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ICRP PUBLICATION 1XX

Radiological Protection in Veterinary Practice

Editor-in-Chief
C.H. CLEMENT

Associate Editor
H. FUJITA

Authors on behalf of ICRP

N. Martinez, L. Van Bladel, L. Balogh, J. Benoit, S. Dorling, J. Gambino, M.
Natsuhori, R.J. Pentreath, K. Peremans, E. Randall, C. Roy, A. Sovik, I. Tanaka, A.
Davila

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RADIOLOGICAL PROTECTION IN VETERINARY PRACTICE

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ICRP PUBLICATION 1XX

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Approved by the Commission in Month 202Y

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84 **Abstract-** Veterinary use of radiation in the diagnosis, management, and treatment of disease has
85 expanded and diversified, as have the corresponding radiological protection concerns. Radiological
86 exposure of personnel involved in veterinary procedures, and where applicable of assisting
87 members of the public, such as owners or handlers, has always been included within the system of
88 radiological protection. Veterinary practice is now explicitly addressed as the modern complexities
89 associated with this practice warrant dedicated consideration, and there is a need for clarifying and
90 strengthening the application of radiological protection principles in this area. Moreover, consistent
91 with the pursuit of a more holistic approach in radiological protection is the consideration and
92 integration of protection beyond humans to include the environment and the life within it. Humans
93 share the biosphere with the flora and fauna of the environment as well as livestock, companion
94 animals, working animals, etc. The Commission therefore now recommends that the system of
95 radiological protection be applied in veterinary practice principally for the protection of humans
96 but also with explicit attention to the protection of the exposed animals. Additionally, consideration
97 should be given to the risk of potential contamination of the environment associated with
98 applications of nuclear medicine in veterinary practice. This report focuses primarily on
99 justification and optimisation in veterinary practice along with the underlying ethical values, and
100 it sets the scene for more detailed guidance to follow in the future recommendations. It is intended
101 for a wide-ranging audience, including radiological protection professionals, veterinary staff,
102 students, education and training providers, and members of the public as an introduction to the
103 issues surrounding radiological protection in veterinary practice.

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Keywords: veterinary practice; animal patient; justification; optimisation; ethics

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- 109
- ## MAIN POINTS
- 110
- 111 • **The objective of this publication is to provide an initial set of relevant observations,**
112 **considerations, and general recommendations related to radiological protection in**
113 **veterinary practice and is intended for a wide-ranging audience as an introduction to the**
related issues.

 - 114 • **Radiological protection challenges specific to veterinary practice arise from the different**
115 **combinations of personnel and members of the public that may be involved and from**
116 **operational environments required when dealing with animals.**

 - 117 • **The priority of radiological protection in veterinary practice is that of the humans**
118 **involved, but the animal’s exposure should also be the object of explicit attention because**
119 **like humans, animals are subject to potential tissue reactions or stochastic effects**
120 **resulting from exposure to radiation.**

 - 121 • **In veterinary practice, the core ethical values of the system of radiological protection are**
122 **complemented with correlated ethical values such as respect for life and animal welfare,**
123 **and the values of empathy and stewardship are needed in the implementation of the**
124 **system of protection in veterinary practice and in its application to animals in general.**

 - 125 • **Veterinary applications of ionising radiation, and their ensuing protection challenges, are**
126 **to a large extent comparable to medical and non-medical human exposure situations and**
127 **could benefit from similar approaches, such as the three levels of justification, and**
128 **optimisation as a process for ensuring that the likelihood and magnitude of exposures and**
129 **the number of individuals exposed are reasonable and appropriate for the situation at**
130 **hand, considering economic, societal, animal welfare, and environmental factors.**

131

1. WHY THIS PUBLICATION?

132 (1) Why this publication on radiological protection in veterinary practice? Modern medical
133 imaging techniques often have a pivotal role to play in the diagnosis of injury and disease in animals
134 and have therefore become an essential tool in the provision of high-quality veterinary care. The
135 same holds true in providing the best possible advice to owners, breeders or potential purchasers
136 on the suitability of an animal for a specific purpose. On the treatment side, different radiotherapy
137 modalities, including nuclear medicine techniques, are now increasingly available and will
138 contribute to providing the quality-of-care owners want for their beloved animals.

139 (2) Factors such as the digitalisation of radiology, the large availability of second-hand
140 equipment from human medicine and the manufacturing of dedicated veterinary equipment have
141 made radiological procedures more widely attainable. Under the rising pressure of public demand,
142 the number of radiological procedures has therefore substantially increased in recent years.

143 (3) Although this evolution can be applauded from the veterinary services side, practitioners
144 need to be more than ever aware of the radiation risks present. Indeed, digitalisation of imaging is
145 not just increasing the mean number of procedures, it may also increase the mean number of views
146 per procedure as it may come with an increase of radiation dose per view. Practitioners need to be
147 aware that the radiation dose from a CT, from a nuclear medicine diagnostic procedure or from a
148 fluoroscopically guided intervention can be substantially higher than the one encountered in
149 standard radiologic imaging.

150 (4) Radiological risks have increased in veterinary practice as a result of these evolutions, and
151 they can affect both the animals examined or treated as well as the humans assisting in these
152 procedures—professionals and members of the public alike. When working with radioactive
153 materials in applications such as nuclear medicine, persons not actually present during the
154 procedures could also be exposed or become radioactively contaminated, as could the environment,
155 for example as a consequence of inadequate management of waste (urine, faeces) passed by an
156 animal following a nuclear medicine procedure.

157 (5) The objective of the current publication is not to discourage veterinarians or animal owners
158 from the beneficial uses of ionising radiation in veterinary practice. Far from it, the benefits of
159 radiological techniques in veterinary practice are more than convincing; such techniques enable the
160 provision of the best possible animal care as well as solid advice to owners, breeders, and
161 purchasers. But the Commission insists on including radiation protection considerations in clinical
162 practice so that procedures can be done safely from that perspective also.

163 (6) The implementation of radiological protection measures does not need to be overly complex
164 or difficult. Although some of the terminology may be unfamiliar at first, such measures are
165 consistent with other approaches to workplace and patient safety. The approach to radiation
166 protection is completely in line with what can be expected from other aspects of day-to-day quality
167 veterinary services. The first principle of radiation protection for instance, that of ‘justification’
168 transposes the ‘primum non nocere’ or first do not harm concept of the Hippocratic Oath: it tells us
169 to only perform radiological procedures that are appropriate in the context at hand, therefore to
170 refrain from superfluous ones. The second principle, that of ‘optimisation’, tells us to adapt the
171 procedural settings in such a way that the diagnostic or therapeutic objective is met while
172 optimising protection and safety, therefore with a radiation dose to the animal itself and to humans
173 involved which is as low as reasonably achievable. Just as one would adapt the dose of a
174 pharmaceutical product to the animal’s weight. In standard radiology for instance, strictly limiting

175 the exposure zone to the region of clinical interest will lead to better image quality for a lower dose.
176 In interventional procedures, on top of restricting the radiation beam to the region of interest, the
177 skilful use of pulsed fluoroscopy mode can make a tremendous difference.

178 (7) But unfortunately, working correctly and safely with complex techniques and advanced
179 equipment is not always that simple. For such applications, in particular the therapeutic ones,
180 additional—and continued—education and training efforts are undoubtedly required.

181 (8) Finally, the constant and safe provision of quality diagnostic and therapeutic services when
182 using ionising radiation demands that radiation protection considerations be integrated in the
183 quality management of the undertaking, be it a small one-person private practice or a big veterinary
184 hospital. This quality system should oversee the facility and its dedicated rooms, the equipment
185 and their quality control, the qualifications of staff and their ongoing education and training, the
186 procedural rules, the records which should include dose indicators, the incident and accident
187 management, etc.

188

2. INTRODUCTION

2.1. Objective

(9) Veterinary practice has changed considerably over the last few decades, and along with it, the number of applications using ionising radiation has increased in type and variety. More specifically, such applications have greatly diversified to now comprise interventional radiology and CT scanning, nuclear medicine applications including unsealed source therapy and mixed modality imaging, as well as brachy- and tele-therapy (Johnson, 2013; LaRue and Custis, 2014; Kent et al., 2018; Scansen and Drees, 2020) with a wide variety of animals beyond cats, dogs, and horses being treated (e.g. Adkesson and Ivančić, 2019; Schilliger et al., 2020). The potential risks associated with radiation exposure have increased and diversified accordingly, with potential impact on veterinary staff, members of the public including animal owners and handlers, the environment, and the exposed animals. This publication seeks to draw attention to these radiological protection challenges and how they can be managed by applying the International Commission on Radiological Protection's (ICRP) framework. It is intended for a wide-ranging audience, including radiological protection professionals, veterinary staff, students, education and training providers, and members of the public as an introduction to the issues surrounding radiological protection in veterinary practice.

2.2. Scope and Context

(10) Radiological protection in the field of human medicine has been the subject of many ICRP publications, both at a general level (ICRP, 2007b) and in relation to specific aspects of it (e.g. ICRP, 2013a,b, 2014, 2018). These publications may provide inspiration for developing specific guidance and advice that can be applied in veterinary practice, keeping in mind that although veterinary practice has many similarities to human medicine in terms of radiological protection considerations, it also has many differences. Both practices involve the need to protect professional workers, who may or may not be classified as being employed in relation to occupational radiological protection, plus the need to protect the general public and the environment, and of course to protect the patient. In the case of veterinary practice, though, the patient is an animal.

(11) The protection of humans in veterinary practice raises a number of challenges because of the different combinations of personnel involved, and the different operational environments required when dealing with animals. The exposure of the animal also raises specific issues, as individual animals have not previously been considered within the context of the system of radiological protection. Following on from the latest extension of the ICRP's mandate beyond that of the protection of humans to one that encompasses the protection of non-human species (i.e. biota) in an environmental context (ICRP, 2003b), the Commission has now determined, through detailed consideration of protection of the animal in many aspects of veterinary practice and based on a report from a Task Group set up to examine the issue, that it is both appropriate and timely to include consideration of exposed animals in its recommendations (Pentreath et al., 2020). The first step, as set out in this current report, is that of considering how this subject may be accommodated within the existing overall framework of radiological protection.

227 (12) The ICRP has always acknowledged that its guidance with regard to all medical practices
228 has necessarily been somewhat different from that relating to other categories of radiation exposure.
229 Thus, for example, human patients are exceptions from the principle of dose limits because generic
230 dose limits might reduce the effectiveness of the diagnosis or treatment, thereby doing more harm than
231 good. Emphasis is therefore placed on the justification of the procedures in the first place, on the
232 optimisation of protection in relation to the source and, for diagnostic procedures, on the use of
233 diagnostic reference levels. Even the justification principle in the radiological protection of human
234 patients is somewhat different from other human exposure situations in that, generally, both the
235 benefits and the risk relate uniquely to the same person (although other aspects may apply – such
236 as doses to medical staff). Also, any specific method or procedure that can be regarded as justified
237 in general does not necessarily imply that its application to a specific patient is in itself fully
238 justified.

239 (13) In the case of veterinary practice, fundamental issues also arise with regard to the
240 principles of justification and optimisation, and these inevitably spill over into morals and ethics
241 relating to the exposed animal's health and well-being. This report therefore dwells upon these
242 topics – ethics, justification, and optimisation in veterinary practice – at some length, and sets the
243 scene for more detailed guidance to follow in the future.

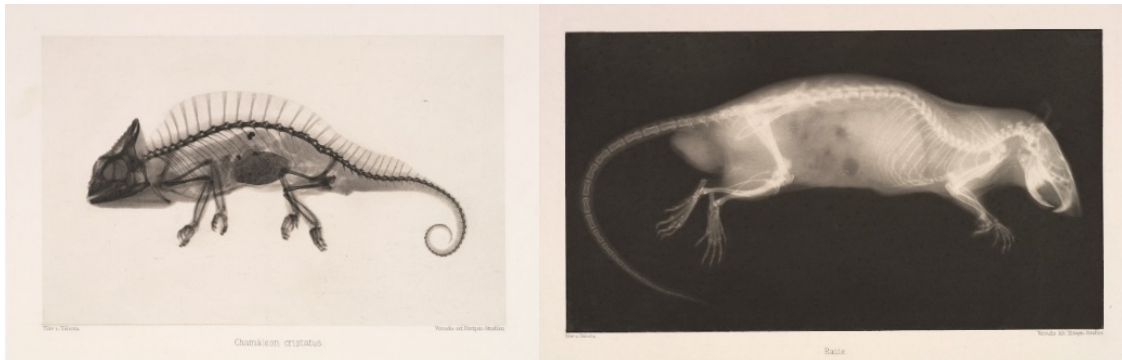
244 **2.3. Background and motivation**

245 (14) After Röntgen's discovery of x-rays, veterinarians were amongst the first to perceive the
246 potential benefits of radiology for animal health care (Beamer, 1939; Schnelle, 1968; Kealy, 2002).
247 In January 1896, post-mortem animal radiographs [fish, frogs, a snake, a lizard, a rabbit, a
248 chameleon (Fig. 2.1, left), and a rat (Fig. 2.1, right), as photogravures] were published, with the
249 first veterinary radiograph of an equine foot published in March of the same year (Eder and Valenta,
250 1896; Johnson, 2013). Diagnostic radiography (or 'Roentgenology') was widely used by military
251 medical departments by World War I, including in veterinary medicine (Fig. 2.2).

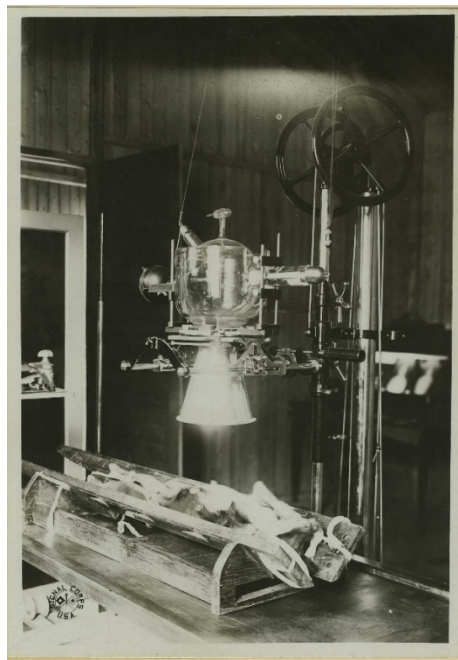
252 (15) Starting with the rise of small animal practice in the 1930s, plain film radiography (Figs
253 1.3 and 1.4) was about the only veterinary application of ionising radiation for many decades.
254 Moreover, the number of procedures was limited and the doses to human bystanders low to trivial,
255 provided that some simple rules were followed (Wantz and Frick, 1937). Consequently, veterinary
256 use of ionising radiation was not a high priority for veterinarians or radiological protection
257 professionals (Wood et al., 1974), although there were some relevant publications that provided
258 guidance or otherwise stressed the importance of radiological protection in veterinary practice (e.g.
259 NCRP, 1970; NHMRC, 1982, 1984; NEB, 1989). Even just over 15 years ago, the prevalence of
260 veterinary radiology was acknowledged to be low (NCRP, 2004). However, since then veterinary
261 procedures making use of ionising radiation have substantially increased and are now as diverse as
262 in human health care, although not necessarily universally available (Johnson, 2013; LaRue and
263 Custis, 2014).

264 (16) Veterinary diagnostic radiology has become more popular for a few reasons, including
265 digitalisation and the wider availability of sophisticated- and higher dose-applications such as
266 computed tomography (CT) and cone beam computed tomography (CBCT) scanning throughout
267 the world (McEvoy, 2015). Digitalisation, which enables images to be processed, stored, and
268 shared electronically, has made radiologic imaging much more convenient compared to traditional
269 film-screen radiography. Images can be viewed immediately, and digital detectors enable images

270 to be interpretable over a wide range of exposure parameters. Although this feature diminishes the
 271 need for retakes, the ease of the digital imaging process often leads to an increase in the mean
 272 number of exposures per study. At the same time, there will be a tendency to choose exposure
 273 parameters at the high end of what is compatible with interpretable images, often referred to as
 274 exposure creep (Gibson and Davidson, 2012). Both these tendencies will result in higher doses to
 275 the animal and to all human bystanders. Interventional radiology procedures have entered the
 276 practice field, and so have nuclear medicine applications, both diagnostic and therapeutic. Lastly,
 277 brachytherapy and external beam radiotherapy have become available in multiple centres around
 278 the world, although there are great differences in local availability.



279
 280 Fig. 2.1. ‘Chamäleon cristatus’, Plate 8 (left) and ‘Ratte’, Plate 13 (right), J.M. Eder and E. Valenta,
 281 Photogravure of x-rays (1896) Versuche über Photographie mittelst der Röntgen'schen Strahlen, The
 282 Metropolitan Museum. <https://www.metmuseum.org/art/collection/search/660046>



283
 284 Fig. 2.2. Operating upon a dog, for instruction, at Central Medical Department Laboratory, Dijon, France,
 285 September 6, 1918 (Reeve 10216). OHA 80 Reeve Photograph Collection. Courtesy of Otis Historical
 286 Archives, National Museum of Health and Medicine.



287
 288 Fig. 2.3. Veterinary lecture on radiography, 1936 (left); Students x-raying a dog, 1969 (right) both at Kansas
 289 State University (KSU), Manhattan, Kansas, United States. Courtesy of College of Veterinary Medicine at
 290 KSU.



291
 292 Fig. 2.4. (Left) Veterinary students and their professor preparing to x-ray a dog, College of Veterinary
 293 Medicine, University of Minnesota, St. Paul, Minnesota (~1965). Courtesy Minnesota Veterinary Historical
 294 Museum. <https://reflections.mndigital.org/catalog/p16022coll525:6> (Right) Radiologist examining a horse
 295 with modern X-ray equipment at the Veterinary Sciences College, Massey University, 1969. The photo is
 296 from Archives New Zealand's National Publicity Studios collection; R. Anderson (photographer); licensed
 297 under CC BY 2.0.

298 (17) Radiation-related risks have also expanded because of these important practice changes.
 299 For example, in addition to the external exposure associated with nuclear medicine procedures,
 300 relevant veterinary clinics also need to consider the risk of contamination by radioactive substances
 301 to staff, owners, handlers, and to the environment. Lessons learned from human medicine inform
 302 us that radiation exposure of veterinary staff involved in interventional procedures also needs to be
 303 closely monitored since doses could be significant (e.g. Klein et al., 2009; Duran et al., 2013; Ko
 304 et al., 2018), as could the doses to the animal patients themselves (e.g. Wagner, 2007; Balter and
 305 Miller, 2014; Arkans et al., 2017). Moreover, unique issues associated with animal patients may
 306 result in higher occupational doses associated with certain procedures. For example, it has been
 307 shown that veterinary positron emission tomography (PET) procedures often result in higher doses

308 to staff than comparative PET procedures with human patients. This increase in dose is associated
309 with the need for additional care associated with animal anaesthesia, which is necessary in a number
310 of radiological procedures to ease patient handling and positioning as well as to reduce motion
311 artefacts (Martinez et al., 2012).

312 (18) Societal changes also play a role in the increasing number and diversity of procedures
313 performed on animals. Many companion animals are considered by their owners as ‘part of the
314 family’, and therefore entitled to the best care available. The same may hold true for working
315 animals, endangered species, exotic and sports animals, also when their monetary value may further
316 stimulate owner interest in their animals’ welfare. More and more, owners make sure that their
317 animals are covered by specific health insurance (NAPHIA, 2020), which may require radiological
318 exams as part of insurability checks, and also removes financial barriers that would otherwise
319 restrict the use of these more expensive imaging or treatment options (Kipperman et al., 2017). The
320 imaging of animals now also has a prominent place in a wide variety of suitability checks, such as
321 suitability for breeding or for a career in sports. These procedures, which may not primarily be
322 performed for the benefit of the animal exposed, can become a radiological protection challenge in
323 terms of the high number of exposures and the fact that a limited number of staff and members of
324 the public may be involved in many procedures.

