NCRP REPORT No. 148

RADIATION PROTECTION IN VETERINARY MEDICINE

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National Council on Radiation Protection and Measurements

NCRP REPORT No. 148

Radiation Protection in Veterinary Medicine

Recommendations of the
NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

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Preface

This Report was developed under the auspices of Program Area Committee 2 of the National Council on Radiation Protection and Measurements (NCRP), the committee concerned with operational radiation safety. The Report provides radiation protection guidance for the use of ionizing and nonionizing radiation in veterinary practice, including advice on shielding design for veterinary ionizing radiation facilities. It supersedes NCRP Report No. 36, *Radiation Protection in Veterinary Medicine*, which was issued in August 1970.

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Thomas S. Tenforde
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Contents

1. Summary

This Report is concerned with the protection of individuals who may be exposed to radiation emitted by x-ray equipment and both sealed and unsealed radioactive sources in the practice of veterinary medicine. To the extent that the animal patient exposure is reduced, there is usually a proportional decrease in the occupational exposure to personnel.

The Report provides guidance for the development of an effective radiation safety program and recommendations for the design of radiological facilities and for the use of radiographic, fluoroscopic and therapeutic equipment in veterinary medicine. Included are recommendations for the use of radiopharmaceuticals in diagnosis and therapy, and for the use of lasers and ultrasonic equipment.

The National Council on Radiation Protection and Measurements (NCRP) provided recommendations for the limitation of exposure to ionizing radiation in Report No. 116 (NCRP, 1993). These recommendations are designed to achieve the objectives of radiation protection: (1) to prevent the occurrence of clinically significant acute radiation damage, and (2) to limit the risk of stochastic effects such as cancer and genetic effects. Radiation exposure to individuals from external radiation sources may be controlled and limited by any one or any combination of the following measures: (1) increasing the distance of the individual from the source (distance), (2) reducing the duration of exposure (time), and (3) using protective barriers between the individual and the source (shielding). For x- and gamma-ray equipment used by veterinarians, shielding and distance are the factors most readily controlled. Exposure to dispersed radioactive material from unsealed sources can be controlled and limited by using precautions in the handling of these materials.

Although x-ray machines are widely used in veterinary medicine, the workload, and thus the potential exposure of both the practitioner and the technical assistants is, on the average, low. However, because practices such as restraining animals and holding film cassettes introduce risks of unnecessary exposure of staff, special attention is given in this Report to proper practices.

Radiation safety program requirements are specified in Section 3. In summary, this radiation safety program *should* be commensurate with the hazards to personnel and to the general

public, *should* be well documented, and *should* be reviewed on a regular basis to determine whether it continues to meet the operational needs and is effective. All veterinary personnel *shall* receive training in radiation safety commensurate with the individual's anticipated risk from radiation exposure. Individual monitoring will be required for some staff. However, when the number of staff is small, it is reasonable to provide individual monitoring for all employees. It is not likely that the potential for exposure to dispersed radioactive material will be sufficient to require a bioassay program to assess internal exposure. However, at veterinary facilities where ^{131}I is used for radiation therapy, consideration *should* be given to instituting periodic thyroid counting of potentially exposed persons.

Surveys to evaluate the radiation safety characteristics of x-ray machines and gamma-ray irradiators are necessary and are especially required for all new installations. Radiation safety surveys *shall* be made when radioactive materials are administered to animals. Although unlikely to be necessary, air sampling *should* be performed when appropriate to determine whether individuals caring for the animals are subjected to airborne contamination and whether bioassay is indicated.

Warning signs, including instructions written in "plain" and unambiguous language, *shall* be used for radioactive material containers, radiation-producing devices, animal cages and pens, stalls, laboratories, and other areas in which radioactive materials or radiation-producing devices are used or stored.

Recommendations for the design of facilities that use fixed and portable radiographic and fluoroscopic equipment, therapy equipment, and radionuclides are detailed in Section 4. For radiographic and fluoroscopic facilities, the required shielding barriers *should* be an integral part of the building or permanently affixed to the equipment. In the event that movable or portable barriers are required due to multiple uses of the room or mobile applications, the operators *shall* receive specific training in the placement of the shields.

Structural shielding design for x- and gamma-ray equipment used for therapy and operating at energies up to 10 MeV is approached in a somewhat different way than the design for diagnostic x-ray equipment, although the same basic model is used. Leaded wallboard can be used to shield interior walls of diagnostic radiographic and therapy facilities operating at $\leq$150 kVp. For x-ray therapy facilities with operating potentials >150 kVp and for gamma-ray facilities, poured or precast concrete is generally the preferred shielding material. Under some circumstances lead and steel can also be used.

The models used to determine shielding requirements are discussed in Section 4. The basic concepts and terminology used in the design of shielding barriers include the *shielding design goals*, the *workload* for the x-ray unit, the *distances* to the areas to be shielded, *occupancy factors* for the areas to be shielded, and the *use factor*. These quantities are defined in the Glossary and examples of their use are given in Appendices A and B.

The selection of shielding design goals is based on the recommendations of NCRP (2004) for controlled and uncontrolled areas. It is clear that implementation of the shielding design goals requires that the management of each facility evaluate the use of its space relative to exposure of its employees and members of the public. A discussion on shielding design goals is presented in Section 4.1.5.1.

For diagnostic facilities, shielding requirements for barriers are given in Appendix A of this Report for lead, gypsum wallboard, and concrete. Typical workloads and operating potentials for veterinary facilities indicate that primary barriers would rarely exceed 3.2 mm (1/8 inch) of lead for both controlled areas and uncontrolled areas. For therapy facilities, shielding requirements for barriers are given in Appendix B of this Report for lead, steel and concrete.

Recommendations for the design features for facilities in which the handling and administration of unsealed radioactive materials take place are based on those unique aspects of the radioactive materials that will be used. Design considerations include preventing or facilitating the removal of contamination, minimizing exposure, preventing airborne and sanitary sewer contamination, and providing for safe and effective radioactive waste disposal.

When animals receive high administered activities of gamma-ray-emitting radionuclides, such as radioiodine for treatment of thyroid cancer, facility walls *should* be shielded to control radiation levels in surrounding occupied areas. In some instances, it would be acceptable to use mobile shields positioned close to the animals or their holding cells to protect areas of concern.

Individuals who handle radioactive materials for administration to animals *shall* be protected from unnecessary exposure. Shields shaped like an "L," with a lead base and a lead wall between the source and the radiation worker, can provide substantial reduction of potential doses to the worker and specific shields are indicated for syringes used to inject radioactive materials.

Almost all radionuclides used in veterinary practice have a half-life <120 d and lend themselves to decay-in-storage as an effective and safe method of disposal. However, waste radionuclides with half-lives >120 d might have to be processed for transfer to a

commercial disposal facility. Radioactive animal carcasses present a special problem as radioactive waste because there is not a shallow land disposal facility that will accept them. For disposal at a licensed radioactive waste disposal facility, animal carcasses are first incinerated at a licensed facility that has the capability of retrieving the radionuclides in ash and processing the ash in a manner that makes it acceptable for shallow land disposal. For those carcasses that can be processed *via* decay-in-storage, the carcasses can be disposed in the manner used for nonradioactive carcasses. However, steps *shall* be taken to ensure that animals used in radionuclide experiments are not subsequently consumed by human beings.

A qualified expert (see Glossary) *shall* evaluate the shielding and radiation safety requirements of any new or modified installation (*i.e.*, room redesigns or changes in shielding configurations) prior to the use of the facility (NCRP, 2004). The evaluation will normally involve direct measurements of the radiation transmitted through each of the shielding barriers. The measurement results *shall* be used to confirm that the shielding design goals have not been exceeded and therefore the respective annual values for effective dose recommended for controlled and uncontrolled areas (NCRP, 2004) have not been exceeded. Visual inspection during construction is important to verify that the specified type and thickness of shielding material and the safety systems are properly installed.

Sections 5, 6 and 7 present details of the design, performance and operation of radiographic [including computed tomography (CT)] (Section 5), fluoroscopic (Section 6), and radiotherapy equipment (including brachytherapy sources) (Section 7), that relate to radiation safety and the protection of staff and visitors. Quality-assurance procedures for radiographic applications (*i.e.*, x-ray equipment used for imaging) are given in Appendix C.

Section 8 covers radiation safety considerations, emergency response, and waste disposal related to the use of radiopharmaceuticals. Radiation safety includes exposure and contamination control, shielding and monitoring of personnel. Quality-control procedures for nuclear medicine components are given in Appendix C. The appropriate steps to control an emergency involving the release of radioactive materials are discussed. Section 8.3 on waste disposal includes a discussion of the types of waste that will be generated and their appropriate disposal. Also, recommendations are given for the use of radiopharmaceuticals in animals, and guidelines for an owner after treatment of an animal with radioiodine therapy are given in Appendix D.

Section 9 covers the nonionizing radiation safety and other associated safety concerns related to the use of lasers and ultrasound in veterinary medicine. For lasers, this includes eye damage and skin burns as well as electrical, fire and hazardous material precautions. With respect to ultrasound, both thermal and nonthermal biological effects are briefly discussed. Considerations are presented for the reasonable use of ultrasound for diagnostic and therapeutic purposes.

2. Introduction

2.1 Scope

The reasons for using radiation in veterinary medicine are to either obtain optimum diagnostic information or to achieve a specific therapeutic effect while maintaining the radiation dose to the radiological personnel and the general public as low as reasonably achievable (the ALARA principle).[1] Similarly, it is also important to avoid all unnecessary irradiation of the animal patient.

This Report is concerned with the protection of individuals who may be exposed to radiation emitted by x-ray equipment and both sealed and unsealed radioactive sources in the practice of veterinary medicine. To the extent that the animal patient exposure is reduced, there is usually a proportional decrease in the occupational exposure to personnel.

2.2 Purpose

The purpose of this Report is to provide guidance for the development of an effective radiation safety program and to offer recommendations for the design of radiological facilities and for the use of radiographic, fluoroscopic and therapeutic equipment in veterinary medicine. Included are recommendations for the use of radiopharmaceuticals in diagnosis and therapy, and for the use of ultrasonic equipment and lasers. The recommendations are not meant to preclude alternative methods of achieving the radiation protection objectives.

It is recognized that blind adherence to rules cannot substitute for the exercise of sound judgment, therefore these recommendations may well be modified in unusual circumstances upon the advice of qualified experts with recognized competence in radiation protection.

[1]An acronym referring to one principle of the system of radiation protection (*i.e.*, the recommendation to keep all radiation exposures as low as reasonably achievable, economic and social factors being taken into account) (NCRP, 1993).

Terms used in this Report are defined in the Glossary. Since, however, recommendations throughout this Report are expressed in terms of "*shall*" and "*should,*" these terms are defined here.

- *Shall* indicates a recommendation that is necessary or essential to meet the currently accepted standards of protection.
- *Should* indicates an advisory recommendation that is to be applied when practicable.

2.3 Limiting the Exposure of Individuals

NCRP provided recommendations for the limitation of exposure to human beings from ionizing radiation in Report No. 116 (NCRP, 1993). These recommendations are designed to achieve the objectives of radiation protection: (1) to prevent the occurrence of clinically significant acute radiation damage, and (2) to limit the risk of stochastic effects such as cancer and genetic effects. The recommendations given in Table 2.1 include annual dose limits for occupational exposure and for exposure of the public, and exclude radiation dose received by an individual as a patient or the dose from natural background radiation.

The risk to individuals exposed to radiation within these recommended limits is considered to be very small; however, risk increases gradually with the dose received. For this reason, NCRP recommends application of the ALARA principle for all exposures. It must be understood that the dose limit represents the upper limit of acceptability. However, the exposure of an individual to a dose slightly exceeding the limit is not likely to cause injury.

Radiation exposure to individuals from external radiation sources may be controlled and limited by any one or any combination of the following measures: (1) increasing the distance of the individual from the source (distance), (2) reducing the duration of exposure (time), and (3) using protective barriers between the individual and the source (shielding). For x- and gamma-ray equipment used by veterinarians, shielding and distance are the factors most readily controlled. Shielding may be a protective barrier incorporated into equipment; it may also consist of mobile or temporary devices used as the occasion demands, such as movable screens, or lead-impregnated aprons and gloves; or it may comprise permanent protective barriers and structural shielding such as walls containing lead, concrete or other materials in thickness sufficient to provide the required degree of attenuation. Additional details on

TABLE 2.1—*Summary of recommendations for ionizing radiation*[a,b] *(NCRP, 1993).*

Occupational exposure	
Effective dose limits	
Annual	50 mSv
Cumulative	10 mSv × age
Public exposure (annual)	
Effective dose limit, continuous or frequent exposure	1 mSv
Effective dose limit, infrequent exposure	5 mSv
Embryo or fetus exposures (monthly)[c]	
Equivalent dose limit for the embryo or fetus	0.5 mSv
Negligible individual dose (annual)[d]	
Effective dose	0.01 mSv

[a]All dose limits exclude medical exposures and exposures to natural sources.
[b]Sum of external and internal exposures.
[c]Due to occupational exposure of a pregnant radiation worker.
[d]Per source or practice.

shielding are covered in Section 4, Appendices A and B, and in NCRP Report No. 147 (NCRP, 2004). Limiting the radiation field size to the requested image area will also reduce the amount of scattered radiation.

Exposure to dispersed radioactive material from unsealed sources can be controlled and limited by using precautions in the handling of these materials. Such precautions may include: (1) preventing contamination or facilitating its removal if it occurs, (2) minimizing exposure to unsealed radioactive material, (3) preventing airborne and sanitary sewer contamination, and (4) providing for safe and effective radioactive waste disposal. Contamination control may include the selection of special surface coatings in areas where unsealed sources are used. Control of airborne releases of material may require the installation of fume hoods, air filters, and controlled airflow animal cubicles. Additional details are covered in Section 4.

2.4 Factors Specifically Pertinent to Radiation Protection in Veterinary Medicine

Although x-ray machines are widely used in veterinary medicine, the workload and thus the potential exposure of both the practitioner and the technical assistants is, on the average, low. However, because practices such as restraining animals and holding film cassettes introduce risks of unnecessary exposure of staff, special attention is given in this Report to proper practices. Using good collimation and mechanical holding devices for grids and cassettes can reduce the exposure of staff, while preventing images of hands and fingers from appearing in animal radiographs due to direct exposure of the hands in the x-ray beam.

Pregnant women, and individuals under 18 y of age, *shall not* be permitted to hold animal patients or film cassettes during radiological examination or treatment. To the extent possible, mechanical restraints or anesthesia *should* be used so that no one has to hold the animal patient during radiographic imaging.

Fluoroscopy *should not* be used as a substitute for radiography, rather it is reserved for the study of dynamics and certain spatial relationships. Because of the higher potential exposure of individuals assisting in veterinary fluoroscopic examinations, particular attention *should* be given to the protection of such personnel during fluoroscopy.

Radiation therapy of animal patients and research animals *shall* be carried out only by, or under the direct authority of, veterinarians specifically and adequately trained in radiation oncology. Because of the higher exposures involved (up to, and sometimes >1,000 times those used in radiography), the potential hazards are greater and considerably more shielding will be required.

The use of unsealed radioactive sources such as ^{99m}Tc and ^{131}I for imaging studies and therapy in veterinary medicine is increasing. Many different radionuclides are used in research animals for biological studies and for the development of new radiopharmaceuticals. These procedures *shall* be performed only in facilities designed especially for their use and by individuals specifically trained in the proper use and handling of these materials.

Pet owners *shall* be informed when their animals have received radionuclides for imaging or therapy. They *shall* be instructed in the appropriate precautions to be taken to avoid unnecessary exposure, particularly of children (Appendix D).

3. Radiation Safety Program Requirements

3.1 General Elements of the Program

Every facility in which radiation-producing devices or radioactive materials are used *shall* have a radiation safety program. Prior to establishing a practice, the veterinary radiologist or veterinary radiation oncologist in charge or the facility management *shall*, with the help of a qualified expert, evaluate the potential radiation hazards and define the scope of the required radiation safety program. This program *should* be well documented and *should* be reviewed annually to determine if it continues to meet the operational needs and is effective. In addition, the program *shall* include consideration of the principles, practices and equipment (including quality-assurance procedures) necessary to maintain radiation exposures to facility personnel and the general public to levels that are consistent with the ALARA principle. The radiation safety program *shall* be in compliance with recommendations of NCRP and all pertinent federal, state and local regulations. The extent of the program *should* be commensurate with the hazards to personnel and to the general public, and to the size and extent of the practice. NCRP provided general guidance on the elements of such a program in NCRP Report No. 105, *Radiation Protection for Medical and Allied Health Personnel* (NCRP, 1989a) and Report No. 127, *Operational Radiation Safety Program* (NCRP, 1998). Specific recommendations for implementing ALARA in a medical setting are given in NCRP Report No. 107, *Implementation of the Principle of As Low As Reasonably Achievable (ALARA) for Medical and Dental Personnel* (NCRP, 1990). Although directed at facilities that are designed for human patients, the fundamentals and elements of radiological protection contained in these reports are applicable to the practice of radiology and radiation oncology in veterinary medicine.

A facility radiation safety officer (RSO) *shall* be designated to assume the responsibilities outlined below and to advise the veterinarian or facility management concerning radiation safety practices and regulations. In a private veterinary practice using radiation, the veterinary radiologist, veterinary radiation oncologist, or veterinarian knowledgeable in radiation safety practice

may function as the RSO and perform the duties normally performed by a radiation safety staff. The RSO *shall* have the appropriate education, training and experience required for the position and *shall* be familiar with the basic principles of radiation protection. Specific qualifications for the RSO vary depending on the type and complexity of the practice, but might include specific course work in radiation protection for medical applications of radiation sources and, for large complex practices, certification by a body such as the American Board of Health Physics, the American Board of Medical Physics, the American Board of Radiology, or the American College of Veterinary Radiology. General qualifications are provided in NCRP Report No. 127 (NCRP, 1998). In addition, the RSO *should* be expected to consult with qualified experts, as necessary, for advice on specific radiation protection practices.

The RSO *shall* have the complete support of facility management[2] and *shall* be given the responsibility and the authority to manage the radiation safety program. Facility management shall communicate its commitment to an effective radiation safety program to all personnel. In addition, facility management *shall* provide the RSO with the appropriate staff, equipment and funds required to conduct an effective program. In large practices, the activities of the RSO and radiation safety staff help ensure a safe work environment. However, all staff approved to handle radiation sources or operate x-ray units *shall* be personally responsible to conduct their activities in a safe manner.

In some cases, it may be appropriate to establish a radiation safety committee to provide oversight for the radiation safety program. This committee *should* be composed of individuals knowledgeable in the use of radiation and radioactive material handling. Meetings of the committee *shall* be scheduled on a routine frequency. The RSO *should* serve as an ex-officio member of the committee.

3.2 Radiation Safety Officer Responsibilities

Specific responsibilities of the RSO are:

- Establish written operating procedures for the facility. These procedures *should* be reviewed annually to ensure their effectiveness and their conformity with the recommendations of this Report and applicable regulations. The

[2]For small practices, the veterinarian in charge is considered to be the facility management.

procedures *should* also document the methods used to maintain radiation doses to workers and the public consistent with the ALARA principle.

- Oversee the conduct of the radiation safety program. For example, these activities may include radiation safety surveys, quality-assurance procedures, contamination surveys, source leak tests, proper posting of areas within the facility, routine testing of interlocks and warning devices, and provision of appropriate individual monitoring devices (see Section 3.4 for more details on individual monitoring).
- Ensure that personnel are instructed in proper radiation safety practices. Section 3.3 provides more detail on necessary training. NCRP has made specific recommendations on radiation safety training in NCRP Report No. 134, *Operational Radiation Safety Training* (NCRP, 2000). In addition, radiation safety training *shall* be in compliance with applicable federal, state and local regulations.
- Maintain records of the conduct of the radiation safety program. These include reviews of the radiation safety program, personnel exposure records, and results of radiation surveys, quality-assurance procedures, source leak tests, interlock tests, and warning device tests. Further recommendations about record keeping are found in NCRP Report No. 114, *Maintaining Radiation Protection Records* (NCRP, 1992).
- Appropriately report radiological incidents and determine the cause of each known or suspected case of abnormal exposure or intake of radioactive material. Recommend corrective actions to prevent recurrence.

3.3 Radiation Safety Training

NCRP has provided recent guidance on radiation safety training and the approaches to be taken (NCRP, 2000). In addition, the American College of Veterinary Medicine and the American Veterinary Medical Association have provided draft guidance on the extent of radiation safety training necessary for those involved in the use of radiation or radioactive materials in the practice of veterinary medicine (ACVR/AVMA, 1995). These documents *should* be consulted for detailed information on the training necessary. However, a general overview of the training requirements is given below.

- All personnel *shall* receive training in radiation safety. This training *should* be commensurate with the individual's

anticipated risk from radiation exposure. As a minimum, individuals *should* receive training on facility specific requirements, the physics of radiation safety, biological hazards of exposure, the pertinent regulations on radiation exposure, methods to keep exposures consistent with the ALARA principle, rights and responsibilities of each individual, proper use of personnel monitoring devices, response to warnings and alarms, specific hazards for women of childbearing age, and other subjects as deemed necessary by the RSO. Training *should* include formal instruction as well as practical demonstrations by the trainees of the skills necessary to perform their job responsibilities.

- The training program *should* incorporate provisions for training new employees (regardless of previous experience); employees given new job assignments; whenever new substances, processes or equipment are introduced; for new or previously unrecognized hazards; and for retraining all personnel periodically. In addition, all training *should* be carefully documented. Records of training *should* include the attendance list for each session, the name of the instructor, the length and subjects covered, the lesson plan, and the results of tests administered or the evaluation of practical demonstrations of skills. These records *shall* be part of the permanent radiation safety records.

3.4 Individual Monitoring

Individual monitoring devices are used to measure radiation exposure to personnel during the course of their work, to provide a check on the adequacy of the radiation safety program, to assist in keeping exposures consistent with the ALARA principle, to reveal improper radiation safety practices, and to detect potentially serious radiation exposure situations.

Individual monitoring *shall* be provided for those individuals likely to receive radiation exposures in excess of 10 percent of the applicable limits (NRC, 1999a), and *should* be considered for workers who are likely to receive an annual effective dose exceeding 1 mSv (NCRP, 1998). Visitors *should* be given individual dosimeters if they might receive an effective dose exceeding 0.25 mSv (NCRP, 1998). The RSO *should* make a determination of those individuals who are likely to be exposed at these levels and record such an evaluation in the radiation safety records. In many cases, when the number of staff is small, it is reasonable simply to provide

individual monitoring for all facility employees. The monitoring devices *shall* be selected, with the aid of a qualified expert, based on a clear understanding of the radiation(s) to which individuals may be exposed. The monitoring period *shall* be established by the RSO based on anticipated exposures and the characteristics of the devices selected.

Individual monitoring devices *shall* be issued and their use required as directed by the RSO. Instructions *shall* include proper wearing of the devices (*e.g.*, when wearing a protective apron), the monitoring period, proper storage of the devices when not in use, procedures for exchanging the devices, and other instructions deemed necessary by the RSO. In some cases, it will be appropriate for the RSO to consult a qualified expert to assist in establishing and evaluating the individual monitoring program.

The RSO, in consultation with a qualified expert, *shall* determine the need for a bioassay program to assess internal exposure. When radioactive iodine is used for radiation therapy, the RSO *should* institute, and oversee, periodic thyroid counting of potentially exposed persons.

3.5 Radiation Safety Surveys

As used in this Report, a radiation safety survey (or radiation survey) means an evaluation of potential radiation exposure. An exposure can result from the use of x-ray equipment, or sealed sources of radioactive material under specific conditions, or unsealed radioactive material. When appropriate, such an evaluation includes inspection of the x-ray equipment or sealed sources of radioactive material, examination of its location with reference to controlled and uncontrolled areas, and measurements of exposure levels arising from operation of the equipment or use of the radioactive material. In the case of unsealed radioactive material, an evaluation may also include measurements to assess dispersed material or contaminated surfaces. Radiation surveys, with appropriate instruments (NCRP, 1966; 1982), are a necessary part of the radiation safety program.

Surveys to evaluate the radiation safety characteristics of x-ray machines and gamma-ray irradiators *shall* be performed as specified by regulation, procedure or as deemed necessary by the RSO. A radiation survey *shall* be required for all new installations and after relocating portable x-ray machines. Resurveys *shall* be made following replacement of irradiation equipment, or modifications that could change the radiation source, whenever the workload

increases significantly, or if other operating conditions are modified that could affect the radiation dose in occupied areas. Resurveys are required after the installation of supplementary shielding to determine the adequacy of the modification.

Measurements to evaluate the adequacy of primary or secondary barriers for x- or gamma-ray equipment *should* be made with a phantom intercepting the useful beam. The exposure *should* be made with the largest field size used clinically and with the current, voltage, and other operating conditions the same as in an actual exposure.

Radiation surveys *shall* be made when radioactive materials are administered to animals. Such surveys *should* be made immediately after administration and periodically thereafter, until the radioactive material has decayed completely or the radioactive material has been removed from the use area. After administration, radiation and contamination levels will change because of radioactive decay, biodistribution, and biological elimination of the material. Surveys *should* consist of the measurement of radiation levels and the extent of contamination. In addition, anyone providing care for or coming into contact with the animals *should* be surveyed before leaving the area. Often, contamination surveying can be done by taking a representative wipe of an area with a filter paper and checking the filter paper with a survey meter to determine if it picked up transferable contamination. Due to background radiation levels from the animal or excreta, the swipe sample may have to be taken to a low background area to get an appropriate reading with the survey meter. Where appropriate, air sampling *should* also be performed to determine if individuals caring for the animals are subjected to airborne contamination and if bioassay is indicated.

