STUK

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RADIATION SAFETY IN VETERINARY X-RAY EXAMINATIONS

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Authorization

The Radiation Act stipulates that the party running a radiation practice is responsible for the safety of the operations. The responsible party is obliged to ensure that the level of safety specified in the ST Guides is attained and maintained.

Under section 70, paragraph 2, of the Radiation Act (592/1991), STUK – Radiation and Nuclear Safety Authority (Finland) issues general instructions, known as Radiation Safety Guides (ST Guides), concerning the use of radiation and operations involving radiation.

Translation. In the event of any differences in interpretation of this guide, the Finnish and Swedish versions shall take precedence over this translation.

1 General

The party running a radiation practice (hereafter the responsible party) shall make sure that no veterinary X-ray examination is undertaken without ensuring the radiation safety of the staff and all other individuals.

This Guide specifies the radiation safety requirements concerning veterinary X-ray examinations, the X-ray equipment and dental X-ray equipment (veterinary X-ray equipment) used in the examinations, the places of use of such equipment and the related quality assurance requirements. This Guide also specifies the duties of a party selling or transferring X-ray equipment to another party.

This Guide shall not apply to radioactive substances used as unsealed sources in veterinary medicine.

The definitions of the terms used in the Guide are presented in Appendix A.

Provisions concerning the responsible party's general duty of care are laid down in section 14 of the Radiation Act (592/1991).

The use of radioactive substances as unsealed sources is discussed in Guides ST 6.1 and ST 6.2.

Provisions concerning a veterinary surgeon's right to decide on a veterinary examination of an animal are laid down in the Act on Access to and Pursuit of the Profession of Veterinary Surgeon (29/2000).

2 The use of veterinary X-ray equipment requires a safety licence

The use of veterinary X-ray equipment requires a safety licence that is granted by STUK upon application. In addition, the installation, repair and service of X-ray equipment in veterinary use require a safety licence if the operations involve the use of radiation or affect the radiation-producing parts of equipment.

Provisions concerning the safety licence and applying for the safety licence are laid down in section 16 of the Radiation Act.

2.1 Applying for a safety licence

A safety licence shall be applied for well in advance, and the device may not be introduced into use before the appropriate licence has been granted. When applying for a safety licence, the applicant is required to specify for STUK the purpose of the use of radiation, the X-ray equipment to be used, and the prospective number of examinations. A safety licence application shall include a floor plan which shows the place of use of the X-ray equipment and the adjacent facilities, indicating the location of the X-ray equipment, the imaging directions, the structural radiation shielding of the room, and the purposes of use of the adjacent facilities. In addition, the responsible party is required to nominate a radiation safety officer, whom STUK shall approve upon the responsible party's proposal. The responsible party shall be responsible for keeping the safety licence up-to-date.

All essential changes require that STUK approves the changes for the respective safety licence before the changes take effect. Examples of such changes include e.g.:

- the holder of a safety licence changes
- X-ray equipment is introduced into use
- equipment is transferred to a new place of use.

STUK shall be notified within two weeks if an appliance is decommissioned. Similarly, if the radiation safety officer named in the safety licence changes, a new safety officer candidate shall be presented for STUK's approval within two weeks.

Provisions concerning the radiation safety officer are laid down in section 18 of the Radiation Act. Provisions concerning information to be included in a safety licence application and provisions concerning changes in practices are laid down in sections 14 and 16 of the Radiation Decree (1512/1991).

2.2 Radiation safety officer

A radiation safety officer shall have passed the radiation safety officers' competence exam in the competence area of veterinary X-ray practices, X-ray practices in health care, or the general use of radiation in the medical sector.

The radiation safety officer appointed to take charge of veterinary X-ray examinations may be a veterinary surgeon or another person who has completed the radiation safety officers' competence exam and has had training in veterinary sciences, veterinary X-ray practices or X-ray practices in health care, combined with a good knowledge of the operations in the particular place of use.

