SCATTERED RADIATION IN VETERINARY DIAGNOSTIC RADIOLOGY

SCATTERED RADIATION LEVELS AND PERSONNEL DOSIMETRY

IN

VETERINARY DIAGNOSTIC RADIOLOGY

by

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A project submitted to the School of Graduate Studies
in partial fulfillment of the requirements for the degree

Master of Science

McMaster University
December 1985

MASTER OF SCIENCE
Health and Radiation Physics

McMaster University
Hamilton, Ontario

TITLE: **Scattered Radiation Levels and Personnel Dosimetry In Veterinary Diagnostic Radiology**

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ABSTRACT

Scattered x-radiation levels associated with various diagnostic procedures were measured with ionization chamber instruments in the small and large animal radiology facilities at the Ontario Veterinary College of the University of Guelph. The occupational radiation exposures incurred by veterinary radiography personnel were monitored using McMaster University's Panasonic UD-702E TLD system. The stray radiation levels and the dosimetric information are compared and discussed. An optimum protocol for radiological health protection surveillance is described.

ACKNOWLEDGEMENTS

This health physics project was possible because of the considerable interest and assistance of Dr. P.W. Pennock at Guelph University, Dr. C.R. Hirning at the Ontario Ministry of Labour, and Dr. J.W. Harvey and Dr. A.J. Rainbow at McMaster University. The kind co-operation of Mrs. Cathy Aquin, Dr. Karen Bateman, and Mr. Carl Basciano, of the Radiology Department at the Ontario Veterinary College, is hereby recognized with sincere appreciation. The encouragement and support of colleagues and friends in the Physical Resources Directorate at the University of Guelph is most gratefully acknowledged.

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INTRODUCTION

Since the 19th century, Guelph has been renowned for academic programs in veterinary medicine, agriculture, and domestic sciences. The University of Guelph was established in 1964 when the Ontario Veterinary College, the Ontario Agricultural College, and the Macdonald Institute were amalgamated with a new college of arts and science. Today, seven colleges within the University offer graduate and undergraduate degree programs in arts, family and consumer studies, veterinary medicine, and the physical, biological, agricultural, and social sciences. The Ontario Veterinary College, the oldest of the three veterinary medical schools serving all of Canada, confers approximately one hundred and fifteen Doctor of Veterinary Medicine degrees each year.

Radiological sciences have been taught in the Ontario Veterinary College since the late 1940's. A one-semester course on diagnostic radiology is compulsory for all D.V.M. students during second year. Traditional instruction involves lectures on radiographic procedures, on the principles of radiation protection, and on the risks of exposure to ionizing radiation. Proper radiographic techniques are emphasized during student participation in small and large animal radiography. One of the unique difficulties in veterinary radiology is that animals tend to be un-co-operative and pharmaceutical restraint is oftentimes impractical or indeed unsafe.

Inevitably attendants must position and restrain the patient or hold the film cassette during a radiographic procedure. Occupational radiological risks are associated with potential exposures to primary radiation and with chronic exposures to secondary radiation. However, there is a paucity of quantitative data in the teaching manuals and in the radiological science and health physics literature on the levels of patient scattered x-radiation and on personnel dosimetry in veterinary diagnostic radiology (1-5). This is perhaps the case because the use of approved protective lead aprons and gloves is widely thought to preclude any radiation exposures of consequence. Previous publications have reported average occupational exposures of 0.07 to 0.18 milliroentgen per radiograph, but they characterize veterinary radiation exposures and describe personnel monitoring using concepts of dose limitation which have since become obsolete (6-7).

The need to more thoroughly investigate veterinary exposures to stray radiation has become essential for several reasons. The Province of Ontario has proposed x-ray safety legislation that incorporates the International Commission on Radiological Protection (ICRP) concept of effective dose equivalent which is applicable to situations of partial or non-uniform irradiation of the body, as is the case in veterinary radiology (8-9). Moreover, there is a long-standing debate about the most appropriate placement of a radiation dosimeter upon the body and about the virtue of one measurement for the purpose of whole body dose equivalent assessment (10-13). Notwithstanding these reasons, students today are more demanding of specific and accurate information pertinent to their occupational health, safety, and well-being. Females frequently enquire about radiation risks and pregnancy (14-15). For these reasons, a study of scattered x-radiation levels associated with typical techniques for various diagnostic procedures used in small and large animal radiography at the Ontario Veterinary College was undertaken. The objective was to investigate the magnitude of occupational radiation exposures of veterinary radiologists, and to elucidate an optimum protocol for radiological health protection surveillance.

At the x-ray energies used in diagnostic radiology (60-150 kVp), Compton scattering in the patient and in the x-ray table is a significant process that causes little degradation of photon energy and produces an essentially isotropic angular distribution of scattered radiation (16-19). The amount of scatter produced will be minimized by a well collimated beam and by using high kV and low mAs settings to yield a diagnostic quality image. Non-uniform irradiation of the body results from source-body geometric relationships and from the use of protective apparel that is only partially covering. Actual occupational exposure due to scatter during a radiographic examination will depend on the specific technique parameters such as kVp, mAs, filtration, source-skin distance, field size, on the patient's thickness, and on the scattering angles and distance between the attendant and the patient. A recent publication by the Radiation Protection Bureau of Health and Welfare Canada discusses these parameters in association with recommendations to minimize operator and human patient exposures, and describes procedures that promote the safe use of diagnostic x-ray equipment (20).

INSTRUMENTATION AND METHODS

All veterinary x-ray systems must function within acceptance limits that assure the production of diagnostic quality images with minimum radiation exposures to the patient and attending radiological staff. Therefore, prior to conducting any measurements of stray radiation levels, quality control measurements were performed on the three fixed and the three mobile radiographic units used in the Veterinary Teaching Hospital. Explicit instructions on quality control methodology have been documented by Gray et al (21). The specific noninvasive tests which facilitate performance evaluations on the x-ray system components included those for:

1. x-ray tube overload protection
2. light field and x-ray field congruence
3. timer accuracy
4. linearity of mA stations
5. accuracy of kVp
6. reproducibility of output
7. half-value layer
8. tube head leakage
9. output vs kVp.

Overload protection assures that the selected combination of high voltage (kVp), tube current (mA), and timer (s) produces an exposure that is compatible with the heat dissipation capability of the x-ray tube and housing. The x-ray generator overload protection circuit was challenged at 100 kVp for each available mA station. The maximum machine allowed exposure time, determined by incrementing the timer settings until the overload warning appeared on the control panel, was compared to 80% of the maximum rated exposure time obtained from the single exposure tube rating chart.

To check that the light field and x-ray field were properly aligned, congruence was assessed by marking the boundaries of the rectangular light field on a cassette and then examining the exposed film.

To assure that the x-ray generator indeed produced the exposure time set on the control panel, timer accuracy was checked by radiographing a motorized synchronous top (RMI timing test tool, serial 121A-26950). This device can be used with single phase (1ϕ) and three phase (3ϕ) x-ray generators. Images of the tool were made using available timer settings. The angle of the exposed arc on each radiograph was measured with a special protractor to determine the actual exposure time.

Consecutive mA station linearity was checked at fixed kVp by testing mA station and timer reciprocity for a constant exposure. Average values of x-ray output, expressed in the unit mR/mAs, were determined at each mA station and then used to compute the coefficient of linearity between adjacent mA stations. The method infers mA calibration upon the assumption of kVp and timer accuracy and constant source-detector distance.

The accuracy of the kVp settings was checked using a Wisconsin test cassette (RMI serial 101-2619). The filtered and unfiltered optical densities on a film exposed to an unknown spectrum can be compared and matched to those of calibration spectra in order to determine kVp. The design of the cassette is such that the match step is nearly a linear function of kVp. Calibration data was provided with the Wisconsin cassette.