3.6 Posting

Individuals *shall* be warned of areas containing radiation sources through appropriate signs, labels or other warning systems. Warning signs *shall* be used for radioactive material containers, radiation-producing devices, animal cages and pens, laboratories, and other areas in which radioactive materials or radiation-producing devices are used or stored. Radiation caution signs vary in shape and size, but they all contain the recognized magenta (or black) radiation symbol on a yellow background (ANSI, 2002). Instructions written on warning signs *shall* be in "plain" and unambiguous language. In certain areas where the

radiation level might exceed 1 mGy (air kerma) in any 1 h, additional warning and protective devices such as lights, bells or interlocks *should* be installed to prevent inadvertent entrance. Specific guidelines for providing warning and access control can be found in NCRP Report No. 88 (NCRP, 1987a) and Report No. 127 (NCRP, 1998). Employees who have occasion to enter such areas *shall* be given appropriate safety instruction and training.

3.7 Use of Veterinary Radiation Devices or Sources on Human Beings

The use of veterinary diagnostic or therapeutic radiation devices or radiation sources on human beings is not permitted. Veterinarians *shall not* allow such devices or sources under their control to be used on human beings.

4. Facility Design

4.1 Shielding for Radiation-Producing Devices

4.1.1 *Planning*

A comprehensive discussion of the design of structural shielding for medical x-ray imaging facilities (*i.e.*, radiographic and fluoroscopic systems) is found in NCRP Report No. 147, *Structural Shielding Design for Medical X-Ray Imaging Facilities* (NCRP, 2004). Although it is directed at facilities that are designed for human patients, the fundamentals and elements of shielding planning and design in Sections 2 and 3 of that Report are relevant to the design of veterinary x-ray facilities.

Structural shielding design for therapy facilities is discussed in NCRP Report No. 49, *Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up to 10 MeV* (NCRP, 1976). An NCRP report that will update the parts of NCRP (1976) that address structural shielding design for megavoltage radiotherapy facilities using x and gamma rays is in preparation. The recommendations presented in this Report for shielding of therapy equipment are taken from NCRP Report No. 49 (NCRP, 1976).

In the design and evaluation of veterinary x-ray installations, possible future increases in the workload, and in the use and occupancy factors *should* be considered. Practitioners may find it less expensive to somewhat overbuild initially rather than remodel when workload or higher capacity equipment results in a requirement for additional shielding.

The required barriers *should* be an integral part of the building or permanently affixed to the equipment. In the event that movable or portable barriers are required due to multiple uses of the room or mobile applications, the operators *shall* receive specific training in the placement of the shields. Painting positioning marks on the floor may be of help in consistently placing the barriers.

Qualified experts *shall* be consulted in shielding design and analysis. State or local regulatory authorities *should* be consulted regarding requirements for shielding design and approval.

The basic model for determining the required thickness of shielding for radiation protection is (NCRP, 1976):

$$\frac{1}{B} = \frac{W\,U\,T}{Pd^2} \tag{4.1}$$

where:

B = allowed *transmission factor*
W = *workload*
U = *use factor*
T = *occupancy factor*
P = *shielding design goal*
d = *distance* from the source to the point to be shielded

As stated in NCRP (2004), the shielding and radiation safety requirements of any new or modified (room redesigns or changes in shielding configurations) installation *shall* be evaluated by a qualified expert prior to the use of the facility. The qualified expert will require the available information about the type of x- or gamma-ray equipment to be installed, the operating potential or operating energy, the contemplated use, the expected workload, the expected use factors, the structural details of the building, and the type of occupancy of all areas that might be impacted by the operation of the radiation-producing equipment. The qualified expert *shall* approve final plans, detailed drawings, and all pertinent specifications before construction begins. Special attention *should* be given to the safety requirements of areas outside of controlled areas.

In an x- or gamma-ray facility, the radiation field consists of *primary* and *secondary* radiation. The primary radiation, sometimes referred to as the useful beam, is radiation emitted directly from the x-ray tube or source and is used for imaging or treatment. Secondary radiation consists of the x- or gamma-rays scattered from the patient and other objects, and radiation that leaks through the shielding in the protective housing surrounding the x-ray tube, accelerator target, or gamma-ray source.

Exposure of individuals to both primary and secondary radiation can be reduced by increasing the *distance* between the individual and the source of radiation, by limiting the *exposure time*, and by interposing *shielding* between the individual and the source of radiation.

The useful beam can be directed at occupied areas provided there is adequate shielding of the primary radiation. However, arranging the installation so that the useful beam is directed only toward unoccupied areas would allow occupied areas to be shielded only for secondary radiation. This may reduce the cost of shielding significantly. Shielding requirements may be reduced also by locating the installation at a greater distance from occupied areas.

If there is more than one radiation source in the facility, it may be possible for an occupied area to receive radiation from more than a single source. This *shall* be taken into consideration in the design of the shielding.

Special attention *should* be given to the protection of areas used for the storage of undeveloped film and of rooms in which low-activity radioactive materials are measured. It is recommended that radiographic film stored in darkrooms *should not* be exposed to an air kerma (see Glossary) >0.1 mGy during the period it is in storage (NCRP, 2004). In addition, film stored in cassettes with intensifying screens should be stored so that the optical density of the base-plus-fog will not be increased by >0.05. A maximum air kerma of 0.5 μGy is recommended for loaded cassettes during the storage period (NCRP, 2004).

4.1.2 *Diagnostic X-Ray Facilities*

4.1.2.1 *Fixed Installations*. A general purpose radiographic system produces brief exposures that are normally made with the x-ray beam directed downwards. However, the x-ray tube can usually be rotated so that it is possible for the x-ray beam to be directed toward a wall or ceiling. Shielding barriers that can be directly irradiated by the primary or useful beams are considered *primary barriers*. In the design and evaluation of fixed x-ray installations, possible future increases in the workload, and in the use and occupancy factors *should* be considered. The required primary barriers *shall* be an integral part of the building or permanently affixed to the equipment.

4.1.2.2 *Portable Equipment*. For portable x-ray units, the recommendations pertaining to radiography with fixed diagnostic equipment apply, except that:

- Permanent protective barriers are not required. However it is the operator's responsibility to keep all personnel, handlers and animal owners away from the primary beam. Portable shields *shall* be provided or protective clothing (such as lead aprons) *shall* be worn.
- The operator *shall* stand at least 1.8 m (~6 feet) from the patient, the x-ray tube and the useful beam.
- A device such as a light localizer to delineate the cross section of the useful beam and a collimation device to restrict the beam to the proper x-ray field size *shall* be used.

- The exposure control switch *shall* be of the "dead-man" type (see definition in Glossary) and arranged so that the operator may stand at least 1.8 m (~6 feet) from the x-ray tube housing and well away from the useful beam.

4.1.2.3 *Fluoroscopic Installations*. Ordinarily fluoroscopic installations require only secondary barriers because the primary beam is almost completely absorbed in the image receptor. For combined fluoroscopic and radiographic installations, the barriers are governed by the requirements for radiographic units.

4.1.3 *Therapy Facilities*

X-ray therapy devices can be either x-ray units with operating potentials up to 300 kVp at currents low enough to permit continuous operation, or they can be electron linear accelerators operating in the energy region from about 4 to 20 MeV. Gamma-ray therapy devices are typically ^{60}Co irradiators. Caution is advised when selecting a linear accelerator for radiation therapy. If the highest energy x-ray beam exceeds 10 MeV, neutron radiation will be present at an intensity that will require consideration for radiation protection. This Report does not discuss the shielding and other protection issues associated with neutron radiation.

Structural shielding design for x- and gamma-ray therapy equipment operating at energies up to 10 MeV is approached in a somewhat different way than the design for diagnostic x-ray equipment, although the same basic model is used. Although NCRP Report No. 49 (NCRP, 1976) is directed at facilities that are designed for human patients, the fundamentals and elements of shielding planning and design presented in that report are relevant to the design of veterinary therapy facilities.

The control station for therapy equipment operating >150 kVp *shall* be outside of the therapy area and behind a protective barrier.

4.1.4 *Shielding Materials*

Leaded[3] wallboard can be used to shield interior walls of diagnostic x-ray facilities and x-ray therapy facilities operating below 150 kVp. Nails or screws used to install the wallboard do not compromise the shielding and need not be covered by supplementary lead (NCRP, 2004). However, where the edges of two lead sheets

[3]Users should note that lead is a toxic material and it must be disposed of as a hazardous waste.

meet, the continuity of the shielding *shall* be ensured at the joint. NCRP Report No. 147, Section 2 (NCRP, 2004) gives additional construction details.

Gypsum wallboard alone provides relatively little shielding, however, it may be sufficient for secondary radiation barriers in certain cases. Concrete block, brick and tile used for interior walls may provide sufficient shielding. Voids in these materials may compromise the shielding, in which case they *shall* be filled. The qualified expert *should* review the shielding requirements and the interior wall design with the architect during the facility design.

Poured or precast concrete is generally the preferred shielding material for therapy facilities operating at x-ray energies >150 kVp and for gamma-ray facilities. Under some circumstances, lead and steel can also be used.

Exterior walls can be constructed using a large variety of materials with very different shielding properties. Typical concrete or brick walls may provide sufficient shielding. However, the qualified expert *should* review the shielding requirements and the exterior wall design with the architect during the facility design.

Doors and door frames, windows and window frames *shall* provide the same x-ray attenuation as that required for the walls in which they are installed. This may require lining the door and the frames with lead and using leaded glass or lead acrylic for the windows. Windows are not recommended for use in accelerator therapy facilities operating at energies of 4 MeV and above. Visual contact with the patient *shall* be maintained with closed circuit television. Additional details concerning construction materials and techniques are discussed by NCRP (1976; 2004).

4.1.5 *Determination of Shielding Requirements*

The basic concepts and terminology used in the determination of shield barrier design include the *shielding design goal*, the *workload* for the x-ray unit, the *distances* to the areas to be shielded, *occupancy factors* for the areas to be shielded, and the *use factor*. A discussion of each of these quantities and some considerations related to their use can be found in NCRP Report No. 147 (NCRP, 2004).

4.1.5.1 *Shielding Design Goals*. Shielding design goals (P) are levels of air kerma used in the design calculations and evaluation of barriers constructed for the protection of workers or the public. The approach for structural shielding design for veterinary facilities that use radiation-producing equipment or sources and the

relationship between shielding design goals and NCRP recommended effective dose limits for workers and the public, as they apply to controlled and uncontrolled areas in the design of new facilities, is discussed below. There are different shielding design goals for controlled and uncontrolled areas.

The recommended quantity for shielding design calculations for low linear-energy-transfer (LET) radiation (x rays, gamma rays, electrons) is *air kerma* (NCRP, 2004) (see Glossary). This is the case for veterinary radiation equipment or sources with energies up to 10 MeV.[4] However, many radiation survey instruments in the United States are currently designed and calibrated to measure the quantity exposure, using the previous unit roentgen. For the direct measurement of radiation protection quantities discussed in this Report for low-LET radiation, the result from an instrument calibrated for exposure in roentgen (R) may be divided by 114 to obtain air kerma in gray (Gy).

The recommended radiation protection quantity for the limitation of exposure to people from sources of ionizing radiation is *effective dose*, defined as the sum of the weighted equivalent doses to specific organs or tissues (*i.e.*, each equivalent dose is weighted by the corresponding tissue weighting factor for the organ or tissue) (NCRP, 1993). The value of the tissue weighting factor for a particular organ or tissue represents the fraction of detriment (*i.e.*, from cancer and hereditary effects) attributed to that organ or tissue when the whole body is irradiated uniformly. The *equivalent dose* to a specific organ or tissue is obtained by weighting the mean absorbed dose in a tissue or organ by a radiation weighting factor to allow for the relative biological effectiveness of the ionizing radiation or radiations of interest. For low-LET radiation, the radiation weighting factor is assigned the value of one. For high-LET radiation, it depends on the LET of the radiation (NCRP, 1993).

The relationship of effective dose to incident air kerma is complex, and depends on the attenuation of the ionizing radiation in the body in penetrating to the radiosensitive organs and hence on the energy of the radiation, and also on the posture of the exposed individual with respect to the source. Rotational exposure *should*

[4]The recommended quantity for shielding design calculations when high-LET (*e.g.*, neutrons) as well as low-LET radiations are present is the dose equivalent (see Glossary). This is the case for veterinary therapy equipment such as linear accelerators operating at energies >10 MeV. Shielding for such equipment is the subject of an upcoming NCRP report, and will not be discussed in this Report.

be assumed, since it is probable that an individual is moving about and would not be exposed from one direction only. It is not practical to base shielding design directly on effective dose, since effective dose cannot be measured directly. Therefore, the shielding design goals for low-LET radiation are stated in terms of air kerma (in milligray) at the point of nearest occupancy beyond the protective barrier. For example, the distance to the occupied area beyond a wall bounding a room with ionizing radiation equipment can be assumed to be not <0.3 m.

A *controlled area* is a limited-access area in which the occupational exposure of personnel to radiation is under the supervision of an individual in charge of radiation protection. This implies that access, occupancy and working conditions are controlled for radiation protection purposes. In veterinary facilities, these areas are usually in the immediate areas where diagnostic or therapeutic equipment is used, such as x-ray procedure rooms and x-ray control booths or other areas that require control of access, occupancy and working conditions for radiation protection purposes. The workers in these areas are primarily veterinarians and technicians who are specifically trained in the use of ionizing radiation and whose radiation exposure is usually individually monitored.

Uncontrolled areas for radiation protection purposes are all other areas in the veterinary facility and the surrounding environs. Note that many areas near controlled areas, such as film-reading rooms or rest rooms, are frequented by trained personnel and other workers, as well as members of the general public. These areas are treated as uncontrolled in this Report. The choice of appropriate occupancy factors ensures the protection of those who are occupationally exposed as well as others that might be exposed in these areas.

Shielding design goals (P) are practical values, for a single veterinary radiation source or set of sources, that are evaluated at a reference point beyond a protective barrier. When used in conjunction with the conservatively safe assumptions recommended in NCRP (2004) (as applied to veterinary radiation sources later in this Section), the shielding design goals will ensure that the respective annual values for effective dose recommended for controlled and uncontrolled areas (NCRP, 2004) are not exceeded. Shielding design goals are expressed as weekly values since the workload for veterinary radiation sources has traditionally utilized a weekly format.

4.1.5.1.1 *Shielding design goal for controlled areas*. The employees who work in controlled areas have significant potential for

exposure to radiation in the course of their assignments or are directly responsible for or involved with the use and control of radiation. They generally have training in radiation management and are subject to routine individual monitoring.

NCRP (1993) recommended that for design of new facilities, the effective dose *should* be <10 mSv y^{-1} and NCRP (2004) recommended an annual effective dose of 5 mSv for controlled areas, with an annual value for the shielding design goal of 5 mGy air kerma. To achieve this, NCRP (2004) recommended a weekly shielding design goal of 0.1 mGy (air kerma) (*i.e.*, an annual air kerma value of 5 mGy) for controlled areas. Another consideration is that a pregnant radiation worker *should not* be exposed to levels that result in greater than the monthly equivalent dose limit of 0.5 mSv to the worker's embryo or fetus (NCRP, 1993). The *P* value adopted in NCRP (2004) would also allow pregnant radiation workers continued access to their work areas.

Recommendation for controlled areas—
Shielding design goal (*P*) (air kerma):
0.1 mGy per week (5 mGy y^{-1})

4.1.5.1.2 *Shielding design goal for uncontrolled areas*. Uncontrolled areas are those occupied either by employees who do not work routinely with or around radiation sources, by visitors to the facility such as animal owners, delivery service representatives and consultants, or by occupants of areas adjacent to but not part of the veterinary facility.

NCRP (2004) concluded that a suitable source control for shielding individuals in uncontrolled areas in or near medical radiation facilities is an effective dose of 1 mSv in any year. This Report concludes that the same source control for uncontrolled areas is applicable to veterinary medicine radiation facilities. This recommendation can be achieved for the veterinary radiation facilities covered in this Report with a weekly shielding design goal of 0.02 mGy (air kerma) (*i.e.*, an annual air kerma value of 1 mGy) for uncontrolled areas (NCRP, 2004).

Recommendation for uncontrolled areas—
Shielding design goal (*P*) (air kerma):
0.02 mGy per week (1 mGy y^{-1})

4.1.5.1.3 *Shielding design assumptions*. A veterinary radiation facility utilizing the *P* values given above would produce annual

effective doses lower than NCRP (2004) recommendations for effective dose for controlled and uncontrolled areas. This is the result of the conservatively safe nature of the shielding design methodology recommended by NCRP (2004). Several examples of this conservatism are given below, and the general impact of each is covered in NCRP Report No. 147 (NCRP, 2004).

- The significant attenuation of the primary beam by the animal patient in veterinary x-ray imaging is neglected (significant attenuation may not apply to small animals).
- The calculations of recommended primary barrier thickness always assume perpendicular incidence of the radiation.
- The shielding design calculation ignores the presence of materials (*e.g.*, lead aprons, equipment cabinets) in the path of the radiation for veterinary x-ray imaging other than the specified shielding material.
- The leakage radiation from veterinary x-ray imaging equipment is assumed to be at the maximum allowable value. For example, the federal performance standard for leakage radiation at the leakage radiation technique factors for a diagnostic x-ray tube is 0.876 mGy air kerma (100 mR exposure) in 1 h (FDA, 2004a), although in practice the leakage radiation is much less than this value. Leakage radiation for accelerators is assumed to be 0.2 percent of the primary beam absorbed dose rate at 1 m from the source (CRCPD, 1999; NCRP, 1989b), but is usually less (Section 7.3.1).
- The field size and phantom used for scattered radiation calculations yield conservatively high values of scattered radiation.
- The recommended occupancy factors for uncontrolled areas are conservatively high. For example, very few people spend 100 percent of their time in their office.
- Lead shielding (and steel, precast concrete, and concrete block) is fabricated in sheets of specific standard thickness. If shielding calculations require a value greater than a standard thickness, the next available greater standard thickness will typically be specified.
- The minimum distance to the occupied area from a shielded wall is assumed to be 0.3 m. This is typically a conservatively safe estimate for most walls and especially for doors.

A new facility can be designed using the methodology recommended in this Report without a significant increase in the cost or amount of structural shielding previously required.

The shielding design goals (P values) in this document apply only to new facilities and new construction and will not require retrofitting of existing facilities. These recommendations are intended for use in planning and designing new facilities and in remodeling existing facilities.

Facilities designed before the publication of NCRP (2004) and meeting the requirements of NCRP Report No. 49 (NCRP, 1976) need not be re-evaluated (NCRP, 1993). The recommendations in this Report apply only to veterinary facilities designed after the date of this publication.

4.1.5.2 *Workload*. The workload (W) for a diagnostic x-ray unit is the time integral of the tube current over a specified period and is conventionally given in units of milliampere minutes (mA min). The most common period of time over which the workload is specified is one week. However, it can also be specified per patient.

For medical diagnosis of human patients, typical radiographic and fluoroscopic x-ray units are operated over a wide range of values of kilovolt peak (kVp). The workload distributions presented in Section 4.1.4 of NCRP Report No. 147 (NCRP, 2004) and used to determine shielding requirements may not be applicable for veterinary facilities. Consequently, the shielding recommendations given in Appendix A are specified in terms of the quantity WUT/Pd^2 (see Equation 4.1). The veterinary radiologist and qualified expert *shall* specify appropriate values of W to be used in the shielding design.

The workload for radiation therapy units is typically specified as the absorbed dose delivered at a designated distance, typically 1 m (meter), from the x-ray target or the gamma-ray source. The most common period of time over which the workload is specified is one week.

4.1.5.3 *Distance*. The distance (d) is measured from the x-ray target or gamma-ray source to a point in the occupied area for which the shielding design goal is specified. The point in the occupied area *should* be the nearest likely approach of an individual to the barrier. Generally, this point is not <0.3 m from the barrier.

4.1.5.4 *Occupancy Factor*. The occupancy factor (T) is the average fraction of the time that the maximally exposed individual is present in the area to be shielded while the x-ray beam is on or the source is exposed. Assignment of occupancy factors to various areas is a matter of judgment and the recommendations given in Table 4.1 of NCRP Report No. 147 (NCRP, 2004) (and reproduced

in this Report as Table 4.1) *should* be used if a default value is desired or as guidance.

4.1.5.5 *Use Factor.* The use factor (U) is the fraction of a primary beam workload that is directed toward a specific primary barrier. This will depend upon the design and use of any particular diagnostic or therapeutic x- or gamma-ray source. Typically, radiographic units will be directed to the floor or to one wall. In this case, the use factor for primary radiation impacting the ceiling and remaining walls would then be zero. The image receptor of a fluoroscopy unit intercepts and absorbs the primary beam. Consequently, the use factor for primary radiation is zero for all barriers in that case.

TABLE 4.1—*Suggested occupancy factors*[a] *(for use as a guide in planning shielding where other occupancy data are not available).*

Location	Occupancy Factor (T)
Administrative or clerical offices; laboratories, pharmacies and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms, film reading areas, nurse stations, x-ray control rooms	1
Rooms used for patient examinations and treatments	1/2
Corridors, patient rooms, employee lounges, staff rest rooms	1/5
Corridor doors[b]	1/8
Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding areas	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), attics, stairways, unattended elevators, janitor closets	1/40

[a]When using a low occupancy factor for a room immediately adjacent to an x-ray room, care *should* be taken to also consider the areas further removed from the x-ray room. These areas may have significantly higher occupancy factors than the adjacent room and may therefore be more important in shielding design despite the larger distances involved.

[b]The occupancy factor for the area just outside a corridor door can often be reasonably assumed to be lower than the occupancy factor for the corridor.

Also, some radiation therapy units have a permanently installed beam stop that intercepts the primary beam. Again, in that case, the primary beam use factor for all barriers is zero. The use factor for secondary radiation is generally assumed to be a value of one for all barriers.

4.1.5.6 *Primary Barriers*. Unless the workload distribution for the operating potential (in kilovolt peak) is known, the primary shielding barrier for a veterinary diagnostic facility *shall* be computed assuming that the entire workload for each x-ray unit is delivered at the expected maximum kVp. Consideration *should* be given to the possibility that the maximum kVp may increase in the future. It is more economical to provide a higher degree of protection initially than to add to it later. The calculated barrier thickness *shall* be rounded to the next higher value of commercially supplied shielding material. For example, leaded wallboard is manufactured in standard thickness with a minimum of 0.8 mm (1/32 inch) lead sheet.

Primary barrier shielding recommendations for diagnostic facilities are derived from the model and data presented in NCRP Report No. 147 (NCRP, 2004). That report gives a model for determining the required barrier thickness based on the workload W in mA min week^{-1} (modified by the use factor U and the occupancy factor T), the shielding design goal P in mGy week^{-1}, the distance d to the area to be protected, and the operating potential (kilovolt peak) of the x-ray unit. Details are given in that report. Primary barrier shielding requirements are given in Appendix A, Table A.1 of this Report for lead, gypsum wallboard, and concrete as a function of the quantity WUT/Pd^2. For typical radiographic installations, the primary barrier in a wall *should* extend to a height of at least 2.1 m (7 feet) above the floor.

Typical workloads and operating potentials for veterinary radiographic facilities indicate that primary barriers would rarely exceed 3.2 mm (1/8 inch) lead for both controlled areas and uncontrolled areas.

The primary barrier for a therapy facility *shall* be computed for an assigned workload and the maximum energy capability of the therapy unit. The transmission factor is determined using Equation 4.1 and usually expressed as the number of tenth-value layers (TVLs) of shielding material required [*i.e.*, log (1/B)]. TVLs for concrete, steel and lead are given in Table B.1 of Appendix B. Primary barrier shielding requirements are given in Table B.2 of Appendix B for lead, steel and concrete as a function of the quantity WUT/Pd^2 for typical combinations of WUT.

To determine the required shielding for a primary barrier, it is usually assumed that the unattenuated primary beam impacts the floor or walls that constitute this barrier. Attenuation of the beam in the animal patient and image receptor is ignored. This provides a safety factor in the determination of the shielding requirements.

4.1.5.7 *Secondary Barriers*. Secondary barriers are those barriers that the primary radiation beam cannot impact under any conditions. They are designed to limit the leakage radiation and scattered radiation to the shielding design goal in adjacent areas. Manufacturers are currently required to limit the leakage radiation to specified values. These values are given in Sections 5.1.1, 6.1.1, 7.2.1, 7.3.1, and 7.4.1 for the various types of diagnostic and therapeutic radiation equipment used in veterinary medicine. The use factor is assumed to be one for all barriers when determining the secondary barrier shielding requirements.

Secondary barrier shielding recommendations for diagnostic x-ray equipment are derived from the model and data presented in NCRP Report No. 147 (NCRP, 2004). Secondary barrier shielding requirements are given in Table A.2 of Appendix A of this Report for lead, gypsum wallboard, and concrete as a function of the quantity WUT/Pd^2.

Secondary barriers for therapy equipment are calculated in the same way as the primary barriers. The secondary radiation is composed of leakage radiation and radiation scattered from the patient. The value of W for leakage radiation is taken as the maximum limit for leakage as specified in the Sections noted above.

The transmission factor for secondary barrier shielding is determined using Equation 4.1 and usually expressed as the number of TVLs of shielding material required [*i.e.*, log (1/B)]. TVLs for concrete, steel and lead are given in Appendix B, Table B.1. Secondary barrier shielding requirements are given in Appendix B, Table B.3, for lead, steel and concrete as a function of the quantity WUT/Pd^2 for typical combinations of WUT.

4.1.5.8 *Evaluation of Shielding Adequacy.* A qualified expert *should* inspect the shielding during installation and *shall* evaluate the adequacy of the shielding after installation and prior to the initial use of any radiation-producing devices or radioactive material. This evaluation *should* determine the number of examinations or treatments (weekly workload) that can be performed without

exceeding the shielding design goal in the areas adjacent to the facility. The evaluation will normally involve direct measurements of the radiation transmitted through each of the shielding barriers. The qualified expert *should* perform an independent assessment of the workloads and other design parameters that are used in the evaluation of shielding adequacy. Local or state regulatory authorities *should* also be consulted for their approval.

Section 6.3 of NCRP Report No. 147 describes in detail the inspections and measurements required to evaluate shielding for a diagnostic x-ray facility (NCRP, 2004). Many of these recommendations are also suitable for the evaluation of a veterinary radiology facility. The NCRP recommendations (NCRP, 2004) are summarized below.