A person to be nominated as a radiation safety officer is required to be actually capable, within his/her regular array of tasks, of handing the duties specified by the responsible party. If one safety licence is to include several places of use at different addresses, an organization description shall be appended to the application. The description shall give the names of all on-site radiation safety persons, describing their tasks related to the use of radiation.

The responsible party shall specify the duties of the radiation safety officer.

The duties and qualification requirements of radiation safety officers as well as radiation users' organizations are discussed in more detail in Guides ST 1.4, ST 1.6 and ST 1.8.

3 Safety shall be ensured

Veterinary X-ray examinations shall be performed in such a way that the objectives set forth for examinations are reached while minimizing the exposure to radiation of the staff and other persons. Success in veterinary X-ray examinations requires e.g. that

- the staff is trained in the use of radiation in veterinary X-ray practices
- the X-ray equipment available is suitable for the particular examinations and in proper working order
- the technology has been optimized (imaging voltage, imaging current, beam limiting, etc.)
- image quality suffices for reliable diagnoses and radiological procedures.

3.1 Training requirements of individuals engaged in X-ray examinations

X-ray examinations may be conducted only by sufficiently skilled individuals trained in the use of the particular devices.

All staff using radiation shall receive sufficient radiation protection training and sufficient user training for the relevant appliances. The responsible party shall maintain the expertise of the staff that operates the X-ray equipment by e.g. ensuring them supplementary training in radiation protection. The operating staff shall be supplied with appliance-specific up-to-date user instructions containing values to be used for examinations and fluoroscopy, as well as instructions for cases of malfunction and hazard.

The supplementary training requirements for radiation safety officers and users of radiation are discussed in Guide ST 1.8.

3.2 Workers' radiation safety

The radiation exposure of the staff shall be kept as low as reasonably achievable. During a veterinary X-ray examination, only those persons may remain in the examination room whose presence is required for the performance of the examination. If it is necessary to remain in the examination room during an examination, all persons there shall use appropriate protective devices such as lead rubber aprons and gloves, thyroid shields or mobile shields. They shall be as distant from the radiation beam and the exposed object as is feasible in view of conducting the examination, and no part of them shall be exposed to primary radiation. Good practices for the reduction of radiation exposure are presented in Appendix D.

The responsible party shall classify workers engaged in radiation work either as category A or category B workers. As necessary, working areas shall also be classified as controlled areas or supervised areas. In veterinary X-ray practices, category A shall include those workers who regularly or repeatedly work in controlled areas (in X-ray examination rooms) during irradiation, and whose effective dose caused by their work exceeds or may exceed 6 mSv per year. Individual monitoring and medical surveillance shall be arranged for these workers. It is often expedient to arrange individual monitoring for category B workers as well. If group dosemeters are used for monitoring working conditions, individuals holding the animals during examinations and other individuals working near the radiation

beam shall be recorded per examination. In addition, the records shall show who used the group dosemeter during the examination. Should dosemeters indicate doses exceeding the recording level, the classification of the workers shall be revisited and the need for individual monitoring shall be reconsidered. The individual who works close to the radiation beam the most may require a personal dosemeter.

Young people under 18, for reasons other than their professional training, shall not be assigned duties in which they may be exposed to radiation. Young people under 16 shall not be assigned such duties even temporarily. The duties of a pregnant woman shall be arranged so that the effective dose of the foetus is kept as low as reasonably achievable, and that it does not, after the woman has notified the relevant parties of her pregnancy, exceed 1 mSv during the remaining pregnancy. The staff shall ensure that no-one under 18 or pregnant holds the animal during the examination.

