equipment used routinely in one location is considered to be a fixed installation, and the facility *should* be shielded accordingly.

5. Radiation Protection Surveys

A radiation protection survey of a facility is intended to demonstrate not only that the X-ray equipment itself functions properly and according to applicable standards, but also that the equipment is installed and used in a way that maximum radiation safety for operators and others. Therefore it is important that X-ray facilities be inspected at regular intervals.

5.1 General Procedures

Before routine operation of any new facility, the owner of the facility *must* contact the appropriate agency to enquire about the inspection procedures in that jurisdiction. Some jurisdictions may require the facility to be declared in compliance with applicable government regulations prior to operation. In an existing facility, a survey *must* be carried out after any change that may increase radiation output of the equipment or affect protection of the operator or others, e.g. alterations of protective barriers, replacement of the X-ray machine with one capable of operating at a higher X-ray tube voltage, changes in operating procedures or increased workload.

The results of such surveys and conclusions drawn by a qualified expert *must* be submitted *to the owner* or responsible user in a written report. All such written reports *must* be retained by the owner or responsible user.

5.2 Survey Report

The survey report *must* present any unusual findings about the equipment itself, the installation or operating procedures that could affect the safety of operators or other persons in the vicinity of the X-ray facility. The survey report *should* also include the results of investigations of any unusually high exposures from previous personal dosimetry reports and recommend whether other persons should use personal dosimeters.

The survey report *must* include at least the following:

1. identification of the X-ray equipment (e.g., name of the manufacturer, model designation and serial number of the generator, control, X-ray tube assembly) and the date, or at least approximate date, of manufacture;
2. observations of the condition (both electrical and mechanical) of the X-ray equipment at the time of the survey;
3. an assessment of the condition of protective aprons, gloves, mobile protective barriers and other protective devices;
4. an estimate of potential exposures to personnel and general public in or around the facility;
5. an assessment of radiological and film processing techniques from the viewpoint of radiation safety. Attention *must* be drawn to any practices that are or could be detrimental to personnel working in the facility. Recommendations of safer techniques *should* be made in such cases; and
6. recommendations regarding the need for a follow-up survey.

6. Equipment Specifications

6.1 X-Ray Equipment

All veterinary X-ray equipment and accessories for such equipment sold in Canada *must* conform to the *Radiation Emitting Devices Act* and the *Food and Drugs Act*. There are no specific standards promulgated for veterinary X-ray equipment under the *Radiation Emitting Devices Act*, but this equipment *must* comply with the general provisions of the Act. The requirements of the *Food and Drugs Act* are specified in the Medical Devices Regulations promulgated under this Act. It is the responsibility of the manufacturer or distributor to ensure that the equipment conforms to the requirements stated in these Acts.

Modifications to these requirements may be made from time to time to keep abreast of changing technology in the field of radiation protection and veterinary medicine. Information on the applicability and currency of the *Radiation Emitting Devices Act* and the Medical Devices Regulations may the obtained by contacting the Bureau of Radiation and Medical Devices, Department of National Health and Welfare, Ottawa, Ontario K1A 1C1.

Whenever possible and to the extent that is practical, existing X-ray equipment *should* be upgraded to incorporate as many as possible of the safety and performance features described below. New X-ray equipment *should* also incorporate as many as possible of the safety and performance features described.

To ensure maximum protection for staff and visitors, all X-ray equipment *should* at least meet certain basic requirements.

1. ***Warning Signs***: the X-ray control panel *must* bear a permanent and conspicuous sign prohibiting unauthorized use and warning that hazardous X-radiation is emitted when the equipment is in operation.
2. ***Markings***: all controls, meters, lights and other indicators relevant to the operation of the equipment *must* be readily discernible and clearly labelled as to function.
3. ***Irradiation Light***: there *must* be a readily discernible separate indicator on the control panel that indicates when X-rays are being produced.

