Equine scintigraphy: assessment of the dose received by the personnel

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ABSTRACT Following a request from the Permanent Secretary of the French Commission for Artificial Radioelements (CIREA) engaged to investigate a request for a licence related to a new scintigraphy unit dedicated to equidae, a dosimetric assessment concerning the personnel attending the examination was carried out. This scintigraphy unit depends on the Goustranville Centre for Imaging and Research on the Locomotive Diseases of Equidae (CIRALE) in the Calvados region. The dosimetric assessment was carried out for the different operators during the successive stages of the scintigraphic examination. Assuming 150 examinations per year, the annual equivalent dose to the fingers skin is 150 mSv maximum for the technologist and 2 mSv for the veterinary surgeon; the annual effective dose ranges from 0.15 to 0.45 mSv, depending on the operators.

RÉSUMÉ Scintigraphie équine : estimation de la dose reçue par le personnel.

Suite à une demande du Secrétariat permanent de la Commission interministérielle des radioéléments artificiels (CIREA) amené à instruire une demande d'autorisation relative à une nouvelle installation dédiée à la scintigraphie équine, une évaluation dosimétrique concernant le personnel présent lors de l'examen a été réalisée. Cette installation dépend du Centre d'imagerie et de recherche sur les affections locomotrices des équidés (CIRALE) situé à Goustranville dans le Calvados. L'évaluation dosimétrique a été réalisée pour les différents opérateurs au cours des étapes successives de l'examen scintigraphique. En prenant l'hypothèse de 150 examens par an, l'équivalent de dose annuel à la peau des doigts est au maximum de 150 mSv pour le manipulateur et de 2 mSv pour le vétérinaire ; la dose efficace annuelle est quant à elle comprise entre 0,15 et 0,45 mSv selon les opérateurs.

1. Introduction

Following a request from the Permanent Secretary of the CIREA engaged to investigate a request for a licence related to a new scintigraphy unit for equidae, a dosimetric assessment concerning the personnel attending the examination was carried out. The operation took place on March 13, 2001. This scintigraphy unit depends on the Goustranville Centre for Imaging and Research on the Locomotive Diseases of Equidae (CIRALE) in the Calvados region.

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The scintigraphic examination operated in CIRALE is skeletal scintigraphy, the most commonly performed equine nuclear medicine procedure. Skeletal scintigraphy (Hoskinson, 2001) offers high sensitivity for detecting diseases of the locomotive system of the horse causing lameness or poor performance. The injuries sought relate to the bones (fractures, cracks, over-strained sub-chondral osteolysis), the joints (degenerative, traumatic, septic diseases) and the soft tissues (muscles, tendons, ligaments). This scintigraphic examination involves the intravenous injection of a phosphonate compound usually radiolabeled with technetium-99m (^{99m}Tc), and subsequent imaging of the distribution of radioactivity within the animal. ^{99m}Tc is pure gamma emitter with energy of 140.5 keV and half-life of 6 hours. To perform this type of examination on a horse weighing 400 to 600 kg, the activity of ^{99m}Tc administered is usually 4 to 6 GBq (10 MBq kg^{-1}), which is 6 to 8 times higher than the activity commonly used for a human bone scintigraphy which is around 0.7 GBq for a standard adult (Gambini and Granier, 1997).

The radiopharmaceutical used here is ^{99m}Tc -labeled dicarboxypropane diphosphonate (^{99m}Tc -DPD). The day of the operation 4.4 GBq of ^{99m}Tc -DPD were administered intravenously to the external jugular vein of the horse after fitting a catheter.

The scintigraphic examination, carried out using a dedicated gamma camera, comprises two acquisition phases. The first phase, known as the “vascular and soft tissue phase”, takes place 15 minutes after injection of the radiopharmaceutical and enables viewing blood vessels and soft tissues. The second phase, known as the “bone phase”, takes place 3 hours after the injection and enables the bones and the joints to be displayed. The duration of each phase may vary from approximately 10 minutes to 1 hour depending on the aim of the examination and the movements of the horse. Hereinafter, the first and second phases that make up the same scintigraphic examination are respectively noted “phase 1” and “phase 2”. Between these two phases and during the 48 hours following the examination, the horse remains in a stall situated in an outside building.

