Radiological safety and assessment of the performance of X-ray systems in veterinary facilities

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Abstract – This paper concerns an analysis regarding the performance of X-ray equipment as well as the radiological safety in veterinary facilities. Data were collected from 380 X-ray veterinary facilities countrywide during the on-site regulatory inspections carried out by the Greek Atomic Energy Commission. The analysis of the results shows that the majority of the veterinary radiographic systems perform within the acceptable limits; moreover, the design and shielding of X-ray rooms as well as the applied procedures ensure a high level of radiological safety for the practitioners, operators and the members of the public. An issue that requires specific attention in the optimization process for the proper implementation of veterinary radiology practices in terms of radiological safety is the continuous training of the personnel. The above findings and the regulatory experience gained were valuable decision-making elements regarding the type of the regulatory control of veterinary radiology practices in the new radiation protection framework.

Keywords: veterinary radiographic systems / radiological safety / regulatory control / graded approach

1 Introduction

Veterinary radiology is a well-developed specialty of veterinary medicine, which includes, inter alia, the performance of radiographic examinations. X-ray examinations for veterinary diagnostic purposes are subject to specific requirements regarding the equipment used, the applied techniques and the radiological safety of the operators and the public (ARPANSA, 2009; NCRP 2004).

Appropriate equipment and examination techniques are prerequisite to obtain a radiographic image of adequate quality. Moreover, quality control, servicing and maintenance of the radiographic equipment are necessary to keep its performance at an optimal level. Regarding the radiological safety of the practitioners, operators and the members of the public, this is accomplished with the proper design and construction of the veterinary radiology rooms, and the implementation of well-established safety procedures (MD, 2019; PD, 2018).

The Greek Atomic Energy Commission (EEAE) is the national regulatory authority, competent for the control, regulation, and supervision in the fields of nuclear energy, nuclear technology, radiological and nuclear safety and radiation protection (Law, 2014). In this regard, EEAE is responsible for proposing and implementing the legislative framework for the regulatory control of practices with radiation sources.

The previous Radiation Protection Regulations (RPR) required veterinary facilities to be authorized through licensing process. A license could be granted only if EEAE had issued a certificate of compliance with the RPR requirements. The compliance of the facility was verified through the review and assessment of undertaking’s supporting documentation and the performance of an onsite inspection. It is stressed out that this combination of review, assessment and inspection was used for the authorisation of all types of practices, e.g. use of linear accelerators or X-ray equipment in medical exposures.

According to the new RPR (PD, 2018) based on the Council Directive 2013/59/Euratom (EU, 2013) and the IAEA basic safety standards (IAEA, 2014), the regulatory control of practices is accomplished through notification or authorisation (registration or licensing) based on the results of a review and assessment process.

Onsite inspections are independent of the notification or authorisation process and performed for verification purposes. They are carried out by EEAE’s Licensing and Inspections Department (LID) and include, inter alia, investigation of applied practices, personnel’s education and training on radiation protection, occupational and public exposures, etc. LID has been accredited according to the terms of ISO/IEC 17020:2012 standard for bodies performing inspections (ISO/IEC, 2012).
To ensure the proper implementation of the new regulatory framework, EEAE had to categorise the practices applied countrywide in line with a graded approach in order to allocate the necessary resources for ensuring safety. In this respect, the type of regulatory control of each practice should be commensurate with the magnitude and the probability of an exposure due to the practice as well as to the effect it may have in the reduction of the exposure or the improvement of the radiological safety.

This paper presents the results of the work carried out by EEAE during the period 2005–2013 in order to assess the performance of X-ray equipment and the radiological safety in veterinary facilities. The analysis of the results was used to facilitate the categorization of the use of X-ray systems in veterinary facilities in the new regulatory framework. In this respect, data from 380 facilities concerning performance of equipment, radiological safety, and occupational and public exposure were collected and analysed.

2 Materials and methods

Three hundred and eighty veterinary facilities, which apply practices with radiation sources for diagnostic or therapeutic purposes operate countrywide. All of them are equipped with radiographic systems while two of them also perform computed tomography (CT) examinations. The workload of a representative percentage of the facilities performing radiographic examinations is given in Figure 1. A main distribution including facilities, which perform few examinations per week, and a second minor one of facilities, performing more than eight examinations per week, are convolved in the diagram.

2.1 Performance of X-ray equipment

The assessment of the performance of the X-ray systems was carried out during EEAE’s visits to veterinary facilities for conducting onsite inspections but independently of them. It was based on certain operational parameters and acceptability criteria (Tab. 1), and in accordance with related scientific protocols (AAPM, 1998, 2002; Cranley, 1995; EC, 2012; NCRP, 1988).