4. ***Mechanical Stability***: the X-ray tube *must* be securely fixed and correctly aligned within the X-ray tube housing. The X-ray source assembly *must* maintain its required position without excessive drift or vibration during operation.
5. ***Irradiation Control***: there *must* be an irradiation switch, timer, or other device to initiate and terminate X-ray production. This control *must* automatically terminate the irradiation after a preset time, product of tube current and time, or irradiation value has been reached. Where an irradiation switch is provided, it *must* require continuous pressure by the operator to produce X-rays. A foot switch is to be constructed so that no X-ray can be produced if it is inadvertently overturned. The irradiation timer *must* be an electronic type: mechanical timers *must not* be used.
6. ***Indication of Loading Factors***: for X-ray equipment having adjustable loading factors, the control panel *must* incorporate indicators that allow these loading factors to be determined. For equipment having non-adjustable loading factors, permanent marks or labels may be used to indicate these parameters.
7. ***Timer Accuracy***: the irradiation timer *should* be such that at each setting it is accurate to 1/60 second or 7% of that setting, whichever is greater.
8. ***X-Ray Tube Voltage Accuracy:*** the generator *should* be such that at each voltage setting it is accurate to 5% of that setting.
9. ***Irradiation Reproducibility:*** for any selected combination of X-ray tube voltage, current and time greater than 1/10 second, the coefficient of variation of any 10 consecutive irradiations taken at the same distance within a period of 1 hour should not exceed 0.1. The coefficient of variation is defined as the ratio of the standard deviation to the mean value of a series of irradiation measurements calculated using the following equation:

$$\mathbf{C} = \frac{1}{\langle X \rangle} = \left\{ \frac{\sum_{i=1}^{n} (X_i - \langle X \rangle)^2}{n-1} \right\}^{1/2}$$

where C = coefficient of variation
Xi = ith irradiation measurement
<X> = mean value of the measurements
n = number of measurements

10. ***X-Ray Tube Shielding:*** the X-ray tube *must* be enclosed in a shielded housing. The leakage radiation from the X-ray tube housing *must not* exceed 0.873 mGy (100 mR) in 1 hour at 1 metre at the nominal X-ray tube voltage on the equipment.
11. ***Beam Limiting Device:*** the X-ray tube housing *must* be equipped with a beam limiting device that enables adjustment of the size of the X-ray field. The beam limiting device *should* incorporate means to indicate the size of the X-ray field at the image reception area.
12. ***Half-Value Layer:*** for a given kilovoltage, the measured value of half-value layer of the useful beam *must* follow the limits below:
    - For equipment designed to operate with X-ray tube potentials below 70 kilovolts, the half-value layer *must not* be less than 1.5 millimetre of aluminium (mmAl).
    - For equipment designed to operate with X-ray tube potentials at and above 70 kilovolts peak the half-value layer *must not* be less than:
      2.1 mmAl at 70 kVp,
      2.3 mmAl at 80 kVp,
      2.5 mmAl at 90 kVp,
      2.7 mmAl at 100 kVp,
      3.0 mmAl at 110 kVp,
      3.2 mmAl at 120 kVp,
      3.5 mmAl at 130 kVp,
      3.8 mmAl at 140 kVp, and
      4.1 mmAl at 150 kVp.

6.2 Protective Clothing

Protective aprons, gloves and thyroid shields used for veterinary X-ray examinations *must* provide attenuation equivalent to at least 0.5 mm of lead at X-ray tube voltages of up to 150 kVp. The lead equivalent thickness of the material used *must* be permanently and legibly marked on the protective device. Protection *must* be provided throughout the glove, including fingers and wrist.

Protective aprons, gloves and thyroid shields *must* be stored and maintained according to manufacturers' recommendations. It is also recommended that protective aprons, gloves and thyroid shields are checked by radiographing them annually or when damage is suspected.

6.3 Darkroom and Film Processing

The irradiation necessary to produce a radiogram of satisfactory diagnostic quality depends not only on the loading technique and the film-screen combination employed but also on the handling and processing of the film. Improper processing of radiographic film can cause films of poor diagnostic quality that may require an increase in loading factors or repeat irradiations. This would lead to an increase in the exposure level of scatter and leakage radiations to the staff. Adherence to the following guidelines on darkroom design, film processing and film storage will improve the diagnostic quality of films and ultimately reduce radiation levels in the facility.