325 (19) The impact of these changes in veterinary practice on the radiological protection needs
326 and challenges have not gone unnoticed, and some authorities and organisations have produced
327 guidance accordingly. For example, the National Council on Radiation Protection and
328 Measurements revised the relevant 1970 report in 2004, and succinctly summarised the goal of
329 radiological protection in veterinary medicine (NCRP 2004):

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

334 (20) The Radiological Protection Institute of Ireland (RPII) and the Australian Radiation
335 Protection and Nuclear Safety Agency (ARPANSA) also both published relevant guidance in the
336 2002 ‘Code of Practice for Radiation Protection in Veterinary Medicine’, and the 2009 ‘Code of
337 Practice & Safety Guide for Radiation Protection in Veterinary Medicine’, respectively, each an
338 update of similar reports from the 1980s (RPII, 2002; ARPANSA, 2009). More recently, the
339 International Atomic Energy Agency (IAEA) has prepared a Safety Guide related to radiological
340 protection and safety in veterinary medicine (IAEA, 2021), and various activities have been
341 developed by a dedicated working group within the Heads of the European Radiological Protection
342 Competent Authorities (HERCA), a voluntary organisation of Europe’s radiological protection
343 regulatory authorities (HERCA, 2012).

344 (21) The ICRP, now recognising that the complexities of veterinary practice warrant dedicated
345 clarification within the system of radiological protection, has decided that there is a need for
346 strengthening the application of its protection principles in this area (Martinez and Van Bladel,
347 2020). As mentioned above, the objective of the current publication is not to provide direct,
348 practice-oriented advice, but rather an initial set of relevant recommendations and considerations.
349 Its primary focus will be the protection of humans involved in or affected by the procedures, both
350 professionals and members of the public. The animal patient’s protection is also considered as well
351 as protection of the environment from nuclear medicine applications.

352

3. BASIC CONCEPTS OF RADIOLOGICAL PROTECTION

3.1. Dosimetric Quantities

354 (22) Quantities and units used in the system of radiological protection are covered in Annex B
355 of the 2007 Recommendations of the ICRP (ICRP, 2007a) as well as the online ICRP Glossary
356 (http://icrpaedia.org/ICRP_Glossary). It should be pointed out, however, that most of these
357 quantities and units have been exclusively developed to fit the protection of humans exposed to
358 ionising radiation.

359 (23) *Absorbed dose* is the energy imparted by ionising radiation to a mass, per unit mass, and
360 has units of J kg^{-1} with the special name gray (Gy). Absorbed dose, which can be measured, is the
361 fundamental physical quantity used in radiological protection as it can be reasonably related to
362 radiation effects, particularly those associated with tissue reactions in people. Absorbed dose is the
363 most appropriate dosimetric quantity for use in setting limits on organ/tissue doses to prevent tissue
364 reactions (i.e. deterministic effects, see section 3.2.1) in people, and it is currently the only
365 appropriate dosimetric quantity for expressing doses to animals (ICRP, 2014, 2021b).

366 (24) *Equivalent dose* is derived from absorbed dose by accounting for biological effectiveness,
367 or *quality*, of the different types of radiation (e.g. alpha, beta, gamma) and generally applies to a
368 specific human organ or tissue. Note that the Commission expects to change from the use of
369 equivalent dose to absorbed dose in setting limits on organ/tissue doses for people at the time that
370 new general recommendations are issued (ICRP, 2021b). Equivalent dose serves, then, as an
371 intermediate step in the calculation of *effective dose*, which is an additionally weighted quantity
372 that accounts for different tissue radiation sensitivities with respect to the induction of stochastic
373 effects and applies to the whole (human) body (ICRP, 2021b). Effective dose is a risk-adjusted
374 quantity that enables consolidation of doses received from all radiation types and from internal and
375 external exposures for the purpose of managing protection of people at low to moderate doses; it is
376 of particular use in the optimisation of protection for workers and members of the public. Effective
377 dose may be considered as an approximate indicator of possible risk in a population of people,
378 recognising that lifetime cancer risks vary with age at exposure, sex, and population group
379 (Harrison et al., 2016; ICRP, 2021b). Equivalent and effective dose have the same SI units as
380 absorbed dose, J kg^{-1} , but are expressed using the special name sievert (Sv). Of note is that these
381 quantities were developed utilising methodology and models specific to humans.

382 (25) *Activity* refers to the amount of radioactive material present and is typically expressed as
383 the number of nuclear transformations (or disintegrations) per second with the unit becquerel (Bq),
384 which is equivalent to s^{-1} . Dose coefficients have been developed for humans to estimate the
385 radiation dose associated with an exposure to a given quantity or concentration of a radioactive
386 substance and are often expressed as Sv Bq^{-1} (ICRP, 2012a, 2020a).

387 (26) Because the radiation sensitivity of animals is known to differ from one species to another
388 and even between different breeds of the same species, current radiation and tissue weighting
389 factors (and thus equivalent and effective dose) cannot be used as such to estimate exposure and
390 ultimately radiation-induced risk incurred by an animal submitted to a procedure in which ionising
391 radiation is used. It should therefore be emphasised that radiation doses for any animal can only be
392 expressed in terms of absorbed dose (Gy). However, recommendations have recently been made
393 for weighting absorbed dose based on radiation quality for (non-human) biota in an environmental

394 context (ICRP, 2021a). Note that twelve ICRP Reference Animals and Plants (RAPs) for relating
395 exposure to dose and dose to biological effect have been described at the taxonomic level of family,
396 two of which are for big and small mammals: *Cervidae* (deer) and *Muridae* (rodent). These RAPs
397 are intended to be broadly representative of environmental biota. Dose coefficients for RAPs are
398 formulated in terms of absorbed dose rate ($\mu\text{Gy d}^{-1}$) per unit activity concentration (Bq kg^{-1}) to
399 which the organism is exposed (ICRP, 2017b). In the development of these dose coefficients, data
400 on biological effects relating to external and internal sources of radiation were drawn from a wide
401 range of relevant literature (ICRP, 2008), which, although not specifically focused on veterinary
402 applications, does provide a useful baseline for information on radiation effects in animals.

403 (27) Although a full suite of veterinary dose coefficients does not exist, some limited
404 experimental research has been done in this area (e.g. Hall, 2011), and in addition there are a variety
405 of computational anatomical animal models available that are suitable for dosimetric modelling
406 (Zaidi, 2018), including at least five for canines (Padilla et al., 2008; Kramer et al., 2012; Stabin et
407 al., 2015), and many databases exist on the effects of radiation on mammals (e.g. Zander et al.,
408 2019). A discussion of currently available dosimetric data in veterinary diagnostic radiology is
409 included in section 6.2.2.

410 **3.2. Summary of biological basis for radiological protection**

411 (28) Adverse biological effects induced by radiation may be divided into two main categories:
412 tissue reactions leading to tissue/organ damage (also called deterministic effects), and cancer and
413 heritable diseases (also called stochastic effects) (ICRP, 2020b). These effects are briefly
414 summarised here; the biological basis for radiological protection is covered thoroughly in Annex
415 A of the 2007 Recommendations (ICRP, 2007a) and other Commission documents (ICRP, 2003a,
416 2012b).

417 (29) Our current knowledge about the detrimental effects of radiation has been developed from
418 a series of sources, to which experiments on animals have significantly contributed. Animal models
419 are frequently used to extrapolate health risk, carcinogenic or otherwise, to humans (Davidson et
420 al., 1986; Fjeld et al., 2007). For these reasons, although not specific to the practice of veterinary
421 medicine, there is a good amount of data on the effects of animal exposure to a variety of radiation
422 types, albeit predominantly at high doses or dose rates. Although large radiobiology studies often
423 focus on murine models, animal species of broader interest in veterinary medicine, such as canines,
424 have been studied as well (see, for example, ICRP, 2008; UNSCEAR, 2010; Haley et al., 2011;
425 Singh et al., 2015; Tang et al., 2017). Effects observed in exposed animals are of the same nature
426 as those seen in humans, although the dose-effect relationships may be different (NRC, 1991).
427 Exposure of animals (companion, livestock, wild animals) to clinically significant doses of ionising
428 radiation similarly results in adverse biological effects as in humans, but to a variable extent (von
429 Zallinger and Tempel, 1998; Fesenko, 2019). Radiation effects vary amongst species, breed/strain
430 (genetic susceptibility and individual radiosensitivity), sex, age at exposure, dose (cumulative) and
431 dose-rate as well as radiation quality and mode of exposure (external or internal) (Misdorp, 1996).

432 **3.2.1. Tissue reactions (deterministic effects)**

433 (30) Tissue reactions result after exposure to high doses of radiation over a relatively short
434 period of time and manifest clinically when the radiation dose received is above a given threshold.

435 These effects are seen in companion animals treated with ionising radiation for therapy (e.g. cancer,
436 pain alleviation). Although originally defined as such for humans, effects are often classified as
437 acute (manifesting shortly after exposure) or late (manifesting months to years after exposure) in
438 animals as well (Collen and Mayer, 2006; ICRP, 2012b). As in humans, as the dose increases, the
439 effect is seen with increasing frequency and severity, and specific effects depend on the tissue
440 irradiated (e.g. LaDue and Klein, 2001).

441 (31) In radiotherapy, high radiation doses delivered to the target tissue induce tissue reactions
442 that ultimately prevent cancerous cells from further out-of-control multiplication. That said, effects
443 such as skin burns and ocular effects are potential undesired effects on healthy tissues in some
444 therapeutic procedures and cannot always be avoided (Gillette et al., 1995; Collen and Mayer,
445 2006; Pinard et al., 2012). For example, in interventional procedures, lesions such as radiation
446 induced skin burns in the area where the primary radiation beam enters the body may appear within
447 weeks, particularly when complex procedures requiring prolonged fluoroscopy times are
448 performed on larger animals. Most such injuries can be managed and are self-limiting, but it is
449 important to remember that unnecessary tissue reactions result in needless suffering; overexposure
450 in radiotherapy can result in excessive and severe tissue reactions that are very painful and can also
451 lead to a variety of long-term complications. The specific complication will depend on the
452 technology being used, dose fraction and total dose, as well as the organ at risk in the target volume.
453 These delayed complications can be benign or more severe and tend to be irreversible (e.g. fibrosis,
454 necrosis, chronic inflammation) and difficult to treat, with detrimental impact to the patient's
455 quality of life in both animals and people (Gillette et al., 1995; Collen and Mayer, 2006; Balter and
456 Miller, 2014; Hall and Giaccia, 2019). Tissue reactions may also appear as a result of prenatal
457 exposure, discussed further in section 3.2.3.

458 (32) Although occupational doses received in veterinary practice are generally too low to
459 observe tissue reactions, some nuclear medicine procedures, interventional or brachytherapy
460 procedures, combined with poor practice, incidents, or accidents, have the potential to result in skin
461 burns or lens of the eye effects, based on experience in human medicine (Miller et al., 2010; Dauer,
462 2014; ICRP, 2018b).

463 **3.2.2. Stochastic effects (cancer and heritable effects)**

464 (33) Stochastic effects are those effects for which the probability of occurrence, but not severity,
465 is a function of dose with no apparent threshold. Ionising radiation can interact with a cell such that
466 the cell is damaged, but can continue through the cell cycle, thus potentially leading to a malignant
467 disease. Stochastic effects resulting from exposure to ionising radiation include cancers, which can
468 result from damage to somatic cells, and heritable effects, which can result from damage to germ
469 cells. Of note is that a wide variety of environmental contaminants as well as naturally occurring
470 mutations in somatic and germ cells also contribute respectively to cancers and hereditary diseases
471 (NRC, 2006; Fjeld et al., 2007).

472 (34) Although there are indications of an increase in cancer risk for exposed children—
473 including after in utero exposures—in the range of 50-100 mSv (Wakeford and Bithell, 2021), an
474 elevation of cancer risk in exposed members of the public at doses below about 100 mSv cannot
475 be firmly demonstrated by epidemiological surveys alone. However, seen in combination with a
476 deliberately prudent interpretation of radiation physics and radiation biology data, the Commission
477 recommends that a linear no threshold model be used for the purpose of applying its system of
478 radiation protection in risk management. This model assumes a linear relationship between dose

479 and stochastic risk, which means that any increase in dose may result in an increase in the stochastic
480 risk, bearing in mind that risks are increasingly uncertain at lower doses (ICRP, 2021b). It is
481 challenging to develop definitive risk predictions for radiogenic disease at low doses because there
482 are a variety of factors that contribute to overall risk as well as additional modifying factors that
483 can influence the promotion or progression of the disease (NRC, 2006; McLean et al., 2017). The
484 risk indicator used by the Commission for humans is the radiation *detriment* which is sex- and age-
485 averaged over a composite reference population. It is determined from the lifetime risk of cancer
486 and considers severity in terms of lethality, quality of life, and years of life lost. It also considers
487 heritable effects based on information from animal studies (ICRP, 2007a, 202X).

488 (35) With respect to exposed animals, a common misconception is that an animal with a short
489 lifespan compared to a human will not experience radiogenic cancer. However, it has been widely
490 observed since the 1970s that, across species, neither an increased body size nor longer lifespan is
491 associated with an increase in carcinogenesis risk as theoretically expected from the associated
492 increase in number of cells or cellular divisions, respectively (Abegglen et al., 2015). This provided
493 foundational insight for the modern recognition that the physiological factors influencing
494 organisms' responses to carcinogens are varied and complex.

495 (36) Cancer patterns in mammals are similar, and in general, relative to life span (Albert et al.,
496 1994; Schiffman and Breen, 2015), or in other words, *risk of cancer in old age is not vastly different*
497 *in species with very different life-spans* (Peto, 2016). Latency periods are less than that in humans
498 for many animals with shorter, physiologically compressed lifespans (NRC, 1991; Backer et al.,
499 2001). Of interest to veterinary practice is the observation that dogs, as compared to other species
500 studied, demonstrate a greater risk of developing cancer as a result of exposure to ionising radiation,
501 and for cancer prevention in dogs it has even been explicitly stated in the literature that *dogs should*
502 *be exposed to radiation only when the expected benefits will outweigh the risks* (Kelsey et al., 1998),
503 consistent with the principle of justification in radiological protection.

504 (37) Inheritance of radiation-induced abnormalities was reported by Hermann Muller in 1927
505 based on studies with x-ray irradiation of *Drosophila* (fruit flies) (Pontecorvo, 1968). Radiation
506 exposure can only increase the incidence of the same mutations that occur spontaneously in a
507 population (Hall and Giaccia, 2019). This makes potential heritable radiogenic effects in humans
508 difficult to study because of the high natural incidence of the same mutations. Thus, hereditary
509 effects in humans have not been definitively or reliably shown to be induced by ionising radiation
510 exposure (Boice, 2020; NCRP, 2021), despite ample evidence of radiogenic hereditary effects in
511 plants and animals (e.g. Russell, 2013). Humans are likely also susceptible to these effects, but with
512 risk much lower than that for carcinogenesis (UNSCEAR, 2001, 2014).

513 (38) In humans, the likelihood of developing cancer in response to exposure to a carcinogenic
514 agent depends on a variety of factors including, but not limited to, age; sex; environmental,
515 socioeconomic, and lifestyle factors; and genotype (Colditz GA et al., 1996). Individual variability
516 in radiosensitivity to carcinogenesis is acknowledged, but not fully understood (Rajaraman et al.,
517 2018). However, there are some clear, population-level attributes, such as age and sex, that
518 influence susceptibility to radiation-induced carcinogenesis (NRC, 2006; Preston et al., 2007). This
519 risk is overall higher for the fetus, children, and adolescents, due to longer life ahead and the
520 comparative sensitivity of developing organs and tissues (ICRP, 2013b), and for females, primarily
521 due to the radiosensitivity of the breast (Boice et al., 1991; NRC, 2006). This age- and sex-
522 dependence of risk should be considered in the process of justification and optimisation,
523 particularly with respect to children. For example, in veterinary practice, children and young

524 adolescents are excluded from assisting in radiological examinations as the exposure is not justified.
525 Similarly, the potential presence of individuals who are or may be pregnant needs careful
526 consideration with respect to justification when radiological procedures are being performed; this
527 has to do with both the radiosensitivity of the unborn child (section 3.2.3) and the possible particular
528 sensitivity of the breast tissue in some stages of its preparing for lactation. The justification process
529 for any such exposure should bear in mind that the dose limit for the unborn child (1 mSv during
530 the pregnancy) is not to be exceeded. If the presence of the pregnant or possibly pregnant individual
531 is deemed justified, and informed consent is given, then the exposure needs to be optimised. This
532 could be achieved by providing instructions on where to stand, how to behave, what protective
533 equipment to use, etc. Strategies for optimisation are discussed further in Chapter 6.

534 (39) It has been similarly shown in laboratory animals that age at exposure and sex influence
535 the risk of carcinogenesis, although to a varying extent (Benjamin et al., 1991; Shuryak et al., 2010;
536 Haley et al., 2011; Tang et al., 2017). These risk dependencies are thus also relevant considerations
537 for animal patients, as some groups receive exposures from a young age (e.g. dysplasia screening
538 in puppies) (Dziuk, 2007) or presale examinations of performance horses (Judy, 2013). Being
539 mindful of these risks is especially important when determining if non-medical exposures are
540 justified (discussed further in section 6.2).

541 3.2.3. Effects of in-utero exposure

542 (40) Radiation effects on the embryo/fetus during pregnancy (i.e. teratogenic effects) depend
543 on the stage of pregnancy at the time of exposure, the absorbed dose to the embryo/fetus and
544 radiation type. At most diagnostic levels, effects include risk of childhood cancer, while at doses
545 in excess of 100-200 mGy during the most radiosensitive fetal time period, there are risks of
546 deterministic effects including nervous system abnormalities, malformations, growth retardation,
547 intellectual disabilities, and fetal death (ICRP, 2000, 2003a). *Publication 84* (ICRP, 2000)
548 discusses the management of pregnant patients and pregnant workers in medical facilities where
549 ionising radiation is used. *Publication 90* (ICRP, 2003a) critically evaluates and summarises the
550 effects of pre-natal irradiation, including evidence from animal studies which are particularly
551 relevant to veterinary practice.

552 (41) In humans, for most properly conducted diagnostic radiology procedures, doses typically
553 do not exceed 20 mGy although interventional procedures involving the pelvis could be higher. If
554 such an examination is medically indicated, the risk to the mother of not doing the procedure is
555 almost always greater than the risk of potential harm to the fetus. However, therapeutic or other
556 higher dose procedures can result in much higher risk. If possible, it is recommended medical
557 radiation procedures should be tailored to reduce fetal dose in pregnant (human) patients (ICRP,
558 2000; Mathews et al., 2013; ACOG, 2017). Similar effects, risks, and management strategies apply
559 to animal patients, particularly as a lot of evidence for teratogenic effects comes from animal
560 studies, as mentioned above (Benjamin et al., 1998; Russell, 2013).

561 3.3. ICRP framework of radiological protection

562 (42) The primary aim of the system of radiological protection is to contribute to an appropriate
563 level of protection for people and the environment against the detrimental effects of radiation
564 exposure without unduly limiting the desirable human actions that may be associated with such

565 exposure (ICRP, 2007a). For people, radiation exposures are managed with the goal of reducing
566 stochastic effects to the extent reasonable and preventing unnecessary tissue reactions in healthy
567 tissues (e.g. in radiotherapy, a tissue reaction may be unavoidable in order to obtain effective
568 treatment). It should be stressed here that the Commission's system of protection has been
569 developed with the primary aim to protect humans. More recently, environmental protection has
570 also been addressed, in which the focus is on protection of populations in the natural environment.
571 Although in general population-level environmental protection is based on knowledge of the effects
572 of radiation on representative animals and plants, little concern has been demonstrated for the
573 possible detrimental effects for an individual animal, except for those belonging to endangered
574 species, although as early as the 1930s it was acknowledged that attention to animal patient
575 exposure should not be neglected (Wantz and Frick, 1937). Of note is that *Publication 146* does
576 include explicit consideration of pets and livestock in its discussion of emergency preparedness
577 and response (ICRP, 2020b).