Visual inspection during construction is important to verify that the specified type and thickness of shielding material, and the safety systems, are properly installed. If it is not possible to obtain all the information necessary by direct observation, the construction contractor *should* be asked to provide appropriate certifications (*e.g.*, the lead equivalent of leaded glass, or the density of the poured concrete). Late design changes that might affect the efficacy of the shielding can be discovered by on-site inspections during construction.

Radiation measurements *shall* be made to determine the transmission factors of the shielding barriers. These measurements can be made using the primary radiation field of the device to be shielded and an appropriate radiation survey instrument (see Appendix D of NCRP, 2000). Measurements on the exit side of a barrier *should* be made at the closest point to the barrier that is likely to be occupied. In the absence of more detailed information, these distances *should* be assumed to be 0.3 m from a wall, 0.5 m above the floor of a room above, and 1.7 m above the floor of a room below a radiological facility. Additionally, measurements *should* be made in the nearest routinely occupied area if it is not immediately adjacent to the barrier. The measurement results are typically used to assess the annual effective dose to the maximally exposed individual occupying that area, using appropriate use and occupancy factors.

The individual who performs the evaluation and survey *shall* report the results to the facility operator and other interested parties (*e.g.*, contractor, architect, state regulatory authority). The report *should* include a record of the visual observations and measurements, including assumptions, measurement methods and instruments used. The report may include recommendations.

4.2 Facility Design Considerations for Unsealed Sources

Recommendations for the design features for facilities in which the handling and administration of unsealed radioactive materials take place are based on those unique aspects of the radioactive materials that will be used. Design considerations include preventing or facilitating the removal of contamination, minimizing exposure, preventing airborne and sanitary sewer contamination, and providing for safe and effective radioactive waste disposal.

4.2.1 *Contamination Control*

4.2.1.1 *Floors and Work Surfaces*. The floors in radioactive material handling areas *should* be nonporous and easily decontaminated. Certain materials such as seamless linoleum, floor tiles, or epoxy coatings make decontamination easier and help to prevent fixed contamination. If floor tile is used, it *should* be heavily waxed prior to the use of radioactive materials in the area to seal joints between tiles and prevent contamination from entering such cracks. Where such materials have not been incorporated into the design, heavy skid-proof plastic coverings can be substituted to make decontamination easier following a spill of radioactive material.

For certain floors, such as those in horse stalls, waxes or epoxy coatings might make them too slippery while creating additional hazards for horses administered radioactive materials. Since the majority of procedures performed on horses involve the use of ^{99m}Tc, natural radioactive decay might be the preferred method of decontamination considering the short 6 h half-life of this radionuclide. However, when decay is used for decontamination, animal handlers *shall* exercise precautions to prevent personal contamination and the tracking of contamination from the stall area to clean areas.

Work surfaces *should* be nonporous and easily decontaminated. An absorbent, nonpermeable surface liner *should* be utilized as well to assist in decontamination of work surfaces.

4.2.1.2 *Walls*. Walls that could become contaminated with radioactive materials require the same consideration as floors. If they are constructed of drywall, they *should* be vinyl covered or painted with a good quality paint that is nonporous and lends itself to easy cleaning. Frequently, in animal facilities, concrete blocks are used as wall materials and they *should* be sealed to make them easy to decontaminate and prevent them from fixing contamination.

4.2.1.3 *Air.* When the radioactive materials used can be released to the air, consideration *shall* be given to protecting the work environment from airborne contamination and controlling the release of radioactive material to the environment (ACGIH, 2001; ANSI/AIHA, 2001; 2003; ANSI/ASHRAE, 2001). Certain radionuclides, such as ^{131}I, are naturally volatile and *should* be handled in a manner that will protect the user. For example, when cleaning litter contaminated with ^{131}I, use disposable litter pans that can be disposed of entirely rather than removing dirty litter and replacing it with fresh litter in the same litter pan.

The breathing zone of the user needs to be protected and the potential for inhalation of radioactive material can be reduced by using fume hoods, laminar-flow hoods (ducted to the outside) and controlled air-flow for animal cubicles. Special consideration also *should* be given to chemical reactions or metabolic processes (of the animals and the action of bacteria on radioactive material in excreta) that can evolve airborne contamination. In most cases, exhaust systems from hoods or animal cubicles will be required to contain high-efficiency particulate air and activated charcoal filters. The charcoal filters can be effective in trapping evolved radioactive gases as well as aiding in odor control. Prior approval of the exhaust system design may need to be received from the local or state health department.

4.2.1.4 *Sewer.* Certain quantities of radioactive materials that are readily soluble or readily dispersible can be disposed of in the sanitary sewer (NRC, 1999a). However, such releases require prior consideration of the concentrations of radioactive material in the effluents and verification of the solubility or dispersal ability of the radioactive material.

When the radioactive material concentration has the potential to exceed that permitted for release (NRC, 1999a), holding tanks *should* be incorporated into the design of the facility to prevent the material from entering the sanitary sewer or to allow for radioactive decay and dilution of the material prior to release. An alternative procedure is to collect such liquids for decay-in-storage or processing for commercial disposal at a licensed disposal facility (see Section 8.3.2 for further discussion of disposal options).

4.2.2 *Shielding*

4.2.2.1 *Facilities.* When animals are administered large quantities of gamma-ray-emitting radionuclides, such as radioiodine for treatment of thyroid cancer, facility walls *should* be shielded to control

radiation levels in surrounding occupied areas. The thickness of lead or concrete needed for the walls will depend on the radionuclides used and the activity levels. For the gamma rays from ^{131}I, the TVL is 12 mm in lead and 14.5 cm in concrete. In some instances, it would be acceptable to use mobile shields positioned close to the animals or their holding cells to protect areas of concern.

4.2.2.2 *Procedures*. Individuals who handle radioactive materials for administration to animals *shall* be protected from unnecessary exposure. This requires consideration of specific shielding. When transporting or storing stock vials of gamma-ray-emitting radionuclides, such as ^{99m}Tc or ^{131}I, lead containers *should* be used. For high-energy beta- particle emitters, such as ^{32}P, plastic containers *should* be used to minimize x-ray production. Appropriate shielding *should* be used for these materials during handling and preparation for administration (*e.g.*, syringe loading). For gamma-ray emitters, the use of leaded glass "L" shields or, in the case of ^{32}P, the use of Lucite™ (Lucite International, Inc., Cordova, Tennessee) "L" shields can provide substantial reduction of potential doses. Specific shields are indicated for syringes used to inject radioactive materials. The user *should* be mindful of the cones of radiation exiting each end of syringe shields and handle the syringes appropriately. Syringes *should* be contained in leaded box shields that can absorb the radiation escaping the syringe shields during transport to the injection area.

4.2.3 *Radioactive Waste*

The design of any radioisotope facility *shall* include consideration for waste processing and storage. Most radionuclides used in veterinary practice have half-lives that lend themselves to decay-in-storage as an effective and safe method of disposal. However, for radionuclides with half-lives >120 d, this might not be practical or acceptable from a licensing standpoint. Long half-lived radionuclide waste might have to be processed for transfer to a licensed commercial disposal facility. In determining the acceptability of facilities for processing and storage of radioactive waste, all the design features for facilities where materials are to be used *should* be considered. Section 8.3 provides additional discussion on radioactive waste topics.

4.2.4 *Radioactive Animal Carcasses*

Radioactive animal carcasses present a special problem as radioactive waste because there is not a shallow land-disposal facility that will accept them. Therefore, they need to be processed in a manner that eliminates both the radiological and the biological decomposition problems associated with radioactive animal carcasses. For disposal at a licensed radioactive waste disposal facility, animal carcasses are first incinerated at a licensed facility that has the capability of retrieving the radionuclides in ash and processing the ash in a manner that makes it acceptable for shallow land disposal. For those carcasses that can be processed *via* decay-in-storage, the carcasses can be disposed in the manner used for nonradioactive carcasses. However, steps need to be taken to ensure that animals used in radionuclide experiments are not subsequently consumed by human beings or used in foodstuff for animals. Incineration (King *et al*., 1988; Tries *et al*., 1996), chemical digestion (Kaye *et al*., 1993), and freeze-drying (Hamawy, 1995) are techniques that have been used effectively to process radioactive animal carcasses. Sufficient refrigeration storage space, with appropriate shielding, *should* be allocated and designed into the facility for the storage of radioactive carcasses. For small animals, a conventional household freezer might be required. Freezers used for storage of radioactive animal carcasses *should* be appropriately labeled, carcasses *should* be bagged or wrapped, and the freezer *should* be locked or located in a secure area. Freezers used for storage of radioactive animal carcasses *shall* not be used to store animal or human food.

5. Radiography

The veterinary medical application of x-ray radiographic equipment *shall* be performed only by or under the direct authority of a veterinarian who is properly trained and credentialed to operate such equipment. Records of each radiographic procedure performed *should* be maintained.

Recommendations for the design, performance and operation of diagnostic x-ray generating equipment are found in NCRP Report No. 102, *Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use)* (NCRP, 1989b). The recommendations in that report *should* apply to similar x-ray equipment used in veterinary medicine, and are summarized here. For specific design, performance and operations criteria refer to NCRP Report No. 102 (NCRP, 1989b).

It is recommended that only electrical equipment that meets the requirements of the National Electrical Code (usually marked on the appliance) be used in the x-ray installation. Periodic inspection of connections, cables and wires is recommended at least annually. Spaces that contain high voltages *should* only be inspected by qualified service personnel.

5.1 Fixed Radiographic Equipment

5.1.1 *Design*

A diagnostic x-ray tube housing assembly with an attached beam-limiting device *shall* be used. This assembly *shall* be constructed so that the air kerma from leakage radiation measured at a distance of 1 m from the source does not exceed 0.876 mGy air kerma (100 mR exposure) in any 1 h when the source is operated at its leakage technique factors (FDA, 2004a). In general, modern diagnostic x-ray tube housings incorporate sufficient shielding and it is usually unnecessary for the practitioner to have leakage tests performed in the field on modern, well-maintained, x-ray machines. For previously used equipment, leakage radiation measurements *should* be made by a qualified expert prior to beginning clinical use. If the system is not covered by a preventative maintenance service, a qualified expert *should* test the integrity of the shielding every 3 to 5 y.

The control panel *shall* include devices for setting and indicating physical factors used for the exposure, such as kVp and *mAs*.

Means *shall* be provided to align the center of the x-ray beam and the center of the indicator light beam to the center of the image receptor.

A device *shall* be provided that terminates the exposure at a preset time interval or exposure. The operator *shall* be able to terminate the exposure at any time. The radiographic exposure switch *shall* be of the "dead-man" type.

The control panel *shall* provide clearly audible and visible indication of the production of x rays whenever the tube is energized.

5.1.2 *Performance*

The primary x-ray beam *shall* be filtered to remove the low energy x rays that are easily scattered and also not useful for imaging. The minimum half-value layer (HVL) (measured) is given in Table 5.1 for various operating potentials.

The air kerma *should* be linear with the x-ray tube current (mA) and constant within 10 percent at any given tube current and operating potential (kVp). Collimator assemblies that provide a visual light field definition *should* be aligned so that the visual and x-ray fields coincide to within $\pm$2 percent of the source-to-image receptor distance.

The duration of x-ray beam exposure *should* agree to within $\pm$10 percent of the timer setting.

TABLE 5.1—*HVLs for various tube operating potentials used in x-ray radiographic equipment (FDA, 2004b).*

Operating Potential (kVp)	Measured HVL (mm aluminum)
50	0.5
70	1.5
80	2.3
90	2.5
100	2.7
120	3.2
150	4.1

5.1.3 *Operation*

The useful beam *shall* be limited to the smallest area compatible with the requirements of the examination. This minimizes radiation exposure to the patient and the operators of the equipment and improves image quality. Rectangular mechanical beam-limiting devices that conform more closely to the shape of the cassette are preferred to cones.

The operating potential, filtration and source-to-skin distance *should* have values as high as is practical. Alignment of the beam, animal patient, and image receptor *should* be done with care. Mechanical mounting devices and stands *should* be provided to hold the x-ray tube housing and image receptor in selected positions. Although some x-ray tube housings are manufactured to be "safely" hand-held, in general the x-ray tube housing *should not* be hand-held during operation.

No person *should* routinely hold patients during diagnostic x-ray examinations. Mechanical supporting or restraining devices or sedation *should* be used. If fixed equipment is used for the radiography of horses, then either a mobile standing cassette holder or a cassette frame on an extension arm *shall* be used.

If it is necessary that someone hold an animal patient, that individual *shall* be protected with appropriate shielding devices (leaded gloves and aprons). Gloves *shall* enclose the whole hand within the lead shielding and the individual holding the patient *should* be positioned so that no part of the holder's body (including gloved hands) is exposed to the useful beam. Pregnant women and persons under the age of 18 y *shall* not be permitted to hold the patient. It may be preferable that the animal's owner or handler hold the animal.

Only those persons whose presence is necessary *shall* be in the x-ray room during the exposure, and they *shall* be protected with appropriate shielding. In general, the operator *should* remain behind a permanent protective shielding barrier during the exposure. When individuals cannot be protected by installed shielding during the examination, protective clothing (aprons and gloves) of at least 0.5 mm lead equivalent *shall* be provided and *shall* be worn by all individuals required to be in controlled areas. Thyroid shields *should* be made available if requested.

When the workload is so low that the shielding design goals can be met without permanently installed shielding, the installation *shall* be so arranged that the operator can stand at least 2 m (~6 feet) from the patient, the x-ray tube, and the useful beam. In facilities without protective barriers, protective garments (such as lead aprons) *shall* be worn without regard to workload.

Protective items such as gloves, aprons and barriers *should* be inspected periodically for significant deterioration. Armored gloves (welding gloves) *should* be used to restrain fractious animals. Since lead-lined gloves will not protect against bites and such a bite will puncture the lead, the radiation protection provided by the garment may be compromised.

Whenever possible, consistent with appropriate diagnostic criteria, fast films and high-speed screens *should* be used to minimize exposure time.

Film processing materials and techniques *should* be those recommended by the x-ray film manufacturer or those otherwise tested to ensure maximum information content of the developed x-ray film. Quality-assurance procedures *should* be employed to ensure proper care and maintenance of automatic processors to obtain optimum results (Appendix C). These would include adherence to the recommended developing time and temperature control. If the darkroom is not a dedicated darkroom (*i.e.*, used for other purposes such as a bathroom or storage area for other chemicals such as pesticides), care *shall* be exercised to prevent contamination of the x-ray film processing chemicals. Also, care *should* be exercised to ensure that the door is sealed against outside light and that appropriate warnings are present to prevent others from entering during the processing of films.

Technique charts *shall* be developed for all animal types that are routinely x rayed.

5.2 Portable Radiographic Equipment

Portable x-ray units are invaluable for imaging in equine or food animal practice when it is impossible or impractical to transport the animal to a fixed unit. However, portable units pose special potential for radiation exposure because they can be "aimed" in any direction at any location and generally require longer exposure times than fixed units. Mechanical mounting devices and stands *should* be used to hold the image receptor to prevent unnecessary exposure of personnel. Appropriate protective equipment such as leaded aprons and gloves, or portable shielding, *shall* be used.

5.2.1 *Design*

The recommendations pertaining to design of fixed diagnostic equipment (Section 5.1.1) apply to portable equipment, except that:

- permanent protective barriers are not required unless the portable x-ray unit is being used as a fixed unit; and
- the operator *shall* stand at least 1.8 m (~6 feet) from the patient, the x-ray tube, and the useful beam, when practicable, and wear a lead apron.

In addition, portable x-ray generators of a "high-frequency" design are recommended. Unless specifically designed to be hand-held, the x-ray tube housing *shall* be supported by a portable stand or tripod. The unit *should* include a device such as a light localizer or laser pointer to delineate the cross section of the useful beam. The unit *shall* have an adjustable collimator to restrict the beam to the appropriate x-ray field size.

The exposure control switch *shall* be of the "dead-man" type and attached to the unit with an exposure cord of no <1.8 m (~6 feet), permitting the operator to stand at least 1.8 m away from the x-ray tube housing and well away from the useful beam.

5.2.2 *Performance*

The recommendations pertaining to performance of fixed diagnostic equipment (Section 5.1.2) apply to portable equipment.

5.2.3 *Operation*

The recommendations pertaining to operation of fixed diagnostic equipment apply to the use of portable equipment (Section 5.1.3). However, additional recommendations are needed for operating portable units. Unless specifically designed and tested to be safe to be hand-held, the portable x-ray generator *shall not* be held in the hand. The cassette itself *should not* be held by hand. Under almost all circumstances, the image receptor *should* be held in a mechanical device.

Only fast films and high-speed screen combinations *should* be used with mobile or portable x-ray equipment.

Portable x-ray equipment *shall not* be used for fluoroscopy unless it is specifically designed to meet the requirements for these uses.

Technique charts *shall* be developed for all animal types that are routinely x rayed.

5.3 Computed Tomography

5.3.1 *Design*

Modern CT scanners consist of a rotating x-ray tube that generates a fan beam of x rays collimated to a nominal width of T_b (centimeters) along the axis of rotation. X-ray tube potentials of 120 to 140 kVp are typically employed and produce relatively high levels of scattered radiation that may require significant shielding. During CT operation in a helical scan mode, the animal patient is positioned on the CT table and continuously moved along the axis of rotation with velocity v. The radiation beam traces out a helix on the surface of a cylindrical phantom (helical or spiral scanner) and the x-ray tube rotation time (τ) is on the order of 1 s or less per 360 degrees. If the patient translation per gantry rotation $b = v\tau$ is greater than the nominal beam width T_b, the pitch (p) of the sequence ($p = b/T_b$) is greater than unity. In a "multi-slice scanner," multiple detector rings along the axis of rotation may be used to collect several image sections per rotation that are thinner than the nominal collimated beam width. For a single-slice acquisition scanner, the nominal beam width (reconstructed slice thickness) is usually variable over the range of 1 to 10 mm. For a "multi-slice" scanner, the nominal beam width may be 40 mm or more and include n reconstructed slices. In each case, the total beam width determines the amount of scattered radiation per rotation.

Only secondary radiation (primarily scattered radiation and some leakage radiation) is considered since the primary beam is normally attenuated to well below the scattered radiation levels by the detectors and gantry hardware. Details of the determination of the scattered air kerma at 1 m for a given patient diameter are found in NCRP (2004) for human patients. If necessary, the same principles can be used to determine scattered air kerma from animal patients.

The scattered air kerma per patient at 1 m (K_S^1) can be expressed in terms of the length of patient scanned $L = N_R b$ and the pitch (p), where N_R is the total number of rotations in a scan series, and b is the scan interval for axial scans, or $b = v\tau$ is the table advance per rotation for helical scans.

$$K_S^1 = \kappa \frac{L}{p} CTDI_{100} \tag{5.1}$$

The computed tomography dose index ($CTDI_{100}$) is measured with a single axial rotation using a 10 cm (100 mm) long ionization

chamber (in units of air kerma) and κ is a proportionality constant (scatter fraction per centimeter). This methodology assumes an isotropic scattered-radiation distribution, rather than the "hourglass" shaped isodose distributions typically given by CT manufacturers. In the plane of x-ray tube rotation, scattered radiation is greatly reduced due to attenuation by the gantry hardware.

Measured values of κ (cm^{-1}) are reported in NCRP Report No. 147 (NCRP, 2004) for the peripheral axes of a standard head and body phantom (FDA, 2004c; Shope *et al.*, 1981) as:

$$\kappa_{head} = 9 \times 10^{-5}\ cm^{-1}$$
$$\kappa_{body} = 3 \times 10^{-4}\ cm^{-1}$$

Since these measured κ values include a small tube leakage radiation component, the air kerma calculated from them is denoted as K_{sec}. Values of the $CTDI_{100}$ for various CT scanner models have been tabulated and are available on the Imaging Performance Assessment of Computed Tomography Scanners web site (ImPACT, 2004). The ImPACT (2004) values are given per 100 mAs at various kVp settings and are periodically updated as new scanner models become available. One must be careful, however, to use the peripheral edge value of $CTDI_{100}$ with the scatter fractions (κ) provided in this Report. $CTDI_{100}$ values scale to other kVp values approximately as the square of the kVp (*e.g.*, the $CTDI_{100}$ at 140 kVp can be obtained by multiplying the 120 kVp value by 1.4, if it is determined that the facility commonly uses 140 kVp). If ${}_{n}CTDI_{100}$ is defined as the $CTDI_{100}$ normalized per *mAs*, then:

$$K_{sec}^{1} = \kappa\, N_R\, T_b\, mAs\ {}_{n}CTDI_{100} = \kappa\, \frac{L}{p}\, mAs\ {}_{n}CTDI_{100}\,. \qquad (5.2)$$

$CTDI_{100}$ values are also obtainable from the manufacturers; however, care should be taken not to confuse $CTDI_{100}$ with $CTDI_{FDA}$ (FDA, 2004b), which is also provided, often as an unsubscripted CTDI value.

Since several CT manufacturers now display a dose-related quantity named dose-length product (*DLP*) for a given scan series on the scanner monitor (Nagel, 2002), it may become more convenient to use the *DLP* to establish the relevant techniques and to compute shielding requirements directly from *DLP* rather than $CTDI_{100}$. The relevant equations are:

$$K_{sec}^{1}\,(\text{head}) = \kappa_{head}\, DLP \qquad (5.3)$$

$$K_{\text{sec}}^{1}\,(\text{body}) = 1.2\,\kappa_{\text{body}}\,DLP \tag{5.4}$$

Examples of the use of $CTDI_{100}$ and *DLP* and the relationship between these two quantitates are given in Section 5.6 of NCRP Report No. 147 (NCRP, 2004).

Expressing workload in mA min week^{-1} is not recommended because a multi-slice scanner acquiring a 2 cm total slice width per rotation will require only one-half the mA min week^{-1} of a single-slice scanner acquiring a 1 cm width, but the scattered air kerma will be approximately the same.

As an alternative method of calculation (Sutton and Williams, 2000), the scattered radiation isodose contour maps provided by the manufacturer may be utilized. Care must be taken, however, to note the total slice width (T_b) and the technique (*i.e.*, kVp and *mAs*) utilized for the measurement of these distributions, in order that they may be normalized to the appropriate clinical techniques. Also, the appropriateness of the phantom utilized *should* be evaluated.

5.3.2 *Operation*

The individual responsible for the operation of CT equipment *shall* be specifically trained and authorized to operate the equipment. CT equipment *should* be operated only under the authority of such a responsible individual.

Animal patients *shall* be immobilized for CT examinations by sedation, general anesthesia, or mechanical restraint; personnel *shall* not manually restrain these animal patients during a CT examination.

Personnel *should* remain behind appropriately located wall barriers, documented to be safe under conditions of maximal radiation output. People *should* not be in the scan room during a CT examination. However, if it is necessary for a person to be in the scan room during the CT examination, the person *shall* stand as far as possible from the machine and animal patient, *shall* wear a lead apron of 0.5 mm lead equivalent, and *shall* wear a radiation monitor positioned at collar level above the lead apron.

The *mAs* values for the CT examination *should* be correlated to the size of the anatomy being imaged, utilizing as low an *mAs* as is consistent with an acceptable signal-to-noise ratio in the resulting image.

The CT slices *should* be as few in number as necessary, be as wide as is consistent with the diagnostic objective, and have slice overlap minimized to that necessary for adequately examining the anatomy in question.

For spiral CT scanning, one *should* use as high a pitch as is consistent with the diagnostic objective.

Either a written or a digital file *shall* be maintained that contains the identity of the animal patient, the date of the CT examination, the CT exposure parameters utilized, and the number of CT slices made.

A quality-assurance program *should* be established that ensures both proper functioning of the CT machine and good image quality from a reasonable radiation dose.

6. Fluoroscopy

Fluoroscopy is used to continuously view dynamic processes in the body and to record static images as indicated by the dynamic viewing. It *should not* be used as a substitute for radiography. The veterinary medical application of x-ray fluoroscopic equipment *shall* be performed only by or under the direct authority of a veterinarian properly trained and credentialed to operate such equipment. Records of each fluoroscopic procedure performed *should* be maintained.

Recommendations for the design and performance of fluoroscopy equipment, and recommendations for the users of that equipment are given in NCRP Report No. 102 (NCRP, 1989b). The recommendations in that report *should* apply to x-ray fluoroscopy equipment used in veterinary medicine, and are summarized here. In many cases, the recommendations are the same as those for radiographic equipment. They are repeated here for emphasis. For specific design, performance and operations criteria refer to NCRP Report No. 102 (NCRP, 1989b).

It is recommended that only electrical equipment that meets the requirements of the National Electrical Code (usually marked on the appliance) be used in the fluoroscopy installation. Equipment to be operated in areas where explosive gases may be used *should* have the approval of the Underwriters' Laboratories, Inc. (UL) for such use.[5] Periodic inspection of connections, cables and wires is recommended at least yearly. Spaces that contain high voltages *should* only be inspected by qualified service personnel.

6.1 Fixed Fluoroscopic Equipment

6.1.1 *Design and Performance*

A diagnostic x-ray tube housing assembly with an attached beam-limiting device *shall* be used. This assembly *shall* be constructed so that the air kerma from leakage radiation measured at a distance of 1 m from the source does not exceed 0.876 mGy air kerma (100 mR exposure) in any 1 h when the source is operated at

[5]Information may be obtained from Underwriters' Laboratories, Inc., 207 East Ohio Street, Chicago, Illinois 60611.

its leakage technique factors (FDA, 2004a). In general, modern diagnostic x-ray tube housings incorporate sufficient shielding and it usually is unnecessary for the practitioner to perform leakage radiation tests in the field on modern, well-maintained, x-ray machines. For previously used equipment, leakage radiation measurements *should* be made by a qualified expert prior to beginning clinical service. Shielding integrity *should* be tested every 3 to 5 y by a qualified expert if the system is not covered by a preventative maintenance service.

The control panel *shall* include devices for setting and indicating physical factors used for the exposure, such as kVp and *mAs*.