Provisions concerning the classification of workers and working areas are laid down in section 32 of the Radiation Act and in section 10 of the Radiation Decree. Classification is discussed in more detail in Guide ST 1.6. Provisions concerning individual monitoring, medical surveillance and the monitoring of working conditions are laid down in sections 32 and 33 of the Radiation Act and in sections 11 and 12 of the Radiation Decree. They are discussed in more detail in Guide ST 7.1. The quantities, units and recording levels for individual monitoring are given in Guide ST 7.4. The provisions concerning young people and pregnant women in tasks involving exposure to radiation are laid down in sections 4 and 5 of the Radiation Decree.

3.3 Structural radiation shieldings in places of use and the radiation-safe use of equipment

Rooms in which veterinary X-ray examinations are performed shall be suitably sized for the purpose and have structural radiation shieldings which serve to keep the radiation exposures caused by examinations to individuals in any adjacent facilities as low as reasonably achievable and at least below the dose constraint 0.3 mSv/year.

Unauthorized access to the examination room shall be prevented by safety interlocks or access control. Should the user of the X-ray equipment not have an unobstructed view to the doors of the examination room, these doors shall be locked during examinations, and all doors to the place of use shall be equipped with signs warning of a radiation hazard. The user of the equipment shall also have an unobstructed view to the animal during the examination, for example through a lead-glass window or a mirror.

Should any equipment be used in an open space or a place other than a regular X-ray facility, in e.g. horse stables, the safety licence application shall specify the procedures to be used for ensuring the radiation-safe use of the equipment (e.g. imaging directions, the radiation protection of relevant individuals, the marking off of the examination site so that external persons are not exposed to radiation).

Appendix E provides additional information concerning the radiation shielding of facilities used for veterinary X-ray examinations.

The principles presented in Guide ST 1.10 shall apply to structural radiation shieldings of places of use of veterinary X-ray equipment. The provisions concerning STUK's authorization to set dose constraints are laid down in section 7 of the Radiation Decree.

4 Notifications are required concerning sales and transfers of X-ray equipment

The party selling or otherwise transferring to another party X-ray equipment shall, no later than at the end of January annually, provide STUK with the following information concerning the X-ray equipment sold or reinstalled during the previous year:

- the owner/holder of the appliance
- the precise address at which the appliance is installed or to which it has been delivered for installation
- information identifying the appliance uniquely (the device type and serial number)
- the date of the delivery or sale of the appliance.

The provisions concerning STUK's authorization to require an importer, manufacturer or seller to furnish

STUK with the information needed for the regulatory control of safety concerning the products which these parties have placed on the market are laid down in section 21 of the Radiation Act.

5 Equipment shall comply with acceptability criteria at time of use

The functions and performance values of veterinary X-ray equipment shall be suited for the intended use. X-ray equipment and the related auxiliaries and other devices shall comply with the acceptability criteria at time of use given in Appendix B.

These criteria represent the minimum requirements (acceptability limits) imposed on the performance capacity of the equipment. If the criteria are not met, then one of the following actions shall be taken:

- repair the appliance and restore its performance to an acceptable level
- restrict the use of the device so that the characteristic exceeding the action level does not affect examinations, or
- decommission the appliance.

6 Quality assurance is required for operations

The responsible party is required to arrange quality assurance for practices involving exposure to radiation. In the case of veterinary X-ray practices, quality assurance shall include technical quality control, examination instructions, recording of examinations, and reporting.

6.1 Monitoring the operating condition of equipment

All equipment shall be acceptance tested and their technical quality shall be controlled for the sake of ascertaining their appropriate operating condition and the sufficiency of their performance. The responsible party shall ensure that any appliance about to be commissioned is acceptance tested before use.

Technical quality control activities shall be performed at specified intervals, following significant repairs or servicing, and at any time when there is cause to suspect a malfunction or a change in the operation of the equipment. Some of the measurements may be included in the regular measurements performed by service firms.

In addition to the proper operation of the X-ray equipment, to ensure correct diagnoses, it is important to inspect at specified intervals the appropriate operating condition of all appliances and instruments intended for image formation and viewing. In practice, quality control procedures differ depending on whether imaging takes place on film or digitally.