578 (43) It is worth re-emphasising that veterinary practice has always been included in the system
579 of radiological protection in the broad sense but is explicitly addressed and elaborated upon here.
580 As such, much of the information herein regarding radiological protection of veterinary staff and
581 members of the public, including animal owners and handlers, is to a large extent drawn from
582 *Publications 103* and *105* (ICRP, 2007a,b). The Commission recommends that the system of
583 radiological protection be applied in veterinary practice principally for the protection of humans
584 and now also includes explicit attention to the radiological protection of the exposed animals and
585 the environment, where applicable.

586 3.3.1. Exposure situations and categories

587 (44) Different exposure situations and categories are defined within the system of radiological
588 protection to take into consideration the specific circumstance under which an exposure occurs.
589 The exposure situations include planned (situations in which protection can be planned ahead of
590 time), emergency (unexpected situations, such as accidents, that may necessitate urgent
591 intervention), and existing (situations that already exist and may need a decision on management
592 or control). The radiological, nuclear medicine and radiotherapy procedures performed in
593 veterinary practice discussed in this publication are considered planned exposure situations.

594 (45) Exposure categories include public (exposure received apart from occupational, medical,
595 and natural background), occupational (exposure received at work due to the nature of the work),
596 and medical (exposure received as a patient/research volunteer or from a patient as a
597 comforter/carer). As the recommendations are currently written (ICRP, 2007a,b), the medical
598 exposure category appears to apply solely to human medicine. Veterinary applications of ionising
599 radiation are to a very large extent comparable to human medical exposures; in fact, the only
600 distinction is that the exposures are aimed at animals in one case, human subjects in the other. In
601 both cases occupational and public exposures may occur. Because veterinary practice appears to
602 fall somewhere in between, or at the intersection of, the above exposure categories, local
603 governments and regulatory agencies manage veterinary exposures in different ways. Where
604 veterinary practice is often considered—from a regulatory perspective—as comparable to an
605 industrial application of ionising radiation rather than a medical one, this may lead to an approach
606 whereby the animal is considered a mere object, without consideration of its characteristics as a
607 sentient living creature.

608 (46) Environmental exposure (that is, exposure to the living environment) is a fourth type of
 609 exposure. Thus far, the ICRP has focused on the natural environment, with the goal of maintaining
 610 biological diversity, conserving species, and maintaining the health status of associated habitats,
 611 communities, and ecosystems (ICRP, 2003b, 2008, 2009, 2014, 2017b, 2021a).

612 **3.3.2. Principles of protection**

613 (47) The core of the system of radiological protection consists of three fundamental principles:
 614 justification, optimisation, and application of dose limits (ICRP, 2007a). The principle of
 615 justification specifies that any activity or intervention that changes the exposure scenario should be
 616 overall beneficial to individuals and/or society (see section 6.1). The principle of optimisation of
 617 protection and safety specifies that doses should be as low as reasonably achievable (ALARA),
 618 considering economic and societal factors as well as other relevant aspects of the prevailing
 619 circumstances (see section 6.2). Of note is that in medical exposures, optimisation involves keeping
 620 patient exposures to the minimum required to achieve the desired medical objective, whether
 621 diagnostic or therapeutic (ICRP, 2013a). Justification and optimisation are source-related
 622 principles, and restrictions on dose from a particular source (e.g. dose constraints) are used to avoid
 623 severely inequitable outcomes of the optimisation process. The final principle, application of dose
 624 limits (see section 6.3), is individual-related, applies to planned exposure situations, and indicates
 625 that radiation doses should not exceed appropriately established limits for radiation workers and
 626 the public (Table 3.1).

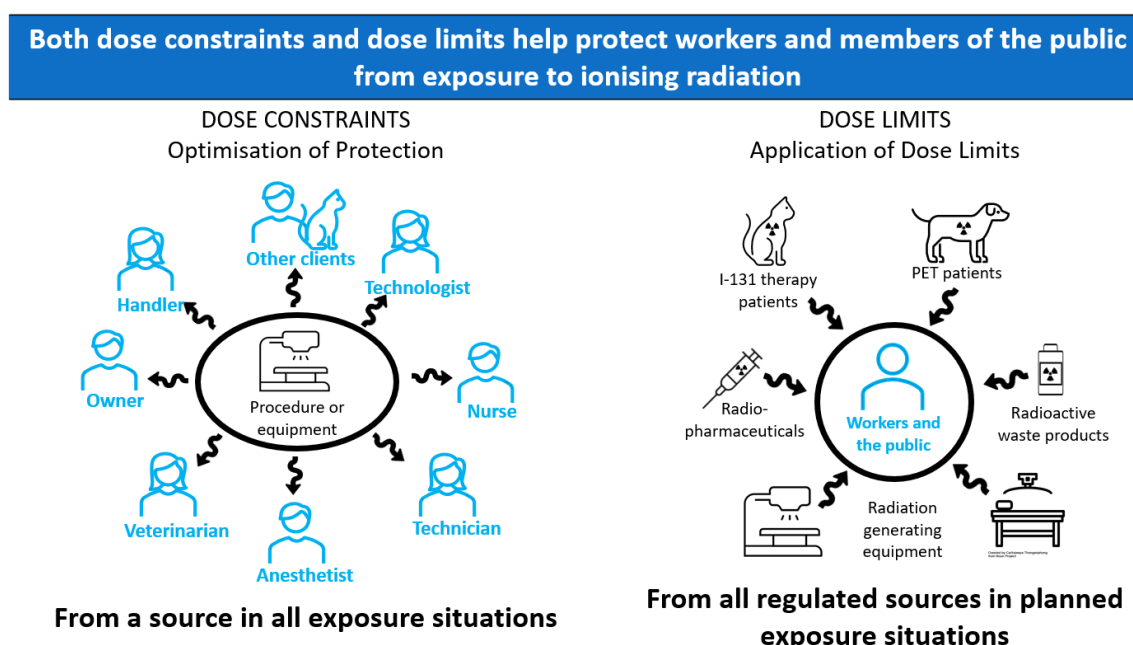
627 Table 3.1. Summary of the dose limits recommended by the ICRP.

Type of dose limit	Limit on dose from occupational exposure	Limit on dose from public exposure
Effective dose	20 mSv y ⁻¹ averaged over 5 years, with no single year exceeding 50 mSv. After a worker declares pregnancy, dose to embryo/fetus should not exceed 1 mSv over the remainder of the pregnancy.	1 mSv y ⁻¹
Equivalent dose (lens of the eye)	20 mSv y ⁻¹ averaged over 5 years, with no single year exceeding 50 mSv	15 mSv y ⁻¹
Equivalent dose (over 1 cm ² skin)	500 mSv y ⁻¹	50 mSv y ⁻¹
Equivalent dose (hands and feet)	500 mSv y ⁻¹	Not applicable

628 (48) Dose constraints are prospective, source-related restrictions on individual dose to workers
 629 and/or members of the public intended to serve as the upper bound of the optimisation goal for that
 630 source (Fig. 3.1). Note that dose constraints are not intended to be hard limits. Rather, consistent
 631 with the core value of justice, dose constraints are intended to serve as a mechanism for limiting
 632 potential inequity that could result from differences in value judgements when implementing the
 633 optimisation process. In fact, interpreting constraints as rigorous limits can distort the outcome of
 634 the optimisation process (ICRP, 2007a). Dose constraints are initially used within the optimisation
 635 process at the planning stage to establish an appropriate level of protection for a given situation
 636 and develop corresponding protective actions. The numerical value taken for a dose constraint will

637 depend on the situation at hand, and could be in terms of individual doses, dose rates, collective
 638 dose or a combination of these.

639 (49) After the planning stage, dose constraints can uncover discrepancies between planning
 640 and implementation, or reveal potential changes that warrant additional consideration. In other
 641 words, a dose constraint can be thought of as an investigation level used as part of the optimisation
 642 process. In fact, the concept behind dose constraints is often used in low dose scenarios such as
 643 occupational medical exposure without naming it as such. For example, if a process or procedure
 644 is known to consistently and appropriately result in an effective dose of 0.5 mSv over three months,
 645 and recently that procedure resulted in 2 mSv over three months, then an investigation would be
 646 conducted to discern the root cause of the increase. This increase may have been warranted, in
 647 which case no further action is necessary, or it may demonstrate a lapse in proper technique,
 648 problem with equipment, or other issues that need to be addressed.



649
 650 Fig. 3.1. Example comparison of dose constraints (left) to dose limits (right) for protecting workers
 651 (occupational exposure) and members of the public (public exposure).

652 (50) The principle of optimisation of protection for human patients is unique in the system of
 653 radiological protection. In diagnostic procedures it is again the same person that gets the benefit
 654 but also suffers the risk. The imposition of individual restrictions on patient dose could also be
 655 counterproductive to the medical purpose of the procedure. Source-related dose constraints for the
 656 individual are therefore not relevant, and thus Diagnostic Reference Levels (DRLs) for a particular
 657 procedure, which apply to groups of similar patients rather than individuals, are used. Radiation
 658 therapy is also very different from other situations in that the dose is intentional and its potential
 659 cell-killing properties are the very purpose of the treatment. In this case optimisation therefore
 660 becomes an exercise in minimising doses (and/or their deleterious effects) to surrounding tissues
 661 without compromising the pre-determined and intentionally lethal dose and effect to the target
 662 volume.

663 (51) These ideas should intuitively also apply to veterinary animal patients (Pentreath, 2016),
664 although if and how these patients fit within the principle of optimisation has not been explicitly
665 defined. Thus, management strategies are inconsistent between different countries (HERCA, 2012).
666 In many countries, veterinary medicine is considered to be an industrial rather than medical practice,
667 the latter of which is considered to only include human medicine. Unfortunately, this philosophy
668 often neglects considerations associated with unique but necessary aspects of veterinary practice
669 such as safety of animal patients under sedation or anaesthesia, or situation dependent risk
670 management as consistent with a graded approach (IAEA, 2018), that is, the implementation of the
671 system of protection in a way that is proportionate to the magnitude and likelihood of the risk, the
672 complexity of the exposure situation, and the prevailing circumstances. Thus, clear delineation of
673 the application of both justification and optimisation for the patient in veterinary practice is
674 warranted.

675 (52) Dose limits do not apply to the patient in medical exposures so as not to interfere with
676 necessary, medically indicated diagnostic or therapeutic procedures; generic dose limits might well
677 reduce the effectiveness of the diagnosis or treatment, thereby doing more harm than good.
678 Emphasis is therefore placed on the justification of the procedures in the first place, on the
679 optimisation of protection in relation to the source and, for diagnostic procedures, on the use of
680 DRLs, which are not seen as limits, but instead indicate if a dose received from an imaging
681 procedure is unusually high or low to guide the optimisation process and thus help manage patient
682 exposures (ICRP, 2007b, 2017a). The Commission recommends that an approach analogous to that
683 applied for human medical exposures be developed and applied for veterinary exposures which
684 includes a quality dose management program that allows for periodic audits, continuous peer
685 learning, and use of incident reporting systems that capture incidents and near misses (e.g.
686 <https://rpop.iaea.org/SAFRAD/About.aspx> or <https://roseis.estro.org/>).

687 (53) Derived Consideration Reference Levels (DCRLs), rather than limits, are used to inform
688 the appropriate level of management or control of an exposure in environmental radiological
689 protection. DCRLs are absorbed dose rates above which, for a given taxonomic class, there is the
690 potential for deleterious effects on individuals of a species that may lead to population-level
691 consequences, and they can be used as points of reference to optimise the level of effort expended
692 on environmental protection, dependent upon the overall management objectives and the relevant
693 exposure situation (ICRP, 2014). As such, although relevant to animals in general, the concepts
694 developed for radiological protection of the environment do not suffice for the adequate protection
695 of individual animals exposed in veterinary settings.

696 (54) Finally, emergency and existing exposure situations utilise reference levels rather than
697 limits, because what defines a reasonable or tolerable exposure is strongly dependent on the
698 prevailing circumstances of the exposure in these situations. The current work on radiological
699 protection in veterinary practice focuses on planned exposure situations, although there may
700 potentially be veterinary concerns in the other exposure situations as well (e.g. emergency
701 exposures following a large-scale nuclear accident). Fig. 3.2 provides a general summary of the
702 principles of radiological protection and associated tools for application in veterinary practice.

Principle	Tools for Application		
<p>Justification</p> <p><i>anything that changes the exposure scenario should be overall beneficial to individuals and/or society</i></p>	<p>Level 1</p> <p><i>the proper use of radiation in veterinary medicine does more good than harm to society</i></p>	<p>Level 2</p> <p><i>a procedure is justified for a specified objective if it does more good than harm to a group of exposed animals</i></p>	<p>Level 3</p> <p><i>the particular application should be judged to do more good than harm to the individual patient</i></p>
<p>Optimisation</p> <p><i>an iterative process for achieving the best level of protection under the prevailing circumstances considering economic, societal, animal welfare, and environmental factors</i></p>	<p>Dose constraints</p> <p><i>guidelines for upper bound of optimisation in a planned exposure situation for workers and members of the public, based on reasonable, good practice</i></p>	<p>Diagnostic reference levels*</p> <p><i>indicate whether, in routine conditions, patient dose is unusually high or low for a certain diagnostic procedure</i></p>	<p>Derived consideration reference levels</p> <p><i>points of reference for optimising the level of effort expended on environmental protection</i></p>
<p>Application of dose limits</p> <p><i>radiation doses to individuals other than patients should not exceed appropriately established limits</i></p>	<p>Dose limits</p> <p><i>maximum dose that would be accepted in any planned exposure situations by regulatory authorities</i></p>		

703
704 Fig. 3.2. The three principles of radiological protection with example tools or administrative strategies for
705 application in veterinary practice. *Note that diagnostic reference levels do not currently exist in
706 veterinary practice but would apply.

707 3.4. Potential exposure pathways and practical protection strategies

708 (55) Ionising radiation can be emitted from an unstable atom undergoing radioactive decay, as
709 is the case with radiopharmaceuticals, or from the acceleration of charged particles, as is the case
710 with radiography equipment and linear accelerators. In other words, there are two broad categories
711 of potential sources of exposure to radiation in veterinary practice: radioactive material and
712 radiation generating equipment. Radiation generating equipment poses a risk of external irradiation
713 for as long as the equipment is ‘on’. Radioactive material poses a risk of both internal and external
714 contamination; for example, if radioiodine is spilled onto uncovered skin, the skin will be externally
715 irradiated, and there will also be the potential for absorption through the skin into the body.
716 Additionally, radioiodine is volatile in its elemental form and thus is potentially an inhalation
717 hazard as well; in general, working with gaseous or volatile radioactive substances poses a risk of
718 internal contamination via inhalation (see section 3.4.2).

719 (56) The type(s) of radiation emitted by the source will also inform the risk(s) to be considered,
720 as different types of radiation present different exposure pathways of concern. Alpha radiation is
721 unlikely to present an external hazard due to its low penetrating power but becomes a concern if an
722 alpha-emitting radionuclide (such as Ra-223, used in the palliative treatment of bone metastasis) is
723 inhaled, ingested, or gets in the eyes. Depending on the energy, beta radiation may have a range of
724 up to a few metres in air and can penetrate tissue on the millimetre scale. The primary radiological
725 protection concern for beta radiation is exposure of the skin (i.e. ‘shallow’ dose) and eyes (i.e. ‘lens’
726 dose). Beta-emitting radionuclides are also a concern if ingested, inhaled, or incorporated through
727 the skin. Gamma- and x- rays are penetrating radiations, capable of whole-body exposure (i.e. ‘deep’
728 dose) as well as shallow dose and lens dose. Thus, different strategies are implemented for dose
729 reduction depending on the specific radiation type, but there are some broad generalisations

730 applicable to external and internal radiological protection (ICRP, 2007b; Martin, 2013; Johnson,
731 2017).

732 3.4.1. External radiological protection

733 (57) The three basic rules of external radiological protection are reducing exposure time,
734 increasing distance from the source, and using appropriate shielding (Fig. 3.3). These factors need
735 to be considered together in the design of buildings and rooms for veterinary facilities, in the design
736 of radiological equipment (including sealed and unsealed sources), and in local rules and
737 procedures. Protection strategies will include consideration of engineering controls (e.g. shielding,
738 interlocks), administrative controls (e.g. written procedures) and personal protective equipment
739 (PPE, e.g. gloves, lead, aprons), consistent and in conjunction with the management of other
740 workplace hazards (de Castro, 2003).



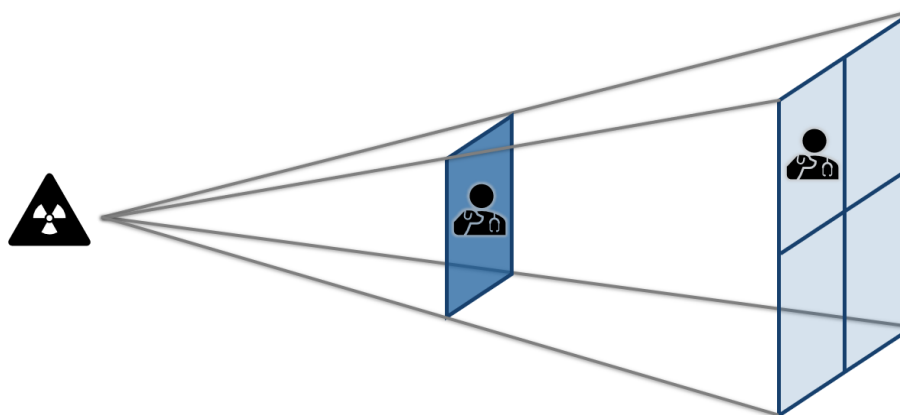
741 Fig. 3.3. The three basic rules of external radiological protection: time, distance, and shielding.
742

743 (58) Significantly limiting the duration of an exposure is not always feasible, because a certain
744 amount of time is usually required to perform a given task. However, detailed work plans with
745 practice runs beforehand (without the source) can help reduce overall exposure time. If practical,
746 splitting tasks(s) between personnel or rotating through personnel can also reduce an individual's
747 exposure time. Another example of optimising time is the use of 'pulsed fluoroscopy' in both
748 fluoroscopy and interventional procedures, in combination with 'last image hold', which can
749 effectively reduce the time of exposure while keeping required image guidance.¹

750 (59) Where reasonably possible, maximising distance from a radiation source is a simple and
751 practical principle for dose reduction. The use of handling tools (e.g. tweezers, tongs) and hand
752 carts should be considered, along with working at 'arm's length' and taking 'one step back' where
753 feasible (Fig. 3.4). However, note that these three basic rules should be used in conjunction with
754 each other, as it could be that using a device like tongs could increase the time spent handling the
755 source (at a greater distance) whereas a short, quick manoeuvre closer to the source may result in
756 less dose. Also, consideration should be given to individuals working for long periods of time in
757 awkward or uncomfortable positions (such as working behinds shields, etc.), which may create an
758 ergonomic/orthopaedic hazard with potential for fatigue-induced mistakes or, again, an increase in
759 the time to complete the task. Where safely applicable, the use of sedation or anaesthesia may
760 considerably reduce the time people need to spend in close proximity to an animal; their radiation

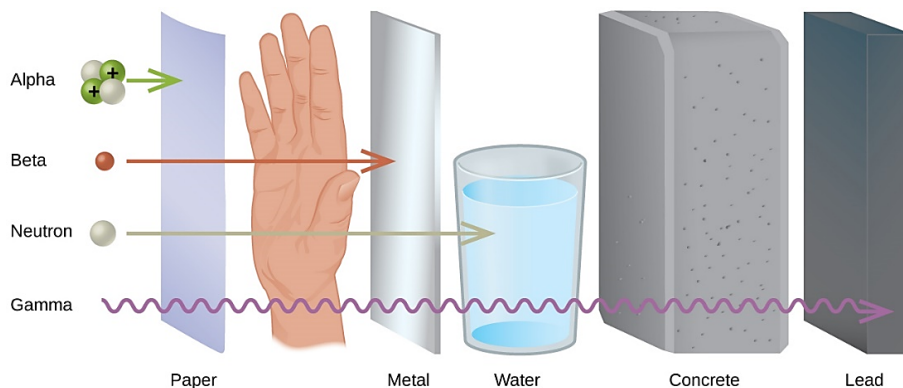
¹ 'Last image hold' refers to the feature of fluoroscopy systems in which the most recent image continues to be displayed on the monitor when fluoroscopy is stopped. See, for example, the discussion of Mahesh (2001).