The examination is marked by several stages during which the personnel is likely to be exposed to the radiation emitted by the ^{99m}Tc . These stages are, in chronological order:

1. preparation of the radiopharmaceutical in the preparation laboratory under a fume hood equipped with lead glass shields,
2. injection of the radiopharmaceutical at time T (Fig. 1),
3. phase 1 at $T + 15 \text{ min}$ (Fig. 2),
4. leading of the horse from the examination room to its stall,
5. waiting phase during which the horse remains in its stall,

Figure 1 – Intravenous injection of the radiopharmaceutical (^{99m}Tc -DPD).
Injection intraveineuse du radiopharmaceutique (^{99m}Tc -DPD).

Figure 2 – Phase 1 of the scintigraphic examination.
Phase 1 de l'examen scintigraphique.

TABLE I
Details of the successive stages of the scintigraphic examination.
Caractéristiques des étapes successives de l'examen scintigraphique.

Examination stage	Duration (min)	Operators present ^(*)	Role of the operator	Additional protection
Stage 1 <i>Preparation of the radiopharmaceutical</i>	15	T	Preparation of the radiopharmaceutical	Fume hood with lead glass shield Tungsten syringe shield Pliers, etc.
Stage 2 <i>Injection of the radiopharmaceutical</i>	< 1	T	Source transport	Transport box Distance
		V	Injection	Pliers, catheter
		S	Holding of the horse	Rigid leading rein (1 m) Lead gloves, lead screen
Stage 3 <i>Phase 1 (vascular and soft tissue phase)</i>	15	T	Gamma-camera operation	Lead screen, distance
		V	Positioning of the horse	Lead gloves, distance
		S	Holding of the horse	Rigid leading rein (1 m) Lead gloves, lead screen
Stage 7 <i>Phase 2 (bone phase)</i>	45	A	Movement of accessories	Lead screen, distance
Stages 4 and 8 <i>Journey of horse from examination room to the stall</i>	< 10	S	Leading of the horse	Rigid leading rein (1 m)
Stage 5 <i>Wait between phases (the horse remains in its stall)</i>	180	/	/	/
Stage 6 <i>Journey of horse from the stall to the examination room</i>	10	S	Removing of overboots from the horse Leading of the horse	Rigid leading rein (1 m)

(*) T: technologist; V: veterinary surgeon; S: stall lad; A: assistant.

6. leading of the horse from the stall to the examination room,
7. phase 2 at $T + 3$ hours,
8. leading of the horse to its stall where it remains for 48 hours.

The contaminated loose straw is removed at least 5 days after the examination and is stored in a dedicated place for decay during several months.

Four persons are present during the examination: the technologist, the veterinary surgeon, the stall lad and the assistant. Each operator wears at least latex gloves, a 0.5 mm thick lead apron and a thyroid shield. Table I details each stage

(from **1.** to **8.**) of the scintigraphic examination, specifying its duration, the role of each operator and the additional radiological protection for certain operators.

This article presents the results of the study carried out by the IRSN, which consisted in assessing the dose received by the personnel based on measurements performed on site during the successive stages of the equine scintigraphic examination.

2. Material and methods

This study consisted in carrying out a spectrometric analysis of the gamma radiation, measurements of the dose to the fingers and to the whole body of the personnel exposed, and measurements of dose rate in air. The personal dosimetry and the determination of the dose rate in air were performed by assessing the operational quantities Hp(0.07), Hp(10) and H*(10), as defined by the International Commission on Radiological Protection (ICRP, 1991) and by the International Commission on Radiation Units and Measurements (ICRU, 1992). The quantities Hp(0.07) and Hp(10) correspond to the personal dose equivalent respectively for 0.07 mm and 10 mm in depth and the quantity H*(10) corresponds to the ambient dose equivalent. The dosimetric assessment was carried out under normal operating conditions, that is, the risk of accidental contamination was not taken into account given the measures implemented for packaging and handling of the radionuclide.

2.1. Spectrometric analysis

Spectrometric analysis of the gamma radiation emitted by the ^{99m}Tc was made using a nanoSPECTM spectrometer (Target) consisting of a scintillator (NaI(Tl)) connected to a multi-channel analyser. Spectrum acquisition was performed in the nearby environment of the injected horse first in the examination room with and without a lead protection screen and second, at the entrance to the stall where the horse remains when the acquisition phases of the scintigraphy examination are not being carried out (Fig. 3). The aim of this measurement was to obtain the spectrum shape and to determine the average energy of the photons in order to make sure of the good response from certain dosimeters that may depend on the energy.