To assure that the x-ray output produced by the same kVp, mA, and timer settings is identical from exposure to exposure, repetitive free-in-air exposure measurements were made. The coefficient of variation was computed to characterize the reproducibility of output.

X-ray beam quality, which is a function of kVp and filtration, is quantified by a half-value layer determination. For conventional radiographic equipment, a single half-value layer measurement at 80 kVp is considered sufficient to determine that the permanent filtration in the x-ray tube is adequate. Accordingly, the half-value layer of aluminum was derived from a series of exposure measurements made at 80 kVp.

Exposure data from measurements in the direct beam and from measurements at one metre from the tube head, perpendicular to the direction of the direct beam with the collimator closed, were used to assess the extent of tube head leakage.

X-ray output, expressed in the unit mR/mAs at a fixed source-detector distance, was determined from free-in-air exposure measurements as a function of kVp over the normal operating range used in veterinary radiography.

All x-ray exposure measurements were made using a 35 cm^3

ionization chamber (serial A37266A) or a 350 cm^3 ionization chamber (serial B37517A) and a portable Pitman model 37C (serial 24785) x-ray dosemeter (22). The former detector was used to measure direct beam exposures and the latter was used for scattered radiation exposure measurements. The small ion chamber was calibrated against a 15 cm^3 ion chamber (model 96035, serial 16775) and a Keithley model 35055 digital dosemeter, which is a derived exposure standard (traceable to the U.S. National Bureau of Standards) and field instrument owned by the Radiology Department at the McMaster University Medical Centre. The response of the 35 cm^3 ion chamber and the Pitman dosemeter was adjusted to closely reproduce the response of the derived standard over the energy range of 50 to 117 kVp at a filtration of approximately 3.25 mm Al. Table 1 illustrates that the energy response calibration was accurate to within 3.3% at the 95.5% confidence level. All measurements with this detector were corrected for photon energy, temperature, and pressure, using the relation:

$$X_{true} = f_p \frac{P_o}{T_o} \frac{T}{P} X_{35}$$

where f_p = 0.982 (±1.5%) is the average energy response correction factor from Table 1; P_o = 760 torr is the pressure at which the derived standard was calibrated; and T_o = 295 degrees Kelvin (22 degrees Celsius) is the temperature at which the derived standard was calibrated. T and P were the temperature and pressure respectively at the time of measurement. The response of the 350 cm^3 detector was compared to that of the 35 cm^3 detector over a similar energy interval as illustrated in Table 2. All scattered radiation measurements were corrected as follows:

$$X_{true} = f_s \quad f_p \quad \frac{P_o}{T_o} \quad \frac{T}{P} \quad X_{350}$$

where f_s = 1.080 (±11.1%) is the average energy response correction factor for the 350 cm^3 detector. Assuming that the reproducibility of the x-ray machines was no better than ±5%, the maximum uncertainty associated with any measurement of stray radiation exposure was ±18%. The detector calibration factors associated with beam filtration, geotropism, and exposure rate are known to be small by comparison and were therefore not investigated.

The response of both the 35 cm^3 and the 350 cm^3 ion chambers with the Pitman 37C dosemeter was further checked at the Radiation Protection Laboratory of the Ontario Ministry of Labour. The energy response correction factors were corroborated; f_p was within 6.7%, and f_s was within 6.9% of the respective mean values determined using McMaster's Keithley derived exposure standard. The data are shown in Table 3. The differences in the respective energy response correction factor values are primarily attributable to different calibration radiation qualities at McMaster University, Guelph University, and at the Ministry of Labour's Radiation Protection Laboratory.

Three radiologists who are full-time employees in the Veterinary Teaching Hospital kindly consented to participate in the dosimetric study. Each person was, by the nature of their duties, involved to a different extent with teaching and clinical activities in the Radiology Department. Their occupational radiation exposures were monitored using McMaster University's Panasonic UD-702E thermoluminescent dosimetry (TLD) system. Two dosimeters were issued to each radiologist; one was worn on the torso under an 0.5 mm lead equivalent apron and the other was worn at the collar outside of the apron. Background monitors were kept in an office in the Veterinary Teaching Hospital. The TLD's were read once per month, and dosimetric data was acquired for twelve months. During one of these months, each radiologist also wore finger ring dosimeters inside his 0.5 mm lead equivalent gloves.

The Panasonic dosimeters are made from lithium tetraborate ($Li_2B_4O_7$) activated with 0.03% copper (23). Each UD-806 dosimeter consists of four elements; the first unfiltered element is designed to measure skin dose, and the remaining filtered elements are used to determine the average dose due to penetrating radiation. Calibration of the Panasonic UD-702E TLD reader and the UD-806 dosimeters was performed by the Senior Health Physicist at McMaster University, in co-operation with the Radiation Protection Service of the Ontario Ministry of Labour (24). The TLD system has since been further tested and found to meet or exceed all of the Ministry's proposed technical requirements for approval as a recognized dosimetry service for x-ray workers in Ontario.

The energy response of the phosphor, the construction of the dosimeter and hanger, and the backscattering properties of the human body combine in such a manner that the observed reading is a direct measure of dose equivalent in tissue within ±10% for photon energies in the interval 0.10 to 1.25 MeV, and within ±25% for photon energies in the interval 0.025 to 0.10 MeV (24). It is this latter interval that is of importance in x-ray dosimetry. In order to challenge the calibration of the dosimeters and the TLD reader, several dosimeters were selected at random and taken to the Radiation Protection Laboratory of the Ontario Ministry of Labour. There the TLD´s were irradiated to known exposures with precise x-ray beam qualities. The x-ray energy responses of the skin (unfiltered) and body (filtered) elements of the Panasonic UD-806 dosimeter were confirmed, as shown in Figure 1.

As the scattered radiation level measurements and the dosimetric data will be compared, it would be appropriate to recall the physical relationships between the quantities exposure, absorbed dose, and dose equivalent. The absorbed dose D_m in a medium such as tissue (or a tissue-equivalent TL phosphor) due to the exposure X in air at the same point of interest by photons of energy E, depends on the medium to air ratio of the mass energy absorption coefficients according to the relation:

$$D_m \text{ (rad)} = 0.869 \frac{[\mu_{en}(E)/\rho]_m}{[\mu_{en}(E)/\rho]_{air}} X \text{ (R)} = f_m X \text{ (R)}.$$

f_m is the rad per roentgen (R) conversion factor used to compute the absorbed dose in the medium receiving the exposure provided that charged particle equilibrium exists. Mean values $\bar{f}_m$ of f_m have been determined by integration over typical x-ray spectra or by direct measurement, and may be found in the literature (18,19,25). For photon energies up to 150 keV, values of f_m for water and muscle fall in the range 0.87 to 0.97 rad/R, while f_m for compact bone has values between 1.06 and 4.39 rad/R. Since the quality factor for x-ray photons is one, an absorbed dose (D) of one rad of x-radiation produces a dose equivalent (H) of one rem, or ten millisievert (mSv). Because the measurements of exposure and dose equivalent are fundamentally different, the responses of the 35 cm^3 ion chamber and Pitman dosemeter and the UD-806 dosimeter were compared at x-ray energies as shown in Table 4. The measurements exhibited agreement within 21%, which is consistent with the error associated with the lithium tetraborate TL phosphor energy response at low energies.