761 exposure would then be reduced by the combination of a shorter exposure time and a greater
 762 distance from an animal seen as a radiation source. The more fractious an animal, the more
 763 personnel will typically have to ‘lean in’ to keep it in position during imaging, and
 764 sedation/anaesthesia can make it easier to work at arm’s length or take a step back. Furthermore,
 765 sedation/anaesthesia will ease patient positioning, reducing the need for retakes, which will reduce
 766 the total exposure time for the personnel involved in restraining animals.

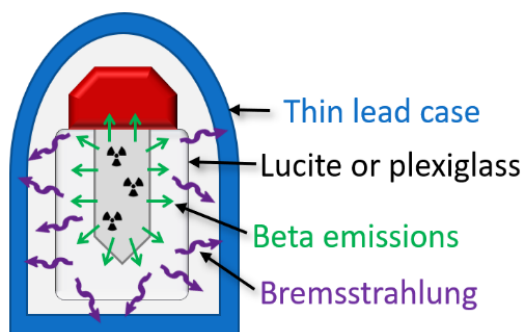


767 Fig. 3.4. Representation of the inverse-square law. Doubling the distance from a point source of ionising
 768 radiation will reduce exposure by a factor of four, as the photons are spread over a larger distance. In
 769 practice, this can often be accomplished by taking one step back.
 770

771 (60) The most appropriate type of shielding to employ is dependent on the circumstance as
 772 well the type and energy of the radiation involved (e.g. Fig. 3.5). For example, the electrons (i.e.
 773 beta particles) produced in beta decay will interact with their surroundings and produce
 774 bremsstrahlung (‘breaking radiation’). Bremsstrahlung refers to the photons produced when the
 775 path of a free electron is diverted by an atomic nucleus; the more protons in a nearby nucleus, the
 776 more bremsstrahlung there will be. It is therefore better to shield beta emitters with low atomic
 777 number (Z) material (e.g. plastic or acrylic glass) as this will block the electrons while producing
 778 less bremsstrahlung than high Z material. High Z material is good at shielding photons, so lead
 779 shielding can be added on the outside of the primary container to shield the resultant photons while
 780 storing or transporting (Fig. 3.6).



781 Fig. 3.5. Different radiation types have different abilities to pass through a material. © OpenStax licensed
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 783 <http://cnx.org/contents/85abf193-2bd2-4908-8563-90b8a7ac8df6@12.2>
 784



785 Fig. 3.6. Schematic of shielding a beta-emitting radiopharmaceutical.
786

787 (61) Lead is commonly used to shield gamma- and x-ray radiation, but in practice any dense
788 material (tungsten, steel, concrete, etc.) can sufficiently attenuate these photons if thick enough.
789 For example, some high activity sources are housed in basement facilities to make use of the natural,
790 earthen shielding. Photon attenuation is exponential, although for broad beam or poor geometry
791 conditions, scattered radiation can result in ‘build-up’ and an exposure higher than that predicted
792 purely by exponential attenuation. Personal protective equipment frequently employs lead (e.g.
793 aprons, gloves) or leaded glass (e.g. eyeglasses) to protect radiosensitive organs. Care should be
794 given that use of PPE optimises protection and safety (e.g. considering level of transmission,
795 ergonomic issues, influence on the time required to perform a task, etc.). For example, lead aprons
796 are not appropriate for use in positron emission tomography (PET) studies, as the transmission of
797 annihilation photons (511 keV) through a typical apron is over 90% (Martinez et al., 2012); the
798 increase in work time associated with wearing an apron negates this fairly trivial reduction in
799 exposure.

800 (62) Shielding should start with assessment of the collective work environment (concrete walls,
801 leaded doors and windows, standing or ceiling-suspended shields, etc.) and be complemented with
802 appropriate personal protective shielding worn by staff and assisting members of the public.

803 3.4.2. Protection against contamination

804 (63) As mentioned above, contamination (the unwanted presence of radioactive material) has
805 the unique potential to be both an internal and external radiation hazard. It is also transferable, so
806 specific precautions relevant to preventing contamination need to be adopted. The potential for
807 contamination is relevant for unsealed sources (i.e. radiopharmaceuticals).

808 (64) Internal exposure to radionuclides is possible through inhalation, ingestion, or absorption
809 through open wounds or even intact skin. Internal radiological protection and contamination
810 prevention measures focus on preventing or minimising the intake of radionuclides into the body
811 and the deposition of radioactive substances on the body. Such protective measures (e.g. confine,
812 contain, enclose) are consistent with general industrial hygiene measures, and generally include
813 strategies for maintaining control of the source and the environment in which the source is handled
814 and used as well as using PPE when appropriate (see section 3.4). Additionally, consistent with the
815 justification principle, the amount of radiopharmaceutical administered to a patient should be
816 selected such that no more is used than that needed to achieve the optimal diagnostic or therapeutic
817 result. This optimises protection and safety of the patient as well as that of workers, the public, and
818 the environment.

819

4. ETHICS AND VALUES

4.1. Ethics of the system of radiological protection

821 (65) The system of radiological protection is rooted in, and informed by the three pillars of
822 science, ethics, and experience, and has evolved over the past several decades (ICRP, 2018a).
823 Ethics, or moral philosophy, seeks to distinguish right from wrong; in other words, it considers the
824 nature of morality and strives to describe and justify how things should be and how we should
825 behave. The practical application of radiological protection has evolved in parallel with
826 considerations of the morals and ethics relating to it; one has not directly emerged from the other.
827 Thus, the primary aim of radiological protection is met by way of a comprehensive framework
828 underpinned by a set of fundamental scientific principles and ethical considerations.

829 (66) *Publication 138* (2018) has recently clarified the ethical basis of the system for human
830 protection and identified core ethical principles (referred to as ‘values’ to distinguish from the three
831 principles of radiological protection) as well as procedural ethical values underlying the system. It
832 did not address the ethical aspects of the protection of animals.

833 (67) Three major theories of ethics that underpin the system of radiological protection are
834 utilitarianism, deontology, and virtue ethics, which respectively argue (albeit simplified) for the
835 furthering of the collective interest, the respect for individuals and their rights, and the promotion
836 of integrity, discernment, and wisdom. The core ethical values in relation to humans, considered to
837 be consistent with each of the aforementioned theories and shared across cultures, include
838 beneficence/non-maleficence, prudence, justice, and dignity. Although these values run through
839 the system and are not specific to any one principle, some direct links are clear. Beneficence/non-
840 maleficence, doing good while avoiding harm, relates directly to the principle of justification.
841 Prudence, the ability to make informed and rational decisions in the face of uncertainty, relates to
842 the principle of optimisation. Justice, or the ensuring of social equity and fairness of decisions,
843 relates directly to the principle of the application of dose limits. Dignity, or the respect for all
844 persons, is evident throughout the system and broadly incorporates autonomy, or the capacity to
845 act freely. It also supports the procedural values, which include accountability, transparency, and
846 inclusiveness. Procedural values emphasise the process for implementation of the core values.
847 Hence, ethics encompasses not only what is done but how it is done. Ethical risk evaluation and
848 management, then, considers factors that go beyond the magnitude of the radiation exposure and
849 the cost associated with reducing the exposure (Oughton, 2013).

850 (68) It is also worth mentioning that although these are the broad values underlying the system
851 of radiological protection, it is not to say that these are the only important values. For example, in
852 environmental protection, additional values such as sustainable development and environmental
853 justice are also emphasised (ICRP, 2003b). Also, since 1979, the seminal principles of biomedical
854 ethics have been beneficence, non-maleficence, justice, and respect for autonomy (Beauchamp and
855 Childress, 2019), which are emphasised in *Publication IXX* (ICRP, 20XX). As the ethics of
856 radiological protection has been more explicitly addressed for humans, a discussion of the ethics
857 and values associated with the radiological protection of animals follows below.

858 **4.2. Radiological protection and veterinary ethics**

859 (69) The three ethical theories mentioned above are also frequently taught in veterinary ethics
 860 (Fawcett et al., 2018). Also, the core ethical values of the system of radiological protection are
 861 consistent with, but of course not the only values important in, veterinary practice. For example,
 862 the ‘One Welfare’ framework (Pinillos et al., 2016; Bourque, 2017; Fawcett et al., 2018) recognises
 863 and emphasises the interrelationships between human health and well-being, animal welfare,
 864 socioeconomic development, biodiversity, and environmental conservation, and highlights
 865 additional ethical principles consistent with a holistic approach to sustainable development, similar
 866 to but broader than those presented in *ICRP Publication 91* for protection of the environment (ICRP,
 867 2003b). See Annex C for additional discussion.

868 (70) The consideration of ethics applied to the veterinary practice can help inform the
 869 application and implementation of the three RP principles. Although there are numerous ethical
 870 values that are relevant to veterinary practice, a few essential, fundamental values are discussed
 871 here (see Table 4.1), consistent with the values of the system of radiological protection, the One
 872 Welfare approach, and the World Veterinarian Association (WVA) Model Veterinarians’ Oath
 873 (ICRP, 2003b, 2018a; Pinillos et al., 2016; WVA, 2019). There is not a strict or unique one-to-one
 874 link between the values in Table 4.1; in fact, there are many inter-relationships and applications of
 875 these and other values that will necessarily come up depending on the circumstances. However,
 876 highlighting the dominant relationships between some key values will help make the ethical ties
 877 between the System, the environment, and veterinary practice clearer.

878 Table 4.1. Core ethical values with correlated and procedural ethical values related to veterinary practice.

ICRP 138 Core Value	Correlated value	Procedural value
Beneficence	Reverence for life	Empathy
Non-maleficence	Animal welfare	Accountability
Prudence	Sustainable development	Stewardship
Justice	Solidarity	Inclusiveness
Dignity	Respect for autonomy	Transparency

879 (71) Veterinarians care for a variety of species of animals, both domestic and wild, and they
 880 frequently make use of modern radiology equipment or nuclear medicine techniques. A wild animal
 881 may be diagnosed and treated as part of broader rehabilitation and conservation efforts whereas
 882 companion and working animals are typically treated for the specific benefit of the animal and its
 883 owner. Regardless of the specific motivation for veterinary intervention, ultimately the general goal
 884 is to do more good than harm, consistent with the ICRP values of beneficence and non-maleficence.
 885 As in human medicine (O’Connor et al., 2019), beneficence is practiced in veterinary medicine not
 886 only by treating disease but in expressing compassion and respect for the patient as well as the
 887 owner. Through empathy, or the ability to understand and share the feelings of others, we recognise
 888 that all living things have a place in the world and deserve to be safe and well, or at the least, to
 889 experience life without suffering. In other words, having reverence for life is an expression of
 890 empathy (Schweitzer and Cicovacki, 2009). Animal welfare is, of course, the core of veterinary
 891 practice. Many definitions and interpretations exist, but animal welfare refers generally to the well-

892 being of nonhuman animals (Hewson, 2003). Animal welfare can be linked to non-maleficence as
893 the avoidance of causing animals unnecessary harm or suffering. Accountability, one of the original
894 ICRP procedural values, refers to the expectation that a person or institution is answerable for their
895 actions or decisions. To avoid doing harm, we hold ourselves and others accountable. This, for
896 example, would include the tracking and reporting of misadministration incidents or over-
897 exposures, having a plan for such accidents, and learning from them to improve care.

898 (72) Sustainable development is, broadly, development that meets the needs of the present
899 without compromising the ability of future generations to meet their own needs. The procedural
900 value most closely associated with sustainable development is stewardship. Stewardship is the
901 careful and responsible management of something entrusted to one's care, whether that is the
902 environment, natural resources, a pet, or a farm animal. It is a responsibility that includes prudent
903 decision-making related to those things for which we have an obligation.

904 (73) Solidarity refers to unity arising from shared responsibilities, interests, and sympathies,
905 which can be implemented through inclusiveness, or involving all relevant parties in the decision-
906 making process. As mentioned above, justice refers to impartiality in behaviours and decisions such
907 that outcomes are as reasonably fair, equal, and as balanced as possible. As an example, the quality
908 and standard of veterinary care should be consistent between patients, regardless of the owner's
909 background. Solidarity is found through the shared desire for the animal's wellbeing, and a decision
910 should be made as to the most reasonable course of action in collaboration with the owner;
911 veterinarians and their staff should of course advocate for and prioritise the animal's welfare, but
912 decisions will also necessarily be made based on economic value and financial means of the owner
913 as well as what the owner is going through (Weil, 1951; Kipperman et al., 2017). In the instance of
914 unreasonable or irresponsible owners, veterinarians should do their best to ensure what is fair to
915 the animal in the given circumstances.

916 (74) Dignity refers to the shared right of all people to be valued and respected, and autonomy
917 is the capacity to make an informed, uncoerced decision; clearly, one cannot exert their autonomy
918 without transparency, or open and honest communication. For example, available and appropriate
919 diagnostic and treatment options with potential outcomes should be clearly discussed with the
920 owner or responsible party. Owners have the right to know the risks, benefits, alternatives, and
921 financial obligations associated with their animal's diagnosis and treatment. Similarly, workers
922 have the right to know their occupational risks. Moreover, the responsible veterinarian should
923 ensure workers are appropriately (1) informed of relevant risks, radiological and otherwise, (2)
924 trained in the technique or procedure at hand, including radiological protection strategies relevant
925 to themselves, the animal, and bystanders, and (3) protected from unnecessary exposure through
926 practical protection strategies and the provision of proper PPE (see section 3.4). Note that Annex
927 A provides a summary of roles and responsibilities related to radiological protection.

928 (75) Table 4.1 depicts illustrative relationships between the ICRP core values and relevant
929 correlated and procedural values, but there are a variety of inter-relationships between these and
930 other ethical values or principles. For example, respect for life and sustainable development
931 together support the maintenance of biodiversity, or the variety and variability of life in the world.
932 Although this latter ethical principle is more related to environmental protection (e.g. ICRP, 2003b;
933 UN, 2015), there is overlap in veterinary practice as maintenance of biodiversity is often an active,
934 inter-disciplinary effort that may benefit from access to veterinary expertise. Additionally,
935 beneficence and non-maleficence are almost always considered and balanced together; they are
936 even expressed as a single value in *Publication 138* (ICRP, 2018a). A specific example of the

937 importance of considering this balance, along with the interplay of empathy, accountability, and
938 stewardship, is the use of research animals. The use of animals for research purposes, either in a
939 laboratory or field setting, is widely recognised as a societal benefit as it has proven invaluable in
940 expanding our fundamental understanding of biology as well as in improving human health,
941 environmental health, and animal welfare (NRC, 1991, 2009; Friend et al., 1999). However,
942 because this can clearly result in harm to the animals concerned, there is also the public expectation
943 that those involved at any stage of the research effort ensure that the animals are used in ways
944 judged to be scientifically, technically and humanely appropriate, avoiding doing harm wherever
945 possible (NRC, 2011). In other words, the research community has stewardship over the animals
946 involved and thus assumes responsibility for the animals' well-being, which necessitates critical
947 and prudent evaluation of study design and outcomes such that discomfort, pain, stress, etc., are
948 minimised (NRC, 2009, 2011; Vasbinder and Locke, 2016). In addition to scientific understanding
949 and experience, elements of empathy can help improve recognition of pain or distress in animals
950 (NRC, 2009; Ellingsen et al., 2010). In this example, accountability is often implemented through
951 legal and regulatory requirements with corresponding consequences for non-compliance
952 (Vasbinder and Locke, 2016).

953

5. UNIQUE ASPECTS OF VETERINARY PRACTICE

954 (76) Because many applications of ionising radiation in veterinary practice may have come
955 about without the active involvement of persons knowledgeable in radiological protection—such
956 as a medical physicist as one example—and often also in the absence of an appropriate radiological
957 protection framework, several issues have arisen. These issues need to be identified and rectified,
958 preferably in close collaboration between the relevant stakeholders (e.g. the practicing veterinarians,
959 their professional societies, the radiological protection competent authorities, and radiation
960 protection experts). The issues listed should be seen as illustrative and by no means have the
961 pretension of being exhaustive.

962 (77) If compared to human medicine applications, challenges for radiological protection could
963 be greater in veterinary practice. Many radiological procedures on large animals are performed in
964 environments that have not been specifically designed, or properly fitted out, for these procedures,
965 including in the field. Justification is not currently supported by a veterinary society's equivalent
966 of the 'referral guidance' or 'appropriateness criteria' we are familiar with in human medicine;
967 there are no DRLs for imaging optimisation; there are important differences with regard to the
968 activities of radiopharmaceuticals administered for therapy purposes for the same disease (e.g.
969 hyperthyroidism) in comparable animals (e.g. average-sized house cats); involvement of a medical
970 physicist is very rare for radiation protection education, training, optimisation, and equipment life
971 cycle issues; and last but not least, not all practitioners performing higher dose diagnostic or even
972 radiotherapy procedures have specific or specialist education and training that is accredited and
973 certified.

974 (78) Conventional radiology is available in many small veterinary practices. CT-scanners, cone
975 beam CT (CBCT), C-arms or O-arms, and non-mobile fluoroscopy can be found in an ever-growing
976 number of veterinary clinics, where shielding strategies may require particular attention because of
977 retrofitted equipment. The use of mobile radiographic equipment is standard in dealing with large
978 animals as it is performed on farms, in stables, on auctions or in the open field. The delimitation of
979 a safe working area, and the proper use of the mobile equipment may require extra attention.
980 Nuclear medicine diagnostics and treatments are not so common but may have been introduced
981 without sufficient consideration of contamination problems, such as in dealing with radioactive
982 waste, in particular the urine. Some therapeutic interventions may be performed outside of
983 veterinary clinics, such as when radioactive substances are administered into a horse's joints at a
984 riding stable, resulting in potential contamination concerns. In nuclear medicine in general, the
985 animal as an ambulatory radiation and possible contamination source deserves specific
986 consideration, particularly when outside the confines of the clinic. Other radiotherapy treatments,
987 either teletherapy or brachytherapy, are still rare and restricted to veterinary clinics, but the
988 potential radiological risks to both the animals and people involved in the procedures should not
989 be neglected. As an aside, as such treatment options become more available, it is possible that
990 veterinary clinics may face unique nuclear security challenges in addition to the radiation protection
991 and safety aspects described herein.

992 (79) Although more and more dedicated veterinary equipment is becoming available, second-
993 hand equipment coming from human medicine is still very prevalent in veterinary practice. Safety
994 and performance of the equipment should be verified before their first use and then on a regular
995 basis afterwards, by means of radiological protection and quality control programs, as elaborated
996 on by the IAEA (2021). Mobile equipment may need to be checked more frequently than fixed

997 installations. Quality checks need to include all pieces of equipment throughout the imaging or
998 treatment chain (e.g. software, cameras in nuclear medicine, image monitors, etc.) and should not
999 be restricted to radiation-emitting equipment or sources. There is also a growing influx of specialty
1000 veterinary equipment (e.g. FIDEX CT) that falls under industrial rather than medical standards.
1001 Additionally, mobile equipment is being marketed as ‘lighter’ because shielding has been reduced
1002 from, say, 6 kg to 4 kg. Although dedicated, fit-for-purpose equipment is certainly welcome in
1003 principle, it must still meet appropriate radiation safety standards. Similarly, clinics may not have
1004 given due consideration to shielding needs. For example, a room may have been designed having
1005 adequate shielding for conventional x-ray applications on a fixed table with the primary beam
1006 directed from the ceiling to the floor, but that room may not be adequately shielded for
1007 interventional procedures using a C-arm.