2.2. Personal dosimetry

Several types of personal dosimeters were fitted to the operators throughout the examination. The dose to the fingers was determined using passive thermoluminescent detectors (TLDs) consisting of lithium fluoride (FLi), calibrated in terms of kerma in the tissue ($\text{kerma}_{\text{tissu}}$). These TLDs were fitted onto the thumb and index finger of each hand (over the latex gloves, under the lead

Figure 3 – Measurement of the energy spectrum at stall entrance, using the nanoSPECT™ (Target) spectrometer.

Mesure du spectre en énergie à l'entrée du box à l'aide du spectromètre nanoSPECT™ (Target).

gloves when the operators wear them) for the veterinary surgeon and the technologist. In addition, active electronic dosimeters, calibrated in terms of Hp(10), of type DOSICARD™ (Eurisy Mesures), EPD™ (Siemens), Stephen-6000™ (Stephen) were fitted onto the chest of the four operators. The technologist and the veterinary surgeon were wearing a DOSICARD™ and an EPD™ over the lead apron and a DOSICARD™ under the lead apron; the stall lad and the assistant were each wearing a Stephen-6000™ dosimeter over the apron and a DOSICARD™ dosimeter under the apron. The values of Hp(10) indicated on the electronic dosimeters were recorded at the end of phase 1 and phase 2.

2.3. Ambient dose equivalent rates

Ambient dose equivalent rates were measured during each stage of the examination, in the preparation laboratory, in near proximity (0.5 m, 1 m and 2 m)

Figure 4 – Points of measurements for the ambient dose equivalent rates $\dot{H}^*(10)$.

Points de mesure des débits d'équivalent de dose ambiant $\dot{H}^(10)$.*

and in contact with the injected horse at several specific anatomical locations (Fig. 4) using two radiation monitors 6150 AD 6 (Befic/Saphymo), calibrated in terms of $\dot{H}^*(10)$.

3. Results

3.1. Spectrometric analysis

Figure 5 shows three gamma fluence spectra collected near to the injected horse first in the examination room behind a lead screen, second in the examination room without lead protection and last in the stall in which the horse remains. The number of pulses per channel has been normalized to 1 for the energy of the photon emitted by the ^{99m}Tc , i.e. 140.5 keV.

The analysis of the gamma spectra first of all reveals a large proportion of photons which energy is much lower than 140.5 keV, this is due to the attenuation of photons in the body of the horse as well as their scattering by the walls of the examination room and by the animal itself. The proportion of radiation attenuated and scattered increases behind a lead screen. The mean energy of the fluence spectrum is around 100 keV in the examination room as well as in the stall. Besides this, behind a lead screen, as the spectrum is modified, the mean energy is 95 keV.

Figure 5 – Gamma spectra collected in the examination room behind a lead screen, without a lead protection, and at the stall entrance.

Spectre gamma recueilli dans la salle d'examen derrière un écran de plomb, sans protection plombée, et à l'entrée du box.

The spectrometric analysis enabled the overresponse of the FLi to be corrected at low energy and the under-estimation of the electronic dosimeters to be corrected for the photons of energy less than 60 keV.

3.2. Personal dosimetry

3.2.1. Dose to the fingers skin expressed in $Hp(0.07)$

Since the calibration of the TLDs leads to the assessment of the dose in term of $\text{kerma}_{\text{tissu}}$, the conversion factors in dose equivalent $Hp(0.07)/\text{kerma}_{\text{tissu}}$ of 1.43 (ISO, 2000) and $Hp(10)/\text{kerma}_{\text{tissu}}$ of 1.68 (ICRU, 1992) corresponding to photons of 100 keV, that is the average energy of the fluence spectrum, have been used. The results, given with a global uncertainty of approximately $\pm 20\%$, are shown in Table II. The overresponse of FLi in the order of 25 % at low energy was taken into account.

The results confirm that, concerning the fingers skin, the most exposed person is the technologist who prepares the radiopharmaceutical. At the end of the scintigraphic examination, the dose equivalent $Hp(0.07)$ measured on the fingers

TABLE II
Skin dose equivalent Hp(0.07) (μSv) measured with FLi.
Équivalent de dose à la peau Hp(0,07) (μSv) mesuré à l'aide des FLi.

	Technologist	Veterinary surgeon
Right thumb	450	4
Right index finger	980	14
Left thumb	320	12
Left index finger	750	3

TABLE III
Dose equivalent Hp(10) (μSv) measured with electronic dosimeters.
Équivalent de dose Hp(10) (μSv) mesuré par les dosimètres électroniques.