For performing the necessary measurements, the following appropriately calibrated instruments were used:

- RTI Electronics AB BARRACUDA;
- RTI Electronics PIRANHA;
- UNFORS Xi.

2.2 Occupational and public exposure

The assessment of occupational and public exposures due to the performance of radiographic examinations was based on estimated values of annual effective doses. For this purpose, the distribution of workloads of Figure 1, and ambient equivalent dose rate $H_p(10) \, (\mu Sv \cdot h^{-1})$ in different areas of the veterinary facilities were considered. To be on the safe side from radiation protection point of view, all areas were treated as continuously occupied.

Fig. 1. Workload of 90 veterinary facilities performing radiographic examinations in the period 2005–2013.

$H_p(10)$ values were measured in X-ray system control room, waiting areas, practitioners’ offices, and other areas accessible to the members of the public. A calibrated Victoreen 451P survey meter was used for performing the necessary measurements. A 20 cm × 20 cm × 20 cm water phantom was used as scattering material, in order to simulate a small animal. Irradiations of the phantom were carried out at a fixed Focus Surface Distance (FSD) of 100 cm and at the maximum kVp and mAs settings applied by the practitioners.

Additionally, the operators’ doses, for those operators who were monitored with the use of a passive dosemeter, for the period 2005–2013 were retrieved from the National Dose Registry kept by EEAE and analysed. The reference quantity is the personal dose equivalent at depth 10 mm, $H_p(10)$.

2.3 Other aspects related to radiation protection and radiological safety

Applied procedures with respect to radiation protection and radiological safety were also investigated during LID’s onsite inspections. The use of radiation protection means (e.g. lead linen aprons and collars) by operators and animal owners and the optimisation of the examination techniques were among the areas addressed.

Finally, the E&T and continuing training of veterinary practitioners and operators on radiation protection were also addressed.

3 Results

3.1 Performance of X-ray equipment

Table 2 presents the analysis results concerning the data related to the performance of X-ray systems in veterinary facilities as well as the results of a Chi-square analysis (Wayne, 1991), which was carried out in order to investigate any statistically significant difference between the radiographic systems used to perform examinations to animals and humans. Additionally, Figure 2 presents the percentage of radiographic systems used to perform examinations to animals and humans respectively with an acceptable performance for each
4.1 Performance of X-ray equipment

Ninety-five percent of the systems have an X-ray tube of acceptable total filtration (Tab. 2). Significantly low total filtration values could be attributed to the possible removal of the tube filtration in order to increase the radiation output of the system. On the contrary, values significantly higher than 2.5 mm correspond mainly to aged systems, where the effects of tungsten build-up on the X-ray tube glass and anode roughness are important.

Seventy and 77% of the radiographic systems were found to operate acceptably regarding tube voltage and exposure time accuracy respectively. Additionally, 100% and 98.5% of the systems were acceptable in terms of tube voltage and exposure time reproducibility.

The investigated X-ray systems showed a wide range of radiation output values (Tab. 2), with 41% of them having an output lower than 44.4 μGy (mAs)⁻¹. The high percentage of systems with low radiation output may be attributed to their aging, system component malfunctions and lack of regular quality control. However, in most cases the operators were well aware of their systems output capabilities and considered appropriately this factor when selected exposure settings.

Radiation output reproducibility and linearity were found acceptable (97.5% and 93.0% respectively) for the vast majority of the radiographic systems examined. This finding is directly related to the systems’ performance regarding tube voltage and exposure time reproducibility (Tab. 2).

Figure 2 and the Chi-square analysis (Tab. 2) indicate that radiographic systems used for examinations to small animals show a comparable and sometimes better performance than the systems used for examinations to humans except for radiation output. The percentage of acceptably performing systems regarding time reproducibility and radiation output reproducibility and linearity is higher for the X-ray systems used in veterinary examination. This can be attributed to the narrower range of these parameters mostly used in veterinary examinations, without reaching the performance limits of the system.

A significant difference (P < 0.001) between the two groups concerns the percentage of systems with acceptable radiation output (Tab. 2). Veterinary radiographic systems exhibit a lower percentage of acceptability regarding radiation output. This “weakness” is easily overcome by the selection of appropriate exposure settings during the examinations.

3.2 Occupational and public exposure

The estimated maximum annual ambient dose equivalent in the different areas of veterinary facilities are given in Table 3.

Based on the data retrieved from the National Dose Registry the higher value of the mean annual $H_p(10)$ of operators in veterinary facilities was estimated equal to 0.08 mSv. Moreover, the higher value of the mean annual $H_p(10)$ of operators with an $H_p(10) > 0.1$ mSv was equal to 0.83 mSv.

3.3 Other aspects related to radiation protection and radiological safety

Radiation protection means (lead linen aprons and collars) are available and used in more than 80% of veterinary facilities. Additionally, the lead linen aprons are also used by the animal owners when they have to remain in the X-ray room during the examination.