A fluoroscopic beam restrictor *shall* be provided to restrict the size of the applied useful beam to an area less than a primary protective barrier permanently incorporated into the equipment, and the diameter of the input phosphor of the image intensifier. It *shall* be impossible to operate fluoroscopic equipment unless the useful beam is intercepted by a primary barrier or an image intensifier.

The radiographic exposure switch *shall* be of the "dead-man" type.

A cumulative timing device, activated by the fluoroscope exposure switch, *shall* be provided to indicate the passage of a predetermined period of irradiation by an audible signal when the increment of exposure time exceeds a predetermined limit not exceeding 5 min.

Shielding *should* be provided as is practicable (leaded screen drapes, table side shields) to attenuate scattered radiation both under and over the table and limit exposure of the operator.

The minimum HVLs *should* be those specified in Table 5.1

6.1.2 *Operation*

Fluoroscopy *should not* be used as a substitute for radiography and is not recommended for general veterinary imaging. It is appropriately reserved for study of dynamics or for guidance with spatial relationships.

The useful beam *shall* be limited to the smallest area and the shortest possible exposure times *should* be employed compatible with the requirements of the examination. The tube operating potential, filtration and the source-to-skin distance *should* be as large as is practical. Alignment of the beam, the animal patient, and image receptor *should* be done with care.

Only those persons whose presence is necessary *shall* be in the fluoroscopy room during exposures, and they *shall* be protected with appropriate shielding. Protective aprons having a lead

equivalence of at least 0.5 mm *shall* be worn by the fluoroscopist and by any other person in the room or in the immediate vicinity of the fluoroscopic beam, especially if there are radiation fields of 0.05 mGy h^{-1} or more. Thyroid shields *should* be made available, if requested.

Protective items such as gloves, aprons and barriers *should* be inspected periodically for significant deterioration (Appendix C). Armored gloves (welding gloves) *should* be used to restrain fractious animals. Since lead-lined gloves will not protect against bites and such a bite will puncture the lead, the radiation protection provided by the garment may be compromised.

If it is necessary that someone hold an animal patient, that individual *shall* be protected with appropriate shielding devices (leaded gloves and aprons). Gloves *shall* enclose the whole hand within the lead shielding and the individual holding the patient *should* be positioned so that no part of the holder's body (including gloved hands) is exposed to the useful beam. Pregnant women and persons under the age of 18 y *shall not* be permitted to hold the patient. It may be preferable that the animal's owner or handler hold the animal.

Whenever possible, consistent with appropriate diagnostic criteria, fast x-ray films, and high-speed screens *should* be used to minimize exposure time.

Film processing materials and techniques *should* be those recommended by the x-ray film manufacturer or those otherwise tested to ensure maximum information content of the developed x-ray film. Quality-assurance procedures *should* be employed to ensure proper care and maintenance of automatic processors to obtain optimum results (Appendix C). These would include adherence to the recommended developing time and temperature control. If the darkroom is not a dedicated darkroom (*i.e.*, used for other purposes such as a bathroom or storage area for other chemicals such as pesticides), care needs to be exercised to prevent contamination of the x-ray film processing chemicals. Also, care needs to be exercised to ensure that the door is sealed against outside light and that the appropriate warnings are present to prevent others from entering during the processing of films.

6.2 Mobile Fluoroscopic Equipment

Mobile fluoroscopic units may be useful for continuously viewing dynamic processes in the body and to record static images as indicated by the dynamic viewing imaging when it is impossible or impractical to transport the animal to a fixed unit. However, mobile

units pose special potential for radiation exposure because they are used outside of standard fluoroscopic facilities and without many of the designed safety features of fixed units.

6.2.1 *Design*

The recommendations pertaining to design of fixed fluoroscopic equipment (Section 6.1.1) apply also to mobile equipment. There are some additional recommendations that apply to mobile units.

The fluoroscopic x-ray tube and collimating system *shall* be linked with the image receptor assembly so that the beam is centered on the image receptor and confined within the useful receptor area.

Image intensification *shall* be provided on all mobile fluoroscopy units.

Prior to the first use of a mobile fluoroscope, a radiation exposure survey *should* be done encompassing a 360 degree area around the fluoroscope, with the x-ray beam at maximum operating potential and with an appropriate test phantom in place, to determine whether there are any areas outside of the useful beam in which there is sufficient scattered radiation that the applicable shielding design goal (Section 4.1.5.1) may be exceeded. If such radiation levels are detected, no individual without radiation protective apparel *shall* be present within those areas during fluoroscopy.

6.2.2 *Performance*

The recommendations pertaining to performance of fixed diagnostic equipment (Section 6.1.2) apply to mobile equipment.

6.2.3 *Operation*

The recommendations pertaining to operation of fixed diagnostic equipment apply to the use of mobile equipment (Section 6.1.3). However, additional recommendations are needed for operating mobile units.

Unless the fluoroscope is specifically designed to be hand-held, a support stand *should* be provided for mobile or mini C-arm fluoroscopes. If it is necessary to hand hold the unit during fluoroscopy, the operator *shall* comply with all radiation safety standards expressed both herein and in the operator's state regulations.

The operator of the mobile fluoroscope and any individual (including owners of animals) in the immediate vicinity of its useful beam *shall* wear a radiation protective lead apron, and no hand or other human body part *shall* be within the useful beam.

7. Radiation Therapy

In veterinary medicine applications, radiation therapy equipment and sources *shall* be used and operated only under the direct authority of a veterinarian who is properly trained and credentialed to perform or to delegate such work.

Recommendations for the design and performance of radiation therapy equipment, and recommendations for the users of that equipment are given in NCRP Report No. 102 (NCRP, 1989b). The recommendations in that report *shall* apply to x- and gamma-ray teletherapy equipment used in veterinary medicine, and are summarized here. For specific design, performance and operations criteria refer to NCRP Report No. 102 (NCRP, 1989b).

It is recommended that only electrical equipment that meets the requirements of the National Electrical Code (usually marked on the appliance) be used in the radiation therapy installation. Equipment to be operated in areas where explosive gases may be used *should* have the approval of UL for such use. Inspection of connections, cables and wires is recommended at least yearly. Spaces that contain high voltages *should* only be inspected by qualified service personnel.

7.1 General Recommendations for Teletherapy

7.1.1 *Equipment and Facility Design*

A qualified expert *shall* design the therapy room, specify the required shielding and provide acceptance testing after installation in accordance with applicable federal, state, or local radiation safety regulations.

Equipment to be operated in areas where explosive gases may be used *should* have the approval of UL for such use.

Permanent diaphragms or cones for restricting the useful beam *shall* afford the same degree of attenuation as is required of the therapeutic protective source housing. Adjustable or removable beam defining devices *shall* transmit not more than five percent of the maximum intensity of the useful beam.

A suitable exposure control device *shall* be provided to terminate the exposure after a preset time interval or a preset air kerma or absorbed dose.

The control panel *shall* have an easily discernible indicator of whether or not a radiation beam is being produced or emitted. Likewise, a warning radiation indicator *shall* be located near the entrance to the treatment room (see Section 4.1.3 and 4.1.4 for shielding of therapy facilities).

Interlocks on access doors to the therapy room *shall* be provided for x-ray therapy equipment capable of operating >150 kVp and for megavoltage electron and gamma-ray teletherapy units, so that when any door to the treatment area is opened, the machine will shut off automatically. When maze type accesses are used in lieu of doors, motion-detecting interlocks *shall* be used at the entry portal to shut off the machine automatically if the portal is transgressed. After a shutoff, it *shall* be possible to reactivate the machine to full operation only from the control panel. These safety devices *should* be checked daily to ensure proper functioning. For additional recommendations on access control and warning systems, refer to NCRP Report No. 88 (NCRP, 1987a).

The control station for teletherapy equipment operating >150 kVp *shall* be located outside of the treatment room. The operator of the therapy machine *shall* be able to view the patient from the control station, either through an appropriate high-density window glass, or by means of mirrors or closed circuit television.

7.1.2 *Performance*

The therapy equipment *shall* be examined for proper electrical and mechanical functioning, and be calibrated for radiation output by a qualified expert, annually or more often if required by the applicable radiation safety authorities and state and federal agencies. These evaluation procedures *shall* also be performed immediately subsequent to replacement of an x-ray tube, or a radiation source. Written, signed and dated documentation of the results of these procedures *shall* be maintained in the user's records.

7.1.3 *Operation*

All radiation therapy installations *shall* have a radiation safety survey performed by a qualified expert. The radiation therapy equipment *shall not* be used for animal treatment until the radiation safety of the installation has been documented as being adequate by a survey.

Both the control panel and the operating area *shall* be kept under observation during radiation therapy procedures. No person *shall* be in the treatment area during the irradiation.

There *shall* be written, signed and dated records of use of the therapy machine, including identification of the animal patients treated, the radiation exposure parameters utilized, and the radiation doses administered.

7.2 X-Ray Therapy Equipment with Operating Potentials ≤500 kV

7.2.1 *Design*

A therapeutic source assembly *shall* be used, such that the leakage air kerma rate at 1 m from the radiation source in any direction *shall not* exceed 10 mGy in any 1 h (NCRP, 1989b).

The control panel *shall* be provided with x-ray tube operating potential and x-ray tube current indicators.

7.2.2 *Performance*

Performance *shall* be as recommended in Section 7.1.2.

7.2.3 *Operation*

Operation *shall* be in accordance with the recommendations in Section 7.1.3.

7.3 X-Ray and Electron-Beam Equipment with Operating Potentials >500 kV

7.3.1 *Design*

A therapeutic source assembly *shall* be used, such that the absorbed dose rate from leakage radiation at any point outside the maximum sized useful beam, but within a circle of radius 2 m which is perpendicular to and centered on the central axis of the useful beam at the normal treatment distance, *shall not* exceed 0.2 percent of the absorbed dose rate on the center axis at the treatment distance (CRCPD, 1999; NCRP, 1989b).[6]

When energy selection is available on linear accelerators, selection and indication of energy *shall* be provided at the control panel.

[6]Another leakage radiation recommendation for electron accelerators operating in the rage 1 to 50 MV is provided by IEC (2002).

Two independently powered integrating dose meters *should* be provided for linear accelerators to assure proper preset dose termination. A timer that automatically terminates the irradiation *shall* also be provided as a back-up device.

7.3.2 *Performance*

Performance *shall* be as recommended in Section 7.1.2. Also, it is good practice to make a daily measurement of the absorbed dose at the location of the absorbed dose maximum in a phantom for a standard field (10×10 cm) for a fixed time or monitor setting.

7.3.3 *Operation*

Operation *shall* be in accordance with the recommendations in Section 7.1.3.

7.4 Gamma Radiation Teletherapy Equipment

7.4.1 *Design*

Sources *shall* be sealed in a welded capsule that is contained in a second welded container and strongly resistant to fire and breakage and *should* be registered with the sealed source and device registry at the U.S. Nuclear Regulatory Commission (NRC).

The therapeutic protective source housing *shall* be constructed so that at 1 m from the source in the OFF (*i.e.*, shielded) position, the maximum and average leakage air-kerma rates through the housing *shall not* exceed 0.1 and 0.02 mGy h^{-1}, respectively. In the ON (*i.e.*, unshielded) position, the housing leakage air-kerma rate *should not* exceed 0.1 percent of the useful beam air-kerma rate at 1 m (NCRP, 1989b).

The source control mechanism *shall* be so constructed that it can be returned manually to the OFF position with minimum irradiation of personnel. It *shall* return automatically to the OFF position in the event of any interruption of the activating source (*e.g.*, electrical power) and *shall* remain in the OFF position until reactivated from the control panel.

There *shall* be an independent radiation monitor in the treatment room.

There *shall* be a timer at the control panel that automatically terminates the exposure after a preset time.

7.4.2 *Performance*

In addition to the performance recommendations in Section 7.1.2, the gamma-ray irradiation apparatus *shall* be checked for possible leakage of radioactive material from the source at installation and at intervals not exceeding six months. If the amount of transferable radioactive material exceeds 185 Bq [becquerel (see Glossary)] per 100 cm^2, action *shall* be taken to prevent the spread of contamination and appropriate authorities *shall* be notified. The apparatus *shall* be removed from service until the condition is corrected.

A measurement of absorbed dose rate at the location of the absorbed dose maximum in a phantom *should* be made annually to verify source calibration. Mechanical inspection and verification of teletherapy equipment performance should be performed at intervals no longer than 5 y.

7.4.3 *Operation*

A new area radiation survey and calibration *shall* be completed prior to any treatments whenever the apparatus is reloaded with a new source.

Emergency procedures to be followed in the event of a failure of the source control mechanism *shall* be established and posted at the control panel.

A log *shall* be kept of all treatment of animal patients.

7.5 Brachytherapy

In veterinary medical applications, brachytherapy *shall* be performed only by a veterinarian properly trained and credentialed for such work. Procedures *shall* be established for the procurement, calibration, transport, storage, application, removal and accountability of brachytherapy sources, and for necessary radiation surveys (NCRP, 1972).

The RSO or other trained and approved individual *shall* be present to assist in the application and removal of the brachytherapy sources for all procedures. This assistance includes removing and transporting the sources from the storage area, returning the sources to proper storage, and verification that all sources are accounted for. A radiation survey of the animal patient *shall* be performed following installation and removal of the sources (Section 7.5.3.2).

7.5.1 *Brachytherapy Sources*

Brachytherapy sources *shall* be manufactured in a manner that will prevent release of the radioactive material under normal use.

Sources and applicators containing sources *shall* be stored in a locked and shielded enclosure that maintains the radiation exposure rate at or below permissible levels, and that prevents unauthorized access. The storage area *should* be located near the preparation area to minimize exposure of personnel during transfers.

Forceps, or other such devices, *shall* be provided for handling the sources. The preparation area for loading and unloading applicators *should* be shielded to reduce the radiation dose to the operating personnel. "L" shields are recommended for this purpose.

7.5.2 *Performance*

The manufacturer *should* provide certification that source integrity has been verified within the past six months. If such certification is not provided, or if there is obvious damage to the sources, all brachytherapy sources *shall* be checked for possible leakage of radioactive material from the source at the time they are received. Routine leakage tests *shall* be made at intervals not exceeding six months as long as they are retained in inventory. If the amount of transferable radioactive material exceeds 185 Bq per 100 cm^2, action *shall* be taken to prevent the spread of contamination and appropriate authorities *shall* be notified. Leaking sources *shall not* be used, but *shall* be sealed in a container to prevent the spread of radioactive contamination and appropriate authorities *shall* be notified. The sources *shall* be properly and safely returned to a person or supplier qualified to repair or dispose of the source.

All sources *shall* be calibrated so that the authorized user can calculate the activity present at any point in time.

7.5.3 *Operation*

7.5.3.1 *Source Handling and Control*. All brachytherapy sources *shall* be maintained so that their encapsulating material is not damaged to an extent that exposes the radioactive material.

If radioactive material contamination occurs, the room or area contaminated *shall* be completely closed and locked, preventing any further traffic through the affected area, until a trained person can arrive to begin decontamination procedures. Only trained personnel *should* perform decontamination procedures. Further information can be found in NCRP Report No. 30, *Safe Handling of Radioactive Materials* (NCRP, 1964).

Any person potentially contaminated with radioactive material *shall* be restricted to a controlled area to prevent spread of the contamination, and the person *shall* be surveyed for radioactive material. If personal radioactive contamination is detected, procedures to decontaminate the person *shall* begin immediately. Contaminated clothing *should* be removed and placed either within a disposable container or on sheets of paper, either for proper disposal or isolation until the clothing can be safely released by the attending RSO. Contaminated skin *should* be washed or bathed using mild soap and water, being careful not to abrade the skin. The personal cleansing procedures *should not* use highly alkaline soaps, abrasives, organic solvents, or cleansers that increase permeability of the skin. Urine, fecal and blood specimens from the contaminated person may be needed to evaluate for potential internal radioactive material.

The facility *shall* have a radiation survey instrument for detecting beta and gamma radiation emitted by sources used, at least capable of measuring radiation fields in the range of 1 μGy h^{-1} to 10 mGy h^{-1}.

Additional guidance on decontamination procedures is given in Section 8.2 and NCRP Report No. 111 (NCRP, 1991).

7.5.3.2 *Source Security.* Written records *shall* be maintained of radioactive sources received and shipped, to at least include the name of the receiving and sending person, the name of the attending veterinarian, the type of source material, the activity of radioactive material present, and the dates of receipt and return. An inventory *shall* be made of radioactive sources in stock at least semi-annually. Radioactive sources *shall* be shipped only to individuals who are licensed to receive such sources.

Brachytherapy sources *shall* be transported within the facility in properly labeled containers that are sufficiently secure and shielded such that individual radiation exposures will remain consistent with the ALARA principle. Public transportation of radioactive materials is governed by the U.S. Department of Transportation, state, and local regulations, and *should* only be done by capable persons fully knowledgeable of those regulations.

Loss of any radiation source *shall* be reported immediately to the applicable radiation safety authority.

7.5.3.3 *Source Administration*. Administration of brachytherapy sources *shall* be performed as expeditiously as possible by appropriately trained and legally authorized personnel, utilizing the

fewest number of individuals necessary. A reasonable effort *shall* be made to maintain radiation doses consistent with the ALARA principle. The user *shall not* directly contact or handle brachytherapy sources.

After installing the brachytherapy sources in an animal patient, the absorbed dose rate at 0.3 m (1 foot) from the center of the source *shall* be measured with a properly calibrated instrument such as an ionization chamber, and that absorbed dose rate *shall* be recorded in writing. If there is to be human contact with the animal during treatment, permitted contact time for the care provider *should* be posted.

Following insertion of the sources, the animal patient *shall* be isolated safely and securely from the public, with appropriate physical barriers to human radiation exposure being in place where required. Distance between human beings and the animal patient *should* be appropriately maximized. Human contact with the animal patient *should* be kept to a clinically necessary minimum. The isolation area *shall* clearly display both the appropriate radiation warning signs, and the name(s) and phone numbers of the attending veterinarian or other radiation safety authorities.

The same radiation safety practices utilized at the time of insertion of the brachytherapy sources *shall* likewise be used at the time of removal of the sources.

After removal of the sources from the animal patient, an appropriately calibrated radiation survey meter *shall* be used to document that neither the animal nor any location (including bedding and litter) in which the animal has resided during radiation treatment contains radioactive material. If an animal ingests a source, procedures *shall* be developed for confining the animal and monitoring excrement until the source is recovered.

Records on each animal patient *shall* be maintained, stating the type and number of radioactive sources used, the activity of radioactive material within each source, the date and time of insertion, the duration of the radiation exposure to the animal patient, and the total absorbed dose delivered.

When brachytherapy sources are removed from their locked storage shield, a carefully documented record *shall* be prepared that indicates the exact sources removed, where they were taken and the animal patient in which they are being used. Upon removal of the sources from the patient, the date and time of removal *shall* be recorded, the sources *shall* be immediately returned to their locked storage shield, and the record, indicated above, *shall* be amended to clearly indicate that the sources are all accounted for and, once again, in their locked storage shield.

8. Radiopharmaceuticals

Table 2.2 in NCRP Report No. 124 (NCRP, 1996), indicates that relatively few radiopharmaceutical procedures constitute the majority of nuclear medicine procedures performed in medical practice. Likewise, a review of the literature (*e.g.*, Berg *et al.*, 1990; Branam *et al.*, 1982; DiBartola *et al.*, 1996; Ehrlich *et al.*, 1999; Guptill *et al.*, 1995; Koblik *et al.*, 1988; Meric and Rubin, 1990; Peterson and Becker, 1995; Pleasant *et al.*, 1992; Turrel *et al.*, 1984) indicates that a few procedures make up the bulk of procedures being performed with radiopharmaceuticals in veterinary practice (Table 8.1).

The predominant diagnostic nuclear medicine procedure appears to be ^{99m}Tc bone scans in horses, while the most frequently used therapeutic radiopharmaceutical is ^{131}I for the treatment of hyperthyroidism or thyroid cancer. Because these procedures are performed with unsealed radionuclides, they present some unique radiation safety problems that need to be considered if they are to be used safely (Wootton, 1993). Often the animal is released before the radioactive material has been completely eliminated through radioactive decay or biological elimination. This practice requires written radiation safety procedures to protect the owner of the animal and anyone from the public sector who might come into contact with the animal. The following general guidelines are presented for the use of unsealed radiopharmaceuticals.

8.1 Radiation Safety Considerations

8.1.1 *Airborne Contamination Control*

Certain radionuclides, due to their nature, present a potential for airborne contamination. Others can be made airborne by metabolic processes that alter the radiopharmaceutical, causing it to release or convert the radionuclide to a form that can be gaseous or can become airborne. For example, radioiodine, in elemental form, sublimes and becomes readily airborne. Carbon-14 labeled compounds can be converted to $^{14}CO_2$ through metabolism while in the animal patient or through the activity of microorganisms on the material in the excreta. Likewise, ^{3}H in labeled compounds can be converted to tritiated water vapor that can become airborne.

TABLE 8.1—*Typical administered activities of radiopharmaceuticals used in veterinary nuclear medicine.*

Radionuclide	Radiopharmaceutical[a]	Animal Species	Nuclear Medicine Study Type	Administered Activity (MBq)[b]
Tc-99m	Pertechnetate	Canine	Thyroid	74–185
Tc-99m	Pertechnetate	Feline	Thyroid	37–148
Tc-99m	Pertechnetate	Equine	Thyroid	1,110
Tc-99m	Pertechnetate	Canine/feline	Portal	148–1,110
Tc-99m	HDP/MDP	Equine	Bone	4,440–8,880
Tc-99m	HDP/MDP	Canine/feline	Bone	148–1,110
Tc-99m	DTPA	Canine/feline	Renal	74–185
Tc-99m	IDA	Canine/feline	Hepatobilary	74–185
Tc-99m	MAA	Equine	Lung	1,110
Tc-99m	MAA	Canine/feline	Lung	74–185
Tc-99m	DMSA	Canine/feline	Renal	74–185
Tc-99m	DMSA	Equine	Renal	1,110
Tc-99m	Sulfur colloid	Canine/feline	Lymphoscintigraphy	37–148
Tc-99m	MAG3	Canine/feline	Renal	74–185
Tc-99m	MIBI	Canine/feline	Parathyroid/tumor	74–185
Tc-99m	HMPAO	Canine/feline	Whole blood count imaging	111–370

Radionuclide	Radiopharmaceutical[a]	Animal Species	Nuclear Medicine Study Type	Administered Activity (MBq)[b]
In-111	Indium chloride	Canine/feline	Inflammatory imaging or enteric protein loss	18.5–37
In-111	Octreoscan	Canine/feline	Neuroendocrine tumor imaging	18.5–74
I-123	Sodium iodide	Canine/feline	Thyroid	7.4–14.8
I-131	Sodium iodide	Feline	Hyperthyroid treatment	148
I-131	Sodium iodide	Feline	Thyroid tumor treatment	1,110–1,480
I-131	Sodium iodide	Canine	Thyroid tumor treatment	1,480–4,440

[a]DMSA = dimercaptosuccinic acid
DTPA = diethylene triamine pentacetic acid
HDP = hydroxymethylene diphosphonate
HMPAO = hexamethylpropyleneamineoxine
IDA = iminodiacetic acid
MAA = macroaggregated albumin
MAG3 = mercaptoacetyltriglycine
MDP = methylene diphosphonate
MIBI = methyl oxy-isobutyl-isonitrile
[b]37 MBq = 1 mCi.

Also, radionuclides in excreta that can become dried to a fine particle form can become airborne through agitation such as the transfer or emptying of animal bedding or litter.

The potential for the radionuclide to become airborne *shall* be considered, in advance, and if significant, *shall* be planned for accordingly. Planning might require the housing of the animal in rooms or cubicles designed with airflow and filtration systems that prevent release of the radionuclide to the environment. Filters *shall* be appropriate for the material under consideration. The high-efficiency particulate air filters work well for particles but not necessarily for gases such as radioiodine, which is best filtered with activated charcoal. Chemical scrubbers might be required to remove organic radiochemicals from effluents. Specific guidance on ventilation systems is available from ACGIH (2001), ANSI/AIHA (2001; 2003), ANSI/ASHRAE (2001), Cooper and Alley (1994), Kathren *et al*. (1980), McDermott (1985), Plog and Quinlan (2002), and UL (1996).

Airborne radioactive material *should* also be considered when prescribing procedures to protect individuals who administer radiopharmaceuticals to the animals or provide care for the animals after administration. Estimates of potential airborne concentrations *shall* be used to determine appropriate stay times in the holding areas or masks to be worn while caring for the animals.

8.1.2 *Radiation Exposure Control*

The physical characteristics of the radionuclide(s) used will determine whether external radiation exposure needs to be considered. For low-energy, pure beta emitters such as ^{3}H, ^{14}C, ^{35}S, radiation levels external to the animal are not significant. Usually, the same is true for ^{32}P, but its high-energy beta particles can undergo interactions that lead to the formation of x rays (bremsstrahlung) that can be an external radiation concern, especially when it is used in small animals. Radiation levels following administration of ^{32}P *shall* be measured and dealt with appropriately.

Alpha particles do not cause an external radiation hazard, but many alpha emitters also emit gamma rays, and if so, they *shall* be considered. External radiation levels from gamma-emitting radionuclides *shall* be measured so appropriate precautions can be issued for caretakers. External radiation levels *shall* also be measured and considered when releasing an animal to its owner and when prescribing written precautions for the owner to follow. NCRP (1993) recommended a limit of 1 mSv as an annual effective

dose limit for continuous exposure of the public and 5 mSv as the annual effective dose limit for infrequent exposure. These recommendations have been adopted by the regulatory agencies for doses from released human patients. No less stringent limits *shall* be used with the release of animal patients.

8.1.3 *Contamination Control*

Once injected into the animal's body, a radionuclide will be readily metabolized or eliminated from the body. All body fluids become contaminated; thus urine, blood and saliva can be sources of contamination. Certain compounds are metabolized and can also be eliminated by respiration or by way of the gastrointestinal tract. Determining the routes by which the material will leave the body is important so contamination measures can be implemented. Also, the handling of materials that are contaminated by the animal (such as bedding) needs to be given appropriate consideration. When unsealed radionuclides are used, contamination control requires careful planning.