	Technologist	Veterinary surgeon	Staff lad	Assistant
Under the lead apron <i>(at the end of phase 1)</i>	1	1	1	/(*)
Over the lead apron <i>(at the end of phase 1)</i>	2	8	0.4	1.2
Under the lead apron <i>(at the end of phase 2 – sum phase 1 + phase 2)</i>	1	3	2	/(*)
Over the lead apron <i>(at the end of phase 2 – sum phase 1 + phase 2)</i>	4	17	/(*)	4.5

(*) Not recorded due to technical problems.

of the technologist ranges from 320 μSv to 980 μSv. The right hand (dominant hand) is on average 1.4 times more exposed than the left one. It should be noted that the preparation time for the radiopharmaceutical here is 15 minutes; given the lack of practice of the technologist on the day of the operation, this will probably be much lower in routine operation. As for the veterinary surgeon, the dose equivalent Hp(0.07) on the fingers skin ranges from 4 to 14 μSv. Taking the maximum value of Hp(0.07) and considering the realistic hypothesis of 150 examinations of this type per year, the annual dose equivalent to the fingers skin of the technologist and the veterinary surgeon is respectively about 150 mSv and 2 mSv.

3.2.2. Dose equivalent Hp(10) and effective dose

Table III shows the dose equivalent Hp(10) measured using the electronic dosimeters worn on the chest of the operators at the end of phase 1 and at the end of phase 2. These latter correspond to Hp(10) integrated during the total time of the scintigraphic examination.

The results are given with a global uncertainty of $\pm 20\%$ for the values around $10 \mu\text{Sv}$. Below this value, the uncertainty is higher as the minimum detectable dose is about $1 \mu\text{Sv}$. Besides, the electronic dosimeters under-estimate the dose for low energy photons ($< 60 \text{ keV}$); in this case, this under-estimation, about 15% with regards to the measured spectrum, has been taken into account.

Based on the electronic dosimeters worn on the chest of the operators under the lead apron, the dose equivalent $\text{Hp}(10)$ integrated throughout the examination ranges from 1 to $3 \mu\text{Sv}$. The highest dose corresponds to that received by the veterinary surgeon who frequently remains close to the horse during the examination. Considering 150 examinations per year, the annual effective dose is thus ranging from 0.15 to 0.45 mSv , depending on the operators. It should be noted, however, that the dose rates behind the lead apron being very low, the uncertainty linked to the measurement using this type of dosimeter is high.

Based on the electronic dosimeters fitted to the chest of the operators over the lead apron, the dose equivalent $\text{Hp}(10)$ ranges from 4 to $17 \mu\text{Sv}$. For 150 examinations per year, the annual effective dose without the lead apron would therefore range from 0.6 to 2.6 mSv .

Phases 1 and 2 lead to very comparable dose equivalents since the longer duration of phase 2 compensates the physical decay of the $^{99\text{m}}\text{Tc}$.

3.3. Ambient dose equivalent rates

Table IV shows the ambient dose equivalent rates $\dot{H}^*(10)$ measured during the various stages of the scintigraphic examination. The ambient dose equivalent rates are given with an uncertainty of $\pm 20\%$.

The ambient dose equivalent rates are very low ($< 1 \mu\text{Sv h}^{-1}$) if the radiation is attenuated by lead shield (screen, glass, syringe-shield or transportation box) including in the preparation laboratory. This indicates the benefit of this type of shielding in this application. The ambient dose equivalent rate measured a few meters from the horse or from the fume hood ranges from 1.5 to $8 \mu\text{Sv h}^{-1}$. Injection of the radiopharmaceutical leads to ambient dose equivalent rates ranging from 10 to $35 \mu\text{Sv h}^{-1}$ for the stall lad and the veterinary surgeon, respectively.

In close proximity to the horse, during the first phase of the examination, the ambient dose equivalent rates may reach levels of about hundreds of $\mu\text{Sv h}^{-1}$ 50 cm away from the horse up to $350 \mu\text{Sv h}^{-1}$ in contact with certain anatomical areas like kidneys, which concentrate more than 30% of the radiopharmaceutical

TABLE IV

Ambient dose equivalent rates $\dot{H}^*(10)$ measured during the various stages of the scintigraphic examination.
Débits d'équivalent de dose ambiant $\dot{H}^*(10)$ mesurés au cours des différentes étapes de l'examen scintigraphique.