1. The darkroom *must* be impervious to light.
2. A warning light or sign *should* be located outside the darkroom to indicate when the room is in use.
3. Safelights, fitted with light bulbs of correct intensity, and filters appropriate to the specifications of the film used *must* be provided above the work area within the darkroom.
4. Manufacturers' recommendations about the strengths and temperatures of the solutions and immersion times *must* be followed to ensure optimum film processing.
5. Manufacturers' recommendations about the operation and servicing of automatic film processors *must* be followed to ensure optimum film processing.
6. Developing solutions *should* be replenished and changed according to the manufacturers' recommendations.
7. Unexposed radiographic films *must* be stored in such a manner that they are shielded from stray radiation. Storage *should* be provided such that no film can be exposed to more than 1.75 μGy (0.2 mR) of stray radiation before use. The amount of shielding required will depend on the storage time and the workload of the facility. It can be determined from the table in Appendix III.
8. Films *should* be stored on end in a cool, dry area.

7. Procedures to Reduce Dose to X-Ray Personnel

The guidelines and procedures outlined in this section are primarily directed toward occupational health protection. Adherence to these guidelines will also provide protection to visitors and other individuals in the vicinity of an X-ray facility. However, the safe work practices and procedures for using various types of X-ray equipment should be regarded as a minimum to be augmented with additional requirements, when warranted, to cover special circumstances in particular facilities.

To achieve optimum safety, operators *must* make every reasonable effort to keep exposures to themselves and to other personnel as low as reasonably achievable, with the limits specified in Appendix I being regarded as maximum values not to be exceeded.

7.1 General Recommendations

1. An X-ray room *must* be used for only one X-ray procedure at a time.
2. All entrance doors to an X-ray room *should* be kept closed while a radiographic procedure is being performed.
3. X-ray machines that are energized and ready to produce radiation *must* be supervised.
4. The X-ray room *must* contain only those persons whose presence is essential when a radiological procedure is carried out.
5. All personnel *must* fully use all protective devices available.
6. The X-ray tube housing *must never* be held by hand or supported by any part of the body during operation.
7. Where a control booth or protective barrier is available, operators *must* remain inside or behind when making an irradiation. If a control booth or protective screen is not available, protective clothing *must* be worn.
8. Personnel *must* keep as far away from the X-ray beam as is practicable at all times. Exposure of personnel to the X-ray beam *must never* be allowed unless the beam is adequately attenuated by the animal and by protective clothing or barriers.

9. If necessary, the animal *should* be sedated or holding devices used during radiography. However, if this is not possible and a person *must* restrain the animal, protective aprons and gloves *must* be worn, and irradiation by the X-ray beam *must* be avoided. Individuals *should* avoid performing these duties regularly.
10. A radiographic cassette holder *must always* be used. The radiographic cassette *must never* be held by hand.
11. All operators of X-ray equipment, together with personnel who routinely participate in radiological procedures and others likely to receive a radiation dose in excess of 1/20 of the permissible dose equivalent limits specified in Appendix I, *must* wear personal dosimeters.
12. When a protective apron is worn the personal dosimeter *must* be worn underneath. Where irradiation to the body may be substantial, a second personal dosimeter located at the neck level may be worn. In such cases consultation with the proper federal or provincial agency may be helpful. If extremities are likely to be exposed to higher doses, additional monitors *should* be worn on the extremities.
13. Where radiation doses in excess of 20% of the maximum specified in Appendix I are being received regularly by any one person, the nature and cause of the irradiation *must* be investigated and appropriate remedial steps *must* be taken to improve techniques and protective measures.
14. X-ray equipment *must* be operated only by or under the direct supervision of qualified individuals.
15. For table-top radiography when the sides of the table are not shielded, a sheet of lead at least 1 mm in thickness and slightly larger than the maximum beam size *should* be placed immediately beneath the cassette or film.
16. The fastest combination of films and intensifying screens consistent with diagnostically acceptable results and within the capability of the equipment *should* be used.

Appendix I
Permissible Dose Equivalent Limits of X-Radiation to Operators and Other Occupationally Exposed Personnel

For the purpose of radiation protection, individuals may be classified in one of two categories: those exposed to radiation during the course of their work (radiation workers), and others. Maximum permissible levels are given for both categories in the following table. These dose equivalent limits are based on the latest recommendations of the International Commission on Radiological Protection (ICRP) as specified in *ICRP Publication 60*.

Permissible dose equivalent limits for radiation workers apply *only* to irradiation resulting directly from their occupations and do not include irradiation from other sources such as medical diagnoses and background radiation.