To prevent cross-contamination of other animal patients, the radioactive animal *should* be kept in a separate cage or stall. Bedding, feeding or drinking utensils *should* not be shared with other animal patients. Care *should* be taken to prevent other animal patients from coming in contact with contaminated bedding or litter. Drainage or run off from runs or stalls *should* flow into a restricted area or sewage in a manner that prevents accidental contamination of hospital personnel or other animal patients.

Care *should* be exercised to ensure that those materials that become contaminated do not lead to further contamination or to exposure of personnel. Bedding that is contaminated *shall* be handled with caution so that it does not lead to spread of contamination or airborne radioactive material. For small animals, metabolism cages *should* be chosen to permit collection of all the material excreted by the animal. Care *should* be taken in emptying bedding and in the manner in which the cages are cleaned so as to control and collect rather than spread the contamination. Any spilled bedding *shall* be cleaned up immediately. Likewise, care *should* be exercised in handling or coming into contact with the treated animal as the animal too will become contaminated through contact with contamination in its excreta or through the process of licking or grooming itself with saliva that might be contaminated.

Following the cleaning of cages for small animals, surveys *should* be done of the cages and the surrounding surfaces (benches,

floors) that might have become contaminated in the cleaning process. Cages that have residual contamination *should* be cleaned by hand and resurveyed to verify decontamination before reuse or before sending them to the cage washers. Individuals involved in the care of such animals *should* be appropriately protected with disposable gloves, laboratory coats, masks, protective eyewear, and shoe covers or booties, as needed. If airborne contamination is possible, appropriate respiratory protection (from surgical mask to self-contained breathing apparatus) *should* be used to prevent inhalation of radioactive material. Effective procedures for surveying and removing shoe covers, gloves and masks *should* be rigidly followed and documented. These actions constitute universal precautions, where the objective is to protect oneself from radioactive contamination *via* inhalation, ingestion or contact.

Large animals such as horses may be encountered in clinical practice, while cows, swine and sheep are more likely to be used as research subjects. Stalls and pens for these animals are of particular concern because the caretaker may have to walk inside the stall or pen in radioactively contaminated excreta from the animal. If this is necessary, appropriate boots *shall* be worn (in addition to the other protective gear mentioned above) and procedures for surveying and removal of contamination upon exit from the pen and documenting the results *shall* be developed. Where possible, the animal *should* be confined to a limited space until the potential for radioactive contamination from the animal has passed. Animals will contaminate themselves through licking or by contact with contamination in their excreta, therefore all surfaces of the animal *should* be considered potentially contaminated. Once the procedure is complete, decontamination of the animal, through bathing, and cleanup of the stall or pen *should* be considered. For short-lived radionuclides such as ^{99m}Tc (6 h half-life), these problems are lessened and radioactive decay can be used as the primary method of decontamination. For longer-lived radionuclides such as ^{131}I (8 d half-life), decay of the radionuclide is an impractical method of decontamination.

8.1.4 *Shielding*

Shielding animals is usually impractical, especially with larger animals. However, where needed, mobile shields can be used as shadow shields to protect anatomical areas of concern. Lead or leaded materials work well for shielding nuclear medicine staff for the gamma rays from ^{99m}Tc and ^{131}I. The HVL in lead (thickness needed to reduce the radiation intensity by 50 percent) for ^{99m}Tc is

0.3 mm and for ^{131}I it is 3 mm. Thus a leaded apron of 0.5 mm might provide appreciable protection for the gamma rays from ^{99m}Tc, but it will provide little protection for the higher gamma-ray energies from ^{131}I. If the exposure to personnel is expected to be low, use of lead aprons *should* be evaluated taking into consideration the potential for injury, inhibition of movement, and extension of exposure time that may result from wearing the apron. Aprons *should* be specifically tested for effectiveness in shielding against the gamma rays from specific radionuclides before relying on them for protection.

Usually, making use of the radiation reduction provided by distance is easier than installing shielding. When distance precautions are necessary, radioactive materials warning tape or rope *should* be used to indicate the safe distance line. The area *should* also be posted to prevent individuals from unknowingly entering the radiation area caused by the animal(s).

8.1.5 *Individual Monitoring*

The requirements for individual monitoring are discussed in Section 3.4. When unsealed radionuclides are used, there exists a potential for both external exposure from radiations emitted by the sources and internal doses from radioactivity taken into the body through inhalation, ingestion, skin absorption, or through body penetrations resulting from accidents.

The RSO, in consultation with a qualified expert, *shall* determine the need for a bioassay program [*i.e.*, an interpretation of dose from radioactive materials taken into the body (NCRP, 1987b) to assess internal exposure]. When radioactive iodine is used for radiation therapy, the RSO *should* institute and oversee periodic thyroid counting of potentially exposed persons. While the most common form of bioassay is a thyroid count for individuals working with radioiodine, for other radionuclides bioassay might involve the analysis of urine, feces, blood, sputum or breath, depending on the radionuclide and its metabolic fate. The taking of such samples is timed to the metabolic process for the radioactive compound to ensure correct interpretation of any activity found in the analyzed sample. While there is a minimal chance of it ever being needed in a veterinary practice, another method of bioassay is through the whole-body counting for gamma-ray emitting radionuclides. Typically, the type and activity of radionuclide used will determine the bioassay method. This information will be derived from survey results, air sample results, or the occurrence of an accident while handling radioactive material.

Bioassay *should* be performed on a regular basis, but the frequency will vary with radionuclide usage. The frequency *should* be about once a month for those using radioiodine in radioimmunoassay. The amount of radioiodine administered to veterinary patients for therapeutic reasons is much higher and bioassay *should* be performed more frequently. If the use of ^{131}I for therapy is infrequent, then a bioassay *should* be performed after each administration to an animal. A typical procedure for individuals involved in the therapeutic administration of radioiodine to a veterinary patient would be: obtain a urine sample the day following the radioiodine administration and count the sample in a sodium-iodide well counter; or, alternatively, the thyroid can be scanned with a sodium-iodide probe within a week following the radioiodine administration if a urine sample was not obtained. Since iodine is concentrated in the thyroid, a thyroid uptake measurement would be preferable and more practical than a whole-body scan. Bioassay normally is not necessary for ^{99m}Tc.

8.1.6 *Surveying and Posting*

Radiation surveying and posting recommendations are discussed in Sections 3.5 and 3.6.

8.2 Emergency Response

A radiation emergency plan *should* be in effect and everyone involved with the use of radioactive materials *should* be aware of the appropriate steps to control an emergency involving radioactive materials. While specific and extensive guidance is given in NCRP Report No. 111 (NCRP, 1991), the general procedures that need to be taken when an emergency occurs that involves radioactive materials are as follows:

- If external radiation levels are high, evacuate personnel from the accident area. If a possibility of contamination exists, assure that evacuees are confined until monitored.
- Confine contamination in the accident area to prevent further spread. If the accident involves liquid, use absorbent material (paper towels, bench pads, etc.) to keep it from spreading. If the material is volatile, leave the room and close the door. Remove contaminated clothing and shoes before going to a clean area. Prevent further personnel access to the radiation area.

- Obtain RSO assistance promptly.
- Locate and monitor all persons who may be contaminated. Perform simple decontamination (mild soap and warm water), if necessary, and re-monitor. Give first aid if needed.
- If injuries are involved, get emergency medical help. If the injured person is possibly contaminated, advise emergency medical personnel so appropriate precautions can be taken.

8.2.1 *Surface Contamination*

Wear gloves, shoe covers, and other protective clothing when cleaning up any spill. First blot up any radioactive liquid (place soaked pads, etc., into a plastic bag). Always wipe from the spill perimeter in toward the center of the spill. Discard towels when wet. Change gloves when the area is dry. Monitor the area to determine if any contamination remains and its extent (look for contamination that might have splashed onto furnishings and fixtures). Use caution when removing contamination to ensure that the decontamination process does not lead to the spread of contamination (*e.g.*, put contaminated paper towel wipes in a plastic bag or radioactive waste container, and do not touch clothing or skin with contaminated gloves).

If contamination remains, reclean with soap and water, again working from the perimeter toward the center. Monitor and repeat this process as often as necessary until no further reduction in count rate is seen.

Contaminated tools and equipment *should* first be wiped with damp soapy disposable towels, then dried and monitored. If necessary, soak the tools and equipment in a strong cleaning solution for several hours. Save the cleaning solution for processing as radioactive waste. Monitor and repeat the process if necessary. All materials used in the cleanup operation *should* also be considered radioactive to prevent cross contamination. Protective apparel including gloves *should* be worn during the process.

8.2.2 *Skin Contamination*

If skin is contaminated with radioactive materials:

- Call the RSO for assistance.
- Carefully wash the affected area with plain soap and warm water. Use caution and minimal water so as not to spread the contamination. If the contamination is on areas of the

body other than the hands and forearms, attempt cleaning using paper towels or gauze pads moistened with soapy water.
- Resurvey the area and repeat washing, as needed. If skin begins to redden, cease efforts immediately.
- For puncture wounds, run water over the puncture for several minutes and let the wound bleed freely. Monitor the wound to determine the presence of contamination. If no contamination is detected, handle the wound in the usual manner for puncture wounds. Seek medical attention as indicated.

8.2.3 *Animal Patient Medical Emergencies*

In some situations (*i.e.*, large veterinary medicine hospitals), the radioactive animal patient may need to be transferred to the hospital's intensive care unit for treatment or surgery. When this happens, an RSO *should* be present. The RSO *should* provide written procedures for safely dealing with and handling the animal and ensure that the intensive care unit veterinarians and staff are appropriately trained and understand the necessary radiation safety procedures.

8.3 Waste Disposal

8.3.1 *Waste Forms*

Radioactive waste can occur as liquids, solids or gases. The appropriate disposal method depends on the form of the waste and the radionuclides.

8.3.1.1 *Liquid Form Radioactive Waste*. Because nearly all radioactive material used in biomedical research and animal nuclear medicine is in liquid form, an appreciable percentage of the waste that is generated in these applications is also liquid. Liquid form radioactive waste is further classified as being either aqueous or nonaqueous and may contain hazardous chemical compounds as well as radioactivity (*i.e.*, making it a mixed waste).

8.3.1.2 *Liquid Scintillation Fluids*. The majority of samples counted in biomedical research make use of liquid scintillation counting. The liquid scintillation counting media (cocktails) traditionally contained toluene or xylene. However, in recent years,

almost all researchers have switched to liquid scintillation cocktails that do not contain these hazardous chemicals and are biodegradable. The elimination of hazardous chemicals such as toluene and xylene in liquid scintillation cocktails has removed the concern over disposal of these wastes as mixed waste and, in many instances, has allowed for disposal *via* the sanitary sewer (Section 8.3.2.2).

8.3.1.3 *Solid Form Radioactive Waste*. Solid form radioactive waste from biomedical research and animal nuclear medicine results from the contamination of materials used to prevent contamination of the user or the work area and from laboratory ware and instruments that are used in the experimental, diagnostic or therapeutic procedures. Occasionally, solid form radioactive material results from contaminated equipment or furnishings that cannot effectively be decontaminated. Solid form radioactive material typically consists of animal feces, litter, bedding, disposable gloves, paper towels, absorbent pads, disposable pipettes, syringes, test tubes, and beakers. Solid form radioactive waste can also be in the form of ash from the incineration of radioactive carcasses or bedding.

8.3.1.4 *Radioactive Animal Carcasses*. Although the use of animals in biomedical research has decreased over the past 10 y, animals continue to play an important role in certain biomedical research projects. Disposal of radioactive animal carcasses by burial is unacceptable, thus requiring disposal by other means.

A clinical animal patient that dies or is euthanized while still radioactive *should* be stored in a refrigerated area until the carcass reaches the release criterion required by the appropriate local, state or federal authority (see also Section 8.4). Refrigeration capabilities *should* have appropriate shielding with adequate storage capability to accommodate the animal species imaged or treated. The storage area *should* be properly marked with radiation signage. Since there will be no biologic clearance of the radiopharmaceutical, the holding time will be longer than it is for a live animal.

When the half-life is too long to allow decay-in-storage, licensed commercial radioactive waste brokers can arrange for incineration of carcasses and disposal of the radioactive ash at a licensed radioactive waste disposal facility. Animals treated with brachytherapy sources *shall* have the sources removed prior to disposal.

8.3.1.5 *Radioactive Gases*. Radioactive gases are rarely used in veterinary nuclear medicine. Xenon-133 has no practical clinical

application but is used in biomedical research. Certain quantities of radioactive gases can be released to the atmosphere provided records are maintained and the releases are within acceptable limits. When large quantities of radioactive gases are generated, trapping systems (Miller *et al*., 1979) can be used to minimize environmental releases.

There are indications for the uses of radioaerosols in veterinary medicine. A small jet nebulizer is used to nebulize ^{99m}Tc-DTPA into small aerosol droplets that are inhaled by the animal. The aerosol particles will pass into the terminal bronchi and alveolar space in the lung. Most particles come in contact with the alveolar membrane and are slowly absorbed. Some aerosol droplets will remain suspended and are exhaled by the animal. A trap or filter is attached to the outflow circuit to remove the aerosol particles from the air. The nebulizer contains a large quantity of ^{99m}Tc (1,480 to 2,220 MBq) (see Glossary) and needs to be adequately shielded. If a mask is used to administer the aerosol to the animal, an air-tight seal needs to be achieved with the muzzle of the animal to prevent the escape of the aerosol into the room. Also the muzzle, nasal and oral cavity will be contaminated with aerosol particles and care needs to be taken to prevent cross-contamination of personnel and facilities. All equipment *should* be held for 10 half-lives to allow for decay.

8.3.2 *Disposal Options*

The method of disposal of radioactive waste material depends on its radionuclide content and its form. Employing a radioactive-waste broker can be an effective and economical alternative for disposal of radioactive waste.

8.3.2.1 *Disposal by Decay-in-Storage*. Decay-in-storage is a permissible (Edwards *et al*., 1996; Emery *et al*., 1992; NRC, 1999b; Party and Gershey, 1989; Ring *et al*., 1993) and effective method of radioactive waste disposal that is usually limited to radionuclides that have half-lives <120 d. The waste shall be surveyed to ensure that the radionuclide has reached its background level prior to disposal as normal trash. All radioactive material signs and labels shall be destroyed or obliterated. Cooperation on the part of users in keeping wastes separated according to half-lives can greatly increase the volumes of radioactive wastes that can be managed in this manner. Animals disposed of in this manner shall not be used for human consumption or animal feed.

8.3.2.2 *Hydrogen-3 and Carbon-14 in Liquid Scintillation Fluids and Animal Carcasses*. 10 CFR Part 20.2005 (NRC, 1999a) permits the disposal of liquid scintillation fluids and animal carcasses as if they were not radioactive, provided the concentration of these two radionuclides is $<1.85 \times 10^3$ Bq g^{-1} for the liquid scintillation fluid or the animal carcass, when averaged over the weight of the entire animal. Animals disposed of in this manner shall not be used for human consumption or animal feed.

8.3.2.3 *Disposal by Release into Sanitary Sewer*. Disposal of animal excreta and waste radiopharmaceuticals *via* the sanitary sewer is permissible (Hamano *et al*., 1993; Party and Gershey, 1989; NRC, 1999a) provided the radioactive material is readily soluble (or readily dispersible biological material) in water; and:

- disposal is done in accordance with federal, state and local regulations;
- the average monthly concentration does not exceed the limits specified by NRC (1999a);
- the sum of the fractions for each radionuclide does not exceed unity; and
- the total quantity of radioactive material released into the sanitary sewer in 1 y does not exceed 185 GBq for ^{3}H, 37 GBq for ^{14}C, and 37 GBq for all other radioactive materials combined.

8.3.2.4 *Disposal by Incineration*. Disposal by incineration is permitted provided the individual or institution has specific license approval for incineration. Incineration can involve the release of radioactive material to the environment and can lead to radioactive ash that requires collection and processing for disposal (Emery *et al*., 1992; Hamrick *et al*., 1989; King *et al*., 1988; Party and Gershey, 1989; Ring *et al*., 1993; Tries *et al*., 1996).

8.3.2.5 *Disposal of Radioactive Animal Carcasses*. Disposal of radioactive animal carcasses can be handled in a variety of ways, depending on the radionuclide(s) used. Radioactive animal carcasses are not accepted at commercial radioactive waste disposal facilities. Therefore, they need to be processed prior to disposal of their radioactive content. Incineration (King *et al*., 1988; Tries *et al*., 1996) is an effective method of disposal. A licensed radioactive waste incineration facility has the capability of incinerating the waste, retrieving the radioactive material in the ash, processing it into acceptable form and transferring it to a commercial disposal facility.

However, incineration is not always available and other techniques have been developed, including chemical digestion (Kaye *et al*., 1993), dry-distillation (Saito *et al*., 1995), freeze-drying (Hamawy, 1995), and the use of dermestid beetles for biodegradation (Party *et al*., 1995). For short-lived radionuclides, freezing of the carcasses until the activity has decayed works best. However, for long-lived radionuclides, incineration at a licensed facility is usually the only solution.

8.3.2.6 *Disposal by Filtration*. Filtration as a means of volume reduction and optimization of storage space has been used both for aqueous radioiodine (Bohner *et al*., 1983; Edwards *et al*., 1996) and radioactive gases (Miller *et al*., 1979).

8.4 Operational Precautions

8.4.1 *Use of Radionuclides in Animals*

Personnel who will be involved in the routine or emergency care of radioactive animals need to be given specific instructions regarding the animals, radionuclides and activities administered, care and feeding, cage or enclosure cleaning, and waste disposal. Such instructions *should* be in writing.

8.4.2 *Release of Treated Animals and Directions for Owners*

External radiation levels *should* be measured and contamination potential *should* be determined when releasing an animal to its owner and in prescribing written precautions for the owner to follow. NCRP (1993) recommended a limit of 1 mSv as an annual effective dose limit for continuous exposure of the public and 5 mSv as the annual effective dose limit for infrequent exposure. These recommendations have been adopted by the regulatory agencies for doses from released human patients. These limits *shall not* be exceeded with the release of animal patients. In general, it will be the animal treated with ^{131}I therapy that will present the potential for exposure and contamination once the animal is released. Veterinarians *shall* provide the owner with written instructions, including caution against holding the animal (see last paragraph of this Section), that provide adequate information so that no problems arise and so that with reasonable precautions, the pet owner will remain below the effective dose limit recommended for members of the public. Typical guidelines for the owner are given in Appendix D.

The most common method for determining the release of a treated animal is by measuring the external exposure rate from the animal to an individual using a Geiger-Mueller counter. Release criteria vary from state to state, depending on whether the state is an NRC Agreement State. A typical release criterion is ≤ 0.5 mR h^{-1} (exposure rate) at 1 m, which would ensure that the owner would not exceed the limit of 1 mSv annual effective dose. Time to release after administration of the radiopharmaceutical is dependent on both the administered activity and the biological clearance of the radionuclide. The biological clearance will vary from animal to animal and therefore an actual external exposure rate measurement for each animal is preferable. Surface exposure rates are very dependent on the probe location, so measurement at 1 m is recommended since there will be less variation than for a surface reading. Also, a distance of 1 m is more typical of the distance a human being may be from the animal. However, the veterinarian *should* still consult with the state regulatory agency to confirm the appropriate release criterion for that state.

This release criterion of ≤ 0.5 mR h^{-1} exposure rate at 1 m may be used for both radioiodine and radiotechnecium. For example, most cats treated for hyperthyroidism with 148 MBq of ^{131}I will reach this exposure rate within one week. Animals scanned using ^{99m}Tc would be releasable within 24 h of injection.

Owners *should* be cautioned against holding the animal for some time following release depending on the exposure rate and the half-life of the radionuclide. If the exposure rate is 0.5 mR h^{-1}, a reasonable time to wait would be two to four half-lives (Appendix D).

8.5 Training

The use of radioactive materials or other sources of radiation demands appropriate training for all who will participate or otherwise be involved. Recommendations for radiation safety training are discussed in Section 3.3.

9. Nonionizing Radiation

9.1 Lasers

For several decades, surgical lasers have been in use in medical practice dealing with human beings, at veterinary schools, and in animal surgical clinics (ANSI, 1996). More recently, veterinarians are introducing lasers into general practice. The disease conditions that lend themselves to the use of laser surgery are varied (*e.g.*, Bennett *et al*., 1998; Blikslager *et al*., 2001; Clark and Sinibaldi, 1994; Dickey *et al*., 1996; Gilger *et al*., 1997; Hawkins *et al*., 2001; Howard *et al*., 1998; Krohne *et al*., 1995; Miserendino *et al*., 1994; Palmer, 1993; Peavey *et al.*, 1992; Rothaug and Tulleners, 1999; Sedrish *et al*., 1997; Shelly *et al*., 1992; Tetens *et al*., 1994).

9.1.1 *Laser Classifications*

Lasers are classified according to the ability of the direct or reflected primary laser beam to cause biological damage to the eye or skin during use (ANSI, 2000). The classification is based on the emission accessible to an individual during normal operation or maintenance (AAPM/ACMP, 2001; ACGIH, 2004, ANSI, 2000; Classic, 1992; FDA, 2004d; ICNIRP, 2000; Marshall and Sliney, 2000).

Class 1. Because these lasers are incapable of producing biological effects under normal operating conditions, no safety requirements exist (this does not apply to embedded Class 3b or 4 lasers that are Class 1 during normal operation but 3b or 4 during service or maintenance, *e.g.*, beam alignment). The Class 1 accessible emission limit (AEL) for continuous-wave lasers ranges from 4×10^{-4} to 100 mW depending on wavelength emitted.

Class 2. This Class includes only lasers emitting in the visible (400 to 700 nm) wavelength range. Eye protection is normally afforded by the aversion response including the blink reflex (assumed to occur in <0.25 s). The AEL for Class 2 is 1 mW.

- *Class 2a*. Those systems intended for a specific use where the output is not intended for viewing belong in Class 2a. Radiation from Class 2a lasers is not considered to be hazardous if viewed for any period of time ≤1,000 s. The radiation is considered to be a chronic viewing hazard for longer exposure times.

Class 3. The AEL of a Class 3 laser is greater than that of a Class 1 but <500 mW. However, the AEL is dependent on wavelength and exposure duration. The direct beam or the specular reflection of the direct beam may be hazardous, but diffuse reflections are not normally hazardous. Two subclasses of Class 3 lasers exist:

- *Class 3a*. Lasers with an AEL up to five times the Class 1 AELs for wavelengths in the invisible range (<400 or >700 nm), or up to five times the Class 2 AELs for wavelengths in the visible range (400 to 700 nm).
- *Class 3b*. All other lasers with an AEL greater than Class 1 but <500 mW.

Class 4. Class 4 represents the highest hazard level lasers and includes continuous-wave lasers with AEL >500 mW. Class 4 lasers are a hazard to the eye or the skin from the direct and reflected beam, including some diffuse reflections. Class 4 lasers can also be a fire hazard and may produce laser generated air contaminants and hazardous plasma radiation.

Manufacturers are required to classify lasers based on maximum accessible output emissions prior to sale. However, any modifications of the unit can affect the emissions and might require reclassification.

9.1.2 *Surgical Lasers*

Surgical lasers are typically of the carbon dioxide or neodymium:yttrium-aluminum-garnet types. They are all Class 4, have invisible laser beams, and represent unique hazards that need to be considered for them to be used safely.

9.1.3 *Direct Hazards*

9.1.3.1 *Eye Damage*. Biological effects in the eye depend on the wavelength of the laser beam and the amount of energy absorbed

by the structure of the eye. The retina absorbs visible and near-infrared wavelengths (400 to 1,400 nm). Focusing by the cornea and lens of the eye can increase the irradiance (W m^{-2}) or radiant exposure (J m^{-2}) of the retina by as much as 10^5. The "blue light region" includes wavelengths in the 400 to 500 nm range and is so-named because of the significant retinal hazard associated with photochemical damage from long-term exposure to those wavelengths. The cornea absorbs middle ultraviolet (200 to 315 nm) wavelengths, possibly causing photokeratitis, and far-infrared (3,000 to 10^6 nm) wavelengths causing corneal burns. Near-ultraviolet (315 to 400 nm) and middle-infrared (1,400 to 3,000 nm) wavelengths penetrate further, to the lens of the eye. These wavelengths may contribute to the production of cataracts. Users of Class 3 and 4 lasers and all personnel in the rooms *shall* wear appropriate protective eyewear.

9.1.3.2 *Skin Burns*. Surgical lasers are designed to burn tissue. In like fashion, they can cause burns to the operator and assistants accidentally exposed to the laser beam.

9.1.4 *Indirect Hazards*

9.1.4.1 *Hazardous Materials*. Products used for laser operations and airborne contaminates created by laser interactions with tissue are potentially hazardous to the user and others in the immediate area. The National Institute for Occupational Safety and Health (Mackison *et al*., 2004) has set permissible exposure limits for the allowable concentration of these contaminants. Smoke evacuation equipment (capable of filtering particles down to 0.1 μm diameter) *should* be used during any process where plumes might ensue from the laser procedure.

9.1.4.2 *Electrical*. The electrical systems associated with Class 4 lasers can be lethal. Only authorized, specifically trained individuals *shall* repair and troubleshoot these laser systems.

9.1.4.3 *Fire*. A Class 4 laser can cause a fire if the beam interacts with flammable materials. The laser *should* be positioned carefully prior to activation of the laser beam. Flammable materials in the target area *should* be dampened prior to activating the beam. Anodized, blackened or brushed instruments *should* be used when performing laser surgery to prevent reflection of the laser beam. An appropriate fire extinguisher *shall* be in the room when laser surgery is in process.