Typical small animal radiographic techniques used in the Ontario Veterinary College are illustrated in Table 5. Representative stray radiation exposures were measured for each of these projections using routine technique parameters and film-screen combinations. The ´teaching´ dogs that were radiographed were sedated with an intravenous dose of 4.5 mg of oxymorphone hydrochloride, 0.1 mg of acepromazine and 0.6 mg of atropine sulfate. Scattered radiation levels were measured at a number of positions around the x-ray table particularly at locations where the radiologist would stand to hold or restrain the animal. Exposures were measured at the gonad and thyroid elevations relative to a 180 cm tall male. The latter measurement was assumed to be representative of the exposure to the lens of the eye. The relationship between stray radiation exposure and distance from the x-ray table was investigated for one radiographic projection, and the exposure rates associated with a typical small animal fluoroscopic examination were also measured. The three dogs that were needed to complete the surveys in small animal radiography were later euthanized. Scattered radiation exposures associated with three typical large animal radiographic projections were ascertained using a cow and a horse. No attempts were made to examine the relationships between scattered radiation levels and kVp, field size, or patient thickness.

RESULTS AND DISCUSSION

The results of the quality control measurements are recorded in Appendix 1. The standards of performance and the acceptance limits cited are those that are generally accepted for quality assurance in diagnostic radiology in Ontario (8,20,21). The QC measurement results for all of the radiographic units were predominantly within the acceptance limits. Problems that were identified were referred to a qualified service engineer. The Philips three phase fixed unit required a collimator adjustment and the Universal single phase mobile unit needed to have the timer mechanism serviced.

Tables 6 to 10 disclose the results of the scattered radiation level surveys for five small animal projections. The data are also expressed as a percentage of the patient´s entrance skin exposure (ESE), both at the point of measurement and at a distance of one metre from the center of the x-ray field measured in a horizontal plane. Tables 11 to 13 record the scattered radiation exposures for three large animal projections.

Table 14 summarizes the scattered radiation levels, expressed as a percentage of the entrance skin exposure, for typical small and large animal radiographic procedures performed at the Ontario Veterinary College. The data shown for the small animal projections are the mean values of the exposures measured at the positions adjacent to the dog´s head and tail where attendants would normally stand while taking the radiograph. The data shown for the two large animal projections are the values measured at the position of an attendant holding the halter. Accordingly, the average exposure to an attendant's head and upper torso during a small animal radiographic procedure was determined to be 2.4 x 10^{-3} x ESE per film. The average exposure at one metre from the center of the x-ray field at the thyroid elevation was 1.6 x 10^{-3} x ESE per film. In contrast, the average exposure to an attendant's head and upper torso during a large animal radiographic procedure was 2.7 x 10^{-3} x ESE per film, while at one metre the average exposure at this elevation was 4.0 x 10^{-3} x ESE per film. At the gonad elevation, the average exposures at the position of the attendant were 1.8 x 10^{-3} x ESE per film and 3.2 x 10^{-3} x ESE per film for small and large animal projections respectively. It should be noted that entrance skin exposures can be measured directly if dosemeters are available; they can be calculated with knowledge of the technique factors if the x-ray output and backscatter factors are known as a function of kVp; or they can be estimated readily from published data (26-27).

As an example, the entrance skin exposure for a particular canine thorax at 74 cm source-skin distance, at 85 kVp and 4.2 mAs, is determined to be 61 mR per film. The exposure to the attendant's head would be:

$X = 61 \times 2.4 \times 10^{-3}\ (\pm 18\%) = 0.15 \pm 0.03$ mR/film.

The average entrance skin exposure for the five small animal projections investigated was 86.6 mR/film. Therefore the exposure to an attendant's head and upper torso, regardless of technique, would be approximately:

$X = 86.6 \times 2.4 \times 10^{-3}$ (±18%) = 0.21 ± 0.04 mR/radiograph.
This general observation is consistent with the information that was reported in those previous studies that were mentioned.

The preceding examples illustrate that the veterinary radiologist is exposed to low but non-trivial levels of scattered x-radiation per film. His exposure could potentially be as high as the entrance skin exposure depending on his proximity to the direct beam. It is obviously prudent for an attendant to maintain as great a distance from the direct beam as is practicable in order to minimize his exposure. This is amply evident from Figures 2 and 3 which compare the scattered radiation exposure versus distance relationship with the theoretical inverse square law. As illustrated, the stray radiation from small animal radiography was found to decrease with distance somewhat faster than predicted by the inverse square law. This is attributable to the attenuation of low energy x-rays in air. The use of protective aprons of 0.5 mm lead equivalent thickness and of protective gloves of 0.5 mm lead equivalent thickness will ensure that occupational exposures to protected areas of the body are reduced. Indeed, during this study, none of the TLD monitors worn under such protective aprons and gloves yielded a measure of dose equivalent statistically significant above background.

Table 15 shows the scattered radiation exposure rates (μR/minute) associated with a small animal fluoroscopic examination using an undertable tube. The average exposure rate to the unprotected head and neck of an attendant holding a small animal underneath the image intensifier was 6 x 10^{-5} x ESER, where the entrance skin exposure rate (ESER) is expressed in the unit mR/minute. The exposure rate at the gonad elevation was not measurable when the lead drapes were properly installed to cover the Bucky slot.

Before discussing the results of the dosimetric study, it would first be appropriate to review several fundamental concepts of radiation protection dosimetry described in the new ICRP system for dose limitation (9). The detrimental biological effects of exposure to ionizing radiations are classified as **somatic** and **hereditary.** The effects are further classified as **stochastic** and **non-stochastic.** Stochastic effects are those for which the probability of the effect occurring, rather than its severity, is regarded as a function of dose without threshold. Non-stochastic effects are those for which the severity varies with dose above some threshold. For occupational exposures in diagnostic radiology, the most important stochastic risk of irradiation at low doses is the induction of malignant disease. Lens opacification that interferes with vision and the production of non-malignant damage to the skin are the non-stochastic risks of paramount concern. The ICRP asserts that the primary aim of radiation protection should be to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable. The prevention of non-stochastic effects is achieved by setting the dose equivalent limits at sufficiently low values so that no threshold dose would be reached. The limitation of stochastic effects is achieved by keeping all justifiable exposures as low as reasonably achievable (the ALARA principle) and within the appropriate dose equivalent limits.

To quantify the risks attributable to occupational radiation exposures, ICRP now asserts that the dose equivalent in certain organs and tissues (H_T) should first be determined. These tissues have different sensitivities to radiation injury and the resultant deleterious effects of exposure have different influences on the overall detriment to health. Relative risk factors (w_T) assigned for the irradiation of different tissues have been based on the estimated likelihood of inducing fatal malignant disease, non-stochastic changes, or substantial genetic defects in liveborn descendants. The risk factors are considered realistic estimates of the effects of irradiation at low doses up to the recommended dose equivalent limits. The important organs and tissues, their sensitivity to harmful stochastic effects, and the associated relative risk factors are:

TISSUE (T)	RISK (Sv^{-1})	w_T	DETRIMENT TO HEALTH
gonads	4.0×10^{-3}	0.25	genetic risk
breast	2.5×10^{-3}	0.15	cancer
red bone marrow	2.0×10^{-3}	0.12	leukaemia
lung	2.0×10^{-3}	0.12	cancer
thyroid	5.0×10^{-4}	0.03	fatal cancer
bone surfaces	5.0×10^{-4}	0.03	osteosarcoma
remainder	5.0×10^{-3}	0.30	neoplasia in organs
TOTAL	1.65×10^{-2}	1.00	

The values of w_T are deemed to be appropriate for the protection of any worker regardless of sources of variability such as age or sex. The entry ´remainder´ refers to the five remaining organs receiving the highest doses equivalent, and for each of these organs $w_T = 0.06$.