The technical quality control of X-ray equipment can be implemented largely in connection with its regular service measurements, applying the X-ray tube and generator tests given in the publication "Quality control guide for health service X-ray appliances" [2] (in Finnish). The guide also includes instructions for testing by the user.

In addition, records must be kept of any equipment faults, functional errors and other incidents that occur during the use of the equipment disturbing its use or endangering safety. All documents required for the assessment of the safety of practices shall be kept safe through the service-life of the equipment. If any abnormal events are observed that are significant for radiation safety, the measures should be taken that are presented in chapter 7.

Appendix C presents the minimum requirements for technical quality control measures, the time limits of the tests to be performed, and examples of technical quality control procedures.

6.2 Examination instructions, recording of examinations, and reporting

In the place of use of X-ray equipment, instructions shall be available for the most common X-ray procedures performed with the equipment and for the use of the equipment. The examination instructions shall include the imaging values for the most common X-ray procedures performed with the equipment, considering the species and size of the animal and the exposed object, as well as any auxiliary

equipment possibly necessary for examinations. Should the equipment be used in a place other than a regular X-ray facility (in e.g. horse stables) the instructions shall provide additional guidance for ensuring the radiation-safe use of the equipment in those circumstances.

The responsible party shall keep records of the number of examinations performed with the equipment. Information of the number of examinations shall be provided to STUK upon request and according to separately issued instructions.

7 Abnormal events shall be reported

An abnormal event in the use of radiation is an event that differs from normal activities and results in a substantial safety hazard at the place where the radiation is used or in its environs. An abnormal event may also consist of an exceptional observation or information concerning an event that is of essential significance for the radiation safety of workers or that of the environment. The disappearance or theft of a radiation source is also considered an abnormal event.

STUK must be promptly notified of any significant abnormal events. In veterinary X-ray practices, an event that must be reported is, for example, an event that unnecessarily exposes a worker or an external person to radiation. The initial report may be submitted by telephone, but it must later be confirmed in writing.

Should an abnormal event take place, the dose to which a staff member or another person was subjected shall be assessed and the reasons leading to the event shall be investigated. In addition, appropriate measures shall be taken and the respective guidelines shall be checked in order to prevent similar events in the future.

Sections 13 a and 17 of the Radiation Decree lay down the provisions concerning abnormal events and notifications of observations significant for safety. Examples of abnormal events, abnormalities significant for safety, and measures to be applied should any such emerge, are presented in Guide ST 1.6

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APPENDIX A

Definitions

Intraoral X-ray unit
An X-ray appliance for dental imaging using an intraoral imaging receptor.

Quality control
The set of techniques and activities used for meeting the required quality criteria.

Quality assurance
A set of planned and systematic functions in the management system, the operation of which is demonstrable when required, used for reaching a sufficient level of trust in that the object of quality assurance activities meets the quality criteria.

Abnormal event
An event which results in a substantial safety hazard in a place where radiation is used or in its environs. An abnormal event may also consist of an exceptional observation or information concerning an event that is of substantial significance for the radiation safety of workers or the environment.

Radiation safety officer
A person in charge, appointed by the responsible party to handle the practical activities to ensure the safe use of radiation, to maintain the safety, and to correct any defects.

Supervised area
A working area subject to appropriate monitoring of working conditions for the sake of protection against radiation.

Technical quality control
Quality assurance procedures designed to show that the equipment and their performances conform to the set criteria.

Party running a radiation practice (the responsible party)
Any business or sole trader, enterprise, corporation, foundation or institution which uses radiation sources in its operations, or any employer or self-employed person engaged in radiation practices.

Additional information: When the responsible party is something other than a physical person (such as a limited liability company, foundation or municipality), the party responsible for the operation as a whole is the party with the highest authority in the organization.

Controlled area
A working area subject to special rules for the sake of protection against radiation, and to which access is controlled.