1008 (80) For historic reasons, most veterinarians learn how to use standard radiologic equipment,
1009 either fixed or mobile or both, in their basic curriculum. This should comprise at least the basic
1010 notions of radiological protection. More risk bearing applications such as the use of CT-scanners,
1011 interventional radiology, nuclear medicine, and radiotherapy certainly call for additional education
1012 and training, including the corresponding radiological protection. Basic or specialist education and
1013 training programs are on offer in a number of veterinary schools and professional societies, for
1014 instance through the American College of Veterinary Radiology (ACVR) and European College of
1015 Veterinary Diagnostic Imaging (ECVDI), but the corresponding curricula do not always include
1016 the necessary theoretical radiation science education and practical training on radiological
1017 protection topics specifically. Note that guidance on radiological protection education and training
1018 specific to veterinary professionals has been developed by HERCA, inspired by the model
1019 developed by the European Commission (EC) for human medicine (HERCA, 2017; IAEA, 2021).
1020 Similarly, ICRP *Publication 113* (ICRP, 2009), while focused on human medical care, contains
1021 information on education and training that may be useful for informing the development of parallel
1022 standards in veterinary practice. Consequently, radiological protection competent authorities may
1023 not automatically consider the diplomates (board-certified specialists) as sufficiently competent in
1024 radiological protection. One could also ask whether practicing the more complex and risk bearing
1025 techniques should not be restricted to veterinarians having successfully gone through ‘specialist’
1026 programs, as this would be beneficial for the quality of care or service delivered and the associated
1027 radiological protection. Across the world, there are striking differences in the basic and specific
1028 education and training requirements related to the application of different imaging and therapy
1029 modalities in veterinary applications of ionising radiation.

1030 (81) These differences can also be observed for the corresponding radiological protection
1031 requirements, where some harmonisation of training requirements is necessary (Gregorich et al.,
1032 2018). This effort should include the continuous refreshing, updating, and, where needed,
1033 extending of theoretical knowledge and practical skills as well as adapting competencies, attitudes,
1034 and behaviours. If other professionals, such as radiographers or radiotherapy technologists, actively
1035 intervene or autonomously perform radiologic or radio-therapeutic procedures of any sort, the same
1036 principles must apply. They should have successfully gone through initial education and training
1037 programs and continue to regularly refresh and update their knowledge, skills, and competencies
1038 throughout their professional life. This should necessarily include radiological protection. It is up
1039 to the licensee or otherwise authorised person or entity responsible for the facility to clearly
1040 establish the roles and responsibilities of all those involved in the procedures, within the bounds of



1041 the appropriate regulatory framework, and ensure that they have, and continue to have,
1042 corresponding education and training.

1043 **6. APPLICATION OF THE SYSTEM OF RADIOLOGICAL PROTECTION**
 1044 **TO VETERINARY PRACTICE**

1045 **6.1. Justification**

1046 (82) As mentioned above, the principle of justification is one of the fundamental principles of
 1047 radiological protection and states that any decision that alters the radiation exposure situation
 1048 should do more good than harm (ICRP, 2007a). In addition to the exposure of the animal, veterinary
 1049 staff are also frequently exposed during veterinary radiological procedures using ionising radiation.
 1050 Sometimes, the animal’s owner or handler, farmworkers, other members of the public or the
 1051 environment may also be exposed as a consequence of veterinary use of ionising radiation. Hence,
 1052 proper justification of veterinary radiological procedures is necessary to avoid unnecessary
 1053 exposures of people, animals, and the environment. It is worth pointing out that the principle of
 1054 justification is rooted in the ICRP core ethical values of beneficence and non-maleficence,
 1055 consistent with veterinary deontology. For example, beneficence/non-maleficence is evident in
 1056 determining whether a procedure fits in the clinical pathway, that is, whether it is indicated and
 1057 appropriate.

1058 (83) The three levels of justification for a radiological practice in medicine, described in
 1059 *Publication 105* (ICRP, 2007b), can also be applied to veterinary medicine as recommended herein
 1060 (Table 6.1). Level 1 justification requires that the proper use of radiation in veterinary medicine
 1061 does more good than harm to society. As radiological procedures are now integral to veterinary
 1062 practice worldwide, Level 1 justification is taken as a given and is not further discussed in this
 1063 document. At Level 2, a specified procedure would be considered generically justified for a
 1064 specified clinical objective if it will improve diagnosis or treatment of a defined group of veterinary
 1065 patients or if it will provide necessary information about exposed animals. Level 3 justification
 1066 requires that the application of a radiological procedure is judged to do more good than harm in the
 1067 management of the individual veterinary patient. Level 2 and Level 3 justification in veterinary
 1068 medicine are discussed further in sections 5.1.1 and 5.1.2.

1069 Table 6.1. Summary of the three levels of justification in human medicine and veterinary practice.

Level	Human medicine	Recommended for veterinary practice
Level 1 (General use)	Proper use of radiation in medicine is accepted as doing more good than harm to society. Now taken as a given.	Proper use of radiation in veterinary medicine is accepted as doing more good than harm to society. Now taken as a given.
Level 2 (Specific procedure and objective)	A specified procedure with a specified objective is justified if it will improve the diagnosis or treatment or if it will provide necessary information about exposed individuals.	A specified procedure with a specified objective is justified if it will improve diagnosis or treatment of a defined group of veterinary patients or if it will provide necessary information about exposed animals.
Level 3 (Particular procedure for the patient)	The application of a radiological procedure is justified if it is judged, in advance, to do more good than harm to the individual patient.	The application of a radiological procedure is justified if it is judged, in advance, to do more good than harm in the management of the individual veterinary patient.

1070 (84) There has been increasing awareness about the overuse of radiological procedures in
1071 human medicine, with a substantial portion of medical imaging procedures deemed unjustified
1072 (Picano, 2004; Holmberg et al., 2010; Malone et al., 2012). While similar surveys have not been
1073 carried out in veterinary medicine, the challenge of avoiding unjustified use of ionising radiation
1074 likely exists here as well, as many of the drivers of overuse in human medicine (Lysdahl and
1075 Hofmann, 2009; Hendee et al., 2010) are also present in veterinary medicine. These include, among
1076 others, desire for greater confidence in the clinical diagnosis, lack of awareness of doses and
1077 associated risks, defensive medicine, lack of access to previously performed examinations at other
1078 veterinary practices, financial conflict of interest, including self-referral and ‘self’-presentation.
1079 Self-referral means that the same clinician holds the roles of both referrer and of radiological
1080 service provider, as ‘ordering physician’ and as ‘imaging services provider’ (they may outsource
1081 the interpretation but provide the imaging itself). Self-presentation in human medicine may also
1082 describe a situation where a person would present at a radiology practice, requesting a procedure
1083 for himself or herself, without this request being backed up by a clinician. Similarly, in veterinary
1084 medicine ‘self’-presentation would then designate the situation in which an animal owner requests
1085 for a radiology procedure, without intervention of a veterinary clinician.

1086 (85) Unlike in human medicine, where the potential for overuse due to the financial incentives
1087 from self-referral is recognised (Kouri et al., 2002), and where regulations and professional codes
1088 of ethics in many countries have been put in place to guard against this practice, self-referral is the
1089 norm rather than the exception in veterinary medicine. Radiographic equipment is widespread, both
1090 in general veterinary practice and in larger veterinary hospitals. Frequently, the veterinary
1091 practitioner ordering a radiological procedure will also be the person performing the imaging
1092 procedure and interpreting its results. This person may also be the owner of the radiographic
1093 equipment or may be employed by a veterinary practice which explicitly or implicitly expects their
1094 staff to ensure return on their investment in radiographic equipment. Hence, financial incentives as
1095 drivers for the use of radiological equipment are often present in veterinary medicine and could be
1096 considered a risk factor for possible overuse.

1097 (86) ‘Self’-presentation, in which the owner/handler of an animal requests a diagnostic imaging
1098 or therapeutic procedure without the previous clinical examination of the animal and hence without
1099 a radiology referral from a veterinary practitioner, or where the owner/handler demands a
1100 diagnostic or therapeutic procedure not considered indicated by their veterinary practitioner, is also
1101 a pertinent issue in veterinary medicine. Since veterinary practice is effectively a service industry
1102 comprised mainly of private practitioners, some veterinarians may feel compelled to comply with
1103 such consumer demands (also relevant in presale examinations) to avoid losing business to
1104 veterinary practices that oblige such requests.

1105 **6.1.1. Justification of medical procedures**

1106 (87) Specialised veterinary radiologists are limited in number worldwide, and most veterinary
1107 practices therefore do not have an in-house veterinary radiologist. Hence, the choice of the
1108 diagnostic procedure as well as the interpretation of its results are often performed by a general
1109 practitioner or a veterinarian of another specialty than radiology, without input from a veterinary
1110 radiologist. The radiological procedure is also often performed by someone not specifically trained
1111 as a veterinary technologist/radiographer (e.g. a general veterinary practitioner or a veterinary
1112 nurse/technician). Appropriate education and training of veterinary staff involved in radiological
1113 procedures, either as part of their basic education or as continuing education, is therefore necessary

1114 to ensure both the justification and the optimisation of such procedures. This training should aim
1115 to create awareness about the doses and the associated risks from the various radiological
1116 procedures. Those completing the training should be able to perform imaging and quality control
1117 on equipment, as well as provide effective risk communication with owners and handlers of animals.

1118 (88) Decision support tools, such as referral guidelines or appropriateness criteria (EC, 2014;
1119 Subramaniam et al., 2019), could also be particularly useful in veterinary medicine to ensure level
1120 2 justification in the absence of direct veterinary radiologist input. These guidelines should be
1121 easily accessible, free of charge and easy to use (e.g. ideally through integration into the electronic
1122 medical record system) to ensure their widespread adoption. Such guidelines, however, need to be
1123 developed collaboratively by national or international professional veterinary radiology societies,
1124 in conjunction with veterinary professional bodies, animal health and regulatory authorities and
1125 would require a substantial commitment of time and resources to their creation and periodic update.

1126 (89) Of note is that referral guidelines or appropriateness criteria not only contain information
1127 on different radiological imaging procedures (e.g. plain X-ray, CT-scanning) but also on imaging
1128 modalities that do not make use of ionising radiation, ultrasound and MRI in particular. From the
1129 point of view of justification, but only after careful consideration of all other factors that come into
1130 play and are judged equal, the imaging method that can provide the required information for the
1131 lowest exposure -or no exposure to ionising radiation at all- should then be preferred, if available.

1132 (90) When new types of radiological equipment are considered and introduced in veterinary
1133 practice, an assessment of their potential implications for radiological protection should also be
1134 made. Recently, there has been an increase in radiological equipment dedicated to veterinary
1135 medicine on the market, and this equipment may not always comply with the imaging quality and/or
1136 radiological protection standards required for medical devices. Vigilance, both from potential
1137 buyers and regulating authorities is therefore required to ensure that the adoption of such new
1138 equipment can be justified.

1139 (91) Level 3 justification requires that the radiological procedure is required for the
1140 management of the individual patient. A diagnostic procedure should be able to answer a given
1141 clinical question and have an impact on the patient's diagnosis, prognosis, or treatment.
1142 Consideration should also be given to alternative modalities that expose less to ionising radiation
1143 or not at all, for example, replacing CT by MRI or ultrasound; one part of justification is
1144 determination of the most appropriate exam, within constraints of available modalities. The
1145 radiology request should contain sufficient clinical information that a radiologist or an internal or
1146 external auditor can assess whether the particular examination is justified.

1147 **6.1.2. Justification of non-medical investigations**

1148 (92) Imaging of asymptomatic animals for purposes other than medical diagnosis or treatment
1149 is frequently performed in veterinary medicine. Screening programs for canine hip and elbow
1150 dysplasia are in place in many countries (Verhoeven et al., 2012; Hazewinkel, 2018) and large
1151 numbers of animals are thus imaged as a part of the breeding selection process. Many equine
1152 studbooks require that a specified radiographic examination has been performed on their approved
1153 stallions (Verwilghen et al., 2009), and pre-sale radiographic examinations of yearling racehorses
1154 has become standard practice in many countries (Cohen et al., 2006; RIRDC, 2009; Miyakoshi et
1155 al., 2017). Other horses, both pleasure and competition horses, also frequently have a radiographic
1156 examination as part of the purchase process; insurance companies may demand a radiographic
1157 study of an animal as part of the insurance process. The trend for presale examinations is currently

1158 for the inclusion of an increasing number of imaging modalities, radiographic projections, and body
1159 areas in the study, sometimes with questionable scientific evidence regarding their value in the
1160 evaluation of asymptomatic animals.

1161 (93) For non-medical radiological procedures, Level 2 justification is therefore important.
1162 Particular attention should be paid to the scientific evidence for the usefulness of the procedure,
1163 ensuring that the chosen imaging procedure is suitable both for the detection of the condition in
1164 question and for screening a potentially large number of animals. Furthermore, there should be a
1165 demonstrable relationship between the imaging findings and the goal of the screening. For example,
1166 for a breeding suitability examination, the trait in question should have a sufficient degree of
1167 heritability as well as a prevalence in the population that makes it a relevant discriminator between
1168 potential breeding animals, while for presale examinations, the results of the imaging should be
1169 predictive of the animal's future performance. Again, appropriateness criteria could be developed
1170 by professional veterinary radiological societies, in conjunction with professional veterinary
1171 societies, regulatory authorities, breed societies, insurance companies, and industry representatives
1172 or other stakeholders, as appropriate.

1173 **6.1.3. Benefit and risk of radiological procedures**

1174 (94) The balance of benefits and risks to the exposed animals and sometimes more generally
1175 the population to which they belong, veterinary staff, animal owners or handlers, the general public,
1176 society at large and the environment must all be considered when determining if a given
1177 radiological procedure is justified in veterinary practice. This includes full consideration of other
1178 modalities that deliver lower or no radiological dose for the indicated need. Along with the
1179 beneficence/non-maleficence aspect of justification, finding the appropriate balance will
1180 necessarily involve exercising prudence.

1181 (95) Benefits to exposed animals include a direct benefit from improved diagnosis and
1182 treatment in the case of veterinary patients, while the results from a presale or breeding suitability
1183 examination may help ensure that the animal is suited for its intended purpose and will not suffer
1184 negative health consequences from its future use. Screening examinations of asymptomatic animals
1185 may help detect subclinical disease, and such early diagnosis may potentially lead to improved
1186 treatment results. In addition to welfare benefits to the individual animal, the welfare of animal
1187 populations may also be improved through breeding suitability examinations, if undesirable traits
1188 or medical conditions can be reduced in the population based on the imaging results.

1189 (96) Benefits to veterinary staff from the appropriate use of ionising radiation include the
1190 ability to provide the best possible diagnosis and treatment to their patients, customer satisfaction
1191 and financial revenue from the radiological procedures (and any follow up treatment). Owners and
1192 handlers may benefit both emotionally and economically from improved diagnosis and appropriate
1193 treatment of their animals.

1194 (97) In addition to individual animals, owners and veterinary staff benefiting directly from the
1195 appropriate use of ionising radiation—or its alternatives—in veterinary practice, society at large
1196 will also benefit from such use. Animal and human health are interlinked, and radiological
1197 procedures or other nuclear technologies that contribute to animal health may also improve public
1198 health, particularly when they contribute to the control of zoonotic diseases (Viljoen and Luckins,
1199 2012). Furthermore, a healthy population of working animals and livestock will also benefit society,
1200 both in terms of public health and economy. Other industries, such as the racing and showing
1201 industries, would likely also benefit economically from improved animal health. In the case of rare

1202 or endangered species, conservation efforts may also sometimes benefit from the use of radiological
1203 procedures, to diagnose and/or treat disease in zoo animals or wild animals. Moreover, with
1204 increasing societal concern over the ethics of the use of animals for production and entertainment,
1205 ensuring good health in these animals could also be seen as a prerequisite for the social acceptance
1206 of such use.

1207 (98) Radiation risks to exposed animals include both the risk of stochastic and deterministic
1208 radiation effects. While stochastic effects predominate in plain radiography, high dose diagnostic
1209 procedures, such as CT-guided and other interventional procedures are increasingly performed in
1210 veterinary medicine and could potentially result in deterministic effects. Furthermore, in veterinary
1211 radiation therapy, adverse effects associated with tissue reactions are frequently encountered in
1212 normal tissues and the probability of their occurrence must be carefully balanced against the clinical
1213 benefits of tumour control or palliation. On the other hand, lack of access to appropriate diagnostic
1214 imaging or therapy or inappropriate choice of diagnostic or therapeutic modality could lead to
1215 adverse health effects for the animal due to misdiagnosis or inappropriate treatment.

1216 (99) Veterinary staff receive most of the radiation doses associated with veterinary radiological
1217 procedures, either when operating radiological equipment, holding image detectors, or restraining
1218 animals during diagnostic procedures, performing or assisting in nuclear medicine, interventional
1219 or therapeutic procedures, or caring for animals after nuclear medicine diagnostics or therapy with
1220 sealed or unsealed radioactive sources. Most doses to staff will be low (see 6.2.2), but over time
1221 could potentially contribute to the development of stochastic effects. Additionally, epidemiologic
1222 studies of radiation workers in human medicine note an association of higher incidences of cataracts
1223 in both interventional proceduralists and nuclear medicine technologists who receive chronic low
1224 dose exposures (ICRP, 2012b). Higher dose procedures, such as long interventional ones, potential
1225 spills in nuclear medicine, or accidents relating to therapeutic procedures could potentially lead to
1226 deterministic effects. Owners or handlers exposed to radiation when assisting in radiological
1227 procedures or caring for animals after nuclear medicine procedures, may also be at risk—albeit
1228 low—mainly for stochastic effects. The assistance of laypersons in radiological procedures is
1229 currently a subject of debate and will be further discussed in the following section (see section
1230 6.2.1).

1231 (100) Environmental contamination may also occur after diagnostic or therapeutic nuclear
1232 medicine procedures, either through releases from the veterinary facility where the procedure is
1233 carried out or through radioactivity eliminated from the animal after its discharge from the
1234 veterinary facility. While releases at the veterinary facility are often well controlled and regulated,
1235 uncertainty exists after the animal is discharged. These uncertainties will depend on the level of
1236 radioactivity in the animal at the time of discharge, the mechanisms of elimination of the
1237 radionuclide used, the veterinary practices' recommendations for isolation of the animal and
1238 management of its waste, as well as the degree of owner or handler compliance with these
1239 recommendations. Environmental contamination may lead to radioecological effects, as well as to
1240 human exposure through external radiation or internal contamination. The nature and extent of the
1241 consequences of environmental contamination will depend on the type, amount, and duration of
1242 the contamination event (ICRP, 2014).

1243 6.2. Optimisation

1244 (101) In the system of protection, ‘optimisation is always aimed at achieving the best level of
1245 protection under the prevailing circumstances through an ongoing, iterative process’ (ICRP, 2007a).
1246 Optimisation in any practice including veterinary care is a process for ensuring that the likelihood
1247 and magnitude of exposures and the number of individuals exposed are as low as reasonably
1248 achievable (ALARA) considering economic, societal, animal welfare, and environmental factors.

1249 6.2.1. General considerations

1250 (102) Although the protection and safety of humans may be considered the priority of
1251 optimisation efforts, it is important to realise that this can already be largely achieved by limiting
1252 the initiating exposure of the animal to what is truly necessary for achieving the clinical objective.
1253 Reducing the exposure of the animal will indeed almost invariably be beneficial for the protection
1254 of humans involved in whatever way in the veterinary procedure and, where applicable, of the
1255 environment. A first step in the optimisation of radiological protection during a veterinary
1256 procedure is therefore to adjust the imaging exposure parameters or adapt the activity of
1257 radiopharmaceutical administered in such a way that the required clinical effect is obtained with
1258 the lowest possible radiation dose and net benefit is maximised.