	Annual permissible dose equivalent limits	
Applicable body organ or tissue	Radiation workers	Other workers and members of the public
Whole body	20 mSv	1 mSv
Lens of the eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands	500 mSv	50 mSv
All other organs	500 mSv	50 mSv

Notes:

1. Any exposure may involve some degree of risk. Although the levels recommended in this Appendix are maximum permitted values, all doses *should* be kept as low as reasonably achievable. Any unnecessary exposures *must* be avoided.
2. ICRP does not recommend discrimination in the dose limits between men and women of reproductive capacity, if the dose is received at an approximately regular rate.

3. Once an occupationally exposed woman has been declared pregnant, the fetus *should* be protected from external exposure by applying a dose equivalent *limit* of 2 mSv to the surface of the woman's abdomen for the remainder of the pregnancy, with no more than 1 mSv in the period from 8 to 15 weeks after conception.
4. For operators-in-training and students, dose equivalent limits for members of the general public *should* apply.
5. ICRP does not recommend different limits for individual organs. For occupationally exposed workers ICRP believes that deterministic effects will be prevented by applying a dose equivalent limit of 500 mSv in a year to all tissues except the lens of the eye, for which it recommends a limit of 150 mSv in a year.
6. For the skin the dose equivalent is averaged over its whole area. In situations where *deterministic effects* are possible, the recommended dose equivalent limit for the skin is 500 mSv and is averaged over areas of no more than about 1 cm^2. This limit applies to the skin of the face and the hands.
7. In special circumstances ICRP limits allow a higher value of effective dose that is allowed in a one-year period, as long as the average dose over a five-year period is not greater than the annual limit. This higher value is 50 mSv for occupationally exposed personnel. However, in veterinary medicine there is no circumstance in which this provision should apply.
8. Some provincial jurisdictions may have permissible dose equivalent limits for some workers that differ from those listed in Appendix I. Consultation with the proper agency may be required to determine the permissible dose equivalent limits in effect in a particular jurisdiction.

Appendix II
Shielding Guides for Veterinary X-Ray Facilities

To determine the shielding necessary for a veterinary X-ray facility, certain preliminary information is essential. In many instances the thickness of lead or concrete required to reduce radiation levels to the maximum permissible level can be determined directly from Tables 1 and 2 of this Appendix. In other cases, contact the appropriate agency to enquire about shielding requirements and calculations. In both instances answers to the following questions are required.

1. What is the distance between the nearest point of the area to be shielded and the usual operational position of the X-ray tube?
2. Is the area to be designated as a controlled or uncontrolled area? (The area occupied by radiation workers is subject to the limit of 20 mSv per year, whereas areas occupied by non-radiation workers are subject to the limit of 1 mSv per year.)
3. Will the intervening shield between the X-ray tube and the occupied area act as a primary or as a secondary protective barrier, i.e. will the barrier be required to attenuate the direct X-ray beam or stray radiation only?
4. What will be the anticipated maximum workload of the X-ray unit? (The workload indicates the operational time of an X-ray machine expressed in terms of milliampere-seconds per week.)
5. What will be the nominal and average X-ray tube voltages?

Table 1.
Primary Protective Barrier Requirements
for 17.5 μGy (2 mR) per Week (Ucontrolled Area)

The tabulated values give the minimum amount of lead or concrete shielding required to reduce the exposure in uncontrolled areas to 17.5 μGy (2 mR) in one week. These thicknesses of shielding are for a single source of radiation. If more than one source irradiates the location of interest, the contribution from each source must be taken into account in determining the amount of shielding required. Planned and existing structural materials should be fully considered when calculating a barrier requirement.

The thicknesses of lead and concrete required have been rounded off to the next highest 0.05 mm and 0.5 cm respectively.

Note: lead sheet is commercially available only in discrete thicknesses given in Table 3.