9.1.5 *Precautions*

- *Signs*. Appropriate "Laser in Use" signs *shall* be placed on the doors leading into the laser use area prior to laser surgery.
- *Windows*. Windows in the laser use area *should* be covered prior to laser surgery.
- *Fire Extinguisher*. An appropriate fire extinguisher *shall* be available in the laser use area before beginning surgery.
- *Protective Eyewear*. Each person in the room *shall* wear appropriate protective eyewear.
- *Smoke Evacuator*. An appropriate smoke evacuator *should* be in place and working before beginning laser surgery.
- *Surgical Instruments*. Only nonreflective surgical instruments *should* be available in the laser surgery area.
- *Flammables*. All flammables in the target area *shall* be appropriately dampened before beginning surgery.
- *Laser Positioning*. The distal end of the light guide *shall* be positioned in place at the site of operation before placing the laser in the "ready" mode.
- *Operation*. The laser *should* be placed in stand-by mode at all times when it is not being used. Occasionally, during the procedure, a visual inspection of the dials and mode indicators *should* be made.

9.1.6 *Post-Operative Procedures*

Following the operation, the laser *shall* be turned off and stored in accordance with manufacturer's instructions. Laser warning signs *should* be removed. Protective eyewear *should* be collected and inspected for damage. All necessary documentation *shall* be completed.

9.2 Ultrasound

In more than three decades of use, there has been no report of injury to patients or to operators from medical ultrasound equipment (AIUM, 1994). The risk to patient and operator are theoretical and not based on clinical findings. Nonetheless, responsible use of diagnostic and therapeutic devices *shall* include safety procedures. The American Institute of Ultrasound in Medicine recommends an ALARA-principle approach to ultrasound safety.

9.2.1 *Bioeffects*

A complete discussion of the mechanisms and biological effects related to the diagnostic use of ultrasound is found in NCRP Report No. 140 (NCRP, 2002). A brief description of the relevant effects is given in this Report.

9.2.2 *Thermal*

Ultrasound causes heating of the medium (tissues). Increases of 15 $^{\circ}$C or greater are considered potentially harmful. Heating is a complex function of which ultrasound output power is only one factor. Highly vascular structures are more tolerant as the blood flow will dissipate the heat. Tissue-bone interfaces or tissue-air interfaces concentrate the ultrasound energy and may form "hot spots" where heating is multiplied.

Stationary application will result in more heating than if the transducer is in motion. Higher frequencies are absorbed to a greater degree than the same power of a lower frequency beam. Some specialized scanners, such as Doppler imagers, may have the capacity for relatively high power output.

9.2.3 *Nonthermal*

The major nonthermal effect is cavitation. The formation of microscopic bubbles is the mechanism for the ultrasonic cleaners and dental equipment. If cavitation occurs, then cells in the region may be disrupted. This effect is felt to be highly improbable at diagnostic output levels (NCRP, 2002).

9.2.4 *Operational Safety*

Presently, the use of diagnostic ultrasound has eclipsed that of therapeutic applications. The power levels and biohazards of diagnostic ultrasound are far less than those of the low frequency (~1 MHz) and higher power of the therapeutic devices.

9.2.4.1 *Diagnostic Ultrasound*. Safety in diagnostic applications consists of using the lowest possible power level consistent with the imaging goal. Operators *should* make maximum use of gain, post processing, and other image manipulation technology to avoid increasing power output to obtain a useful image. The simple procedure of dimming the room lights may make it possible to complete a study with a lower power output. The transducer *should* not

be placed in a stationary position for an extended time. Some experimental work indicates that stationary imaging of 10 to 20 min would be required to cause significant heating. This is unlikely to occur in veterinary examinations. Special consideration *should* be given to Doppler studies to limit the exposure to the minimum time consistent with the study's goals.

9.2.4.2 *Therapeutic Ultrasound*. Therapeutic ultrasound produces heating in the tissues and this may be a major component to the therapeutic effect. The high power output makes therapeutic ultrasound capable of causing pain and injury. The machine's output is limited to 3 to 5 W cm^{-2} and few operators will run at a lower power even if the machine offers such an option. Therefore, careful positioning is essential to avoid building up a reflection over a tissue-bone interface. The transducer *shall not* be allowed to become stationary. Therapeutic ultrasound is intended for stimulation of deep muscles and *should not* be used over major joints or other locations where there is minimal soft tissue overlying the bone.

9.2.5 *Use of Veterinary Ultrasound on Human Beings*

No practice permits the use of veterinary diagnostic or therapeutic ultrasound devices on human beings except at the direction of a physician or other human health care provider. Veterinarians *shall not* allow such devices under their control to be used on human beings.

Appendix A

Shielding Recommendations for Veterinary X-Ray Imaging Facilities

The tables in this Appendix present recommendations for primary (Table A.1) and secondary (Table A.2) barrier shielding for veterinary x-ray imaging facilities, including fluoroscopy. The recommendations are given in thickness of lead, gypsum wallboard, and concrete normalized to the quantity WUT/Pd^2 (see Equation 4.1) where W is in units of mA min week^{-1}, P is in units of mGy week^{-1}, d is in meters, and U and T are dimensionless.

As an example, consider a radiographic unit operating at a maximum 125 kVp with W = 50 mA min week^{-1}. Assume that half of the exposures are made with the beam directed horizontally at a wall (U = 0.5) separating the examination room from a public waiting area (uncontrolled) that is occupied full-time during the day by a receptionist. The receptionist works in an uncontrolled area, so the shielding design goal (P) is 1 mGy y^{-1} (0.02 mGy week^{-1}), while T = 1 (Table 4.1). The occupancy factor (T) for members of the public who may be in the waiting area from time-to-time can be taken as 1/20 (Table 4.1) (NCRP, 2004), and again P is 1 mGy y^{-1} (0.02 mGy week^{-1}). Under these conditions, P/T for the receptionist is 0.02 mGy week^{-1}, while P/T for the rest of the occupants is 0.4 mGy week^{-1}. Thus P/T for the receptionist is the limiting condition. Finally, the distance from the x-ray source to the location of the receptionist's workstation is d = 3 m.

For this example, WUT/Pd^2 is approximately 140. The required shielding for the barrier wall is determined from the data in Table A.1 to be about 2 mm of lead (~3/32 inch of lead wallboard) or 15 cm of concrete.

TABLE A.1—*Typical shielding requirements for primary barriers (veterinary x-ray imaging facilities).*

Operating Potential (kVp)	WUT/Pd^2	Lead Thickness (mm)	Gypsum Wallboard Thickness (mm)	Concrete Thickness (mm)
50	20	0.12	39	15
	40	0.15	52	19
	60	0.18	60	21
	80	0.20	66	23
	100	0.21	70	25
	200	0.26	86	29
	400	0.31	101	35
	800	0.36	118	40
	1,000	0.38	123	42
	2,000	0.44	140	47
	5,000	0.52	163	55
70	20	0.29	91	29
	40	0.39	117	37
	60	0.45	133	42
	80	0.49	144	46
	100	0.52	155	49
	200	0.64	182	59
	400	0.75	212	70
	800	0.88	241	81
	1,000	0.91	251	84
	2,000	1.04	281	96
	5,000	1.21	320	112
100	20	0.87	211	63
	40	1.11	256	77
	60	1.26	283	85
	80	1.37	303	92

Operating Potential (kVp)	WUT/Pd^2	Lead Thickness (mm)	Gypsum Wallboard Thickness (mm)	Concrete Thickness (mm)
	100	1.45	318	96
	200	1.72	365	112
	400	1.99	412	128
	800	2.26	459	144
	1,000	2.35	474	150
	2,000	2.62	521	167
	5,000	2.99	584	189
125	20	1.19	312	99
	40	1.45	370	118
	60	1.61	403	129
	80	1.73	427	137
	100	1.82	446	143
	200	2.11	504	163
	400	2.41	562	182
	800	2.71	620	202
	1,000	2.81	639	208
	2,000	3.11	697	228
150	20	1.32	403	135
	40	1.59	470	157
	60	1.75	509	169
	80	1.87	537	178
	100	1.96	559	185
	200	2.27	626	206
	400	2.58	693	228
	800	2.91	761	249
	1,000	3.02	782	256
	2,000	3.37	850	277

TABLE A.2—*Typical shielding requirements for secondary barriers (veterinary x-ray imaging facilities).*

Operating Potential (kVp)	WUT/Pd^2	Lead Thickness (mm)	Gypsum Wallboard Thickness (mm)	Concrete Thickness (mm)
50	20	0	0	0
	40	0	0	0
	60	0	0	0
	80	0	0	0
	100	0	0.4	0.2
	200	0.02	6.7	3.0
	400	0.05	14.0	6.0
	800	0.07	24.0	10.0
	1,000	0.08	37.0	11.0
	2,000	0.12	39.0	14.0
	5,000	0.17	56.0	20.0
70	20	0	0	0
	40	0	0	0
	60	0.01	1.7	0.7
	80	0.02	5.2	2.1
	100	0.03	8.4	3.3
	200	0.06	20.0	7.5
	400	0.11	36.0	12.0
	800	0.18	56.0	18.0
	1,000	0.20	63.0	20.0
	2,000	0.28	86.0	27.0
	5,000	0.40	121.0	38.0
100	20	0.01	2	1
	40	0.06	19	7
	60	0.11	32	12
	80	0.15	44	15

Operating Potential (kVp)	WUT/Pd^2	Lead Thickness (mm)	Gypsum Wallboard Thickness (mm)	Concrete Thickness (mm)
	100	0.18	53	18
	200	0.33	88	28
	400	0.51	127	40
	800	0.73	170	53
	1,000	0.80	185	57
	2,000	1.05	230	72
	5,000	1.40	291	92
125	20	0.07	19	7
	40	0.18	51	17
	60	0.27	75	25
	80	0.33	93	30
	100	0.39	108	35
	200	0.59	159	51
	400	0.82	213	68
	800	1.08	269	86
	1,000	1.17	287	92
	2,000	1.45	344	111
150	20	0.17	45	14
	40	0.32	91	31
	60	0.43	123	42
	80	0.52	146	50
	100	0.59	166	57
	200	0.84	228	77
	400	1.11	292	99
	800	1.42	358	120
	1,000	1.52	379	127
	2,000	1.86	446	148

Appendix B

Shielding Recommendations for Veterinary Radiation Therapy Facilities

The tables in this Appendix present TVLs for common barrier materials used with radiation therapy sources (Table B.1) and recommendations for primary (Table B.2) and secondary (Table B.3) barrier shielding for therapy facilities. The recommendations are given in thickness of lead, steel and concrete normalized to the quantity WUT/Pd^2 (see Equation 4.1) where W is in units of mA min week^{-1}, P is in units of mGy week^{-1}, d is in meters, and U and T are dimensionless.

As an example, consider primary shielding for a therapy unit operating at 6 MV with W = 50 Gy week^{-1}. Assume that 25 percent of the treatments are given with the beam directed horizontally at a wall (U = 0.25) separating the treatment room from a public waiting area (uncontrolled) that is occupied full-time during the day by a receptionist. The receptionist works in an uncontrolled area so the shielding design goal (P) is 1 mGy y^{-1} (2×10^{-5} Gy week^{-1}), while T = 1 (Table 4.1). The occupancy factor (T) for members of the public who may be in the waiting area from time-to-time can be taken as 1/20 (Table 4.1) (NCRP, 2004), and again P is 1 mGy y^{-1} (2×10^{-5} Gy week^{-1}). Under these conditions, P/T for the receptionist is 2×10^{-5} Gy week^{-1}, while P/T for the rest of the occupants is 4×10^{-4} Gy week^{-1}. Thus P/T for the receptionist is the limiting condition. Finally, the distance from the radiation therapy source to the location of the receptionist's workstation is d = 4 m.

For this example, WUT/Pd^2 is ~40,000. The required shielding for the primary barrier wall is determined from the data in Table B.2 to be ~155 cm (~5 feet) of concrete. Assume the secondary

radiation is due primarily to leakage radiation at 0.002 times (0.2 percent) the primary workload (Section 7.3.1), and that the use factor is one. So WUT/Pd^2 is approximately 315 for the secondary barrier walls assuming the same distance. The required shielding for the secondary barrier is determined from Table B.3 to be ~66 cm (~2 feet 2 inches) of concrete.

TABLE B.1—*TVL for common shielding materials used with veterinary radiation therapy sources (NCRP, 1977; Nelson and LaRiviere, 1984; Varian, 1991).*

Operating Potential or Energy	TVL (cm)		
	Concrete	Steel[a]	Lead
Primary radiation			
X rays (kVp)			
150	7.4		0.10
200	8.4		0.17
250	9.4		0.29
300	10.4		0.48
^{60}Co gamma rays	21	6.9	4.0
Electron linear accelerators (MV)			
4	28	8.9	5.3
6	34	9.9	5.5
10	40	10.5	5.6
Secondary radiation			
X rays (kVp)			
150	7.4		0.10
200	8.4		0.17
250	9.4		0.29
300	10.4		0.48
^{60}Co gamma rays	19	6.6	2.2
Electron linear accelerators (MV)			
4	25	8.4	5.2
6	27	8.9	5.3
10	36	10.2	5.5

[a]Steel is not used as a barrier material for x-ray sources in the range 150 to 300 kVp.

TABLE B.2—*Typical shielding requirements for primary barriers (veterinary radiation therapy sources).*

Operating Potential or Energy	WUT/Pd^2	Lead Thickness (cm)	Steel[a] Thickness (cm)	Concrete Thickness (cm)
150 kVp	100	0.2		15
	200	0.2		17
	500	0.3		20
	1,000	0.3		22
	2,000	0.3		24
	5,000	0.4		27
	10,000	0.4		30
	20,000	0.4		32
	50,000	0.5		35
	100,000	0.5		37
	200,000	0.5		39
	500,000	0.6		42
200 kVp	100	0.3		17
	200	0.4		19
	500	0.5		23
	1,000	0.5		25
	2,000	0.6		28
	5,000	0.6		31
	10,000	0.7		34
	20,000	0.7		36
	50,000	0.8		39
	100,000	0.9		42
	200,000	0.9		45
	500,000	1.0		48
250 kVp	100	0.6		19
	200	0.7		22
	500	0.8		25
	1,000	0.9		28
	2,000	1.0		31
	5,000	1.1		35
	10,000	1.2		38
	20,000	1.2		40
	50,000	1.4		44

Operating Potential or Energy	WUT/Pd^2	Lead Thickness (cm)	Steel[a] Thickness (cm)	Concrete Thickness (cm)
	100,000	1.5		47
	200,000	1.5		50
	500,000	1.7		54
300 kVp	100	1.0		21
	200	1.1		24
	500	1.3		28
	1,000	1.4		31
	2,000	1.6		34
	5,000	1.8		38
	10,000	1.9		42
	20,000	2.1		45
	50,000	2.3		49
	100,000	2.4		52
	200,000	2.5		55
	500,000	2.7		59
^{60}Co gamma rays	100	8	14	42
	200	9	16	48
	500	11	19	57
	1,000	12	21	63
	2,000	13	23	69
	5,000	15	26	78
	10,000	16	28	84
	20,000	17	30	90
	50,000	19	32	99
	100,000	20	35	105
	200,000	21	37	111
	500,000	23	39	120
4 MV	100	11	18	56
	200	12	20	64
	500	14	24	76
	1,000	16	27	84
	2,000	17	29	92
	5,000	20	33	104

Operating Potential or Energy	WUT/Pd^2	Lead Thickness (cm)	Steel[a] Thickness (cm)	Concrete Thickness (cm)
	10,000	21	36	112
	20,000	23	38	120
	50,000	25	42	132
	100,000	27	45	140
	200,000	28	47	148
	500,000	30	51	160
6 MV	100	11	20	68
	200	13	23	78
	500	15	27	92
	1,000	17	30	102
	2,000	18	33	112
	5,000	20	37	126
	10,000	22	40	136
	20,000	24	43	146
	50,000	26	47	160
	100,000	28	50	170
	200,000	29	52	180
	500,000	31	56	194
10 MV	100	11	21	80
	200	13	24	92
	500	15	28	108
	1,000	17	32	120
	2,000	18	35	132
	5,000	21	39	148
	10,000	22	42	160
	20,000	24	45	172
	50,000	26	49	188
	100,000	28	53	200
	200,000	30	56	212
	500,000	32	60	228

[a]Steel is not used as a barrier material for x-ray sources in the range 150 to 300 kVp.

TABLE B.3—*Typical shielding requirements for secondary barriers (veterinary therapeutic radiology facilities).*

Operating Potential or Energy	WUT/Pd^2	Lead Thickness (cm)	Steel[a] Thickness (cm)	Concrete Thickness (cm)
150 kVp	1	0		0
	2	0		2.2
	5	0.1		5.2
	10	0.1		7.4
	20	0.1		9.6
	50	0.2		12.6
	100	0.2		14.8
	200	0.2		17.0
	500	0.3		20.0
	1,000	0.3		22.2
200 kVp	1	0		0
	2	0.1		2.5
	5	0.1		5.9
	10	0.2		8.4
	20	0.2		10.9
	50	0.3		14.3
	100	0.3		16.8
	200	0.4		19.3
	500	0.5		22.7
	1,000	0.5		25.2
250 kVp	1	0		0
	2	0.1		2.8
	5	0.2		6.6
	10	0.3		9.4
	20	0.4		12.2
	50	0.5		16.0
	100	0.6		18.8
	200	0.7		21.6
	500	0.8		25.4
	1,000	0.9		28.2
300 kVp	1	0		0
	2	0.1		3.1

Operating Potential or Energy	WUT/Pd^2	Lead Thickness (cm)	Steel[a] Thickness (cm)	Concrete Thickness (cm)
	5	0.3		7.3
	10	0.5		10.4
	20	0.6		13.5
	50	0.8		17.7
	100	1.0		20.8
	200	1.1		23.9
	500	1.3		28.1
	1,000	1.4		31.2
^{60}Co gamma rays	1	0	0	0
	2	0.7	2	6
	5	1.5	5	13
	10	2.2	7	19
	20	2.9	9	25
	50	3.7	11	32
	100	4.4	13	38
	200	5.1	15	44
	500	5.9	18	51
	1,000	6.6	20	57
4 MV	1	0	0	0
	2	1.6	3	8
	5	3.6	6	17
	10	5.2	8	25
	20	6.8	11	33
	50	8.8	14	42
	100	10	17	50
	200	12	19	58
	500	14	23	67
	1,000	16	25	75
6 MV	1	0	0	0
	2	1.6	3	8
	5	3.7	6	19
	10	5.3	9	27
	20	6.9	12	35

Operating Potential or Energy	WUT/Pd^2	Lead Thickness (cm)	Steel[a] Thickness (cm)	Concrete Thickness (cm)
	50	9.0	15	46
	100	11	18	54
	200	12	20	62
	500	14	24	73
	1,000	16	27	81
10 MV	1	0	0	0
	2	1.7	3	11
	5	3.8	7	25
	10	5.5	10	36
	20	7.2	13	47
	50	9.3	17	61
	100	11	20	72
	200	13	23	83
	500	15	28	97
	1,000	17	31	108

[a]Steel is not used as a barrier material for x-ray sources in the range 150 to 300 kVp.

Appendix C

Quality Assurance for Radiographic and Nuclear Medicine Applications

C.1 Radiographic Quality Assurance

Radiation exposure to the animal patient, operator and members of the public can be reduced by minimizing the need for repeat exposures because of inadequate image quality. NCRP Report No. 99 (NCRP, 1988) is a comprehensive set of recommendations for quality assurance for diagnostic imaging. The term "quality assurance" describes a program for periodic assessment of the performance of all parts of the radiographic procedure. In addition to determination of x-ray machine performance by a qualified expert, film processing chemistry and procedures, image-receptor performance characteristics, and darkroom integrity need to be evaluated at appropriate intervals. These routine quality-assurance procedures can be performed by properly-trained veterinary office staff.

A written protocol for periodic quality control tests *shall* be developed and implemented for each x-ray machine, image-receptor system, and processor or darkroom.

C.1.1 *Radiographic X-Ray Equipment Performance*

All new veterinary x-ray installations and existing installations not previously surveyed *shall* have a radiation safety survey performed by, or under the direction of, a qualified expert. Resurveys *shall* be performed at regular intervals thereafter. The resurvey interval *should not* exceed 4 y. In addition, a resurvey *shall* be made after any change in the installation, workload or

operating conditions that might significantly increase occupational or public exposure (including x-ray machine service or repair that could affect the x-ray machine output or performance).

C.1.2 *Film Processing*

Processing solutions are subject to gradual deterioration. The deterioration may go unnoticed as it becomes severe enough to degrade image quality (*i.e.*, constancy of optical density and contrast, and overall quality of the resulting films). Darkroom chemistry and each film processor used in the veterinary facility *shall* be evaluated daily for performance.

C.1.2.1 *Sensitometry and Densitometry.* The most sensitive and rigorous method of darkroom quality assurance requires the use of a sensitometer, a precise optical device to expose a film to produce a defined pattern of optical densities in the processed film. These densities are then measured with a densitometer, and compared to the densities in a similarly-exposed film previously processed in fresh solutions under ideal conditions. A daily log is maintained; any change indicates a problem with processing, either development time or temperature or contaminated solutions. This method requires additional equipment but only a few minutes of operator time to execute. It is highly recommended for the busy veterinary facility, but simpler, less costly methods may be adequate for average veterinary offices.

C.1.2.2 *Stepwedge*. A standard radiographic film exposed through an aluminum stepwedge to a defined x-ray exposure may be substituted for the sensitometrically-exposed film. Overall size of the stepwedge *should* be similar to that of a standard veterinary film. It is made to resemble stairs. Each step of an aluminum stepwedge is 1 mm thick and about 3 to 4 mm wide. There *should* be at least six steps. Exposure parameters, including x-ray machine settings and exposure geometry are reproduced precisely for each exposure. The structure on which the film is placed will provide backscattered radiation that will affect film density. Thus the film and source are placed in the same position on the same structure for each exposure. The processed film is then compared visually with a reference film identically exposed and processed in fresh solutions under ideal conditions. Devices that facilitate this process are commercially available at modest cost. A reproducible change of one step or more in density, which is readily detectable visually and

readily confirmed by repeating the test, *should* signal the need for corrective action. The change in density may be the result of either a different x-ray exposure or differences in processing. Darkroom problems are more likely and *should* be corrected first. This method is less sensitive than sensitometry and densitometry, but *should* suffice for many veterinary facilities.

C.1.3 *Image Receptor*

Radiographic films, screen-film systems, and digital image receptors constitute an important part of veterinary radiology. Their performance is tested periodically to ensure that they function according to specifications.

C.1.3.1 *Film*. Unexposed film may become "fogged" by gradual chemical deterioration, which is temperature dependent and therefore may be slowed by storing film in a refrigerator. Alternatively, stray light or x rays may produce an increase in density of exposed or unexposed film. Exposure to certain chemicals, heat or pressure may produce fog or other artifacts. These artifacts may be detected by processing and evaluating an unexposed film. Evaluation is best performed with a densitometer but may be approximated by visual comparison of the current film with an unfogged film from a new box and processed in fresh solutions.

Each type of film used in the facility *shall* be evaluated for fog and artifacts monthly and each time a new box or batch of film is opened. When excessive fog is identified, the affected box or batch of film *shall* be discarded or returned to the vendor for replacement.

C.1.3.2 *Screen-Film Systems*. Both cassettes and screens may acquire defects during normal use. Integrity of cassettes is determined by visual inspection and by processing of an unexposed film that has been in the cassette for at least 1 h while the cassette is exposed to normal room illumination. Light leaks from the cassette will appear as dark streaks on the film. Screens are evaluated visually for surface defects such as scratches or fingerprints. Screen maintenance requires periodic cleaning, following the manufacturer's instructions. Poor screen-film contact leads to unsharpness in images. Screen-film contact and uniformity of response are best evaluated by exposing a film (in its cassette) overlaid with a piece of copper test screen. Visual inspection of the processed film for sharpness and uniformity of the image can assess performance of the imaging system.

Screen-film cassettes, including screens, *shall* be visually evaluated after any accident (such as dropping) for integrity and performance. Tests for screen-film contact *should* be performed every six months. Any defective items *shall* be promptly repaired or replaced.

C.1.3.3 *Digital-Imaging Systems*. Procedures for evaluating the performance of digital-imaging systems are quite different from those used with film or screen-film image receptors. By using appropriately designed phantoms and software, image quality aspects such as resolution, contrast, signal-to-noise ratio, and contrast-to-noise ratio may be measured directly (ICRP, 2004; NCRP, 1988). These image quality aspects are important factors when considering the purchase of digital-imaging systems.

Patient dose from digital-imaging procedures should adhere to the ALARA principle without compromising the necessary clinical image quality. Considerable guidance for management of patient dose and quality-assurance procedures in digital imaging is given by ICRP (2004).

C.1.4 *Darkroom Integrity*

Each darkroom is evaluated for light leaks and safelight performance. The test for fogging should use the fastest film normally handled in the darkroom. If more than one type of film is used, then the fastest film of each type should be tested. A visible light exposure should be made on the film with a stepwedge or sensitometer so that a complete range of densities is obtained. Exposure of this test film for 1 min in the darkroom with the safelight on should produce less than a 0.05 increase in the mid-density portion of the film (*i.e.*, at a density of about 1.2). Ideally, less than a 0.05 increase should also be obtained with a 2 min exposure to the darkroom lights.

Each darkroom *shall* be evaluated for integrity at initial installation, and then at least every six months, any time that fog or increased film speed may be suspected, anytime light bulbs or filters are changed in the darkroom safelights, or any time maintenance is done on the processor or in the darkroom (NCRP, 1988).

C.1.5 *Leaded Aprons and Thyroid Collars*

Minimum acceptable evaluation of leaded aprons and thyroid collars consists of periodic (*e.g.*, monthly) visual inspection for defects or more frequently if they are damaged. More functional evaluation, when available, consists of fluoroscopy to detect hidden shielding defects.

C.1.6 *Documentation*

All quality-assurance procedures, together with their dates, results and any corrective actions, are documented. This information is important in troubleshooting chronic problems. Comparison of new results with previous ones may be the best way to detect any change in performance of equipment or procedures.