1259 (103) Radiological exams are now common practice from a young age (screening tests) and for
1260 the life of certain animals. Pet animals tend to live much longer than they used to due in part to
1261 robust veterinary care, including earlier diagnosis and specialised medicine (Cozzi et al., 2017).
1262 With the increase in prevalence and frequency of radiological exams, and the increased lifespan of
1263 companion animals, there is a corresponding increase in the risk of radiogenic effects in this
1264 population. These facts call for more attention to optimisation of protection and safety in veterinary
1265 procedures that explicitly include radiological protection considerations with regard to the exposed
1266 animals.

1267 (104) Optimisation can generally be achieved by (1) appropriate design and construction of
1268 installations, careful selection of equipment; and (2) day-to-day strategies such as adequate and
1269 regularly updated education and training of staff, clarity with regard to their exact roles and
1270 responsibilities, regular checks of equipment performance, systematic application of procedural
1271 rules, all this embedded in a safety culture at organisation level. This approach is consistent with
1272 what is advocated for the practice of human medicine (ICRP, 2007b). However, since the specific
1273 risks induced by radiation exposure in animals are not yet quantified, currently no guidance is
1274 available related to, for instance, animal specific DRLs. Considering the societal value of animals,
1275 though, optimisation strategies relevant for human patients should be valid for animal patients as
1276 well.

1277 (105) Optimisation should not be confounded with dose minimisation. Too much focus on dose
1278 reduction alone may impede the diagnostic or therapeutic quality of the procedure and result in
1279 suboptimal care or necessitate a repeat procedure. This clear distinction between dose optimisation
1280 and dose minimisation is critical in radiotherapy, where underdosage may lead to insufficient
1281 tumour control and even optimal procedures may result in the inevitable appearance of early or late
1282 side effects. Moreover, risk induced by the radiation exposure is only one of the elements to be
1283 taken into consideration and optimisation of protection and safety therefore needs a holistic view
1284 comprising not only broad animal welfare considerations but also general safety aspects for staff
1285 members and members of the public.

1286 (106) Veterinarians and associated staff face many occupational challenges and hazards, of
1287 which exposure to ionising radiation is just one. For example, other hazards such as bites, scratches,
1288 or kicks may be more important, and certainly more acute issues. Thus, the optimisation process
1289 for veterinary workers should broadly encompass consideration of risk, benefit, and practicality. In
1290 other words, the level of protection should be optimised in a way that most reasonably accounts for
1291 the given circumstances, as consistent with other exposure situations. Gloves might be worn when
1292 handling a patient prone to biting, but if said patient is afraid of gloves to the extent that an exam
1293 cannot be conducted, it may be prudent to leave them off and consider an alternate strategy.

1294 (107) Similarly, sedation and anaesthesia are frequently advocated from a radioprotection point
1295 of view, but in some cases the associated detrimental impact on the animal's health may lead to the
1296 conclusion that this may not be the best option for patient restraint. Where permitted, optimisation
1297 could then consist in having the owner restrain the animal, even though this might result in some
1298 radiation exposure to this person, which in turn should be mitigated by providing clear instructions
1299 and -where applicable- adapted protective equipment.

1300 (108) Optimisation clearly also applies to members of the public, defined in the system of
1301 protection as individuals who receive an exposure to ionising radiation that is neither occupational
1302 nor medical (ICRP, 2007a). With respect to veterinary practice, the public may include pet
1303 owners/handlers, clients in a waiting area, farm hands assisting with an equine exam, etc. In some
1304 countries, laypersons will not be allowed to assist in veterinary radiological procedures. Where
1305 laypersons can be allowed to assist in some procedures (see §114 for example), the following
1306 conditions should be fulfilled: 1) the procedure is justified, 2) the person's presence is overall
1307 beneficial from a 'holistic' perspective as discussed above (see §105), 3) the person, after having
1308 received relevant information regarding potential risks, agrees to undergo some limited exposure
1309 (with a dose constraint of the order of a few μSv maximum) and 4) after having been instructed on
1310 how to behave (where to stand, where to put their hands, possibly what protective equipment to
1311 use, etc.) in order to minimise their exposure. Children or pregnant laypersons should not be
1312 allowed to assist in such radiological procedures.

1313 (109) Given the great number and diversity of elements to consider in any specific case,
1314 optimisation needs to be tailored to best fit, within the boundaries of what is prudent and reasonable,
1315 and the needs of each case individually. This individual approach should first consider the clinical
1316 needs, but also the whole environment in which the procedure takes place (e.g. owners' wishes,
1317 location and transport facilities, available equipment, etc.).

1318 (110) Prudence is highly relevant to the process of optimisation, consistent with other areas of
1319 veterinary practice that use potentially harmful substances or principles; for example, if 50 mg of
1320 a drug would suffice to obtain the desired clinical effect, it would not make sense to use 100 mg.
1321 Considering the wide variety of risk factors present in a given circumstance and making value
1322 judgements as to the most reasonable choice necessarily involves prudence. In situations that are
1323 unfamiliar, rare, or without precedent [as may be the case with exotics or zoo animals (e.g.
1324 Adkesson and Ivančić, 2019; Schilliger et al., 2020)], it may be prudent to consult a qualified expert
1325 (board certified veterinary radiologist, radiation physicist, safety officer or other individual with
1326 recognised competence in radiation safety) in advance of the procedure for guidance.

1327 **6.2.2. Optimisation in veterinary radiology**

1328 (111) The main source of veterinary occupational exposure is from diagnostic radiography
1329 (UNSCEAR, 2010). Occupational exposures from this modality are mainly due to scattered

1330 radiation, so individual effective doses should be low. However, it has long been recognised that
1331 poor practice may result in unnecessary exposure (Wantz and Frick, 1937; UNSCEAR, 2010).
1332 Additionally, we know from human medicine that doses to staff and patients from more modern,
1333 higher dose modalities can be consequential for both patients and staff. This is even more
1334 pronounced in interventional procedures (Wagner, 2007; Miller et al., 2010; Balter and Miller,
1335 2014; ICRP, 2018b). Of note is that education and training of staff is crucial for optimisation.
1336 Guidance material, such as infographics or posted signage, can be very helpful in that respect (see
1337 Annex B for an example) (Root et al., 2020).

1338 (112) Radiologic procedures should be performed in an adequately safe environment. The room
1339 should be spacious enough to allow people to keep sufficient distance from the radiation sources.
1340 And it should be equipped with shielding commensurate with the procedures performed. Hazards
1341 may arise when in a room initially conceived for occasional standard small animal radiographic
1342 procedures, has become a room in which CT- or interventional procedures are now being performed
1343 or simply when the number of procedures performed rises well beyond those that were taken into
1344 consideration when the room was first conceived and constructed.

1345 (113) To limit unnecessary public exposure, a designated or controlled area for radiological
1346 exams or therapy procedures should be established and physically demarcated with warning signs
1347 (e.g. Fig. 6.1). As many equine radiography exams are performed in stables with mobile generators,
1348 additional measures should be taken to delineate the exposure area to avoid unforeseen exposure
1349 of members of the public not involved in the examination. Performing such procedures in stables
1350 with solid concrete or brick walls should be preferred where this is possible, because of the
1351 shielding offered. Placing signage at the entrance can then suffice. If procedures need to take place
1352 in the open field, delineating the controlled area with appropriate signage is much more demanding
1353 as it needs to consider all risks involved, not just radiological hazards.



1354 Fig. 6.1 The trefoil radiation warning sign.
1355

1356 (114) In general, members of the public should be kept outside controlled radiation areas, and
1357 in the small animal veterinary setting, pet owners should typically not be asked to help during
1358 radiological procedures. However, there may be some circumstances in which an owner's presence
1359 comforts the animal in a significant way, resulting in a more efficient and, in some cases, physically
1360 safer exam. This in turn could reduce the overall exposure of the technologist, for instance by
1361 reducing the need for repeat exposures. In other instances, it might be inappropriate to include
1362 members of the public or comforters/carers due to the nature and frequency of the exposure and/or
1363 the characteristics of the person considered. For example, a young person working at a stable may
1364 want to assist in every horse's radiograph series, yet this would likely do more overall harm than

1365 good. The decision on whether to allow lay-person assistance in an exam results from a balancing
1366 exercise of pros and cons and is similar to that in human paediatrics (parents, carers, but here
1367 owners, handlers) (ICRP, 2013b), and needs to be made prudently, focused on beneficence and
1368 non-maleficence, and considering the prevailing circumstances. Minors and those who are pregnant
1369 need specific consideration and may be legally excluded from participating in such activities. If the
1370 presence of members of the public is judged required or useful, then rotation of these persons may
1371 be considered so as to limit the exposure of any single individual. Similarly, when deciding on
1372 where to perform a procedure, it may be that leaving an animal in a familiar environment (e.g. a
1373 horse at its stable) may bear more risk of radiation exposure yet be overall beneficial, and thus the
1374 most reasonable and optimised choice.

1375 (115) Any individual involved in a radiological exam should avoid—as much as possible—
1376 being exposed where the radiation field is highest, such as in the primary radiation beam. Where
1377 reasonable, positioning and immobilisation aids and/or patient sedation/anaesthesia should be
1378 considered to reduce staff and comforter/carer exposures. Similarly, when possible, personnel
1379 should stand behind fixed or mobile protective shields; for example, exposure of the head, neck,
1380 and upper body of the veterinarian performing an interventional procedure can be greatly reduced
1381 by the adequate use of a ceiling-suspended shield. Optimally, neither portable x-ray generators nor
1382 the associated cassettes should be handheld. In some cases, such as with interventional radiology,
1383 it is necessary for staff to perform a variety of jobs within the radiation field for varying times and
1384 at different distances from the source. Where external radiation exposure is a concern, in addition
1385 to the use of protective shields, the use of shielding PPE should be considered, including protective
1386 wraparound aprons, hand/forearm protectors, thyroid collars, and eye protection (e.g. lead safety
1387 glasses), depending on the specific circumstance. It should be borne in mind that leaded gloves
1388 only provide limited protection when the hands are positioned in the primary x-ray beam, which
1389 should always be avoided. Shielding properties of the PPE selected for a procedure should be
1390 balanced against other workplace hazards. For example, the weight of a lead apron can result in
1391 orthopaedic issues such as strain on the lower back if worn for long periods of time (Martin and
1392 Sutton, 2015; Alexandre et al., 2017). This, along with the restriction of movement, can increase
1393 working time as well as result in physical injury, thus, a vest/skirt configuration or the use of lighter
1394 aprons, made of so-called lead-equivalent materials, may be preferred. Similarly, wearing radiation
1395 protective gloves while working close to the animal's irradiated body volume will reduce dose to
1396 the extremities and are frequently warranted (Stoeckelhuber et al., 2005). However, use of these
1397 gloves will also negatively affect dexterity and range of motion which might lead to safety concerns
1398 associated with increased muscle fatigue and working time (Martin and Sutton, 2015).

1399 (116) With respect to equipment, optimisation of radiological protection involves ensuring that
1400 radiological equipment is suitable for the task at hand, and that technical parameters are adequately
1401 tailored to veterinary patients and veterinary working routines. The use of radiological equipment
1402 in a veterinary setting may be off-label (i.e. not used as originally intended or designed) for new or
1403 refurbished medical equipment or dedicated to veterinary practice by design. For all types, it is
1404 recommended that the manufacturer continue to maintain the equipment and that no modification
1405 occurs that would decrease image quality and/or radioprotection properties (e.g. inner shielding,
1406 collimator). For equipment specifically designed for veterinary use, the manufacturer is often able
1407 to alter the components of the equipment for which medical standards are no longer legally 'needed'
1408 (no established standards of installation and performance). Such changes often have a positive
1409 impact on the selling price of the equipment yet possibly a negative impact on image quality, output

1410 stability, and radiological protection of the animal patient, the veterinary professional, and
1411 members of the public. For example, reduced inner shielding of portable radiography units results
1412 in significantly increased leakage and scatter. In a number of countries, industrial standards are
1413 applied when dealing with veterinary equipment and this may be insufficient both from a veterinary
1414 care and radiological protection perspective. The Commission therefore recommends that adequate,
1415 fit-for-purpose standards be applied on all equipment marketed and used in veterinary applications
1416 of ionising radiation and suggests that responsible authorities consider applying appropriate
1417 standards for the accreditation of the equipment and for the credentialing of staff members. Ideally,
1418 these standards would be internationally recognised as manufacturers often sell equipment in
1419 multiple countries. Of note is that equipment standards should also include requirements on the
1420 device connections that allow installation in a dedicated veterinary room (e.g. light signalling at
1421 the room entrances, emergency stops, door switches).

1422 (117) Optimisation measures for patient protection in diagnostic radiology, for the same image
1423 quality, should be discussed with the manufacturer and installation engineer and implemented when
1424 possible. This would include considerations such as limitation of views to those necessary for
1425 common diagnostic protocols and technique charts for the range of animal sizes relevant to the
1426 facility. Similar strategies apply for CT examinations with a special procedure for auditing repeat
1427 examinations and requests for systematic whole-body imaging. Standardisation of national referral
1428 guidelines for when and what imaging should be done for common situations and then standard
1429 protocols that describe how to perform the imaging examination would greatly aid the veterinary
1430 practice worldwide in caring for animals and increasing radiation safety. Examinations should not
1431 be repeated if no clinical benefit would be obtained. In other words, aesthetically pleasing images
1432 should not be the preponderant consideration, but instead that the image quality is sufficient to
1433 confidently make a diagnosis or proceed with an interventional procedure with the lowest possible
1434 exposure. The priority for a diagnostic image is that it is interpretable, which relies on not just the
1435 physics of the image (e.g. resolution and contrast) but also factors like how and where the data is
1436 displayed, the ambient environment, and the experience of the person reading the images.
1437 Reasonable reduction of the animal dose and improvement of study quality contribute to the
1438 optimisation of protection and safety by reducing doses received by both the animal patient and
1439 staff.

1440 (118) A highly important step in optimisation of radiographic procedures of any kind is to limit
1441 the exposed tissue volume to what is relevant for the clinical case at hand. In standard diagnostic
1442 radiology and interventional fluoroscopy this should be achieved by appropriate beam collimation,
1443 in CT by scan length limitation. These simple measures lower patient dose and -by reducing
1444 radiation scatter generated in the exposed tissues and materials- improve image quality and reduce
1445 the exposure of professionally exposed persons as well as members of the public.

1446 (119) A prerequisite for optimisation is a thorough knowledge of the doses associated with a
1447 given exposure situation, as well as the factors that influence this dose. Reported doses per image
1448 to persons participating in radiographic examinations of small and large animals (Ackerman et al.,
1449 1988; Hupe and Ankerhold, 2008, 2011; Barber and McNulty, 2012; Eckert et al., 2015), or per
1450 examination for personnel present during standing CT examinations of the equine head (Dakin et
1451 al., 2014), fall in the range from 0.1 μSv – 34 μSv . Doses towards the higher end of the range are
1452 typically encountered when thicker body parts are being radiographed, such as the abdomen in
1453 large dogs or the equine head, spine (especially thoracic and lumbar region), and proximal
1454 extremities. While several of the above studies state that estimated annual doses will be well below

1455 regulatory limits for a given caseload, other studies of occupational doses in veterinary medicine
1456 have found that personnel doses may approach annual dose limits recommended by ICRP (Table
1457 4.1) (Hernández-Ruiz et al., 2012; Canato et al., 2014). Recently, dosimetric data has been
1458 published for veterinary interventional radiology and intraoperative fluoroscopically guided
1459 surgery, where there is close proximity between personnel and veterinary patients during exposure,
1460 often for extended periods (Sung et al., 2018; An et al., 2019; Hersh-Boyle et al., 2019). Reported
1461 operator dose levels may approach or even exceed regulatory limits, which emphasises the need
1462 for both quantitative radiation monitoring and the use of appropriate protective measures during
1463 these procedures.

1464 (120) With regards to dose to the animal patient, few dosimetric studies have been published.
1465 Primary beam doses or entrance surface skin doses, typically in the order of 1 mGy have been
1466 reported with the aim of assessing their contribution to personnel dose (Veneziani et al., 2010;
1467 Barber and McNulty, 2012). Dosimetric publications aimed at the radiation protection of the
1468 veterinary patient are however emerging. Nemanic et al. (2015) addressed the potential of lead
1469 shielding to reduce animal dose during elbow radiography in dogs, and Hersh-Boyle (2019)
1470 reported radiation exposure of dogs and cats undergoing intraoperative fluoroscopic procedures. In
1471 the latter study, doses up to 617.5 mGy were reported. However, systematic reporting of dose
1472 descriptors such as the dose area product (DAP) and CT dose index (CTDI) for clinically relevant
1473 protocols, both within and between institutions, are lacking in veterinary medicine and hence,
1474 diagnostic reference levels (DRLs) do not exist. Furthermore, while the relationship between these
1475 dose descriptors and radiation risk in the form of effective dose has been established in human
1476 medicine through the use, for example, of anthropomorphic or patient-based voxel phantoms and
1477 Monte Carlo simulations, such links still have to be established in veterinary medicine (although
1478 as mentioned earlier, some phantoms such as these have been developed for animals, including
1479 canines). The number of different species involved, as well as the range of patient sizes within a
1480 species may be relevant challenges in veterinary medicine.

1481 (121) More dosimetric data is needed, both for personnel and veterinary patients, particularly
1482 for potentially high dose procedures, such as interventional radiology fluoroscopically guided
1483 surgical procedures. Furthermore, as CT interventional procedures become more prevalent in
1484 veterinary medicine, dosimetric aspects of these procedures should also be addressed. Systematic
1485 reporting of dose descriptors for clinically relevant protocols will be necessary to compare such
1486 protocols both within and between institutions and thus to optimise such protocols with respect to
1487 dose. The relationship between dose descriptors, organ doses and associated radiation risk also
1488 must be determined for veterinary medicine.

1489 **6.2.3. Nuclear Medicine**

1490 (122) Nuclear medicine procedures involve both external irradiation and contamination hazards.
1491 Unsealed sources such as radiopharmaceuticals have the potential to land on the skin or directly be
1492 taken into the body, so care should be taken to employ reasonable methods for reducing this risk
1493 of contamination. The radiopharmaceutical, the animal to which it has been administered and all
1494 substances then produced by the animal, in particular the urine, are also potential contamination
1495 sources. All these should be properly managed, so facilities should be designed and operated (e.g.
1496 careful source management, regular checks on possible contamination of the work environment,
1497 waste collection and disposal) to reduce the risk of exposure and of unplanned releases of any of
1498 these into the environment. Practical strategies for reducing time spent nearby, increasing distance,

1499 and using appropriate shielding should at the same time be applied to reduce exposure to external
1500 irradiation.

1501 (123) Safety measures to prevent contamination with radioactive substances can be
1502 implemented at the source or the worker and are consistent with general industrial hygiene practices
1503 for protecting workers from non-radioactive contaminants. Example methods for confining or
1504 containing a radioactive source include storing radioactive material in a secure, shielded location,
1505 limiting the handling of radioactive materials to well-defined areas within a practice (e.g. a secure
1506 drawing up area with appropriate mobile shielding); using secondary containment (e.g. trays,
1507 buckets) to limit the consequences of possible spills; using a ventilated hood with sufficient and
1508 consistent airflow. Good housekeeping practices (i.e. cleanliness and organisation), regular
1509 radiological surveys, and detailed record keeping are also important for the prevention of
1510 contamination.

1511 (124) External radiation safety measures follow those described in section 3.4.1; specific
1512 examples in nuclear medicine include using an appropriately shielded syringe, using lead
1513 containers and/or hand carts to transport the radiopharmaceutical to the receiving patient, and
1514 taking one step back from the injected patient where possible.

1515 (125) The PPE used is essentially aimed at preventing contamination risks by the radioactive
1516 material involved. For example, when injecting, radiopharmaceutical impermeable gloves, a lab
1517 coat (long sleeves) and face mask or shield should be worn to limit skin exposure in the situation
1518 of back pressure when injecting into a catheter.