APPENDIX B

Criteria for veterinary X-ray equipment at time of use

Performance measurement results depend on the measurement conditions and the methods used.

Test	Criterion
X-ray tube voltage	In the case of equipment introduced into use after this Guide has entered into force, the measured imaging voltage of an X-ray tube shall not deviate from the nominal value by any more than 10%. In the case of older equipment, the imaging voltage may exceptionally deviate even more if the practice uses established imaging values and the equipment fulfils the voltage reproducibility requirement below. When an X-ray tube voltage measurement is reproduced five times in a row with varying the adjustments between the measurements, the voltage may deviate by a maximum of 5% from the average result of these measurements.
Total filtration	Total filtration of primary radiation must be equivalent to at least 1.5 mmAl when the imaging voltage is less than or equal to 70 kV, and to at least 2.5 mm Al when the imaging voltage is greater than 70 kV. The value of the total filtration of radiation shall be marked on the housing of the X-ray tube.
Radiation output of an X-ray tube	When imaging is reproduced five times in a row with varying the adjustments between the images, the radiation output may deviate by a maximum of 20% from the average result of these measurements. If the equipment contains imaging current or exposure time controls, the air kerma must be proportional to the indicated current-time product Q in such a way that: $\left\lvert \frac{\bar{K}_1}{Q_1} - \frac{\bar{K}_2}{Q_2} \right\rvert \leq 0,2 \cdot \frac{\frac{\bar{K}_1}{Q_1} + \frac{\bar{K}_2}{Q_2}}{2}$, in which $\bar{K}_1$, $\bar{K}_2$ are the measured air kerma values and Q_1, Q_2 are the products of the imaging current and exposure time. Q_1, Q_2 differ from one another by a factor which is as close as possible to factor 2 without exceeding it. Exceptionally in the case of older equipment, the proportionality requirement for radiation output is not required to be completely met if the practice uses established imaging values and the equipment fulfils the radiation output reproducibility requirement.
Radiation and light fields	The discrepancy of the edges of the radiation and light fields shall not exceed 1 cm at the imaging distance in use. The edges of the light field shall be clearly discernible under normal working lights.

APPENDIX C

Technical quality control of veterinary X-ray equipment and the required control intervals

Item to be checked	Control interval not more than
Voltage, radiation output, exposure time, image quality	36 months, 12 months recommended for capacitor devices
Radiation and light fields	12 months
The operation of the X-ray equipment's mechanical functions, emergency switches, radiation detectors and warning lights	12 months
Condition of radiation protection devices	12 months
Films, cassettes, film development and viewing screens	12 months
Digital image receptors and CR readers	12 months
Monitors and work stations, working environment	1 month

Examples of technical quality control

Acceptance testing
The purpose of the acceptance test is to verify that after the transportation, installation and connection of all parts, the equipment functions appropriately and safely so that the requirements imposed by legislation and the key performance values and safety features specified by the manufacturer are all met. During the acceptance test, it is expedient to determine the reference performance values needed for monitoring the operating condition and performance of the equipment. In the case of a used portable X-ray appliance with documented technical measurements and less than 36 months from the previous measurements, tests specified by the responsible party and conducted before commissioning the device, shall suffice as acceptance testing.

Voltage, radiation output, exposure time
Voltage, radiation output and exposure time shall comply with the acceptability criteria at time of use given in Appendix B.

Image quality
Image quality is checked using an image taken of a phantom prepared for the purpose. This enables the testing of e.g. the device's resolution and contrast resolution. The image is compared to earlier images taken with the device, ensuring that the performance of the device has not essentially deteriorated.

Radiation and light fields
Metal markers (such as coins) set in the corners of the light field are exposed. The edges of the radiation field are compared to the markers of the corresponding edges of the light field.