ICRP recommends a summation procedure to determine the total risk attributable to the exposures of all tissues irradiated. For the purpose of stochastic risk assessment, the effective dose equivalent (H_E) is defined as:

$$H_E = \Sigma w_T H_T.$$

The total risk of somatic and hereditary ill-health to an individual per unit dose equivalent from uniform irradiation of the whole body is 1.65×10^{-2} Sv^{-1}. For stochastic effects, the Commission´s recommended system for dose limitation is based on the principle that the risk should be equal regardless of whether there is uniform or non-uniform irradiation. This requirement is fulfilled by the limitation of the effective dose equivalent to less than 0.05 sievert per year. Non-stochastic risks will be prevented by imposing annual dose equivalent limits of 0.5 sievert to all tissues except the lens of the eye, for which 0.15 sievert has been stipulated. Furthermore, the dose equivalent limits for non-stochastic effects are intended to constrain any exposure that fulfills the limitation of stochastic effects.

The ICRP system of dose limitation imposes practical difficulties in radiation protection dosimetry. Effective dose equivalent for stochastic risk assessment is evaluated by summing the product of certain organ doses and their respective weighting factors. The problem, however, is to garner knowledge of these organ doses from an externally placed dosimeter! Consequently it is virtually impossible to measure effective dose equivalent directly, and reliance upon a dosimetric model is required (28). Several dosimetric models have been derived for occupational exposure assessment in diagnostic radiology, and are based upon theoretical considerations or upon organ dose measurements using phantoms (29-31). One model that is conservative by comparison with other models is that proposed by J.R. Gill, P.F. Beaver, and J.A. Dennis (31). The authors assume occupational exposure to an isotropic radiation field and define H_1 as the dose equivalent measured by a dosimeter worn on the trunk under an apron and H_2 as the dose equivalent measured by a dosimeter worn on the collar. The apron protects the gonads, the breast, and the lung, and leaves the head, neck, arms, and legs exposed. Gill et al further assume that red bone marrow is distributed so that 80% is protected and 20% is unprotected and that the distribution of bone surface between protected and unprotected regions is equal. The five ´remainder´ organs and tissues are assumed to be those in the unprotected head and neck. The derivation of the effective dose equivalent when a lead apron is worn is as follows:

TISSUE (T)	w_T	H_T	$w_T H_T$
gonads	0.25	H_1	$0.25\ H_1$
breast	0.15	H_1	$0.15\ H_1$
red bone marrow	0.12	$0.8\ H_1 + 0.2\ H_2$	$0.096\ H_1 + 0.024\ H_2$
lung	0.12	H_1	$0.12\ H_1$
thyroid	0.03	H_2	$0.03\ H_2$
bone surfaces	0.03	$0.5\ H_1 + 0.5\ H_2$	$0.015\ H_1 + 0.015\ H_2$
remainder	0.30	H_2	$0.30\ H_2$
Effective Dose Equivalent	H_E =	$\Sigma\ w_T H_T$ =	$0.631\ H_1 + 0.369\ H_2$

The effective dose equivalent for stochastic risk limitation derived from their model is simplified to:

$H_E = 0.6\ H_1 + 0.4\ H_2$ mSv.

The uniformity of irradiation of organs and tissues within protected and unprotected regions of the body is implicitly assumed.

The application of this model for the purpose of applied health physics is now considered. If the transmission factor for the lead apron is very small, then H_1 will be negligible. The effective dose equivalent, which has an annual limit of 50 mSv, would be monitored by the collar dosimeter only. The derived annual limit for H_2 would be:

$H_E = 0.4\ H_2 = 50$ mSv/year, which implies $H_2 = 125$ mSv/year.

The transmission factor for an 0.5 mm lead equivalent apron at diagnostic x-ray energies (less than 150 kVp) is most unlikely to exceed 5-10% (17). Assume, for example, that $H_1 = 0.10\ H_2$ in the expression for H_E; then:

$H_E = 0.6(0.10)\ H_2 + 0.4\ H_2 = 50$ mSv, which implies $H_2 = 108.7$ mSv.

The derived dose equivalent limit for H_2 would be 108 mSv per year. Finally, if the transmission factor for the apron is not small and exposure to the torso cannot be neglected, then let H_1 approach H_2 and observe:

$H_E = 0.6\ H_2 + 0.4\ H_2 = H_2$.

In this situation, a single dosimeter worn on the collar may still be sufficient for radiological health protection surveillance provided that the annual dose equivalent limit is:

$H_E = H_2 = 50$ mSv/year.

In this model, disregard for the protection afforded by an approved apron, regardless of its lead equivalency, introduces at the very least a conservative factor of two reduction in the derived annual dose equivalent limit for the collar monitor.

In order that individual tissue doses are constrained for non-stochastic risk prevention, ICRP recommends that the annual dose equivalent limit in any tissue (such as the thyroid) be:

$H_T < 500$ mSv/year to all tissues, except

$H_T < 150$ mSv/year to the lens of the eye.

Non-stochastic risk prevention is the foremost concern in the judicious selection of a derived dose equivalent limit for the collar monitor. Another consideration is that the protection factor afforded by the lead apron is a function of photon energy (kVp). It must also be recognized that no dosimeter is absolute. Indeed the lithium tetraborate dosimeters used in this veterinary dosimetric study underestimated the occupational x-ray exposures by as much as 25%. A derived annual dose equivalent limit of 125 mSv for the collar monitor is therefore unacceptable because of the resultant non-stochastic risk to the lens. Stochastic risk considerations supersede those for the non-stochastic risk when H_2 is restricted to less than 120 mSv per year. If it is assumed that the 0.5 mm lead equivalent apron is worn and that the collar monitor underestimates dose equivalent by 25%, then the derived annual limit for H_2 is 86 mSv. Other estimates for the annual limit on H_2 can be made. However, the 25% error associated with the dosimeter reading can be obviated by the assumption of no protection when a lead apron of unspecified lead equivalency is in fact worn. In practise, if the dose equivalent measured by a single dosimeter worn at the collar is limited to 50 mSv/year, the effective dose equivalent limit will not be exceeded. Consequently, the dose equivalent limits for the lens (150 mSv/year) and for the thyroid (500 mSv/year) are most unlikely to be exceeded.

The results of the dosimetric study involving three veterinary radiologists are presented in Table 16. TLD monitors worn on the torso under the protective apron provided no data that was meaningful for occupational exposure assessment. The data only served to corroborate the background readings which averaged 0.11 mSv per month. Data from the filtered elements of the unprotected collar monitors were used for effective dose equivalent assessment, and 50 mSv was the derived annual limit selected for H_2. The radiologist assuming the greatest workload in the Veterinary Teaching Hospital received (13.6 ± 3.4)% of this derived annual dose limit, (4.5 ± 1.1)% of the annual dose limit for the lens, and (1.4 ± 0.4)% of the annual dose limit for the thyroid. The other two radiologists received (5.2 ± 1.3)% and (4.4 ± 1.1)% respectively, of the derived annual dose limit for the collar monitor. The Ontario Veterinary College has a very heavy small animal case load. In 1984, a total of 3,403 exams involved 5,275 radiographs. The occupational exposures in private veterinary clinics should be considerably lower than those observed in the Veterinary Teaching Hospital. Perusal of the dosimetric data shown in Table 16 would suggest that routine processing of collar dosimeters at a frequency greater than once per quarter is unwarranted, and may be undesirable depending on the sensitivity of the dosimetry system actually used.

Table 17 compares the measured and estimated occupational radiation exposures for each radiologist. Estimates were made using the scattered radiation level data for each small animal projection and knowledge of the number of films taken. The measured doses equivalent corroborate the estimated doses equivalent in spite of the recognized sources of error.

A female radiologist is well advised to inform her employer should she plan to become pregnant. A dosimeter worn on the abdomen beneath a wrap-around 0.5 mm lead equivalent apron would serve to monitor any measurable conceptus dose. Under normal circumstances, this monitor is expected to record only background and this should prove beneficial to peace of mind. Regardless, an employer must take reasonable precautions to ensure that a pregnant woman´s abdominal dose does not exceed 5 mSv from the time pregnancy is known until the end of term (8). A conceptus dose of 5 mSv could reduce the probability of bearing a normal healthy child from 95.93% to 95.88% (15).