1519 (126) With respect to the patient, it is important to be aware of the potential for deterministic
1520 effects in patients undergoing certain nuclear medicine procedures. These effects may be
1521 unavoidable to some extent (e.g. therapy). In nuclear medicine therapy, there may well be side
1522 effects, for example, effects on salivary glands when treated for thyroid cancer with radioiodine.
1523 Of course, there are also the potential consequences of extravasation, that is, when the
1524 radiopharmaceutical ends up next to the vein through which it was supposed to enter the body (van
1525 der Pol et al., 2017).

1526 (127) It should be kept in mind that the administered activity of a given radioisotope or
1527 radiopharmaceutical will to a large extent determine the radiation risks to the animal itself, to
1528 humans involved and to the environment. Prudence can provide insight into whether additional
1529 dose (activity) should be used to speed up a nuclear medicine procedure or whether longer sedation
1530 or anaesthesia would be appropriate. Different situations require different approaches, always
1531 considering the ALARA principle. For example, there are two standard protocols in PET imaging,
1532 based on the timing of radiopharmaceutical injection and induction of anaesthesia. The protocol in
1533 which anaesthesia is induced prior to injection has longer anaesthesia time (up to ~2 hours) but
1534 lower radiation doses to personnel compared to the protocol in which anaesthesia is induced after
1535 injection. Of note though is that the total annual effective doses to personnel associated with the
1536 latter protocol are well within the annual occupational dose limit (max ~5 mSv assuming 100
1537 animal patients per year) (Martinez et al., 2014). Other considerations beyond anaesthesia time and
1538 radiation dose include keeping the animal as still as possible during the radiopharmaceutical uptake
1539 period in order to avoid unwanted uptake in active muscles.

1540 (128) In order to protect staff, members of the public, and the environment from the
1541 consequences of radionuclide administration to an animal, and particularly after therapy procedures,
1542 the animal may need to be hospitalised, so that its excrements may be collected and treated as
1543 radioactive waste. The risk of contamination from the animal itself usually subsides rather rapidly

1544 because of natural elimination, mostly by kidney through the urine. However, it may take several
1545 days or even weeks before the dose rate emitted by the animal has fallen below the threshold values
1546 for its release and it can return home (e.g. 3+ weeks in some countries following iodine therapy).

1547 (129) Hospitalisation, particularly for long durations, needs to be considered as a potential
1548 welfare issue for both the animal and its owner or carer (Graf, 1999; Boland et al., 2014; Johansson
1549 et al., 2014). Again, radiological protection concerns need to be balanced against and considered
1550 together with all other values at stake. Hospitalisation creates a stressful situation, especially in
1551 small animal pets (dogs, cats) as has now been shown that animals have feelings, likely evolved to
1552 protect primary needs (Hewson, 2003; Lloyd, 2017). With the progressively more prominent place
1553 that animals, particularly companion animals, have gained in human society, it can be equally
1554 stressful for pet owners to have their animal in the hospital for a long duration, as it is for the
1555 animals themselves (McConnell et al., 2011; Amiot et al., 2016; McConnell et al., 2017).

1556 (130) In view of the complexity of nuclear medicine procedures on animals, in part resulting
1557 from the need to simultaneously manage external exposure and contamination risks, veterinary
1558 nuclear medicine should only be performed by veterinarians and staff members that have
1559 successfully gone through specialist training programs. This is even more compelling for therapy
1560 applications.

1561 **6.2.4. External Beam Radiotherapy and Brachytherapy**

1562 (131) Optimisation has a crucial role to play in all therapeutic applications of ionising radiation.
1563 As such treatments gain prevalence in veterinary care, this importance is increasing both from the
1564 perspective of the animals treated and the professionals providing this type of care. For the animal
1565 patient, optimisation means making sure that in spite of the very high doses delivered to the target
1566 volume and needed to obtain the desired therapeutic effect, the exposure of other tissues and organs
1567 is kept as low as reasonably achievable (ALARA). The objective is that deterministic side effects
1568 are avoided to the extent possible and that the overall exposure of healthy tissues, particularly of
1569 radiosensitive ones, is minimised so as to limit the probability for induction of delayed tissue
1570 reactions or second primary cancers.

1571 (132) The high doses and dose rates applied also have the potential of causing serious risks to
1572 staff members involved in these procedures. Blocked sources in remote after-loading or accidental
1573 ‘beam on’ situations in teletherapy could generate these kinds of risks, whereby other deterministic
1574 effects than just skin burns cannot be excluded. Strict procedures must be in place to allow the most
1575 optimal and safe use. Such complex and high-risk procedures should only be performed by
1576 veterinarians who have completed extensive education and training in radiological protection.
1577 From a veterinary care perspective, it may be preferable that the radiological practitioners
1578 responsible for these procedures be diplomates of speciality education and training programs,
1579 bearing in mind the current curricula may be insufficient when it comes to specifically addressing
1580 the radiation hazards. The Commission therefore recommends that the providers of such education
1581 and training programs better embrace radiological protection as an indispensable and integrated
1582 element of quality care.

1583 **6.3. Application of dose limits**

1584 (133) All individuals working with radiation in a veterinary practice must do so within the
1585 applicable legal requirements to ensure that neither occupational nor public radiation dose limits
1586 are exceeded. Although dose limits are maximum permitted values (Table 3.1), all doses are to be
1587 kept as low as reasonably achievable. Radiation workers should be subject to personal dose
1588 monitoring (where deemed appropriate by risk assessment) to ensure that dose limits are not being
1589 exceeded and working procedures are optimised. Except for pregnancy, the basis for dose limitation
1590 is the same for men and women, but once pregnancy is declared, additional controls need to be
1591 considered to protect the unborn child, reflected with a recommended fetal dose limit (ICRP, 2000).

1592 (134) The concept of *carer* refers to an individual who may be exposed to radiation as a helper
1593 providing care for a patient (ICRP, 2007a). Whereas carers are members of the public, they are
1594 susceptible to being exposed to doses exceeding public dose limits, which is considered appropriate
1595 within reason by the system of radiological protection. Although thus far in veterinary medicine
1596 animals have not been legally recognised as ‘patients’ and thus the concept of a pet owner serving
1597 as a ‘carer’ has not been applicable, it is recommended that the concepts of patient and carer be
1598 tailored to be applicable within reason in veterinary practice. Of note is that the suggested dose
1599 constraint for carers of human patients is 5 mSv per episode (Table 8, ICRP, 2007a).

1600 **6.4. Quality aspects of radiological protection and managerial responsibilities**

1601 (135) Radiological protection should be approached with a holistic perspective, covering all
1602 aspects of ionising radiation practice. As such, quality aspects of a sustainably effective radiation
1603 safety program would include, broadly, consideration of equipment and facilities, education and
1604 training, assignment of responsibilities, procedural protocols, follow-up of outcomes, and dose and
1605 incident monitoring and reporting. These aspects should be included within the overall quality
1606 assurance program and are important to ensure and maintain the best attainable veterinary services.

1607 (136) When fixed installations are concerned, this starts with design and layout of the facility,
1608 considering the architectural requirements of the building and rooms, in particular those where
1609 radioactive sources will be stored, and ionising radiation will be applied. Important considerations
1610 would include, for example, accessibility and access control, the optimal positioning of the
1611 equipment, and the shielding requirements for the walls and doors. When mobile equipment is used,
1612 similar considerations come into play. In nuclear medicine, where unsealed radioactive sources are
1613 used and/or stored, specific attention should be devoted to the safe and secure storage of sources
1614 along with the collection and further handling of radioactive waste. In radiotherapy, room shielding
1615 and access control are of crucial importance, as is the safe storage of possibly present radioactive
1616 sources (e.g. those used in brachytherapy).

1617 (137) The next step is to consider the applications themselves (i.e. the way in which ionising
1618 radiation is used). Tasks and associated responsibilities for each procedure or treatment should be
1619 explicitly assigned to staff members, so that they know exactly what is expected from them, and
1620 that all staff have had, and continue to have, adequate and regularly updated education and training
1621 commensurate with these tasks and responsibilities. Members of staff should have sufficient
1622 theoretical knowledge, practical skills as well as the right mindset: the attitude to adopt a radiation
1623 safety culture while working with ionising radiation.

1624 (138) Equipment should work adequately; this is not limited to radiation emitting devices but
1625 should cover the complete imaging or treatment chain (e.g. image displays, planning software, etc.),
1626 along with the more obvious items such as shielding equipment, PPE, and dosimeters that serve to
1627 protection and monitor staff and, where applicable, members of the public assisting with a
1628 procedure. All equipment should be regularly monitored and maintained for adequacy of
1629 performance. Making sure that quality services are being consistently provided safely makes the
1630 application of procedure guidelines or handbooks necessary.

1631 (139) In the event of incidents, accidents, or near misses, a system should be implemented to
1632 ensure these are thoroughly investigated. Any such events should serve as an opportunity for further
1633 improvement of radiation and general safety. Reporting of anything unusual should be encouraged
1634 and immediate actions to prevent any possible worsening or repetition should be taken until the
1635 situation has been fully understood and, whenever applicable, remediated. Learning from incidents,
1636 accidents, or near misses could be much more profitable than just for the undertaking where such
1637 event occurred; they could in fact be shared between colleagues -for instance through a platform
1638 offered by professional societies or international organisations such as the IAEA- as a means to
1639 prevent the same or a similar event from happening in a comparable professional context elsewhere.

1640 (140) Systematic follow-up should be made of procedure outcomes, in terms of their
1641 contribution to the cure pathway or to the adequacy of the suitability guidance delivered. Such
1642 follow-up would be a strong help in constructing or enlarging the evidence base for justification of
1643 veterinary exposures.

1644 (141) Finally, doses to animals, staff, members of the public, and the environment, as applicable,
1645 should be monitored. The systematic recording and follow-up of dose indicators, and
1646 intercomparisons with those registered by others in similar conditions, will contribute to
1647 optimisation of procedures and will allow for the early detection of malfunctioning devices or the
1648 systematic performance of insufficiently optimised procedures.

1649

1650 **7. SUMMARY OF RECOMMENDATIONS AND CONSIDERATIONS**

1651 (142) Veterinary use of radiation in the diagnosis, management, and treatment of disease has
1652 expanded and diversified considerably over the last few decades. Diagnostic imaging procedures
1653 are performed in an increasing number of situations where the animal's health care is not the
1654 primary objective of the investigation. These practice changes have come with an increase of
1655 exposure-related risks to veterinary professional staff, to members of the public, to the environment
1656 and to the animals submitted to these procedures. Radiological protection concerns have therefore
1657 increased, and the many unique aspects of veterinary practice compared to human medicine add to
1658 these concerns. Radiological protection challenges specific to veterinary practice arise from the
1659 different combinations of personnel and members of the public that may be involved and from
1660 operational environments required when dealing with animals.

1661 (143) The priority of radiological protection is that of humans, but the animal's exposure should
1662 also be the object of explicit attention from a radiological protection perspective in veterinary
1663 practice, because like humans, animals are subject to potential tissue reactions or stochastic effects
1664 resulting from exposure to radiation. Moreover, animals are not just objects, but sentient living
1665 beings able to feel and suffer. In veterinary practice, the core ethical values of the system of
1666 radiological protection therefore need to be complemented with correlated ethical values such as
1667 respect for life and animal welfare. In addition to the procedural ethical values of transparency,
1668 accountability and inclusiveness highlighted in *Publication 138* (ICRP, 2018), the values of
1669 empathy and stewardship are needed in the implementation of the system of protection in veterinary
1670 practice and in its application to animals in general.

1671 (144) As in all applications of ionising radiation, radiation safety management needs to be
1672 commensurate with the implied risks. As risks in veterinary applications have clearly increased and
1673 diversified, radiation protection should get more, and more explicit, attention by the full application
1674 of the Commission's system of protection. Despite some differences, the radiological protection
1675 concerns originating from the use of ionising radiation in veterinary practice is to a very large extent
1676 comparable to equivalent human medicine applications and non-medical human imaging. It is
1677 therefore recommended that veterinary applications be treated in a comparable way. This
1678 recommendation applies to the radiation safety requirements of the installations, but equipment too
1679 should meet the standards set for medical devices rather than just industrial standards.

1680 (145) It is recommended that the safe execution of veterinary applications be guaranteed by the
1681 implementation a quality assurance program at managerial level. The analysis of incidents and
1682 accidents should be part of such a program as it may contribute to the continuous improvement of
1683 safety. International organisations and professional societies could set up and recommend the use
1684 of incident/accident reporting tools, which could then provide lessons learned to all professionals
1685 in a no shame-no blame setting.

1686 (146) Veterinarians and their co-workers should be sufficiently educated and trained in the
1687 radiation safety aspects of the applications they make. The Commission recommends that specific
1688 applications such as interventional radiology, nuclear medicine and radiotherapy be reserved for
1689 professionals that can demonstrate having successfully gone through an education and training
1690 program which provides them with the necessary knowledge, skills and attitudes to provide
1691 adequate care to the animals whilst taking responsibility for the radiation safety aspects of their
1692 activities. This responsibility covers staff and possible members of the public present, the
1693 individual animal and the environment, where applicable.

1694 (147) The protection principles of justification, optimisation and dose limits should apply in full
1695 to veterinary applications. Thereby, the three levels of justification for radiological practice in
1696 medicine can also be applied to veterinary medicine. Level 1 requires that the proper use of
1697 radiation in veterinary medicine does more good than harm to society. At Level 2, a specified
1698 procedure would be considered generically justified for a specified clinical objective if it will
1699 improve diagnosis or treatment of a defined group of veterinary patients or if it will provide
1700 necessary information about exposed animals. It is recommended that scientific organisations and
1701 specialist professional societies provide guidelines that could assist clinicians in making
1702 appropriate choices; examples can be taken from referral guidelines and appropriateness criteria
1703 that have been in use in human medicine for years (ICRP, 2007b). Similar guidance would be
1704 particularly welcome when presale and insurability examinations on horses (or other animals as
1705 relevant) are concerned. Level 3 justification requires that the application of a radiological
1706 procedure is judged to do more good than harm in the management of the individual veterinary
1707 patient. The balance of benefits and risks to the exposed animals, veterinary staff, animal owners
1708 or handlers, the general public, society at large and, where applicable, the environment must all be
1709 considered when determining if a given radiological procedure is justified in veterinary medicine.

1710 (148) Optimisation in veterinary care should be considered a process for ensuring that the
1711 likelihood and magnitude of exposures and the number of individuals exposed are as low as
1712 reasonably achievable considering economic, societal, animal welfare, and environmental factors.
1713 Given the great number and diversity of elements to consider in any specific case, optimisation
1714 needs to be tailored to best fit, within the boundaries of what is prudent and reasonable, the needs
1715 of each case individually. This individual approach should first consider the clinical needs in a
1716 health care setting or the added value of a given test in case of non-medical animal imaging
1717 procedures, but also the whole environment in which the procedure takes place (e.g. owner wishes,
1718 location and transport facilities, available equipment, etc.). The Commission acknowledges that
1719 managing the exposure of the individual animal as an integrative part of the optimisation process
1720 may be challenging as this type of exposure has not previously been specifically addressed within
1721 the context of the system of radiological protection.

1722 (149) Prudence is highly relevant to radiological protection. In a situation where solid proof of
1723 a causal relation between low dose exposures and the induction of cancer or hereditary effects in
1724 humans is still lacking, the Commission has opted, in its 2007 Recommendations, for the continued
1725 application of the LNT model, which assumes that a given increment in dose will produce a directly
1726 proportionate increment in stochastic effects (ICRP, 2007a). The Commission recommends that a
1727 similarly prudent approach be applied when exposures of animals are concerned, noting also that
1728 radiological hazards are just one of many risk elements in veterinary practice and therefore needs
1729 to be considered in the context of the complete procedure.

1730 (150) This publication, being meant for a broad audience, provides a general overview of the
1731 issues and concerns related to radiological protection in veterinary practice. The intent of current
1732 ICRP publication is to explicitly acknowledge the importance and unique aspects of radiological
1733 protection in veterinary practice, lay the foundations, and develop additional guidance in the future,
1734 similar to the approach for radiological protection in human medicine. For detailed, practice-
1735 oriented guidance, the IAEA has developed a thorough report with modality specific approaches to
1736 radiological protection (IAEA, 2021). The Commission hopes that highlighting radiological
1737 protection concerns and related knowledge gaps will inspire additional research and development
1738 related to the evidence-based use of ionising radiation in veterinary practice in support of the

1739 justification process, dedicated facilities and equipment, improved understanding of the
1740 radiosensitivity of different types of animals along with practice guidelines in support of exposure
1741 management, and other relevant areas to promote health and safety of personnel, the general public
1742 and the environment while further improving the quality of care for the patients and healthy animals
1743 submitted to radiological procedures. This is sure to be a collaborative approach between
1744 veterinarians and their societies, research institutions, veterinary schools and colleges, radiation
1745 protection professionals, regulatory authorities, and other organisations.

1746

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2119

ANNEX A. ROLES AND RESPONSIBILITIES

2120 (A 1) In radiological protection, every party involved has a role and responsibility to contribute
2121 to the overall system of protection. That principle also applies to the intervening organisations and
2122 authorities. Data regarding the exposure to ionising radiation and the effects observed are gathered
2123 on a worldwide scale by the United Nations Scientific Committee on the Effects of Atomic
2124 Radiation (UNSCEAR; e.g. UNSCEAR, 2001, 2010, 2014). These data and their scientific analysis
2125 serve as a basis for radiation protection worldwide. In the United States, similar activities are
2126 undertaken by the Biological Effects of Ionizing Radiation (BEIR) Committee of the National
2127 Academy of Sciences (e.g. NRC, 2006). The ICRP then provides recommendations as on how to
2128 manage radiation risks. These recommendations are not only based on the available scientific data,
2129 but also on value judgements. These value judgements take into account societal expectations,
2130 ethics, and experience gained. Although ICRP's recommendations are illustrative rather than
2131 prescriptive, they are generally followed worldwide. The International Atomic Energy Agency
2132 (IAEA), together with other members of the United Nations (UN) family like the ILO International
2133 Labour Office (ILO), the Food and Agricultural Organisation (FAO) and the World Health
2134 Organisation (WHO) make use of ICRP's recommendations to formulate requirements which are
2135 binding to their many member countries. These organisations also provide practice-oriented
2136 guidance on how to implement these requirements. National governments are then responsible for
2137 implementation through their legislative system, which gives room to adapting the specified
2138 requirements to fit into the economic, societal and political realities of the country considered.

2139 (A 2) When it comes to veterinary practice, a number of important roles can be identified, each
2140 with specific responsibilities with regard to radiological protection. It is important to realise that
2141 one single person may hold several roles, even simultaneously, and also that some roles can be
2142 attributed to a legal entity rather than to a physical person. It is also worth emphasising that
2143 although responsibilities with respect to radiological protection are highlighted here, radiological
2144 protection is one aspect of a broader suite of concerns in veterinary practice, and it should be
2145 managed in the context of the practice or procedure as a whole.

2146 (A 3) The first role to consider is linked to the installation or location (e.g. a veterinary hospital
2147 or private practice), where ionising radiation is being used. There is clear responsibility with regard
2148 to the fitness-for-purpose of the building, rooms, equipment (including protective devices), and
2149 qualifications of the staff who work there. This responsibility is on-going and should be supported
2150 by a quality assurance system, which includes regular quality control of equipment performance,
2151 the initial and continuous education and training of staff members, the procedural rules, etc.

2152 (A 4) The next important role is that of the 'radiological practitioner', or the person performing
2153 or overseeing the procedure which results in exposure to ionising radiation. Most often a veterinary
2154 doctor, the role could also be attributed to a nurse or radiographer who in some countries can
2155 perform these procedures independently. It is the radiological practitioner who has the ultimate
2156 responsibility for the appropriateness of the procedure in the presenting clinical context, in
2157 application of the justification principle: in case another procedure would be requested by a
2158 clinician or animal owner, the radiological practitioner should act as an expert advisor. The
2159 radiological practitioner is also responsible for the way the procedure is performed and in doing so
2160 will have to consider all radiation protection aspects of the procedure at hand. This includes staff
2161 exposure, exposure of possibly assisting members of the public such as the owner or handler, and
2162 more broadly possible exposure of other members of the public. In nuclear medicine or in

2163 radiotherapy when radioactive source materials are being used, protection of the environment
2164 should also be considered by the practitioner. In some settings, the radiological practitioner may
2165 be assisted for certain technical and practical aspects of the procedure by dedicated staff members,
2166 who then become responsible for these particular aspects.