Operators showed good knowledge of the imaging techniques applied to small animals and the necessary radiation protection precautions to be taken.

Regarding E&T on radiation protection, it was noted that only a small percentage of veterinary practitioners have attended a related course either at undergraduate or post graduate level.

4 Discussion

4.1 Performance of X-ray equipment

Table 1. Assessed parameters of veterinary X-ray systems’ performance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptance limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam filtration</td>
<td>$\geq 2.5$ mm Al</td>
</tr>
<tr>
<td>Tube voltage accuracy</td>
<td>$\leq 10%$</td>
</tr>
<tr>
<td>Tube voltage reproducibility</td>
<td>$\leq 5%$</td>
</tr>
<tr>
<td>Time accuracy</td>
<td>$\leq 10%$</td>
</tr>
<tr>
<td>Time reproducibility</td>
<td>$\leq 5%$</td>
</tr>
<tr>
<td>Radiation output</td>
<td>$\geq 44.4$ $\mu$Gy $(mAs)^{-1}$</td>
</tr>
<tr>
<td>Linearity of radiation output</td>
<td>$\leq 10%$</td>
</tr>
<tr>
<td>Reproducibility of radiation output</td>
<td>$\leq 5%$</td>
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</tbody>
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investigated parameter. The performance of X-ray systems used for diagnostic examinations in humans has been investigated in a similar study (Economides et al., 2007).

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A significant difference (P < 0.001) between the two groups concerns the percentage of systems with acceptable radiation output (Tab. 2). Veterinary radiographic systems exhibit a lower percentage of acceptability regarding radiation output. This “weakness” is easily overcome by the selection of appropriate exposure settings during the examinations.

4.2 Occupational and public exposure

The maximum annual $H^*(10)$ values estimated for the different areas in veterinary facilities (Tab. 3) are less than 0.40 mSv. Considering that annual $H^*(10)$ calculations were based on the “worst” case scenario regarding exposure settings and occupancy factors and that this quantity may significantly overestimate effective dose (EC, 2009) it is easily concluded that it is unlikely to record any doses exceeding the respective limits (PD, 2018) in veterinary facilities. Moreover, the exposure levels at outdoor spaces adjacent to the X-ray rooms were found comparable to those due to background radiation.

The above findings fully agree with the estimated mean annual $H_p(10)$ values of operators in veterinary facilities based on data retrieved from the National Dose Registry.

It is stressed out that the X-ray rooms in the veterinary facilities inspected were designed, constructed and shielded in accordance with radiation protection experts’ studies based on information such as: type of examinations to be performed, expected workload, occupancy factors, applied procedures, etc. In case this information changes (e.g. application of new types of practices, use of different X-ray equipment, etc.), the regulatory framework requests the re-assessment of the potential occupational and public exposures in an updated study.
4.3 Other aspects related to radiation protection and radiological safety

Radiation protection and radiological safety are effectively implemented in veterinary facilities performing radiographic examinations. The vast majority of the facilities inspected were equipped with appropriate means of radiation protection (i.e., lead linen aprons and collars), which were used by pet owners when necessary. Moreover, the operators showed to be aware of issues concerning radiation protection and radiological safety.

Table 3. Estimated maximum annual $H^*(10)$ in veterinary facilities.

<table>
<thead>
<tr>
<th>Area</th>
<th>Control room</th>
<th>Waiting room</th>
<th>Practitioner’s office</th>
<th>Outside areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total filtration (mmAl)</td>
<td>151</td>
<td>145</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Tube voltage accuracy (%)</td>
<td>(1.5, 3.8)</td>
<td>(−15.2, 33.8)</td>
<td>(0.0, 1.5)</td>
<td></td>
</tr>
<tr>
<td>Tube voltage reproducibility (%)</td>
<td>70</td>
<td>134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure time accuracy (%)</td>
<td>(−32.2, 96.2)</td>
<td>(0.0, 5.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure time reproducibility (%)</td>
<td>77.0</td>
<td>98.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation output (μGy.mA$^{-1}.s^{-1}$)</td>
<td>109</td>
<td>125</td>
<td></td>
<td>125</td>
</tr>
<tr>
<td>Reproducibility of radiation output (%)</td>
<td>59.0</td>
<td>97.5</td>
<td></td>
<td>93.0</td>
</tr>
<tr>
<td>Linearity of radiation output (%)</td>
<td>$P &lt; 0.05$</td>
<td>$P &lt; 0.1$</td>
<td>$P &lt; 0.1$</td>
<td>$P &lt; 0.01$</td>
</tr>
<tr>
<td>Sample size</td>
<td>151</td>
<td>145</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>(1.5, 3.8)</td>
<td>(−15.2, 33.8)</td>
<td>(0.0, 1.5)</td>
<td></td>
</tr>
<tr>
<td>Acceptable (%)</td>
<td>95.0</td>
<td>70.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Chi-square level of significance</td>
<td>$P &lt; 0.05$</td>
<td>$P &lt; 0.1$</td>
<td>$P &lt; 0.1$</td>
<td>$P &lt; 0.001$</td>
</tr>
</tbody>
</table>

Fig. 2. Percentage of X-ray systems with an acceptable performance.