A. Lead

X-ray tube voltage kVp	Effective workload mA-sec/week	mm of lead required at a source distance of					
		1m	2m	3m	4m	5m	8m
70	500	0.75	0.50	0.40	0.30	0.25	0.20
	250	0.65	0.40	0.30	0.25	0.20	0.15
	100	0.50	0.30	0.20	0.15	0.15	0.10
	50	0.40	0.20	0.15	0.10	0.10	0.05
	25	0.30	0.15	0.10	0.10	0.10	-
	10	0.20	0.10	0.10	0.05	-	
	5	0.15	0.10	0.05	-		
100	500	1.90	1.35	1.05	0.85	0.75	0.45
	250	1.60	1.10	0.85	0.65	0.55	0.30
	100	1.30	0.80	0.55	0.40	0.30	0.20
	50	1.05	0.60	0.40	0.30	0.20	0.10
	25	0.80	0.40	0.25	0.20	0.15	0.05
	10	0.55	0.25	0.15	0.10	0.05	-
	5	0.35	0.15	0.10	0.05	-	
125	500	2.30	1.70	1.40	1.20	1.05	0.70
	250	2.00	1.45	1.15	0.95	0.80	0.50
	100	1.60	1.10	0.85	0.65	0.50	0.30
	50	1.35	0.85	0.60	0.45	0.35	0.20
	25	1.10	0.65	0.40	0.30	0.20	0.10
	10	0.80	0.40	0.20	0.15	0.10	-
	5	0.60	0.25	0.15	0.10	0.05	-

Table 1 (cont'd)

X-ray tube voltage kVp	Effective workload mA-sec/week	mm of lead required at a source distance of					
		1m	2m	3m	4m	5m	8m
150	500	2.60	2.00	1.70	1.45	1.30	0.95
	250	2.30	1.75	1.40	1.20	1.05	0.75
	100	1.90	1.35	1.10	0.90	0.75	0.45
	50	1.65	1.10	0.85	0.65	0.55	0.30
	25	1.35	0.90	0.60	0.45	0.35	0.15
	10	1.05	0.60	0.35	0.25	0.15	0.05
	5	0.80	0.40	0.20	0.15	0.10	-

B. Concrete

		cm of concrete required at a source distance of					
70	500	8.5	6.5	5.0	4.5	3.5	2.5
	250	7.5	5.5	4.0	3.5	3.0	1.5
	100	6.0	4.0	3.0	2.0	1.5	1.0
	50	5.0	3.0	2.0	1.5	1.0	0.5
	25	4.0	2.0	1.5	1.0	0.5	-
	10	3.0	1.0	0.5	0.5	-	
	5	2.0	1.0	0.5	-		
100	500	15.0	11.5	10.0	9.0	7.5	5.5
	250	13.0	10.0	8.0	7.0	6.0	4.0
	100	11.0	8.0	6.0	5.0	4.0	2.0
	50	9.5	6.5	4.5	3.5	2.5	1.0
	25	8.0	5.0	3.5	2.0	1.5	1.0
	10	6.0	3.0	1.5	1.0	0.5	-
	5	4.5	2.0	1.0	0.5	-	
125	500	19.0	15.0	12.5	11.0	10.0	7.5
	250	17.0	13.0	11.0	9.0	8.0	5.5
	100	14.5	10.5	8.5	7.0	5.5	3.5
	50	12.5	8.5	6.5	5.0	4.0	2.0
	25	10.5	7.0	5.0	3.5	2.5	1.0
	10	8.0	4.5	3.0	1.5	1.0	-
	5	6.5	3.0	1.5	0.5	0.5	-
150	500	23.0	18.5	16.0	14.0	12.5	9.5
	250	20.5	16.0	13.5	12.0	10.5	7.5
	100	18.0	13.0	11.0	9.0	7.5	4.5
	50	15.5	11.0	8.5	7.0	5.5	2.5
	25	13.0	9.0	6.5	4.5	3.0	1.5
	10	10.5	6.5	3.5	2.5	1.5	0.5
	5	8.5	4.0	2.0	1.0	0.5	-

Table 2.
Secondary Protection Barrier Requirements
for 17.5 μGy (2 mR) per Week (Uncontrolled Area)

In using this table refer to the explanatory comments in Table 1.

A. Lead

X-ray tube voltage kVp	Effective workload mA-sec/week	mm of lead required at a source distance of					
		1m	2m	3m	4m	5m	8m
70	500	0.15	-				
	250	0.05	-				
	100	-					
	50						
	25						
	10						
	5						
100	500	0.30	0.10	-			
	250	0.15	-				
	100	0.05	-				
	50	-					
	25						
	10						
	5						
125	500	0.45	0.10	0.05	-		
	250	0.25	0.05	-			
	100	0.10	-				
	50	0.05	-				
	25	-					
	10						
	5						
150	500	0.60	0.20	0.10	-		
	250	0.35	0.10	-			
	100	0.15	-				
	50	0.05	-				
	25	-					
	10						
	5						

Table 2. (Cont'd.)