The operation of the X-ray equipment's mechanical functions, emergency switches, radiation detectors and warning lights
The mechanical function of the X-ray equipment is checked. The stability of the direction and positioning of the X-ray tube is checked for conventional imaging situations. The conditions of all cables in the device are checked. In addition, it is checked that all emergency switches, radiation detectors and warning lights work as intended.

Condition of radiation protection devices
It is ensured by visual and manual checks that radiation protection devices are intact and in working order. Should deficiencies be suspected in any protective devices, the matter can be ascertained by taking an image of these devices.

Films, cassettes, film development and viewing screens

The locking of a film cassette shall operate in a reliable manner and the cassette shall be light-proof. The compression material shall be elastic and the compression shall be good and even on every part of the film. The locking and light-proofing of a film cassette can be checked by setting the cassette which contains an unexposed X-ray film on a viewing screen for 10 minutes per side. Once developed, the film should not show black edges. The contact of the intensifying screens and the film can be checked by imaging a perforated metal plate or a metal grid set on top of the cassette. The image should not show areas that vary in darkness or sharpness.

A darkroom in which X-ray films are developed shall be light-proof. The safelight used in a darkroom shall be appropriate for the film in use. In order to prevent scattered radiation on films and cassettes, they shall not be stored in imaging rooms. Sufficient quality control measures for film processing devices consist of conforming to developer and film manufacturers' recommendations concerning the standard development times, temperatures and mixing proportions, and of changing the solutions as recommended.

All viewing devices and screens shall be sufficiently luminous and the light shall be even. All viewing devices and screens shall be placed so that the lights in the room do not produce reflections. The compatibility of the intensifying screens and the film type shall be ascertained.

Digital image receptors and CR readers

Similarly to films and cassettes, digital imaging plates shall be stored safe from scattered radiation. Any charges on imaging plates that have been unused for extensive periods of time should be erased before the plates are used for imaging. The information on imaging plates must be read within a reasonable period of time in order to keep fading and the accumulation of background radiation from weakening image quality.

The cleanness and condition of imaging plates shall be checked visually. If needed, plates are cleansed according to the manufacturer's instructions, using appropriate chemicals.

The mechanical wear of image receptors, and possible image disturbances, can be tested by irradiating a cassette evenly with an appropriate dose, then checking the evenness of the image visually, also ascertaining that it is free of defects. The image should not show any essential unevenness or disturbances that may disturb a diagnosis. Manufacturers may recommend certain image receptors to be calibrated at regular intervals; this must take place according to their instructions.

Instructions applicable to veterinary X-ray equipment, concerning the quality assurance of digital image receptors, are available in Item 4.3 of the publication "Quality control guide for health service X-ray appliances" [2] (in Finnish).

Monitors and work stations, working environment

The operation of monitors can be tested with special test images. Test images can be used for ascertaining that monitors meet the criteria set by manufacturers. The comparison of a test result with earlier results may reveal deterioration in the monitor quality. Attention shall also be paid to the conditions in which images are viewed, e.g. the lighting of the room and reflections on the screen. It is necessary to ascertain that light cannot reach the monitor directly from any source such as a lamp or window. Neither should such sources be present in the field of vision of the viewer.

APPENDIX D

Good practices for the reduction of radiation exposure

To avoid anyone having to hold the animal down during examination or fluoroscopy, the animal should be sufficiently calmed down and its position should be maintained by, for example, sand bags, wedge pillows and other similar positioning aids. If it is necessary to stay in the imaging room during exposure, veterinary X-ray examination staff will be exposed mainly to radiation scattered from the animal, if appropriate working methods are applied. The amount of scattered radiation can be significantly reduced by using field sizes as small as is feasible in view of conducting the examination. A reduction of the imaging values (imaging voltage and imaging current; not increasing one while reducing the other) also leads to a reduction in scattered radiation. An increase in the distance between the animal and the person reduces the exposure of the person significantly; doubling the distance reduces the person's exposure to approximately a quarter. Therefore, the person holding the animal should stay as far from the animal as possible during exposure. If a cassette or plate cannot be set on the treatment table or in a separate holder when X-raying e.g. a horse, an extension arm cassette holder shall be used.