The unprotected organs of the head and neck are those that would receive the highest doses equivalent when the stochastic risks of exposure to scattered x-ray radiation are considered. Pursuant to the ICRP principle that the limitation of stochastic effects is achieved by keeping all justifiable exposures as low as reasonably achievable, it would be noteworthy to mention some precautionary measures that may be appropriate for high workload clinics. These include the use of lead-impregnated acrylic panels suspended from the ceiling which, though perhaps awkward, would eliminate essentially all exposure of unprotected organs to scattered radiation (32-33). The use of protective eye glasses is often recommended. The transmission factors depend on kVp and on the type of glass lens, and range anywhere from 70% to better than 10% (34-35). However, it has been reported that only a two to three-fold dose reduction can be realistically expected because radiation scattered within the head also exposes the eyes (36). A thyroid collar may also be worn, but its effectiveness would again be limited by similar considerations. Additional procedures and specific techniques for the minimization of occupational exposures during large and small animal radiography have been well documented (1,2,37).

SUMMARY AND CONCLUSIONS

An investigation of typical occupational radiation exposures in veterinary diagnostic radiology was undertaken in the Veterinary Teaching Hospital of the University of Guelph. Quality control measurements were performed on all x-ray units to ensure that diagnostic quality images were being produced with minimum x-ray exposures. The ion chambers used for direct beam and scattered radiation exposure measurements were calibrated at diagnostic x-ray energies. Stray radiation level surveys were conducted during actual small and large animal radiographic examinations. The personal exposures of three veterinary radiologists were monitored each month for a period of one year using McMaster University's Panasonic UD-702E TLD system. The integrity of the TLD system calibration was challenged using test dosimeters irradiated at the Radiation Protection Laboratory of the Ontario Ministry of Labour. The exposure response of the primary ion chamber was compared to that of the UD-806 lithium tetraborate dosimeters at diagnostic x-ray energies in order to validate the comparison of scattered radiation level and dosimetric data. An optimum protocol for radiological health protection surveillance was discussed.

The results of this study indicate that the occupational exposures of veterinary radiologists to patient scattered x-radiation are reassuringly small; the order of 0.2% to 0.3% of the patient's entrance skin exposure per film. This is the exposure incurred at the head and torso elevations when the radiologist stands at a usual position to hold or restrain an animal during a typical radiographic examination. At the Ontario Veterinary College, this currently equates to an average exposure of 0.21 ± 0.04 mR per small animal radiograph. Average exposures arising from a large animal radiograph are up to 75% higher. For the purposes of x-ray protection of unprotected regions, the numerical value of an exposure can be considered identical to the numerical value of the dose equivalent at the point of interest. Exposures outside the apron at the gonad elevation are comparable to those at the thyroid elevation. However, protective apparel of 0.5 mm lead equivalent thickness was found to reduce the exposures of protected regions to background levels.

Every person who is occupationally exposed in veterinary radiology must wear a dosimeter (8). Radiation dosimeters worn unprotected at the collar are recommended for effective dose equivalent assessment and radiation protection surveillance. It should be noted that this procedure is presently contrary to that recommended by the Radiation Protection Bureau of Health and Welfare Canada (38)! An appropriate restriction on the annual dose equivalent recorded by the collar monitor will ensure that the effective dose equivalent limit for occupational radiation exposure will not be reached, thereby limiting the stochastic risks and preventing the non-stochastic risks of patient scattered x-radiation. A radiation dosimeter worn on the collar further serves to monitor trends in occupational radiation exposure. An undesirable trend should prompt an assessment of the exposure situations and the precautions exercised. A single radiation dosimeter worn on the torso under a protective apron cannot provide information essential for these purposes. Albeit, a dosimeter worn on the abdomen beneath an 0.5 mm lead equivalent apron does enable assurance that the abdominal dose to a pregnant woman is restricted.

Experience in the Veterinary Teaching Hospital at the University of Guelph substantiated the utility of the dosimetric model of Gill et al for a diagnostic radiology setting. In accord with their model, the derived dose equivalent limit for the collar monitor was determined to be 108 mSv per year provided that the use of an 0.5 mm lead equivalent apron is assured. If the lead equivalency of a wrap-around protective apron is unspecified, then a derived dose equivalent limit of 50 mSv per year is recommended. The collar dosimeters may have to be read quarterly in order to obtain statistically reliable data.

Carcinogenesis is considered the chief somatic risk of irradiation at low doses and necessitates radiation protection activity. This stochastic risk is cautiously and conservatively assumed to be proportional to dose equivalent without threshold. The veterinary radiologist can minimize his personal somatic risk during each and every radiograph by using prudent techniques that uphold the ALARA principle. It is hoped that the information presented herewith will further promote the veterinarian´s confidence in safe radiographic techniques as well as his commitment towards the practise of radiological health protection.

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TABLE 1

ENERGY RESPONSE CORRECTION FOR THE 35 cm^3 ION CHAMBER

kVp	X_{true} (mR)	X_{35} (mR)	$f_p = \frac{X_{true}}{X_{35}}$
50	60.175	61.750	0.974
60	75.750	77.750	0.974
70	60.725	62.000	0.979
81	58.450	59.500	0.982
90	76.150	77.000	0.989
102	101.533	103.333	0.983
117	273.000	274.750	0.994
AVERAGE ENERGY RESPONSE CORRECTION FACTOR:			0.982 ± 0.015

The 35 cm^3 ion chamber and Pitman 37C dosemeter were taken to the McMaster University Medical Centre for calibration. The x-ray machine used had a total filtration of approximately 3.25 mm of aluminum. X_{true} was measured using the 15 cm^3 ion chamber and the Keithley model 35055 digital dosemeter, which is a derived exposure standard traceable to NBS. X_{35} was the reading given by the 35 cm^3 ion chamber and the Pitman 37C dosemeter. Both x-ray detectors were exposed simultaneously. The values tabulated are averages of four consecutive direct beam exposures. From this data, the average energy response correction factor for the 35 cm^3 ion chamber and the Pitman dosemeter was f_p = 0.982 (±1.5%) at the 95.5% confidence level.

TABLE 2

RELATIVE ENERGY RESPONSE CORRECTION FOR THE 350 cm^3 ION CHAMBER

kVp	X_{35} (mR)	X_{350} (mR)	$f_s = \frac{X_{35}}{X_{350}}$
50	55.333	53.933	1.026
60	115.667	112.500	1.028
70	197.667	192.333	1.028
80	147.000	131.667	1.116
100	236.000	210.667	1.120
110	154.333	132.667	1.163
AVERAGE ENERGY RESPONSE CORRECTION FACTOR:			1.080 ± 0.120

The 350 cm^3 ion chamber and the Pitman 37C dosemeter were calibrated at the Veterinary Teaching Hospital using the Philips 3ϕ fixed radiographic unit which had a total filtration of 4.0 mm of aluminum. The values tabulated are averages of three consecutive exposure measurements. The average energy response correction factor for the 350 cm^3 ion chamber and the Pitman 37C dosemeter was $f_s = 1.080$ (±11.1%) at the 95.5% confidence level.