B. Concrete

X-ray tube voltage kVp	Effective workload mA-sec/week	cm of concrete required at a source distance of					
		1m	2m	3m	4m	5m	8m
70	500	1.0	-				
	250	0.5	-				
	100	-					
	50						
	25						
	10						
	5						
100	500	3.0	0.5	-			
	250	1.5	-				
	100	0.5	-				
	50	-					
	25						
	10						
	5						
125	500	4.5	1.5	0.5	-		
	250	2.5	0.5	-			
	100	1.0	-				
	50	0.5	-				
	25	-					
	10						
	5						
150	500	6.0	1.5	1.0	-		
	250	3.5	1.0	-			
	100	1.5	-				
	50	0.5	-				
	25	-					
	10						
	5						

Table 3.
Commercial Lead Sheets

Thickness		Nominal weight	Nominal weight
Inches	Millimetres	lb/ft^2	kg/m^2
1/64	0.4	1	4.9
3/128	0.6	1 ½	7.3
1/32	0.8	2	9.8
5/128	1.0	2 ½	12.2
3/64	1.2	3	14.6
7/128	1.4	3 ½	17.1
1/16	1.6	4	19.5
5/64	2.0	5	24.4
3/32	2.4	6	29.3

Notes:

1. The density of commercially rolled lead is 11.36 $g.cm^{-3}$.
2. The commercial tolerances are ± 0.13 mm for lead up to 1.4 mm and ± 0.8 mm for heavier sheets.
3. Material and installation costs for lead sheet less than 0.8 mm thick are frequently higher than for heavier sheet.
4. Acoustical type lead is not suitable for lead shielding.

Use of Common Construction Materials For X-Ray Shielding

Commonly used construction materials provide a certain degree of protection against X-radiation. This degree will depend on the type and thickness of the material in question and on the X-ray tube voltage at which the equipment is operated. In some cases a judicious use of common building materials or a careful selection of location and orientation of the X-ray unit may eliminate the need for additional shielding without compromising the X-ray safety of the installation.

X-ray shielding properties of some common construction materials and their combinations are given below. Note that thicknesses of different materials that provide equivalent attenuation under one set of conditions may behave quite differently under other conditions. The materials described in Table 4 are not well suited for use as primary shielding. They should be regarded as materials for use in secondary shielding.

Table 4.
Approximate Concrete Equivalence of Common Construction Materials

Material	Thickness of concrete (cm)					
	50 kVp	70 kVp	85 kVp	100 kVp	125 kVp	150 kVp
1	10	10	10	10	10	10
2	7	7	7	7	7	7
3	2.3	2.3	2.3	2.3	(*)	(*)
4	0.5	0.5	0.5	0.5	(*)	(*)
5	0.8	0.8	0.8	0.8	(*)	(*)
6	1.0	1.0	1.0	1.0	(*)	(*)
7	1.4	1.4	1.4	1.4	(*)	(*)
8	1.2	1.2	1.2	1.2	1.2	1.2
9	2.4	2.2	2.2	2.2	2.2	2.2

Material

1: Hollow cinder block + 2 layers of 2.2 cm mortar + 2 layers of 0.8 cm tile
2: Gypsum pyrobar + 2 layers of 2.2 cm mortar
3: 5 cm of gypsum plaster
4: 1.0 cm of gypsum wallboard
5: 1.9 cm of gypsum wallboard
6: 2.54 cm of gypsum wallboard
7: 3.2 cm of gypsum wallboard
8: 1.0 cm of plate glass
9: 2.0 cm of plate glass

(*) Gypsum materials alone are not recommended for shielding above 100 kVp.