The use of lead linen gloves by pet owners was not encouraged, as they may intervene in the primary X-ray beam, resulting in images of unacceptable quality and thus, in the repetition of the examinations. In this case, the maximum equivalent dose to the pet owners’ hands is not expected to exceed 55 μSv (Seifert et al., 2007), while the respective annual equivalent dose limit for the skin is 50 mSv (PD, 2018).

With respect to E&T in radiation protection of veterinary practitioners, the topic is partially covered in the curricula of the national veterinary schools, usually during radiology courses. Although, no incidents related to radiological safety...
were registered during LID’s onsite inspections, certain actions should be taken to ensure that the veterinary practitioners are fully aware of the risks related to the uses of ionizing radiation and develop the necessary safety culture.

It is stressed out that the new RPR (PD, 2018) set as one of the overarching requirements the establishment of an adequate legislative and administrative framework ensuring the provision of appropriate radiation protection education, training and information to all individuals whose tasks require specific competences in radiation protection.

Moreover, EEAE undertakes E&T initiatives, which are based on a strategy established and implemented in accordance with the IAEA general safety standards (IAEA, 2010, 2014) and guides (IAEA, 2001, 2018). In this respect, EEAE has already organized two seminars (2015 and 2016) on radiation protection in cooperation with the veterinary schools, which were attended by 20 participants. Similar initiatives will be included in the revised national strategy, in line with the increased E&T requirements introduced by the transposition of the European Directive 2013/59/Euratom (EU, 2013) to the national legislation.

4.4 Regulatory control of practices applied in veterinary facilities

The study’s results indicate that: (a) the probability of accidental exposures and (b) magnitude of occupational and public exposures in veterinary facilities performing radiographic examinations are low. Thus, the related radiological risk for the practitioners, operators and members of the public is consequently low.

Additionally, European Directive 2013/59/Euratom (EU, 2013) requires Member States to apply the regulatory control of practices with radiation sources, by way of notification, authorisation (registration or licensing) and appropriate inspections, commensurate (a) with the magnitude and likelihood of exposures resulting from the practices, and (b) with the impact that regulatory control may have in reducing such exposures or improving radiological safety.

Based on the findings of the study and the regulatory experience gained in the study’s period 2005–2013 it was decided (MD, 2019) the use of X-ray systems for radiographic examinations to animals to be authorised by means of registration in accordance with a graded approach. The certificate of registration which is granted after a positive evaluation of the applicants’ submitted documentation has a validity period of 10 years. Moreover, EEAE performs verification inspections to veterinary facilities, independently from the authorisation process, with a frequency of 5–7 years.

The new authorisation approach contributes to a more realistic allocation of EEAE’s human resources as 50% less person months are needed for the authorisation of veterinary facilities in a 10-year period. This gain in person months is appropriately distributed to the authorisation and inspection of higher risk practices or other EEAE’s activities.

Moreover, the authorization process is fully supported by the electronic services provided by EEAE. Thus, it has become more convenient for the applicants, as it requires less time and effort for the completion of the related paperwork.

4.5 Limitations

The use of portable X-ray systems for performing X-ray examinations to large animals outdoors introduces increased radiation protection concerns for the operators and their assistants. As only a few vet clinics perform this kind of examinations in the country the related radiation protection data were not sufficient to be analyzed and presented in this study. However, this important issue is expected to be appropriately addressed in a similar study in the future.

5 Conclusions

According to the findings of this study, radiographic systems used for examinations to small animals perform comparably and in some cases better than those used for examinations to humans. Moreover, the radiological risk, which is associated with the radiographic examinations is low for the practitioners, operators and members of the public. In this respect, the new national regulatory framework requires the respective practices to be authorised by means of registration, instead of licensing, based on a graded approach. So far, the new authorization approach seems to meet the expectations regarding the effective regulatory control of veterinary facilities. However, if new justified types of practices are applied in these facilities (e.g. for nuclear medicine or radiotherapy purposes) the related regulatory framework should be reviewed and amended accordingly.

Conflict of interest

The authors declare that they have no conflicts of interest in relation to this article.

Ethical approval

All procedures performed in the study did not involve human participants.

Informed consent

There was no need to obtain informed consent in the framework of the study.

References