Examination stage	Measurements conditions	Dose rate ($\mu\text{Sv h}^{-1}$)
Stage 1 <i>Preparation of the radiopharmaceutical</i>	Contact with the fume hood lead glass shield, syringe (+ syringe-shield) out of the dose calibrator	1
	Contact with the fume hood lead glass shield, syringe (+ syringe-shield) out of the dose calibrator	50
	Ambience	3
Stage 2 <i>Injection of the radiopharmaceutical</i>	Contact with the transport box containing the syringe (+ syringe-shield)	0.7
	In the area of the veterinary surgeon during the injection	35
	In the area of the stall lad during the injection	10
	Control panel for the gamma camera (protected by a lead screen)	0.4
	Behind lead screen in the examination room	0.9
	50 cm from the flank of the horse	107
	1 m from the flank of the horse	34
Stage 3 <i>Phase 1</i> <i>(vascular and soft tissue phase)</i>	2 m from the flank of the horse	25
	In contact with the horse: shoulder ^(*)	220
	In contact with the horse: bladder ^(*)	136
	In contact with the horse: kidneys ^(*)	357
	In contact with the horse: hindquarters ^(*)	116
	In contact with the horse: rear leg ^(*)	43
	Ambience	8
	Contact with the stall, horse in the centre of the stall	0.7
Stage 5 <i>Waiting phase inside the stall</i>	Contact with the stall, horse near the stall bars	4.5
	In the middle of the corridor (1 m from the stall) near full wall, horse against the stall bars	0.7
	In the middle of the corridor (1 m from the stall) near the bars, horse against the stall bars	3.5
	Behind lead screen in the examination room	0.5
	50 cm from the flank of the horse	34
	1 m from the flank of the horse	17
	2 m from the flank of the horse	6
Stage 7 <i>Phase 2</i> <i>(bone phase)</i>	In contact with the horse: shoulder ^(*)	85
	In contact with the horse: bladder ^(*)	85
	In contact with the horse: kidneys ^(*)	102
	In contact with the horse: hindquarters ^(*)	55
	Ambience	1.5

(*) See Figure 4.

(Attenburrow *et al.*, 1984). The second phase leads to ambient dose equivalent rates in the vicinity of the horse on average three times lower due to the physical decay of the ^{99m}Tc and the biological elimination of the radiopharmaceutical.

4. Discussion

The mean dose to the fingers skin of the technologist who prepares the radiopharmaceutical is $150 \mu\text{Sv GBq}^{-1}$. This value is relatively high when compared to the data published in the literature. Some measurements performed using TLDs during the preparation of the ^{99m}Tc in human nuclear medicine refer to doses to the fingers skin on average about $70 \mu\text{Sv GBq}^{-1}$ (Williams *et al.*, 1987; Harding *et al.*, 1990; Hastings *et al.*, 1997; Mackenzie, 1997). The dose to the fingers skin here is therefore twice higher than the usual doses in human medicine. This is explained by the lack of practice of the technologist; the preparation time for the radiopharmaceutical will no doubt be greatly reduced in routine operation. There is no specific remark to be made concerning the dose to the fingers of the veterinary surgeon who injected the radiopharmaceutical as this is very low, about $2 \mu\text{Sv GBq}^{-1}$. For information, the dose annual limit for the skin is 500 mSv averaged over any 1 cm^2 (ICRP, 1991).

The dose rates in air measured during this equine scintigraphy are fully comparable to the data published in the literature (Attenburrow and Vennart, 1989; Whitelock, 1997) within the framework of measurements taken under conditions similar to those for this study. Despite the relatively high values of the dose rates in air, the use of appropriate radiological protection during the examination leads to an annual effective dose of less than 1 mSv.

Finally, the time scale of 48 hours prior to the horse leaving, which was the subject of a consensus amongst the various teams who work in this field (Voute *et al.*, 1995; Attenburrow and Vennart, 1989; Whitelock, 1997), seems to be a wholly acceptable compromise from the radiation protection point of view.

5. Conclusion

Assuming 150 examinations per year, the annual dose equivalent to the fingers skin of the technologist is at maximum 150 mSv and 2 mSv for the veterinary surgeon; the annual effective dose ranges from 0.15 to 0.45 mSv, depending on the operators (the maximum dose corresponding to that received by the veterinary surgeon). In the hypothesis where there would have no lead apron, the effective annual dose would range from 0.6 to 2.6 mSv.

This type of installation needs to keep in mind the three main means of protection against external exposure: distance, time and screen. During the operation, the good practices implemented in relation to the radiological risk were noted, both in the use of appropriate protective equipment and in the optimisation of the distribution of roles for each person.

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