During the use of radiation, the lead equivalents of the rubber-lead aprons and coats of the persons working near the animal and near the radiation beam should be no less than 0.5 mm. In general, 0.25 mmPb suffices for persons working at greater distances. When working close to the radiation beam, the persons holding the animal and the cassette holder are required to wear, in addition to rubber-lead aprons or coats and thyroid shields, also protective gloves with a lead equivalent of no less than 0.5 mm. Should the equipment be used in several locations, it shall be ascertained that there always is a sufficient number of protective devices available for ensuring the radiation safety of the staff and any external persons when radiation is used. It is recommended that, when possible, the person holding the animal down be the owner of the animal. However, a person under 18 or pregnant must not hold an animal during an examination.

APPENDIX E

Structural radiation shieldings at places of use

The requirements presented here shall apply to places in which conventional X-ray equipment and dental X-ray equipment are used for veterinary X-ray examinations. More information concerning the radiation shielding requirements of places of use of other X-ray equipment, e.g. computed tomography equipment, is available in Guide ST 1.10.

The need for radiation shielding in the imaging room depends on e.g. the number of X-ray examinations, on the imaging voltage, on the product of the imaging current and exposure time (mAs), on the size and orientation of the beam, on the location of the X-ray appliance in the imaging room, and on the intended use of the adjacent areas. When a place of use is being designed, attention should be paid to e.g. the future changes in the scope of the imaging activity and in the intended uses of the adjacent facilities.

In small-animal examinations, the radiation beam is almost always directed downwards; in such cases it suffices that the radiation shielding of the imaging room walls, observation windows, doors and their frames equals 1 mmPb if people are expected to occupy the adjacent facilities. If there are people in the direction of the primary radiation beam during examinations, the shielding in this direction shall equal no less than 2 mmPb. If the imaging direction of an intraoral device used in veterinary radiography is generally towards the floor, the walls of the imaging room usually do not require additional shielding.

However, if the number of images and the imaging values are exceptionally large, the need for shielding may be greater than said above. More information concerning how to determine radiation shielding is available in Guide ST 1.10; the case of intraoral X-ray units is specified in Guide ST 3.1 and the publication Advice from STUK / September 2011.

Sufficient radiation shielding is also achievable with other building materials than lead. Lead equivalents of alternative building materials are presented in Table 1.

Should examinations be performed in an open space or a place other than a regular X-ray facility, in e.g. horse stables, the structural radiation shielding of the walls might not suffice. In such cases it must be ascertained that no external individuals remain near the equipment and the animal during exposure. For example, in any open space in the direction of the primary beam, several dozens of metres of space must be vacated for the time of exposure. When possible, radiographs should be taken in the direction of stone-structured loadbearing walls because such walls are structurally strong and have better shielding characteristics than other walls.

Table 1. Lead equivalents of alternative building materials.

Building material and its density	**Thickness of lead (mmPb)**	**Material thickness (mm) corresponding to the thickness of lead at different X-ray tube voltages**			
		50 kV	**70 kV**	**100 kV**	**125 kV**
Concrete (2300 kg/m^3) or glass (2600 kg/m^3)	0.5 1 2	65 115	58 106 195	51 87 140	54 98 165
Brick (solid, 1800 kg/m^3)	0.5 1 2	94 166	84 153	74 126 195	78 142
Plasterboard (750 kg/m^3)	0.5 1	157 284	145 270	132 234	146 276
Barium-containing radiation shield plate (60% $BaSO_4$, 1360 kg/m^3)	0.5 1		10 21	8.9 18	13 25
Steel (7900 kg/m^3)	0.5 1 2	3.0 5.6	3.2 6.8	3.4 7.0 13	4.2 9.8