TABLE 3

CORROBORATION OF AVERAGE ENERGY RESPONSE CORRECTION FACTORS AT THE RADIATION PROTECTION LABORATORY, ONTARIO MINISTRY OF LABOUR

BEAM QUALITY	E_{eff} (keV)	$f_p = \frac{X_{true}}{X_{35}}$	$f_s = \frac{X_{35}}{X_{350}}$
60 kVp + 0.5 mm Al	23	1.025	1.020
80 kVp + 1.0 mm Al	28	1.045	1.007
100 kVp + 2.5 mm Al	35	1.064	0.995
120 kVp + 2.5 mm Al	38	1.059	0.999
Average energy response factor:		1.048 ± 0.035	1.005 ± 0.022

At the Radiation Protection Laboratory of the Ontario Ministry of Labour, X_{true} was determined using a charge measuring electrometer and a calibration ion chamber exposed simultaneously to the direct beam. The values tabulated for f_p are the averages of three consecutive direct beam exposures. The average energy response correction factor for the 35 cm^3 ion chamber and Pitman dosemeter was $f_p = 1.048$ (±3.3%) at the 95.5% confidence level. The values of f_s tabulated are from single exposure data. The average energy response correction factor for the 350 cm^3 ion chamber and Pitman dosemeter was $f_s = 1.005$ (±2.2%) at the 95.5 % confidence level.

TABLE 4

EXPOSURE RESPONSE COMPARISON OF THE UD-806 TLD AND THE 35 cm^3 ION CHAMBER & PITMAN 37C DOSEMETER

kVp	X_{true} (mR)	$\bar{f}_m$ (rad/R) (muscle/air)	H_{true} (mSv)	UD-806 TLD Skin (mSv)	UD-806 TLD Body (mSv)
60	141.3	0.92	1.29	1.26	1.05
70	259.0	0.92	2.38	2.52	2.04
80	191.9	0.92	1.76	1.78	1.40
90	250.2	0.92	2.30	2.18	1.87
100	162.1	0.92	1.49	1.40	1.29

The responses of the UD-806 TLD and the 35 cm^3 ion chamber and Pitman 37C dosemeter were compared following simultaneous exposures using the Philips 3ϕ fixed radiographic unit in the Veterinary Teaching Hospital. This x-ray machine had a total filtration of 4.0 mm aluminum. X_{true} is the corrected exposure reading from the 35 cm^3 ion chamber and the Pitman 37C dosemeter. The assumed true dose equivalent H_{true} is the product of X_{true} and the conversion factor $\bar{f}_m$ and a quality factor of unity. The Panasonic UD-806 thermoluminescent dosimeter measured dose equivalent within 21% of the assumed true dose equivalent.

$\bar{f}_m$ is a mean conversion factor obtained from Reference 19.

The dosimetric information is expressed in millisievert (mSv).
One millisievert is equal to 100 millirem.

TABLE 5

ONTARIO VETERINARY COLLEGE
TYPICAL SMALL ANIMAL RADIOGRAPHIC TECHNIQUES

PROJECTION	kVp	mA	s	mAs	films/month	%
thorax	80	500	0.008	4	126	35
cervical spine*	68	200	0.050	10	12	3
lumbar spine*	66	300	0.050	15	9	2
pelvis*	80	300	0.100	30	50	14
extremity	66	300	0.067	20	47	13
abdomen	70	500	0.016	8	60	17
other					56	16
TOTAL					360	100

The technique factors are for Kodak XR-1 x-ray film with par speed calcium tungstate screens. The number of films per month is typical of the small animal radiographic workload in the Veterinary Teaching Hospital.

* These projections do not always require an attendant.

TABLE 6

SMALL ANIMAL RADIOGRAPHY

X-RAY UNIT: Philips three phase, 4 mm Al total filtration.

PATIENT: 25 kg female labrador cross

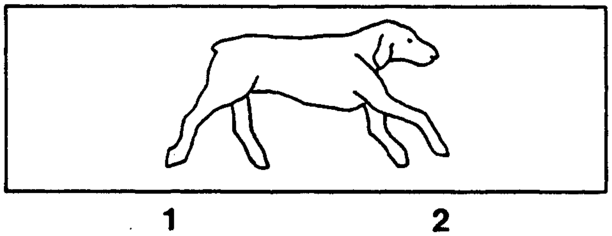
PROJECTION: THORAX, 18 cm thick

FIELD: 35 cm x 43 cm

TECHNIQUE: 85 kVp 500 mA 1/120 s 4.17 mAs
source-image distance: 102 cm source-skin distance: 74 cm

ENTRANCE SKIN EXPOSURE (ESE): 61.0 mR or 14.6 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ATTENDING RADIOLOGIST					AT ONE METRE
LOCATION*	ELEVATION**	mR	mR/mAs	% ESE	% ESE
1 @ 99 cm	gonads	0.092	0.022	0.15	0.15
	thyroid	0.161	0.039	0.26	0.26
2 @ 69 cm	gonads	0.248	0.060	0.41	0.19
	thyroid	0.278	0.067	0.46	0.22

* Distance was measured in a horizontal plane from the centre of the x-ray field to the attendant´s position.

** Elevations are relative to a 180 cm tall male.

TABLE 7

SMALL ANIMAL RADIOGRAPHY

X-RAY UNIT: Philips three phase, 4 mm Al total filtration.

PATIENT: 25 kg female labrador cross

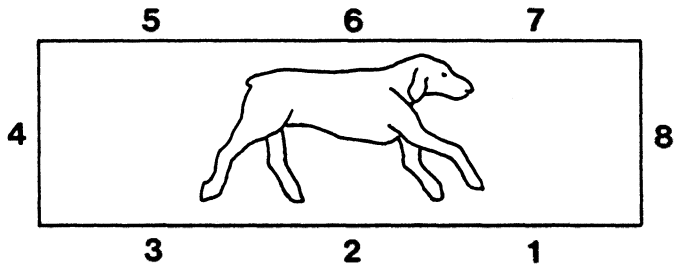
PROJECTION: LUMBAR SPINE, 15 cm thick

FIELD: 25 cm x 30 cm

TECHNIQUE: 68 kVp 200 mA 0.12 s 24 mAs
source-image distance: 102 cm source-skin distance: 77 cm

ENTRANCE SKIN EXPOSURE (ESE): 121.6 mR or 5.1 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ATTENDING RADIOLOGIST					AT ONE METRE
LOCATION	ELEVATION	mR	mR/mAs	% ESE	% ESE
1 @ 76 cm	gonads	0.093	0.004	0.08	0.04
	thyroid	0.199	0.008	0.16	0.09
2 @ 43 cm	gonads	0.934	0.039	0.77	0.14
	thyroid	0.824	0.034	0.68	0.12
3 @ 64 cm	gonads	0.187	0.008	0.15	0.06
	thyroid	0.422	0.018	0.35	0.14
4 @ 96 cm	gonads	0.055	0.002	0.04	0.04
	thyroid	0.165	0.007	0.14	0.12
5 @ 69 cm	gonads	0.309	0.013	0.25	0.12
	thyroid	0.396	0.016	0.32	0.16
6 @ 51 cm	gonads	0.615	0.026	0.51	0.13
	thyroid	0.615	0.026	0.51	0.13
7 @ 81 cm	gonads	0.066	0.003	0.05	0.04
	thyroid	0.187	0.008	0.15	0.10
8 @ 140 cm	gonads	0.022	0.001	0.02	0.04
	thyroid	0.055	0.002	0.04	0.09

TABLE 8

SMALL ANIMAL RADIOGRAPHY

X-RAY UNIT: York single phase, 2.5 mm Al total filtration.