Appendix III
Shielding Guides for Storage of Radiographic Film

To reduce the radiation level to the film to 1.75 μGy (0.2 mR) for weekly workloads of:

500 mA-sec at 100 kVp
200 mA-sec at 125 kVp
100 mA-sec at 150 kVp

	Distance from X-ray tube to stored film							
	2.0 m		3.0 m		4.0 m		5.0 m	
	lead mm	concrete cm	lead mm	concrete cm	lead mm	concrete cm	lead mm	concrete cm
Storage time for primary barriers								
1 day	1.6	15.2	1.3	12.6	1.1	10.9	1.0	9.6
1 week	2.3	20.4	1.9	17.9	1.7	15.9	1.5	14.5
1 month	2.8	24.8	2.5	22.3	2.3	20.4	2.1	19.0
1 year	3.9	33.0	3.6	30.5	3.3	28.6	3.1	27.0
For secondary barriers								
1 day	0.2	1.5	0.1	1.0	-	-	-	-
1 week	0.6	5.4	0.3	2.5	0.2	1.5	0.1	1.0
1 month	1.0	9.6	0.7	7.1	0.5	5.4	0.4	3.7
1 year	2.1	17.5	1.7	14.8	1.5	13.0	1.3	11.6

Appendix IV
Agencies Responsible for Radiation Safety of Veterinary X-Ray Facilities

Alberta
Radiation Health Section
Occupational Health Branch
Division of Policy and Professional Services
Government of Alberta
10709 Jasper Avenue
Edmonton, Alberta
T5J 3N3

British Columbia
Worker's Compensation Board of British Columbia
P.O. Box 5350 Stn Terminal
Vancouver, British Columbia
V6B 5L5

Manitoba
Radiation Protection Section
Manitoba Cancer Treatment and Research Foundation
100 Olivia Street
Winnipeg, Manitoba
R3E 0V9

New Brunswick
Radiation Protection Services
Department of Health and Community Services
Government of New Brunswick
P.O. Box 5100
348 King Street
Fredericton, New Brunswick
E3B 5G8

Newfoundland
Medical and Hygiene Services
Employment and Labour Relations
Government of Newfoundland
Beothuck Building
P.O. Box 8700
St. John's, Newfoundland
A1C 4J6

Northwest Territories
Occupational Health and Safety Division
Safety and Public Services
Government of the Northwest Territories
Box 1320
Yellowknife, Northwest Territories
X1A 2L9

Nova Scotia
Department of Health and Fitness
Government of Nova Scotia
7th Floor, Joseph Howe Building
P.O. Box 488
Halifax, Nova Scotia
B3J 2R8

Ontario
Radiation Protection Service
Ontario Ministry of Labour
81 Resources Road
Weston, Ontario
M9P 3T1

Prince Edward Island
Division of Community Hygiene
Department of Health and Social Services
Government of Prince Edward Island
P.O. Box 2000
Charlottetown, Prince Edward Island
C1A 7N8

Quebec
Division de la radioprotection
Ministère de l'environnement
Gouvernement du Québec
5199 est, rue Sherbrooke
Montréal (Québec)
H1T 3X9

Saskatchewan
Radiation Safety Unit
Department of Human Resources,
Labour and Employment
Government of Saskatchewan
1870 Albert Place
Regina, Saskatchewan
S4P 3V7

Yukon Territory
Occupational Health and Safety
Government of the Yukon Territory
P.O. Box 2703
Whitehorse, Yukon Territory
Y1A 2C6

Appendix V
Radiation Measurement Units - International (SI) System

Exposure

The unit of COULOMB/KILOGRAM (C/kg) has not found acceptance as the replacement of the ROENTGEN (R) as a unit of irradiation. Following the lead of the International Electrotechnical Commission, the AIR KERMA (in GRAYS) replaces the EXPOSURE (in ROENTGENS) as the measure of irradiation. The relationship between the two units is as follows:

1 Gy	~	114.55 R	1 R	~	8.73 mGy
1 mGy	~	114.55 mR	1 mR	~	8.73 μGy

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 rad	=	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

Note: m = milli = 10^{-3}; μ = micro = 10^{-6}

Bibliography

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

1. "1990 Recommendations of the International Commission on Radiological Protection." *ICRP Publication 60*, *Annals of the ICRP*, 21, 1-3 (1991).

2. "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).

3. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation." *National Academy of Sciences, National Research Council, Washington, D.C.* (1972).

4. "Radiation Quantities and Units." *International Commission on Radiation Units and Measurements, ICRU Publication 33* (1980).