C.1.7 *Suggested Quality-Assurance Procedures*

The following is an outline of a recommended basic quality-assurance protocol for a typical veterinary facility using radiographic x-ray equipment:

Daily
- replenish processing solutions
- check temperature of processing solutions before processing film
- perform sensitometry and densitometry, or stepwedge test
- enter findings in quality-assurance log

Weekly
- clean processing equipment
- evaluate processing solutions and replace, if necessary
- check and clean view boxes
- document in quality-assurance log
- review quality-assurance log and adequacy of corrective actions

Monthly
- check and clean all intensifying screens
- check that exposure charts are posted at each x-ray machine
- inspect leaded aprons and thyroid collars

Biannually
- check darkroom and safelight for leaks
- check screen-film contact

Yearly to quadrennially
- calibrate all x-ray machines

In addition, quality-assurance procedures *should* be performed whenever the radiographic x-ray equipment is serviced to ensure that the equipment is working properly before it is used for animal patient examinations.

C.2 Nuclear Medicine Quality-Control Tests

C.2.1 *Gamma Camera*

Routine quality-control tests are necessary to monitor equipment function and assure that images are of highest quality. Quality-control tests should be performed at regular intervals. Table C.1 is a summary of the quality-control tests for the gamma camera. Additional information can be found in Daniel (1991), Sandler *et al*. (2002), and Smith (1998).

C.2.1.1 *Peaking the Pulse-Height Analyzer.* The pulse-height analyzer is an energy discriminator that allows the gamma camera to record only photons within a specified energy range. The process of centering the window over the photopeak is referred to as peaking the camera. Peaking the camera should be performed at the beginning of each day and before performing quality control. It is best to use a ^{99m}Tc source and not the patient when peaking the camera. Ideally, a source that produces 10,000 to 20,000 cps (counts per second), such as a 3.7 to 11.1 MBq point source, will be sufficient to create the desired photon flux for intrinsic measurements or autopeaking.

C.2.1.2 *Field Uniformity.* A properly functioning gamma camera should have a uniform response across the entire field-of-view of the crystal. To test field uniformity, a uniform photon flux is

TABLE C.1—*List of quality-control tests for the gamma camera and recommended frequency for the test*.

Test for Gamma Camera	Daily	Weekly	Periodically (biannually)
Peaking the pulse-height analyzer	×	×	×
Field uniformity (visual inspection)	Optional	×	×
Field uniformity (quantitative assessment)		Optional	×
Spatial resolution		×	×
Sensitivity		×	×

applied to the camera. Measurements made with the collimator in place are called extrinsic measurements and measurements made with the collimator removed are called intrinsic measurements. To measure intrinsic uniformity, a uniform flux of radioactivity must bombard the detector. The collimator is removed and a point source of radioactivity is placed a distance equal to five useful fields-of-view from the detector. The radioactivity of the source should be sufficient to provide a count rate between 10,000 and 20,000 cps. Extrinsic field uniformity takes into account the performance characteristics of the gamma camera and the collimator. To measure extrinsic uniformity, a uniform source of radioactivity (usually a flat source) is placed directly on the collimator surface. The radioactivity of the source should be sufficient to provide a count rate between 10,000 and 20,000 cps. The image intensity of all flood images should be uniform across the entire field of view. The methodology for performing intrinsic uniformity quality-control tests can vary. The National Electronics Manufacturers Association has established standards to characterize a specific performance parameter such as field uniformity (NEMA, 2001).

C.2.1.3 *Spatial Resolution*. The spatial resolution of a gamma camera is the ability to distinguish two objects as separate and distinct on the final image. The better the resolution of the camera, the closer the objects can be and still be separately seen. Spatial resolution is typically tested using a resolution phantom which is composed of lead bars or small holes in a lead sheet. The distances between the bars or holes will test the resolution limits of the camera.

C.2.1.4 *Sensitivity.* Gamma camera sensitivity is the parameter that characterizes the ability of the gamma camera to efficiently detect incident gamma rays. Sensitivity serves as an easily reproducible procedure for verifying the response of the entire system. An accurate assessment of sensitivity requires that the radionuclide source be accurately measured and there are no geometric influences of source position that may artificially decrease the sensitivity measurement. The National Electronics Manufacturers Association has outlined procedures for measuring sensitivity (NEMA, 2001).

C.2.2 *Dose Calibrator*

Quality control of the dose calibrator is necessary to ensure the patient is administered the proper activity of the radionuclide.

The dose calibrator is subject to the following quality-control tests: zero calibration, accuracy, precision, linearity and geometry. Table C.2 is a summary of the quality-control tests for the dose calibrator. Additional information can be found in Lanzisera *et al*. (2001) and Sandler *et al*. (2002).

C.2.2.1 *Zero Calibration*. The first daily quality-control test is to ensure zero calibration that will correct for any background activity in the radiopharmacy. Be sure to place all radionuclides into their lead shields so that background activity around the dose calibrator is minimized. Adjust the background to read zero on the dose calibrator. Many dose calibrators will do this automatically or by using the zero calibration button to make any manual adjustments.

C.2.2.2 *Precision or Constancy.* The precision or constancy test ensures that the radioactivity the dose calibrator records is reproducible over a long period of time. Regulations regarding use require daily testing of precision. Precision is the ability to measure a source of constant activity repeatedly within a stated degree of reproducibility. Satisfactory performance of this test will ensure that the dose calibrator is operating consistently from day to day.

C.2.2.3 *Accuracy.* This test ensures that the measured radioactivity is equivalent to the true radioactivity. Accuracy is defined as the closeness of a measured value to its true value. Accuracy is tested at installation of the dose calibrator and biannually with at least two different radionuclide sources. These sealed radioactive sources (^{137}Cs, ^{57}Co, or ^{133}Ba) have long physical half-lives.

TABLE C.2—*List of quality-control tests for the dose calibrator and recommended frequency for the test*.

Test for Dose Calibrator	Daily	Weekly	Periodically (biannually)
Zero calibration	×	×	×
Precision or constancy	Optional	×	×
Accuracy			×
Linearity			×
Geometry			×

C.2.2.4 *Linearity.* Linearity is an assessment of the dose calibrator's ability to measure radioactivity accurately over a wide range of activities. The dose calibrator should have a linear response below radioactivities of 3.7 GBq. The linearity test is conducted over the range of radioactivities that are likely to be measured in the practice. The linearity of the dose calibrator can be established by a decay method, that is, placing a source in the dose calibrator and measuring it at various times as the activity decreases by physical decay. The measured activity is compared to the calculated activity. The linearity test is performed at installation of the dose calibrator and biannually.

C.2.2.5 *Geometry.* The geometry test determines whether the source configuration, volume or position in the dose calibrator well has any significant effect on the accuracy of measurement. Volumetric variations are evaluated by placing 37 MBq of the sample radionuclide into a vial and changing the volume by adding water. Variations of radioactivity can be checked with respect to position in the ion chamber by measuring a 37 MBq source at prescribed distances from the bottom to the top of the dose calibrator well. This test is used to establish the position of greatest accuracy and this position should be used for routine measuring of all radionuclides. The geometry test is performed at installation of the dose calibrator and again following dose calibrator repair, movement or adjustment, and biannually.

C.2.3 *Radiopharmaceuticals*

Quality control of radiopharmaceuticals includes evaluation for radionuclide and radiochemical purity. Table C.3 is a summary of the quality-control tests for radiopharmaceuticals. Additional information can be found in Chilton and Witcofski (1986), Robbins (1984), and Sandler *et al*. (2002).

TABLE C.3—*List of quality-control tests for radiopharmaceuticals and recommended frequency for the tests*.

Radiopharmaceutical Quality-Control Test	Daily
Radionuclide purity	×
Radiochemical purity	×

C.2.3.1 *Radionuclide Purity.* Radionuclide purity measures the fraction of the total activity that is in the form of the stated radionuclide. In nuclear medicine laboratories with their own $^{99}Mo/^{99m}Tc$ generator, the amount of ^{99}Mo in the elution vial of $^{99m}TcO_4^-$ determines the radionuclide purity. The amount of molybdenum must be <5.55 kBq of ^{99}Mo per 37 MBq of ^{99m}Tc at the time of injection and there cannot be more than a total of 185 kBq of ^{99}Mo per dose administered.

C.2.3.2 *Radiochemical Purity.* Radiochemical purity is the fraction of the radionuclide present in the stated chemical form. The most common method of assessing radiochemical purity is instant thin-layer chromatography (ITLC) (Robbins, 1984). ITLC is performed by placing a small quantity of the radiopharmaceutical near the end of an ITLC strip. A solvent will separate radiochemical components by absorption and capillary action. The radiochemical impurities are separated based on their solubility. Constituents that are insoluble in the solvent stay at the origin and those that are soluble move up the support column with the solvent front. A two-strip ITLC system is necessary to evaluate radiochemical impurities of most radiopharmaceuticals.

Appendix D

Guidelines for Owner After Treatment of Animal with Radioiodine Therapy

The veterinarian *should* explain the radioiodine procedure to the owner prior to treatment. This would include the description of the procedure, the isolation of the animal in the hospital and the restrictions to the owner at the time of release, the prognosis, and in the event of the death of the animal, the proper disposal of the body. The owners need to agree to these restrictions before radioiodine is administered.

Since the animal may still contain a small quantity of the radionuclide at time of release, instructions to the owner *should* be given. The veterinarian *should* go over written instructions with the owner and the owner *should* sign and retain a copy of the document to indicate that the owner understands and will follow the guidelines.

Sample Guidelines to Owners for a Treated Animal

Your animal has been treated with radioactive iodine and still possesses a low level of radioactivity. Your animal will emanate radiation and will continue to excrete small amounts of radioactive iodine. The present level of radioactivity is below a level that requires total isolation of the animal from people. However, because of the residual radioactivity present, it is required that you agree to all of the following precautions:

General Guidelines

- For the next two to four weeks, do not hold the animal, allow the animal to sit in a chair with you, or allow the animal to

sleep on the bed with you. This also applies to all others who may be in your household. Minimize contact with the animal. Association of your pet with any other animals you might have is not considered a problem.
- For the next two to four weeks, no one who is pregnant can have contact with the animal or be involved in cleaning the litter.
- All bedding, toys and other potentially contaminated materials should be isolated for three months or washed thoroughly.

Special Handling Instructions for Cat Litter
- Plastic liners should be used in the litter box. If using liners is impossible, you must dispose of the litter box after the specified restriction period.
- Use flushable litter in the box if you are on public sewer. Simply scoop dirtied litter into the toilet and flush it down. If you are not on a public sewer and absolutely cannot flush the litter, directions for alternate disposal are available. Litter cannot be thrown out with your household garbage for at least three months to prevent problems caused when radioactivity is detected in trash at landfills.

Special Handling Instructions for Dog Excreta
- If your dog excretes on a newspaper or pad, feces should be scooped up using a shovel and disposed of by way of the toilet. Urine soaked newspapers or pads will need to be folded and placed into a plastic bag for storage in a remote area of your home (*e.g.*, locked cabinet in the garage). This waste cannot be thrown out with your household garbage for at least three months to prevent problems caused when radioactivity is detected in trash at landfills.
- If your dog excretes in the yard, feces should be scooped up using a shovel and disposed of by way of the toilet. Urine spots should be thoroughly hosed down immediately after the dog is finished.

Additional Precautions
- Avoid prolonged contact with your pet. Wash your hands thoroughly after any contact with your pet or after handling litter or excreta.
- If your pet is a cat, do not allow it to walk on the counter tops.

- Do not allow your pet to eat off of your plate.
- Young children should avoid the pet for the specified restriction period after you bring it home. Young children should be closely supervised to make sure that contact with the pet does not occur. If contact does occur, wash the child's hands or body part that came in contact with the pet thoroughly.
- Your pet should be confined to your home (or property if a dog) during the specified restriction period after the pet is brought home, and you should arrange for it to sleep in an unoccupied area.
- Emergency care: If your pet needs emergency care during the specified restriction period, the emergency care provider will need to know that your pet contains radioactivity and to contact: [*fill in name*] at [*fill in contact information*].
- If your pet dies within three months after treatment and you plan to have it cremated, you need to understand that it might have to be frozen until the three-month period is up before cremation can occur.

If you have any questions, please contact: [*fill in name*] at [*fill in contact information*].

Glossary

absorbed dose: The energy imparted by ionizing radiation to matter per unit mass of irradiated material. In the Systeme Internationale (SI), the unit is joule per kilogram (J kg^{-1}) with the special name gray (Gy). 1 Gy = 1 J kg^{-1}.

accessible emission limit (AEL): The maximum accessible emission level permitted within a particular class of lasers (FDA, 2004a).

activity: The number of nuclear disintegrations occurring in a given quantity of material per unit time (see **becquerel**).

air kerma: (see **kerma**).

animal patient (or research animal): In veterinary medicine, the patient (or research animal) is an animal under the care of the veterinarian.

as low as reasonably achievable (ALARA): The principle of reducing the radiation dose of exposed persons to levels as low as reasonably achievable, economic and social factors taken into account.

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

barrier: (see **protective barrier**).

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

becquerel (Bq): The special name for the unit of radioactivity. 1 Bq equals one disintegration per second. 37 MBq (megabecquerels) = 1 mCi (millicurie) (see **curie**).

controlled area: A limited-access area in which the exposure of persons to radiation is under the supervision of a radiation safety officer. This implies that a controlled area is one that requires control of access, occupancy and working conditions for radiation protection purposes.

curie (Ci): The previous special name for the unit of radioactivity equal to 3.70×10^{10} becquerels (or disintegrations per second) (see **becquerel**).

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

diagnostic x-ray tube housing: An enclosure so constructed that the leakage radiation from the housing does not exceed specified limits (see Section 4.1.5.1.3, Section 5.1.1, and Section 6.1.1).

dose equivalent: The mean absorbed dose at a point, modified by the quality factor at that point. The unit for dose equivalent is the joule per kilogram (J kg^{-1}) with the special name sievert (Sv).

effective dose: The sum of the weighted equivalent doses (*i.e.*, each equivalent dose weighted by a tissue weighting factor) for the radiosensitive tissues and organs of the body. The tissue weighting factor represents the relative contribution of that organ or tissue to the total detriment due to stochastic effects resulting from uniform irradiation of the whole body (see also **equivalent dose**).

equivalent dose: The mean absorbed dose in an organ or tissue (in gray) modified by an appropriate radiation weighting factor for the type of radiation involved. The SI unit for equivalent dose is joule per kilogram (J kg^{-1}) with the special name sievert (Sv). (For radiation protection purposes in this Report, the equivalent dose in sieverts may be considered numerically equal to the absorbed dose in grays because the type of radiation involved has been assigned a radiation weighting factor of unity.

exposure: A measure of the ionization produced in air by x or gamma rays. It is the sum of the electrical charges on all of the ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The unit of exposure is coulomb per kilogram (C kg^{-1}) with the special name roentgen (R).

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

gray (Gy): The special name for the unit of absorbed dose (*i.e.*, 1 J kg^{-1}).

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

individual (personal) monitor or dosimeter: A small radiation detector that is worn by an individual. Common individual dosimeters contain film, thermoluminescent or optically-stimulated luminescent materials as the radiation detector.

installation: Radiation sources with associated equipment, and the space in which they are located.

interlock: A device which automatically terminates exposure upon entry by personnel into a high radiation area. Alternatively, an interlock may prevent entry into a high radiation area.

kerma (kinetic energy released per unit mass): The sum of the initial kinetic energies of all the charged particles liberated by uncharged particles per unit mass of specified material. If all the energy liberated in a small mass is also imparted to the matter (*i.e.*, absorbed) in that mass, the kerma is numerically equal to the absorbed dose at that point. The SI unit for kerma is joule per kilogram (J kg^{-1}), with the special name gray (Gy). Kerma can be quoted for any specified material at a point in free space or in an absorbing medium (*e.g.*, air kerma).

kilovolt (kV): A unit of electrical potential difference equal to 1,000 volts.

kilovolt peak (kVp): (also see **operating potential**).The crest value in kilovolts of the potential difference of a pulsating potential generator.

When only one-half of the wave is used, the value refers to the useful half of the cycle.

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

leakage radiation: All radiation coming from within the source or x-ray tube housing except the useful beam. Leakage radiation includes the portion of the direct radiation not absorbed by the protective source or x-ray tube housing as well as the scattered radiation produced within the housing.

monitoring: Periodic or continuous estimation of the exposure rate in an area (area monitoring) or the exposure received by a person (individual or personal monitoring).

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

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

operating potential: (also see **kilovolt peak**). The potential difference between the anode and cathode of an x-ray tube.

primary beam: (see **useful beam**).

primary radiation: Radiation emitted directly from the x-ray tube or other source that is used for imaging or treatment (see also **useful beam**).

protective barrier: A barrier of radiation-attenuating material(s) used to reduce radiation exposure.

primary (or primary protective) barrier: A barrier sufficient to attenuate the useful beam to the required degree.

secondary (or secondary protective) barrier: A barrier sufficient to attenuate the secondary radiation (*i.e.*, scattered and leakage radiation) to the required degree.

protective clothing: Gloves, aprons, gowns, etc., made of radiation absorbing materials used to reduce radiation exposure.

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

radiation (ionizing): Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter (*e.g.*, x and gamma rays).

radiation safety officer (RSO): The person directly responsible for radiation protection.

radiation safety survey: An evaluation of the radiation safety in and around an installation.

roentgen (R): The special name for the unit of exposure. Exposure is a specific quantity of ionization (charge) produced by the absorption of x- or gamma-radiation energy in a specified mass of air under standard conditions. 1 R = 2.58×10^{-4} coulomb per kilogram (C kg^{-1}). 1 milliroentgen (mR) is one thousandth of an R.

scattered radiation: Radiation that, during passage through matter, has been deviated in direction, usually *via* Compton scattering. Scattered radiation may have been modified also by a decrease in energy.

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

secondary radiation: The sum of leakage and scattered radiation.

shielding design goals (*P*): Practical values, for a single veterinary radiation source or set of sources, that are evaluated at a reference point beyond a protective barrier. When used in conjunction with the conservatively safe assumptions recommended by NCRP (2004) (as applied to veterinary radiation sources), the shielding design goals will ensure that the respective annual values for effective dose recommended for controlled and uncontrolled areas (NCRP, 2004) are not exceeded. For low linear-energy-transfer radiation, the quantity air kerma is used. *P* can be expressed as a weekly or annual value (*e.g.*, mGy $week^{-1}$ or mGy y^{-1} air kerma), but is most often expressed as a weekly value since the workload for a veterinary radiation source has traditionally utilized a weekly value.

sievert (Sv): The special name for the unit of equivalent dose, dose equivalent, and effective dose (see **equivalent dose**, **dose equivalent**, and **effective dose**).

source-to-image receptor distance: The distance between the center of the source's front surface (*i.e.*, the x-ray focal spot or sealed radioactive source) and the surface of the image receptor.

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

tenth-value layer (TVL): The thickness of any material that reduces the transmitted radiation to one-tenth of its initial intensity.

therapeutic protective source housing (or therapeutic source assembly): An enclosure or assembly so constructed that the leakage radiation from the housing or assembly does not exceed specified limits. For x-ray therapy equipment with operating potentials $\leq$500 kV, see Section 7.2.1. For x-ray and electron-beam equipment

with operating potentials >500 kV, see Section 7.3.1. For gamma radiation teletherapy equipment, see Section 7.4.1.

uncontrolled area: Any space not meeting the definition of controlled area.

use factor (*U*): Fraction of the workload during which the radiation under consideration is directed at a particular barrier.

useful (or primary) beam: Radiation that passes through the window, aperture or other collimating device of the radiation source housing (see also **primary radiation**).

user (of a radiation source): Any individual who personally utilizes or manipulates a source of radiation.

veterinary medicine: The branch of medicine that deals with the diagnosis and treatment of diseases and injuries of animals by a licensed veterinarian.

workload (*W*): The degree of use of an x- or gamma-ray source. For diagnostic x-ray equipment, the workload is usually expressed in milliampere minutes per week (mA min week^{-1}). For x- and gamma-ray therapy equipment, the workload is usually expressed in gray per week (Gy week^{-1}).

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The NCRP

The National Council on Radiation Protection and Measurements is a nonprofit corporation chartered by Congress in 1964 to:

1. Collect, analyze, develop and disseminate in the public interest information and recommendations about (a) protection against radiation and (b) radiation measurements, quantities and units, particularly those concerned with radiation protection.
2. Provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations.
3. Develop basic concepts about radiation quantities, units and measurements, about the application of these concepts, and about radiation protection.
4. Cooperate with the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units and measurements and with radiation protection.

The Council is the successor to the unincorporated association of scientists known as the National Committee on Radiation Protection and Measurements and was formed to carry on the work begun by the Committee in 1929.

The participants in the Council's work are the Council members and members of scientific and administrative committees. Council members are selected solely on the basis of their scientific expertise and serve as individuals, not as representatives of any particular organization. The scientific committees, composed of experts having detailed knowledge and competence in the particular area of the committee's interest, draft proposed recommendations. These are then submitted to the full membership of the Council for careful review and approval before being published.

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R. Julian Preston (2002) *Developing Mechanistic Data for Incorporation into Cancer Risk Assessment: Old Problems and New Approaches*

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William J. Bair (1997) *Radionuclides in the Body: Meeting the Challenge!*

Seymour Abrahamson (1996) *70 Years of Radiation Genetics: Fruit Flies, Mice and Humans*

Albrecht Kellerer (1995) *Certainty and Uncertainty in Radiation Protection*

R.J. Michael Fry (1994) *Mice, Myths and Men*

Warren K. Sinclair (1993) *Science, Radiation Protection and the NCRP*

Edward W. Webster (1992) *Dose and Risk in Diagnostic Radiology: How Big? How Little?*

Victor P. Bond (1991) *When is a Dose Not a Dose?*

J. Newell Stannard (1990) *Radiation Protection and the Internal Emitter Saga*

Arthur C. Upton (1989) *Radiobiology and Radiation Protection: The Past Century and Prospects for the Future*

Bo Lindell (1988) *How Safe is Safe Enough?*

Seymour Jablon (1987) *How to be Quantitative about Radiation Risk Estimates*

Herman P. Schwan (1986) *Biological Effects of Non-ionizing Radiations: Cellular Properties and Interactions*

John H. Harley (1985) *Truth (and Beauty) in Radiation Measurement*

Harald H. Rossi (1984) *Limitation and Assessment in Radiation Protection*

Merril Eisenbud (1983) *The Human Environment—Past, Present and Future*

Eugene L. Saenger (1982) *Ethics, Trade-Offs and Medical Radiation*

James F. Crow (1981) *How Well Can We Assess Genetic Risk? Not Very*

Harold O. Wyckoff (1980) *From "Quantity of Radiation" and "Dose" to "Exposure" and "Absorbed Dose"—An Historical Review*

Hymer L. Friedell (1979) *Radiation Protection—Concepts and Trade Offs*

Sir Edward Pochin (1978) *Why be Quantitative about Radiation Risk Estimates?*

Herbert M. Parker (1977) *The Squares of the Natural Numbers in Radiation Protection*

Currently, the following committees are actively engaged in formulating recommendations:

Program Area Committee 1: Basic Criteria, Epidemiology, Radiobiology, and Risk
- SC 1-4 Extrapolation of Risks from Nonhuman Experimental Systems to Man
- SC 1-7 Information Needed to Make Radiation Protection Recommendations for Travel Beyond Low-Earth Orbit
- SC 1-8 Risk to Thyroid from Ionizing Radiation
- SC 1-13 Effects of Therapeutic Medical Treatment and Genetic Background
- SC 1-15 Radiation Safety in NASA Lunar Missions
- SC 85 Risk of Lung Cancer from Radon

Program Area Committee 2: Operational Radiation Safety
- SC 2-1 Radiation Protection Recommendations for First Responders
- SC 46-13 Design of Facilities for Medical Radiation Therapy
- SC 46-17 Radiation Protection in Educational Institutions

Program Area Committee 3: Nonionizing Radiation
- SC 89-5 Study and Critical Evaluation of Radiofrequency Exposure Guidelines

Program Area Committee 4: Radiation Protection in Medicine
- SC 4-1 Management of Persons Contaminated with Radionuclides
- SC 72 Radiation Protection in Mammography
- SC 91-1 Precautions in the Management of Patients Who Have Received Therapeutic Amounts of Radionuclides

Program Area Committee 5: Environmental Radiation and Radioactive Waste Issues
- SC 64-22 Design of Effective Effluent and Environmental Monitoring Programs
- SC 64-23 Cesium in the Environment
- SC 87-3 Performance Assessment of Near Surface Radioactive Waste Facilities

Program Area Committee 6: Radiation Measurements and Dosimetry
- SC 6-1 Uncertainties in the Measurement and Dosimetry of External Radiation Sources
- SC 57-17 Radionuclide Dosimetry Models for Wounds

Advisory Committee 1: Public Policy and Risk Communication

In recognition of its responsibility to facilitate and stimulate cooperation among organizations concerned with the scientific and related aspects of radiation protection and measurement, the Council has created a category of NCRP Collaborating Organizations. Organizations or groups of organizations that are national or international in scope and are concerned with scientific problems involving radiation quantities, units, measurements and effects, or radiation protection may be admitted to collaborating

status by the Council. Collaborating Organizations provide a means by which the NCRP can gain input into its activities from a wider segment of society. At the same time, the relationships with the Collaborating Organizations facilitate wider dissemination of information about the Council's activities, interests and concerns. Collaborating Organizations have the opportunity to comment on draft reports (at the time that these are submitted to the members of the Council). This is intended to capitalize on the fact that Collaborating Organizations are in an excellent position to both contribute to the identification of what needs to be treated in NCRP reports and to identify problems that might result from proposed recommendations. The present Collaborating Organizations with which the NCRP maintains liaison are as follows:

American Academy of Dermatology
American Academy of Environmental Engineers
American Academy of Health Physics
American Association of Physicists in Medicine
American College of Medical Physics
American College of Nuclear Physicians
American College of Occupational and Environmental Medicine
American College of Radiology
American Dental Association
American Industrial Hygiene Association
American Institute of Ultrasound in Medicine
American Medical Association
American Nuclear Society
American Pharmaceutical Association
American Podiatric Medical Association
American Public Health Association
American Radium Society
American Roentgen Ray Society
American Society for Therapeutic Radiology and Oncology
American Society of Emergency Radiology
American Society of Health-System Pharmacists
American Society of Radiologic Technologists
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Bioelectromagnetics Society
Campus Radiation Safety Officers
College of American Pathologists
Conference of Radiation Control Program Directors, Inc.
Council on Radionuclides and Radiopharmaceuticals
Defense Threat Reduction Agency
Electric Power Research Institute
Federal Communications Commission
Federal Emergency Management Agency
Genetics Society of America
Health Physics Society

Institute of Electrical and Electronics Engineers, Inc.
Institute of Nuclear Power Operations
International Brotherhood of Electrical Workers
National Aeronautics and Space Administration
National Association of Environmental Professionals
National Center for Environmental Health/Agency for Toxic Substances
National Electrical Manufacturers Association
National Institute for Occupational Safety and Health
National Institute of Standards and Technology
Nuclear Energy Institute
Office of Science and Technology Policy
Paper, Allied-Industrial, Chemical and Energy Workers International Union
Product Stewardship Institute
Radiation Research Society
Radiological Society of North America
Society for Risk Analysis
Society of Chairmen of Academic Radiology Departments
Society of Nuclear Medicine
Society of Radiologists in Ultrasound
Society of Skeletal Radiology
U.S. Air Force
U.S. Army
U.S. Coast Guard
U.S. Department of Energy
U.S. Department of Housing and Urban Development
U.S. Department of Labor
U.S. Department of Transportation
U.S. Environmental Protection Agency
U.S. Navy
U.S. Nuclear Regulatory Commission
U.S. Public Health Service
Utility Workers Union of America

The NCRP has found its relationships with these organizations to be extremely valuable to continued progress in its program.