PATIENT: 15 kg male chow chow

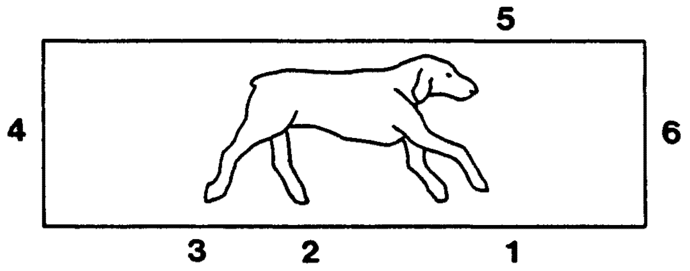
PROJECTION: PELVIS, 16 cm thick

FIELD: 30 cm x 38 cm

TECHNIQUE: 80 kVp 300 mA 0.10 s 30 mAs
source-image distance: 96 cm source-skin distance: 76 cm

ENTRANCE SKIN EXPOSURE (ESE): 134.1 mR or 4.47 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ATTENDING RADIOLOGIST					AT ONE METRE
LOCATION	ELEVATION	mR	mR/mAs	% ESE	% ESE
1 @ 102 cm	gonads	0.139	0.005	0.10	0.11
	thyroid	0.238	0.008	0.18	0.18
2 @ 51 cm	gonads	1.330	0.044	0.99	0.26
	thyroid	0.793	0.026	0.59	0.15
3 @ 91 cm	gonads	0.266	0.009	0.20	0.16
	thyroid	0.349	0.012	0.26	0.22
4 @ 102 cm	gonads	0.116	0.004	0.09	0.09
	thyroid	0.260	0.009	0.19	0.20
5 @ 102 cm	gonads	0.144	0.005	0.11	0.11
	thyroid	0.238	0.008	0.18	0.18
6 @ 145 cm	gonads	0.028	0.001	0.02	0.04
	thyroid	0.094	0.003	0.07	0.15

TABLE 9

SMALL ANIMAL RADIOGRAPHY

X-RAY UNIT: York single phase, 2.5 mm Al total filtration.

PATIENT: 15 kg male chow chow

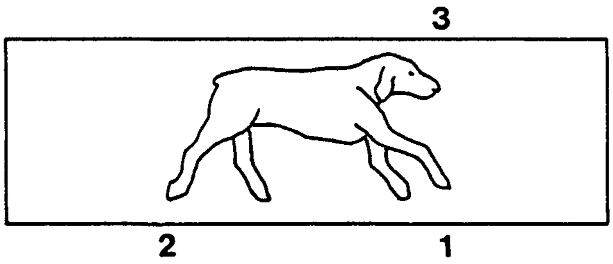
PROJECTION: MEDIAL TO LATERAL OF FORELEG, 5 cm thick

FIELD: 15 cm x 20 cm

TECHNIQUE: 62 kVp 300 mA 0.067 s 20 mAs
source-image distance: 100 cm source-skin distance: 91 cm

ENTRANCE SKIN EXPOSURE (ESE): 25.0 mR or 1.25 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ATTENDING RADIOLOGIST					AT ONE METRE
LOCATION	ELEVATION	mR	mR/mAs	% ESE	% ESE
1 @ 61 cm	gonads	0.078	0.004	0.31	0.12
	thyroid	0.066	0.003	0.26	0.10
2 @ 132 cm	gonads	0.004	2×10^{-4}	0.02	0.03
	thyroid	0.007	4×10^{-4}	0.03	0.05
3 @ 69 cm	gonads	0.020	0.001	0.08	0.04
	thyroid	0.029	0.001	0.12	0.06

TABLE 10

SMALL ANIMAL RADIOGRAPHY

X-RAY UNIT: Philips three phase, 4 mm Al total filtration.

PATIENT: 12 kg female collie cross

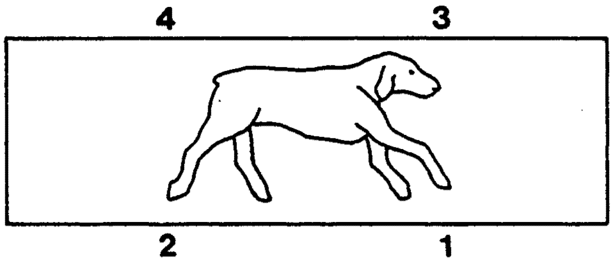
PROJECTION: ABDOMEN, 15 cm thick

FIELD: 23 cm x 25 cm

TECHNIQUE: 73 kVp 500 mA 1/60 s 8.33 mAs
source-image distance: 102 cm source-skin distance: 77 cm

ENTRANCE SKIN EXPOSURE (ESE): 91.4 mR or 11.0 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ATTENDING RADIOLOGIST					AT ONE METRE
LOCATION	ELEVATION	mR	mR/mAs	% ESE	% ESE
1 @ 91 cm	gonads	0.116	0.014	0.13	0.10
	thyroid	0.166	0.020	0.18	0.15
2 @ 76 cm	gonads	0.193	0.023	0.21	0.12
	thyroid	0.210	0.025	0.23	0.13
3 @ 86 cm	gonads	0.130	0.016	0.14	0.10
	thyroid	0.204	0.024	0.22	0.16
4 @ 71 cm	gonads	0.232	0.028	0.25	0.13
	thyroid	0.263	0.032	0.29	0.14

TABLE 11

LARGE ANIMAL RADIOGRAPHY

X-RAY UNIT: Picker three phase, 2.5 mm Al total filtration.

PATIENT: 350 kg holstein

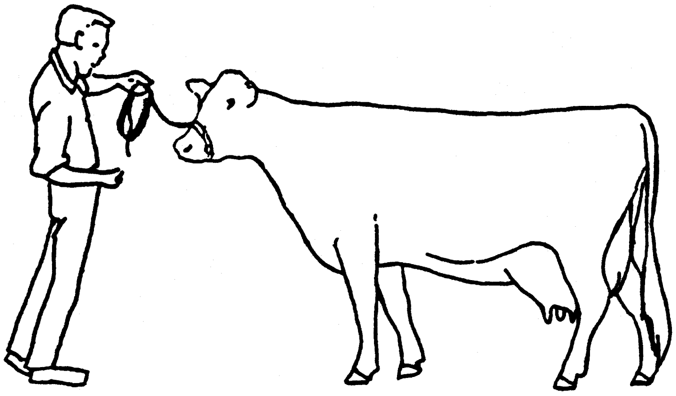
PROJECTION: THORAX, 80 cm thick

FIELD: 43 cm x 71 cm

TECHNIQUE: 130 kVp 700 mA 0.014 s 9.8 mAs
source-image distance: 190 cm source-skin distance: 105 cm

ENTRANCE SKIN EXPOSURE (ESE): 99.7 mR or 10.18 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ANIMAL ATTENDANT*					AT ONE METRE
LOCATION	ELEVATION	mR	mR/mAs	% ESE	% ESE
122 cm ⊥ beam	gonads	0.317	0.032	0.32	0.47
	thyroid	0.339	0.035	0.34	0.51

* holding the halter

TABLE 12

LARGE ANIMAL RADIOGRAPHY

X-RAY UNIT: Picker three phase, 2.5 mm Al total filtration.

PATIENT: 350 kg holstein

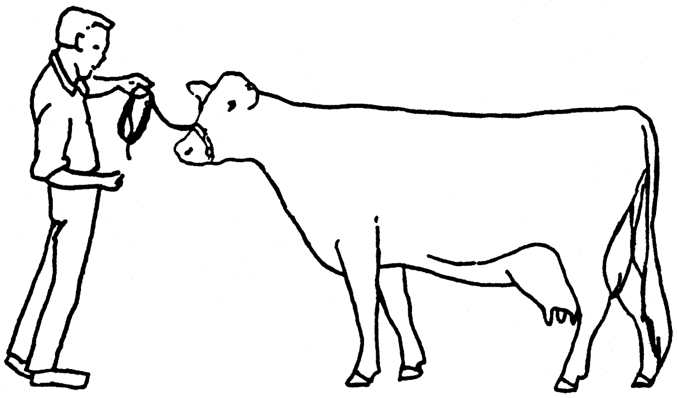
PROJECTION: RETICULUM, 80 cm thick

FIELD: 28 cm x 17 cm

TECHNIQUE: 130 kVp 700 mA 0.022 s 15.4 mAs
source-image distance: 192 cm source-skin distance: 107 cm

ENTRANCE SKIN EXPOSURE (ESE): 132.6 mR or 8.61 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ANIMAL ATTENDANT*					AT ONE METRE
LOCATION	ELEVATION	mR	mR/mAs	% ESE	% ESE
122 cm ⊥ beam	gonads	0.438	0.028	0.33	0.49
	thyroid	0.271	0.018	0.20	0.30

* holding the halter

TABLE 13

LARGE ANIMAL RADIOGRAPHY

X-RAY UNIT: Picker three phase, 2.5 mm Al total filtration.