2167 (A 5) Members of the public that will be or may be exposed because of a procedure on an
2168 animal should not only be transparently informed about the possible radiation risks but also be
2169 instructed on how to behave in order to minimise or avoid these risks. In principle this provision
2170 of information and instructions is a responsibility of the practitioner, but it may be transferred to a
2171 dedicated staff member. Once duly informed and instructed, the member of the public also becomes
2172 responsible for part of the radiation protection, because this person's behaviour may greatly
2173 influence their own exposure, that of others, and in some cases, that of the environment.

2174 (A 6) Universities, colleges, and schools are responsible for the adequate education and
2175 training of veterinary professionals who perform procedures making use of ionising radiation.
2176 Many programs would benefit from more explicitly addressing the radiological protection aspects
2177 of these activities. This would allow diplomates (board-certified specialists) to perform state of the
2178 art radiological procedures while duly considering the protection of exposed workers, assisting
2179 members of the public, the public, the environment, and of the animal examined or treated.

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- 2192

2193 **ANNEX B. EXAMPLE GUIDANCE FOR RADIOLOGICAL PROTECTION**
 2194 **IN RADIOGRAPHY OF LARGE AND SMALL ANIMALS**

Radiation protection
Radiography of large animals



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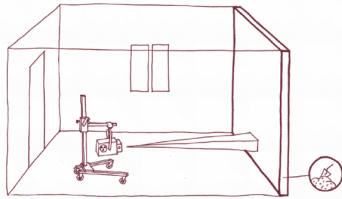
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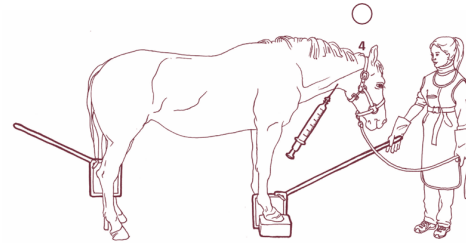
Personal protection
Protective clothing & dosimeter

- Align the protective clothing to face the examined object
- Wear the personal dosimeter under the protective clothing on the upper torso
- Optimal: use all-round aprons



Preparation
Tripod / mechanical holder

- Use the X-ray tripod or mechanical holder



Preparation
Choice of room / Designated room

- Avoid uneven floors, windows and wooden walls
- Direct the primary X-ray beam in the direction of a solid wall
- Darken the room

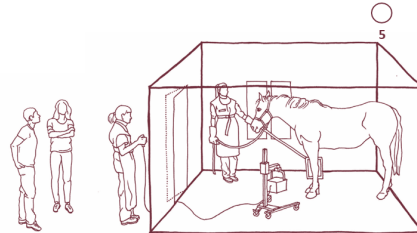


Preparation
Sedative & ancillary equipment

- Use aids (cassette holders, blocks of wood, tripods)
- Sedate uncooperative patients

Personal protection
Distance & correct settings

- Use third-parties (pet owner) to hold patients
- Ensure that no body part of any person is in the direct X-ray beam
- Adjust collimation to the region of interest
- Select exposure parameters (kV, mAs) correctly, including for digital radiography
- Maximise distance between persons and the scattered radiation source (animal)



Personal protection
Supervised area

- Limit the number of persons in the supervised area
- No adolescents (<16 years) or pregnant individuals in the supervised area

2195 Fig. B.1. Example of posted guidelines for radiological protection in large animal radiography. Courtesy
 2196 Radiation Protection Division, Federal Office of Public Health (FOPH), Switzerland.
 2197

Radiation protection Radiography of small animals

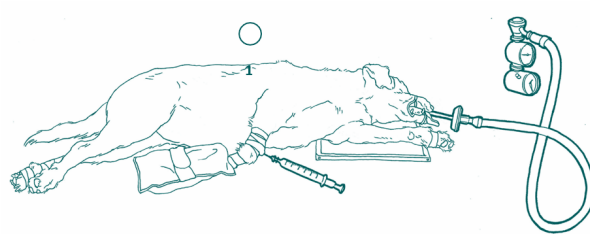


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Further information Federal Office of Public
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Division Radiation Protection
Postfach, 3005 Bern
post@bag.admin.ch

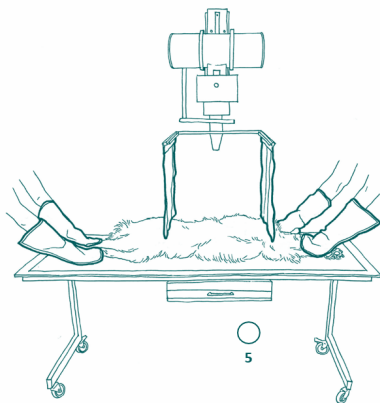
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Preparation Sedation / Anesthesia

- Utilize sedation during limb, back and skull examinations



Preparation Positioning & correct settings

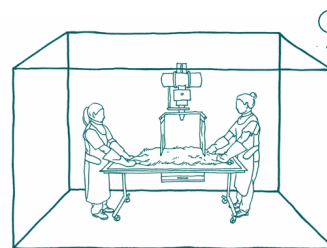
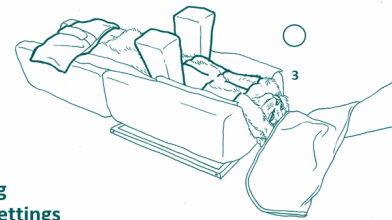
- Adjust collimation to the region of interest
- Select exposure parameters (kV, mAs) correctly, including for digital radiography
- Use positioning aids (sand bags, bandages, positioning troughs, foam wedges)
- Use high resolution image detectors for scatter reduction (Protection of staff)

Personal protection Distance

- Use third-parties (pet owner) to hold patients
- Ensure no body part of any person is in the direct X-ray beam
- Maximise distance between persons and the scattered radiation source (animal)
- Optimal: place sandbags over the hind legs

Personal protection Protective clothing & dosimeter

- Align the protective clothing to face the examined object
- Wear the personal dosimeter under the protective clothing on the upper torso
- Optimal: use all-round aprons



Personal protection Supervised area

- Limit the number of persons in the supervised area
- No adolescents (<16 years) or pregnant individuals in supervised area

2198
2199
2200

Fig. B.2. Example of posted guidelines for radiological protection in small animal radiography. Courtesy Radiation Protection Division, Federal Office of Public Health (FOPH), Switzerland.

2201 **ANNEX C. ETHICAL ISSUES ASSOCIATED WITH THE PROTECTION**
2202 **OF ANIMALS AND THE ENVIRONMENT**

2203 **C.1. Our relationship with animals and the environment**

2204 (C 1) Humanity shares the environment with many other lifeforms – from bacteria in the soil
2205 that help recycle nutrients, to plants that produce our oxygen, to top predators who help keep the
2206 ecosystem healthy and balanced. Part of humanity’s responsibility to the environment and future
2207 generations is the preservation of ecosystem biodiversity and fair, conscientious use of natural
2208 resources (ICRP, 2003) as, for example, reflected in the UN Sustainable Development Goals (UN,
2209 2015). Since the distant past, humans have engaged in domestication of both plants and animals,
2210 which is considered by some to be a coevolutionary and mutualistic process (Zeder, 2015). Our
2211 modern responsibility thus expands from the natural environment into the care of what we might
2212 call the managed environment. The specific obligations to the natural and managed environment
2213 differ, as the resources derived from and associated values for them differ. Societally, we share
2214 responsibility for our environment, focusing on the ecosystem and natural resources as a whole. As
2215 we shift into the managed environment, responsibility narrows to country, community, and
2216 individuals. Moreover, depending on the resource provided, the level and type of care can also shift.
2217 Animals serve as companions, providing comfort or entertainment; as livestock, providing farm
2218 labour, food products, or other commodities; as workers, providing an array of non-food services
2219 from therapy to military and police operations; or as research subjects, improving fundamental
2220 understanding of biology and medicine.

2221 (C 2) Humanity has a long and complex relationship with animals, a relationship that has
2222 changed over generations but that can also change over a single lifetime with shifting cultures,
2223 attitudes, and environments (Walsh, 2009; Shir-Vertesh, 2012). Animals have deep cultural and
2224 spiritual significance in many societies, however, there are also several sources of potential conflict
2225 (Herrmann et al., 2013). Human-wildlife conflict can result from competition for habitat and
2226 resources, which can lead to economic or even life loss for humans and ecosystem alteration,
2227 reduction in species, or even extinction for wildlife (Nyhus, 2016). Conflict also exists with
2228 domesticated animals from such sources as bites, scratches, or kicks; financial or time burden;
2229 excess noise; overpopulation or abandonment of companion animals; and spread of disease or other
2230 health impacts (e.g. allergies) (Voith, 2009; Wells et al., 2019). Regardless of these sources of
2231 conflict, animal interactions serve an important role in human survival and well-being (Herrmann
2232 et al., 2013), and consistent with the general ethical principles of respect for life, empathy, and
2233 rejection of cruelty (Warren, 1997), we have the responsibility to mitigate conflict and promote
2234 animal welfare as part of a holistic approach to sustainable development and maintenance of human
2235 health and well-being.

2236 **C.2. Radiological protection and environmental ethics**

2237 (C 3) The primary aim of the ICRP relates to protection of both humans and ‘the environment’
2238 and thus implicitly includes biota other than humans. Such an aim is also based on a number of
2239 ethical considerations, although it has to be accepted that attitudes associated with protection of

2240 any particular species differ from one society to another, and from one situation or circumstance to
2241 another within any one society. The subject was first explored by the IAEA (IAEA, 2002) and then
2242 discussed further in *Publication 91* (ICRP, 2003b). In these studies a useful three-component
2243 ethical spectrum of views was identified. These views arise from philosophical debates about what
2244 has moral standing in the world and why. Essentially they may be briefly summarised as follows:
2245 anthropocentric, in which human beings are the main or only thing of moral standing, and thus the
2246 environment is of concern only as it affects humans; biocentric, in which moral standing can be,
2247 and usually is, extended to individual members of other species, and thus obligations pertaining to
2248 such individuals arise as a consequence; and ecocentric, in which moral standing can be extended
2249 to virtually everything in the environment (including physical features, such as rivers and
2250 mountains) but the focus lies more on the entirety and diversity of the ecosystem rather than, say,
2251 the moral significance of each and every individual component of it. There are, of course,
2252 considerable ranges of views within each of these three broad categories.

2253 (C 4) The anthropocentric view is the most easily recognised and is reflected in many world
2254 religions; the other two are less easy to define. Biocentric views vary considerably, but a common
2255 feature of many of them is recognition of the moral obligations that arise from the fact that many
2256 animal species can be shown to be sentient, in that they can experience pleasure and pain. The
2257 results of these considerations are reflected in attitudes to animal ‘rights’ and animal ‘welfare’, and
2258 thus in national laws - such as those relating to experiments on animals, for whatever reason.
2259 Biological characteristics other than sentience may also be considered relevant, and some
2260 biocentric views assume that all individual living things have an inherent value and should be
2261 respected for what they are. Those with an ecocentric view, in contrast, believe that one should
2262 optimise ecosystem welfare, and although they may disagree about how to carry out such an
2263 optimisation, they agree that primacy, in moral standing, rests with ecosystems. The place of
2264 humans and the degree to which they can be considered to have special ‘rights’ compared with
2265 those afforded to other species and to physical components of the environment also vary. Such
2266 views can often be clearly recognised in many cultures and beliefs. It also has to be admitted that
2267 individuals may change their ethical views during their life, or when faced with different
2268 circumstances. But such views are also, and importantly, collectively reflected at social, cultural,
2269 and religious levels of society.

2270 (C 5) The Commission therefore acknowledged (ICRP, 2007) that, in contrast to human
2271 radiological protection, the objectives of environmental protection are both complex and difficult
2272 to articulate. It did however subscribe to the global needs and efforts required to maintain biological
2273 diversity, to ensure the conservation of species, and to protect the health and status of natural
2274 habitats, communities, and ecosystems. It therefore developed a framework in order to meet these
2275 objectives by way of a practical system using a set of Reference Animals and Plants (seven animals
2276 and three plants), which included numerical approaches to their dosimetry, radiation effects, and
2277 data sets to help guide decision making for Representative Organisms under different exposure
2278 situations (ICRP, 2008, 2009, 2014, 2017).

2279 **C.3. Ethical issues in veterinary practice**

2280 (C 6) None of the above described approaches to the protection of the environment, nor that
2281 in relation to the protection of humans, clearly relates to the situation experienced in veterinary
2282 medicine. With regard to the protection of animal species in an environmental context, the

2283 emphasis is on their protection at a population level rather than at the level of individual animals
2284 (except in rare cases) and in this sense both anthropocentric and biocentric ethics may apply. Thus
2285 species are protected because of their human ‘value’, but they are also often protected because of
2286 biocentric concerns, and actions are therefore taken to save individual animals, or to alleviate their
2287 pain or discomfort as, for example, in the case of stranded cetaceans, and to do so if necessary by
2288 euthanasia.

2289 (C 7) Veterinary medicine, like human medicine, is regarded as being conducted under
2290 Aesculapian (i.e. the healing arts) authority which is essentially the uniquely powerful authority
2291 vested in those practitioners that society perceives as ‘healers’. It is Aesculapian authority that
2292 licenses a medical (or veterinary) practitioner to handle their patients, and to treat them in various
2293 ways. The human medicine situation is however somewhat different from that of veterinary
2294 medicine in that there are usually, but not always, two parties involved: the health professional and
2295 the patient. But in certain cases there are three: the health professional, the patient, and the patient’s
2296 guardian, carer, or parent. Although it may be assumed that all of those parties who are capable of
2297 coming to a decision on what to do best are acting in the highest moral way, differences of opinion
2298 may nevertheless emerge - such as between the views of the health professional and the parent or
2299 guardian of a small child on what to do in the best interests of the child. In such cases, mechanisms
2300 usually exist such that the final decision may be made by a court of law, but the overall aim is not
2301 usually in dispute: the well-being, and thus ‘good’ of the patient.

2302 (C 8) In the case of veterinary medicine there are also (usually) three relevant parties: the
2303 veterinarian, the animal patient, and the animal’s owner or guardian. But considerable differences
2304 may exist between the value judgements applicable to each party: in particular, who takes the risk,
2305 who reaps the benefit, and why. This dilemma has often been central to the development of ethics
2306 within the veterinary profession.

2307 (C 9) This development may be viewed as the combination of two different but related subjects.
2308 One is that of ‘animal ethics’ or what is often called ‘the animal problem’ that has been a matter of
2309 discussion since the days of Aristotle: it tries to tease out what the morally relevant differences are
2310 between humans and animals (e.g. Beauchamp and Frey, 2011). Essentially, if there is no
2311 difference, then how do we justify treating animals in the ways that we do; and if there is a
2312 difference, then what is it about this difference that allows us to treat animals in the way that we
2313 do? The second is essentially that of the more recent subject of animal welfare: how the lives of
2314 individual animals may be impoverished such that they suffer as a result, or are harmed; or, on the
2315 other hand, how their lives may be improved. The result is an ethic that is very similar to that of
2316 medicine, but key basic differences are also apparent, particularly with regard to the objective of
2317 preserving life. Thus although this is essentially an all-pervading one in medicine, in veterinary
2318 practice such decisions are also tempered by the different life expectancies, quality of life, or even
2319 assumed purpose in life (as in the case of livestock) of the animal in question.

2320 (C 10) One fundamental problem has usually been that of to whom should the veterinarians’
2321 primary responsibility be: to the animal, or to the animal’s owner? This question is exacerbated by
2322 the fact that, in the law of many countries, a person may hold ‘property rights’ over animals, thus
2323 implying that they may own animals as private goods, make use of them for economic gains, and
2324 dispose of them in a manner deemed ‘fit’ within the law. The veterinarian’s client will, therefore,
2325 be the holder of these property rights. This view of animals as a ‘property’ is a source of some of
2326 the ethical dilemmas faced by veterinarians and has an effect on the vet-animal-client (owner)
2327 relationship. The owner may demand that the veterinarian opinion should be secondary, because

2328 he/she owns the animal and may thus ask the veterinarian to comply with his/her decision. This
2329 may particularly be the case with regard to livestock. Different again is recognition of the extremely
2330 strong bonding between owners and their domestic (pet or companion) animals which may create
2331 a psychological barrier between the veterinarian and the client, especially in issues connected with
2332 euthanasia. A further consideration may be the owners' willingness and ability to pay. Moreover,
2333 of note is that irrespective of the debate about duty to the animal or the owner, there is a duty of
2334 the veterinarian to protect their staff members from undue radiation exposure.

2335 (C 11) One also has to accept that the world of veterinary practice is fairly dynamic. Private
2336 practices are run essentially as businesses, and there is thus competition amongst private practices
2337 and between those that are run 'for profit' and those that are not. These realities are likely to
2338 increase friction and therefore ethical dilemmas amongst veterinarians because some may adopt
2339 methods to undercut the 'competition' or behave opportunistically toward their clients. In the long
2340 run, however, it may well be considered that 'fair competition' is good for the client.

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2376

2417

2418 **Committee 3 members during preparation of this publication**

2419

2420 *(2017-2021)*

2421

2422 K. Applegate (Chair) M.C. Cantone J.M. Marti-Climent

2423 C. J. Martin (Vice-chair) S. Demeter Y. Niu

2424 M. Rehani (Secretary) M. Hosono W. Small

2425 J.S. Alsuwaidi K. Kang D. Sutton

2426 M. Bourguignon R. Loose L. Van Bladel

2427

2428 *(2021-2025)*

2429

2430 K. Applegate (Chair) M. Hosono C.E. Ruebe

2431 C. J. Martin (Vice-chair) A. Isambert W. Small

2432 D. Sutton (Secretary) M. Kortensniemi A. Sovik

2433 M.C. Cantone M. Mahesh I. Thierry-Chef

2434 J. Damilakis J.M. Marti-Climent I. Williams

2435 S. Demeter J.C. Paeng W. Zhuo

2436

2437 **Committee 3 emeritus members**

2438

2439 S. Mattsson M.M. Rehani M. Rosenstein

2440

2441 **Committee 4 members during preparation of this publication**

2442

2443 *(2017-2021)*

2444 D.A. Cool (Chair) A. Canoba Y. Mao

2445 K.A. Higley (Vice-Chair) D. Copplesstone N. Martinez

2446 J-F. Lecomte (Secretary) E. Gallego A. Nisbet

2447 N. Ban G. Hirth T. Schneider

2448 F. Bochud T. Homma S. Shinkarev

2449 M. Boyd C. Koch J. Takala

2450

2451 *(2021-2025)*

2452 T. Schneider (Chair) J. Burt A. Mayall

2453 N. Martinez (Vice-Chair) A. Canoba A. Nisbet

2454 J. Garnier-Laplace (Secretary) E. Gallego S. Shinkarev

2455 M. Baek D. Giuffrida J. Takala

2456 N. Ban C.B. Koch H. Yoshida

2457 Y. Billarand Y. Mao F. Zölzer

2458

2459 **Committee 4 emeritus members**

2460

2461 J.F. Lecomte

2462
2463
2464
2465
2466
2467
2468
2469
2470
2471
2472
2473
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2477
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Main Commission members at the time of approval of this publication

Chair: W. Rühm, *Germany*
Vice-Chair: D.A. Cool, *USA*
Scientific Secretary: C.H. Clement, *Canada*; sci.sec@icrp.org *

K.E. Applegate, <i>USA</i>	D. Laurier, <i>France</i>	Emeritus Members
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M. Kai, <i>Japan</i>		C. Streffer, <i>Germany</i>
		E. Vaño, <i>Spain</i>

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