Another aspect of the cooperative efforts of the NCRP relates to the Special Liaison relationships established with various governmental organizations that have an interest in radiation protection and measurements. This liaison relationship provides: (1) an opportunity for participating organizations to designate an individual to provide liaison between the organization and the NCRP; (2) that the individual designated will receive copies of draft NCRP reports (at the time that these are submitted to the members of the Council) with an invitation to comment, but not vote; and (3) that new NCRP efforts might be discussed with liaison individuals as appropriate, so that they might have an opportunity to make suggestions

on new studies and related matters. The following organizations participate in the Special Liaison Program:

Australian Radiation Laboratory
Bundesamt fur Strahlenschutz (Germany)
Canadian Nuclear Safety Commission
Central Laboratory for Radiological Protection (Poland)
China Institute for Radiation Protection
Commonwealth Scientific Instrumentation Research Organization (Australia)
European Commission
Health Council of the Netherlands
Institut de Radioprotection et de Surete Nucleaire
International Commission on Non-ionizing Radiation Protection
International Commission on Radiation Units and Measurements
Japan Radiation Council
Korea Institute of Nuclear Safety
National Radiological Protection Board (United Kingdom)
Russian Scientific Commission on Radiation Protection
South African Forum for Radiation Protection
World Association of Nuclear Operations
World Health Organization, Radiation and Environmental Health

The NCRP values highly the participation of these organizations in the Special Liaison Program.

The Council also benefits significantly from the relationships established pursuant to the Corporate Sponsor's Program. The program facilitates the interchange of information and ideas and corporate sponsors provide valuable fiscal support for the Council's program. This developing program currently includes the following Corporate Sponsors:

3M Corporate Health Physics
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Nuclear Energy Institute
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The Council's activities have been made possible by the voluntary contribution of time and effort by its members and participants and the generous support of the following organizations:

3M Health Physics Services
Agfa Corporation
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Alliance of American Insurers
American Academy of Dermatology
American Academy of Health Physics
American Academy of Oral and Maxillofacial Radiology
American Association of Physicists in Medicine
American Cancer Society
American College of Medical Physics
American College of Nuclear Physicians
American College of Occupational and Environmental Medicine
American College of Radiology
American College of Radiology Foundation
American Dental Association
American Healthcare Radiology Administrators
American Industrial Hygiene Association
American Insurance Services Group
American Medical Association
American Nuclear Society
American Osteopathic College of Radiology
American Podiatric Medical Association
American Public Health Association
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NCRP seeks to promulgate information and recommendations based on leading scientific judgment on matters of radiation protection and measurement and to foster cooperation among organizations concerned with these matters. These efforts are intended to serve the public interest and the Council welcomes comments and suggestions on its reports or activities.

NCRP Publications

Information on NCRP publications may be obtained from the NCRP website (http://NCRPonline.org) or by telephone (800-229-2652, ext. 25) and fax (301-907-8768). The address is:

NCRP Publications
7910 Woodmont Avenue
Suite 400
Bethesda, MD 20814-3095

Abstracts of NCRP reports published since 1980, abstracts of all NCRP commentaries, and the text of all NCRP statements are available at the NCRP website. Currently available publications are listed below.

NCRP Reports

No.	Title
8	*Control and Removal of Radioactive Contamination in Laboratories* (1951)
22	*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (1959) [includes Addendum 1 issued in August 1963]
25	*Measurement of Absorbed Dose of Neutrons, and of Mixtures of Neutrons and Gamma Rays* (1961)
27	*Stopping Powers for Use with Cavity Chambers* (1961)
30	*Safe Handling of Radioactive Materials* (1964)
32	*Radiation Protection in Educational Institutions* (1966)
35	*Dental X-Ray Protection* (1970)
36	*Radiation Protection in Veterinary Medicine* (1970)
37	*Precautions in the Management of Patients Who Have Received Therapeutic Amounts of Radionuclides* (1970)
38	*Protection Against Neutron Radiation* (1971)
40	*Protection Against Radiation from Brachytherapy Sources* (1972)
41	*Specification of Gamma-Ray Brachytherapy Sources* (1974)

42 *Radiological Factors Affecting Decision-Making in a Nuclear Attack* (1974)
44 *Krypton-85 in the Atmosphere—Accumulation, Biological Significance, and Control Technology* (1975)
46 *Alpha-Emitting Particles in Lungs* (1975)
47 *Tritium Measurement Techniques* (1976)
49 *Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up to 10 MeV* (1976)
50 *Environmental Radiation Measurements* (1976)
52 *Cesium-137 from the Environment to Man: Metabolism and Dose* (1977)
54 *Medical Radiation Exposure of Pregnant and Potentially Pregnant Women* (1977)
55 *Protection of the Thyroid Gland in the Event of Releases of Radioiodine* (1977)
57 *Instrumentation and Monitoring Methods for Radiation Protection* (1978)
58 *A Handbook of Radioactivity Measurements Procedures*, 2nd ed. (1985)
60 *Physical, Chemical, and Biological Properties of Radiocerium Relevant to Radiation Protection Guidelines* (1978)
61 *Radiation Safety Training Criteria for Industrial Radiography* (1978)
62 *Tritium in the Environment* (1979)
63 *Tritium and Other Radionuclide Labeled Organic Compounds Incorporated in Genetic Material* (1979)
64 *Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations* (1980)
65 *Management of Persons Accidentally Contaminated with Radionuclides* (1980)
67 *Radiofrequency Electromagnetic Fields—Properties, Quantities and Units, Biophysical Interaction, and Measurements* (1981)
68 *Radiation Protection in Pediatric Radiology* (1981)
69 *Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV* (1981)
70 *Nuclear Medicine—Factors Influencing the Choice and Use of Radionuclides in Diagnosis and Therapy* (1982)
72 *Radiation Protection and Measurement for Low-Voltage Neutron Generators* (1983)
73 *Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children* (1983)
74 *Biological Effects of Ultrasound: Mechanisms and Clinical Implications* (1983)
75 *Iodine-129: Evaluation of Releases from Nuclear Power Generation* (1983)
77 *Exposures from the Uranium Series with Emphasis on Radon and Its Daughters* (1984)

78 *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States* (1984)
79 *Neutron Contamination from Medical Electron Accelerators* (1984)
80 *Induction of Thyroid Cancer by Ionizing Radiation* (1985)
81 *Carbon-14 in the Environment* (1985)
82 *SI Units in Radiation Protection and Measurements* (1985)
83 *The Experimental Basis for Absorbed-Dose Calculations in Medical Uses of Radionuclides* (1985)
84 *General Concepts for the Dosimetry of Internally Deposited Radionuclides* (1985)
85 *Mammography—A User's Guide* (1986)
86 *Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields* (1986)
87 *Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition* (1987)
88 *Radiation Alarms and Access Control Systems* (1986)
89 *Genetic Effects from Internally Deposited Radionuclides* (1987)
90 *Neptunium: Radiation Protection Guidelines* (1988)
92 *Public Radiation Exposure from Nuclear Power Generation in the United States* (1987)
93 *Ionizing Radiation Exposure of the Population of the United States* (1987)
94 *Exposure of the Population in the United States and Canada from Natural Background Radiation* (1987)
95 *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources* (1987)
96 *Comparative Carcinogenicity of Ionizing Radiation and Chemicals* (1989)
97 *Measurement of Radon and Radon Daughters in Air* (1988)
99 *Quality Assurance for Diagnostic Imaging* (1988)
100 *Exposure of the U.S. Population from Diagnostic Medical Radiation* (1989)
101 *Exposure of the U.S. Population from Occupational Radiation* (1989)
102 *Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use)* (1989)
103 *Control of Radon in Houses* (1989)
104 *The Relative Biological Effectiveness of Radiations of Different Quality* (1990)
105 *Radiation Protection for Medical and Allied Health Personnel* (1989)
106 *Limit for Exposure to "Hot Particles" on the Skin* (1989)
107 *Implementation of the Principle of As Low As Reasonably Achievable (ALARA) for Medical and Dental Personnel* (1990)

108 *Conceptual Basis for Calculations of Absorbed-Dose Distributions* (1991)
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119 *A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields* (1993)
120 *Dose Control at Nuclear Power Plants* (1994)
121 *Principles and Application of Collective Dose in Radiation Protection* (1995)
122 *Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation* (1995)
123 *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground* (1996)
124 *Sources and Magnitude of Occupational and Public Exposures from Nuclear Medicine Procedures* (1996)
125 *Deposition, Retention and Dosimetry of Inhaled Radioactive Substances* (1997)
126 *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection* (1997)
127 *Operational Radiation Safety Program* (1998)
128 *Radionuclide Exposure of the Embryo/Fetus* (1998)
129 *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies* (1999)
130 *Biological Effects and Exposure Limits for "Hot Particles"* (1999)
131 *Scientific Basis for Evaluating the Risks to Populations from Space Applications of Plutonium* (2001)
132 *Radiation Protection Guidance for Activities in Low-Earth Orbit* (2000)
133 *Radiation Protection for Procedures Performed Outside the Radiology Department* (2000)
134 *Operational Radiation Safety Training* (2000)
135 *Liver Cancer Risk from Internally-Deposited Radionuclides* (2001)
136 *Evaluation of the Linear-Nonthreshold Dose-Response Model for Ionizing Radiation* (2001)

137 *Fluence-Based and Microdosimetric Event-Based Methods for Radiation Protection in Space* (2001)
138 *Management of Terrorist Events Involving Radioactive Material* (2001)
139 *Risk-Based Classification of Radioactive and Hazardous Chemical Wastes* (2002)
140 *Exposure Criteria for Medical Diagnostic Ultrasound: II. Criteria Based on all Known Mechanisms* (2002)
141 *Managing Potentially Radioactive Scrap Metal* (2002)
142 *Operational Radiation Safety Program for Astronauts in Low-Earth Orbit: A Basic Framework* (2002)
143 *Management Techniques for Laboratories and Other Small Institutional Generators to Minimize Off-Site Disposal of Low-Level Radioactive Waste* (2003)
144 *Radiation Protection for Particle Accelerator Facilities* (2003)
145 *Radiation Protection in Dentistry* (2003)
146 *Approaches to Risk Management in Remediation of Radioactively Contaminated Sites* (2004)
147 *Structural Shielding Design for Medical X-Ray Imaging Facilities* (2004)
148 *Radiation Protection in Veterinary Medicine* (2004)

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The following bound sets of NCRP reports are also available:

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Volume V. NCRP Reports Nos. 42, 44, 46
Volume VI. NCRP Reports Nos. 47, 49, 50, 51
Volume VII. NCRP Reports Nos. 52, 53, 54, 55, 57
Volume VIII. NCRP Report No. 58
Volume IX. NCRP Reports Nos. 59, 60, 61, 62, 63
Volume X. NCRP Reports Nos. 64, 65, 66, 67
Volume XI. NCRP Reports Nos. 68, 69, 70, 71, 72
Volume XII. NCRP Reports Nos. 73, 74, 75, 76
Volume XIII. NCRP Reports Nos. 77, 78, 79, 80
Volume XIV. NCRP Reports Nos. 81, 82, 83, 84, 85
Volume XV. NCRP Reports Nos. 86, 87, 88, 89
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Volume XVII. NCRP Reports Nos. 94, 95, 96, 97
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Volume XXVIII. NCRP Reports Nos. 131, 132, 133
Volume XXIX. NCRP Reports Nos. 134, 135, 136, 137
Volume XXX. NCRP Reports Nos. 138, 139
Volume XXXI. NCRP Report No. 140

(Titles of the individual reports contained in each volume are given previously.)

NCRP Commentaries

No.	Title
1	*Krypton-85 in the Atmosphere—With Specific Reference to the Public Health Significance of the Proposed Controlled Release at Three Mile Island* (1980)
4	*Guidelines for the Release of Waste Water from Nuclear Facilities with Special Reference to the Public Health Significance of the Proposed Release of Treated Waste Waters at Three Mile Island* (1987)
5	*Review of the Publication, Living Without Landfills* (1989)
6	*Radon Exposure of the U.S. Population—Status of the Problem* (1991)
7	*Misadministration of Radioactive Material in Medicine—Scientific Background* (1991)
8	*Uncertainty in NCRP Screening Models Relating to Atmospheric Transport, Deposition and Uptake by Humans* (1993)
9	*Considerations Regarding the Unintended Radiation Exposure of the Embryo, Fetus or Nursing Child* (1994)
10	*Advising the Public about Radiation Emergencies: A Document for Public Comment* (1994)
11	*Dose Limits for Individuals Who Receive Exposure from Radionuclide Therapy Patients* (1995)
12	*Radiation Exposure and High-Altitude Flight* (1995)
13	*An Introduction to Efficacy in Diagnostic Radiology and Nuclear Medicine (Justification of Medical Radiation Exposure)* (1995)

14 *A Guide for Uncertainty Analysis in Dose and Risk Assessments Related to Environmental Contamination* (1996)
15 *Evaluating the Reliability of Biokinetic and Dosimetric Models and Parameters Used to Assess Individual Doses for Risk Assessment Purposes* (1998)
16 *Screening of Humans for Security Purposes Using Ionizing Radiation Scanning Systems* (2003)
17 *Pulsed Fast Neutron Analysis System Used in Security Surveillance* (2003)
18 *Biological Effects of Modulated Radiofrequency Fields* (2003)

Proceedings of the Annual Meeting

No.	Title
1	*Perceptions of Risk*, Proceedings of the Fifteenth Annual Meeting held on March 14-15, 1979 (including Taylor Lecture No. 3) (1980)
3	*Critical Issues in Setting Radiation Dose Limits*, Proceedings of the Seventeenth Annual Meeting held on April 8-9, 1981 (including Taylor Lecture No. 5) (1982)
4	*Radiation Protection and New Medical Diagnostic Approaches,* Proceedings of the Eighteenth Annual Meeting held on April 6-7, 1982 (including Taylor Lecture No. 6) (1983)
5	*Environmental Radioactivity,* Proceedings of the Nineteenth Annual Meeting held on April 6-7, 1983 (including Taylor Lecture No. 7) (1983)
6	*Some Issues Important in Developing Basic Radiation Protection Recommendations*, Proceedings of the Twentieth Annual Meeting held on April 4-5, 1984 (including Taylor Lecture No. 8) (1985)
7	*Radioactive Waste*, Proceedings of the Twenty-first Annual Meeting held on April 3-4, 1985 (including Taylor Lecture No. 9)(1986)
8	*Nonionizing Electromagnetic Radiations and Ultrasound,* Proceedings of the Twenty-second Annual Meeting held on April 2-3, 1986 (including Taylor Lecture No. 10) (1988)
9	*New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates*, Proceedings of the Twenty-third Annual Meeting held on April 8-9, 1987 (including Taylor Lecture No. 11) (1988)
10	*Radon*, Proceedings of the Twenty-fourth Annual Meeting held on March 30-31, 1988 (including Taylor Lecture No. 12) (1989)
11	*Radiation Protection Today—The NCRP at Sixty Years*, Proceedings of the Twenty-fifth Annual Meeting held on April 5-6, 1989 (including Taylor Lecture No. 13) (1990)

12 *Health and Ecological Implications of Radioactively Contaminated Environments*, Proceedings of the Twenty-sixth Annual Meeting held on April 4-5, 1990 (including Taylor Lecture No. 14) (1991)

13 *Genes, Cancer and Radiation Protection,* Proceedings of the Twenty-seventh Annual Meeting held on April 3-4, 1991 (including Taylor Lecture No. 15) (1992)

14 *Radiation Protection in Medicine,* Proceedings of the Twenty-eighth Annual Meeting held on April 1-2, 1992 (including Taylor Lecture No. 16) (1993)

15 *Radiation Science and Societal Decision Making,* Proceedings of the Twenty-ninth Annual Meeting held on April 7-8, 1993 (including Taylor Lecture No. 17) (1994)

16 *Extremely-Low-Frequency Electromagnetic Fields: Issues in Biological Effects and Public Health*, Proceedings of the Thirtieth Annual Meeting held on April 6-7, 1994 (not published).

17 *Environmental Dose Reconstruction and Risk Implications,* Proceedings of the Thirty-first Annual Meeting held on April 12-13, 1995 (including Taylor Lecture No. 19) (1996)

18 *Implications of New Data on Radiation Cancer Risk*, Proceedings of the Thirty-second Annual Meeting held on April 3-4, 1996 (including Taylor Lecture No. 20) (1997)

19 *The Effects of Pre- and Postconception Exposure to Radiation*, Proceedings of the Thirty-third Annual Meeting held on April 2-3, 1997, Teratology **59**, 181–317 (1999)

20 *Cosmic Radiation Exposure of Airline Crews, Passengers and Astronauts*, Proceedings of the Thirty-fourth Annual Meeting held on April 1-2, 1998, Health Phys. **79**, 466–613 (2000)

21 *Radiation Protection in Medicine: Contemporary Issues*, Proceedings of the Thirty-fifth Annual Meeting held on April 7-8, 1999 (including Taylor Lecture No. 23) (1999)

22 *Ionizing Radiation Science and Protection in the 21st Century*, Proceedings of the Thirty-sixth Annual Meeting held on April 5-6, 2000, Health Phys. **80**, 317–402 (2001)

23 *Fallout from Atmospheric Nuclear Tests—Impact on Science and Society*, Proceedings of the Thirty-seventh Annual Meeting held on April 4-5, 2001, Health Phys. **82**, 573–748 (2002)

24 *Where the New Biology Meets Epidemiology: Impact on Radiation Risk Estimates*, Proceedings of the Thirty-eighth Annual Meeting held on April 10-11, 2002, Health Phys. **85**, 1–108 (2003)

25 *Radiation Protection at the Beginning of the 21st Century–A Look Forward*, Proceedings of the Thirty-ninth Annual Meeting held on April 9–10, 2003, Health Phys. **87**, 237–319 (2004)

Lauriston S. Taylor Lectures

No.	Title
1	*The Squares of the Natural Numbers in Radiation Protection by* Herbert M. Parker (1977)
2	*Why be Quantitative about Radiation Risk Estimates?* by Sir Edward Pochin (1978)
3	*Radiation Protection—Concepts and Trade Offs* by Hymer L. Friedell (1979) [available also in *Perceptions of Risk*, see above]
4	*From "Quantity of Radiation" and "Dose" to "Exposure" and "Absorbed Dose"—An Historical Review* by Harold O. Wyckoff (1980)
5	*How Well Can We Assess Genetic Risk? Not Very* by James F. Crow (1981) [available also in *Critical Issues in Setting Radiation Dose Limits*, see above]
6	*Ethics, Trade-offs and Medical Radiation* by Eugene L. Saenger (1982) [available also in *Radiation Protection and New Medical Diagnostic Approaches*, see above]
7	*The Human Environment—Past, Present and Future* by Merril Eisenbud (1983) [available also in *Environmental Radioactivity*, see above]
8	*Limitation and Assessment in Radiation Protection* by Harald H. Rossi (1984) [available also in *Some Issues Important in Developing Basic Radiation Protection Recommendations*, see above]
9	*Truth (and Beauty) in Radiation Measurement* by John H. Harley (1985) [available also in *Radioactive Waste*, see above]
10	*Biological Effects of Non-ionizing Radiations: Cellular Properties and Interactions* by Herman P. Schwan (1987) [available also in *Nonionizing Electromagnetic Radiations and Ultrasound*, see above]
11	*How to be Quantitative about Radiation Risk Estimates* by Seymour Jablon (1988) [available also in *New Dosimetry at Hiroshima and Nagasaki and its Implications for Risk Estimates*, see above]
12	*How Safe is Safe Enough?* by Bo Lindell (1988) [available also in *Radon*, see above]
13	*Radiobiology and Radiation Protection: The Past Century and Prospects for the Future* by Arthur C. Upton (1989) [available also in *Radiation Protection Today*, see above]
14	*Radiation Protection and the Internal Emitter Saga* by J. Newell Stannard (1990) [available also in *Health and Ecological Implications of Radioactively Contaminated Environments*, see above]
15	*When is a Dose Not a Dose?* by Victor P. Bond (1992) [available also in *Genes, Cancer and Radiation Protection*, see above]

16 *Dose and Risk in Diagnostic Radiology: How Big? How Little?* by Edward W. Webster (1992) [available also in *Radiation Protection in Medicine*, see above]

17 *Science, Radiation Protection and the NCRP* by Warren K. Sinclair (1993) [available also in *Radiation Science and Societal Decision Making,* see above]

18 *Mice, Myths and Men* by R.J. Michael Fry (1995)

19 *Certainty and Uncertainty in Radiation Research* by Albrecht M. Kellerer. Health Phys. **69**, 446–453 (1995)

20 *70 Years of Radiation Genetics: Fruit Flies, Mice and Humans* by Seymour Abrahamson. Health Phys. **71**, 624–633 (1996)

21 *Radionuclides in the Body: Meeting the Challenge* by William J. Bair. Health Phys. **73**, 423–432 (1997)

22 *From Chimney Sweeps to Astronauts: Cancer Risks in the Work Place* by Eric J. Hall. Health Phys. **75**, 357–366 (1998)

23 *Back to Background: Natural Radiation and Radioactivity Exposed* by Naomi H. Harley. Health Phys. **79**, 121–128 (2000)

24 *Administered Radioactivity: Unde Venimus Quoque Imus* by S. James Adelstein. Health Phys. **80**, 317–324 (2001)

25 *Assuring the Safety of Medical Diagnostic Ultrasound* by Wesley L. Nyborg. Health Phys. **82**, 578–587 (2002)

26 *Developing Mechanistic Data for Incorporation into Cancer and Genetic Risk Assessments: Old Problems and New Approaches* by R. Julian Preston. Health Phys. **85**, 4–12 (2003)

27 *The Evolution of Radiation Protection–From Erythema to Genetic Risks to Risks of Cancer to ?* by Charles B. Meinhold, Health Phys. **87**, 240–248 (2004)

Symposium Proceedings

No. Title

1 *The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack*, Proceedings of a Symposium held April 27-29, 1981 (1982)

2 *Radioactive and Mixed Waste—Risk as a Basis for Waste Classification,* Proceedings of a Symposium held November 9, 1994 (1995)

3 *Acceptability of Risk from Radiation—Application to Human Space Flight,* Proceedings of a Symposium held May 29, 1996 (1997)

4 *21st Century Biodosimetry: Quantifying the Past and Predicting the Future*, Proceedings of a Symposium held February 22, 2001, Radiat. Prot. Dosim. **97**(1), (2001)

5 *National Conference on Dose Reduction in CT, with an Emphasis on Pediatric Patients*, Summary of a Symposium held November 6-7, 2002, Am. J. Roentgenol. **181**(2), 321–339 (2003)

NCRP Statements

No.	Title
1	"Blood Counts, Statement of the National Committee on Radiation Protection," Radiology **63**, 428 (1954)
2	"Statements on Maximum Permissible Dose from Television Receivers and Maximum Permissible Dose to the Skin of the Whole Body," Am. J. Roentgenol., Radium Ther. and Nucl. Med. **84**, 152 (1960) and Radiology **75**, 122 (1960)
3	*X-Ray Protection Standards for Home Television Receivers, Interim Statement of the National Council on Radiation Protection and Measurements* (1968)
4	*Specification of Units of Natural Uranium and Natural Thorium, Statement of the National Council on Radiation Protection and Measurements* (1973)
5	*NCRP Statement on Dose Limit for Neutrons* (1980)
6	*Control of Air Emissions of Radionuclides* (1984)
7	*The Probability That a Particular Malignancy May Have Been Caused by a Specified Irradiation* (1992)
8	*The Application of ALARA for Occupational Exposures* (1999)
9	*Extension of the Skin Dose Limit for Hot Particles to Other External Sources of Skin Irradiation* (2001)
10	*Recent Applications of the NCRP Public Dose Limit Recommendation for Ionizing Radiation* (2004)

Other Documents

The following documents of the NCRP were published outside of the NCRP report, commentary and statement series:

Somatic Radiation Dose for the General Population, Report of the Ad Hoc Committee of the National Council on Radiation Protection and Measurements, 6 May 1959, Science **131** (3399), February 19, 1960, 482–486

Dose Effect Modifying Factors in Radiation Protection, Report of Subcommittee M-4 (Relative Biological Effectiveness) of the National Council on Radiation Protection and Measurements, Report BNL 50073 (T-471) (1967) Brookhaven National Laboratory (National Technical Information Service, Springfield, Virginia)

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