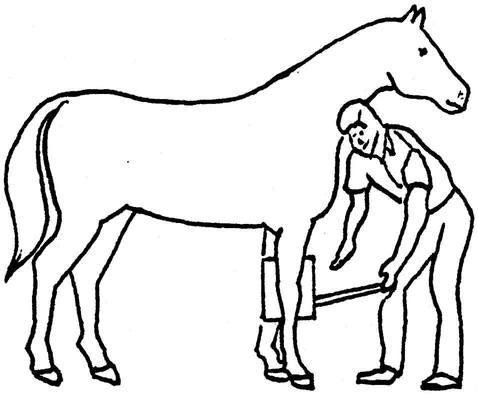
PATIENT: horse **FIELD:** 30 cm x 36 cm

PROJECTION: LATERAL TO MEDIAL RIGHT FRONT CARPUS, 10 cm thick

TECHNIQUE: 60 kVp 700 mA 0.014 s 9.8 mAs
source-image distance: 91 cm source-skin distance: 79 cm

ENTRANCE SKIN EXPOSURE (ESE): 41.9 mR or 4.28 mR/mAs (±7%)

SCATTERED RADIATION LEVELS (±18%)



AT THE POSITION OF THE ANIMAL ATTENDANT					AT ONE METRE
LOCATION	**ELEVATION**	**mR**	**mR/mAs**	**% ESE**	**% ESE**
66 cm $\perp$ beam*	hands	0.071	0.007	0.17	0.07
109 cm $\perp$ beam*	gonads	0.028	0.003	0.07	0.08
94 cm $\perp$ beam*	thyroid	0.026	0.003	0.06	0.05
94 cm $\perp$ beam**	thyroid	0.016	0.002	0.04	0.03

* Measured for an attendant facing the horse in a stooped posture in order to position the cassette holder in the beam.

** Measured for an attendant holding the halter.

TABLE 14

SUMMARY OF SCATTERED RADIATION LEVELS

SMALL ANIMAL RADIOGRAPHY

PROJECTION	% ESE AT RADIOLOGIST		% ESE AT ONE METRE	
	gonads	thyroid	gonads	thyroid
thorax	0.28	0.36	0.17	0.24
lumbar spine	0.13	0.24	0.06	0.12
pelvis	0.15	0.22	0.14	0.20
extremity	0.16	0.15	0.08	0.08
abdomen	0.18	0.23	0.11	0.14
AVERAGE:	0.18	0.24	0.11	0.16

LARGE ANIMAL RADIOGRAPHY

PROJECTION	% ESE AT RADIOLOGIST		% ESE AT ONE METRE	
	gonads	thyroid	gonads	thyroid
thorax	0.32	0.34	0.47	0.51
reticulum	0.33	0.20	0.49	0.30
AVERAGE:	0.32	0.27	0.48	0.40

TABLE 15

SMALL ANIMAL FLUOROSCOPY

X-RAY UNIT: Philips three phase, undertable tube

PATIENT: 12 kg female collie cross

PROJECTION: ABDOMEN, 15 cm thick

FIELD: 13 cm x 10 cm

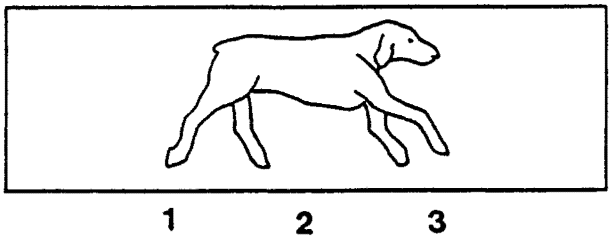
TABLE-TOP TO IMAGE INTENSIFIER DISTANCE: 23 cm

TECHNIQUE: 70 kVp 3 mA

ENTRANCE SKIN EXPOSURE RATE (ESER): 124.5 mR/minute (±7%) maximum
87.0 mR/minute (±7%) average

EXPOSURE RATE AT IMAGE INTENSIFIER: 11.2 mR/minute (±7%) maximum
8.9 mR/minute (±7%) average

SCATTERED RADIATION EXPOSURE RATES (±18%)



AT THE POSITION OF THE ATTENDING RADIOLOGIST				AT ONE METRE
LOCATION	ELEVATION	μR/minute	% ESER	% ESER
1 @ 66 cm	gonads*	3.3	0.004	1.7×10^{-3}
	thyroid	4.7	0.005	2.4×10^{-3}
2 @ 48 cm	gonads*	23.2	0.027	6.1×10^{-3}
	thyroid	5.9	0.007	1.6×10^{-3}
3 @ 74 cm	gonads*	2.1	0.002	1.3×10^{-3}
	thyroid	0.7	8.0×10^{-4}	4.4×10^{-4}

* Measured with the lead drape removed. The exposure rates were non-measurable when the drape was in place to cover the Bucky slot.

TABLE 16

OCCUPATIONAL RADIATION EXPOSURES (mSv)

RADIOLOGIST	A		B		C	
	Skin	Body	Skin	Body	Skin	Body
November	0.33	0.31	0.05	0.08	0.01	0.01
December	0.29	0.26	0.11	0.10	0.15	0.16
January	0.72	0.71	0.09	0.10	0.04	0.03
February	0.43	0.48	0.22	0.22	0.10	0.14
March	0.57	0.57	0.12	0.11	0.02	0.00
April	0.97	0.91	0.52	0.45	0.58	0.53
May	0.45	0.46	0.33	0.43	0.40	0.47
June	1.12	0.97	0.09	0.11	0.09	0.13
July	0.37	0.40	0.34	0.28	0.22	0.26
August	0.14	0.11	0.36	0.38	0.22	0.25
September	0.78	0.79	0.15	0.16	0.04	0.05
October	0.92	0.84	0.16	0.18	0.12	0.16
mSv Per Year:	7.09	6.81	2.54	2.60	1.99	2.19
mSv Per Quarter:	1.77	1.70	0.64	0.65	0.50	0.55
mSv Per Month:	0.59	0.57	0.21	0.22	0.17	0.18
% of limit on H_2:		13.6%		5.2%		4.4%
% of limit on H_{lens}:		4.5%		1.7%		1.5%
% of limit on $H_{thyroid}$:		1.4%		0.5%		0.4%

The dosimetric data was obtained using McMaster University's Panasonic lithium tetraborate TLD's (±25%) worn unprotected at the collar.

TABLE 17

COMPARISON OF SCATTERED RADIATION LEVELS & OCCUPATIONAL EXPOSURES

CANINE PROJECTION	ATTENDANT´S POSITION	ESE mR/film	% ESE @ thyroid	FILMS/YEAR from Table 5	ANNUAL mR
thorax	2	61.0	0.46	1512	424.3
spine	3	121.6	0.35	252	107.3
pelvis	3	134.1	0.26	600	209.2
extremity	1	25.0	0.26	564	36.7
abdomen	2	91.4	0.23	720	151.4
other		86.6*	0.31*	672	180.4
TOTAL ANNUAL EXPOSURE AT THE ATTENDANT´S POSITION:					1109.3

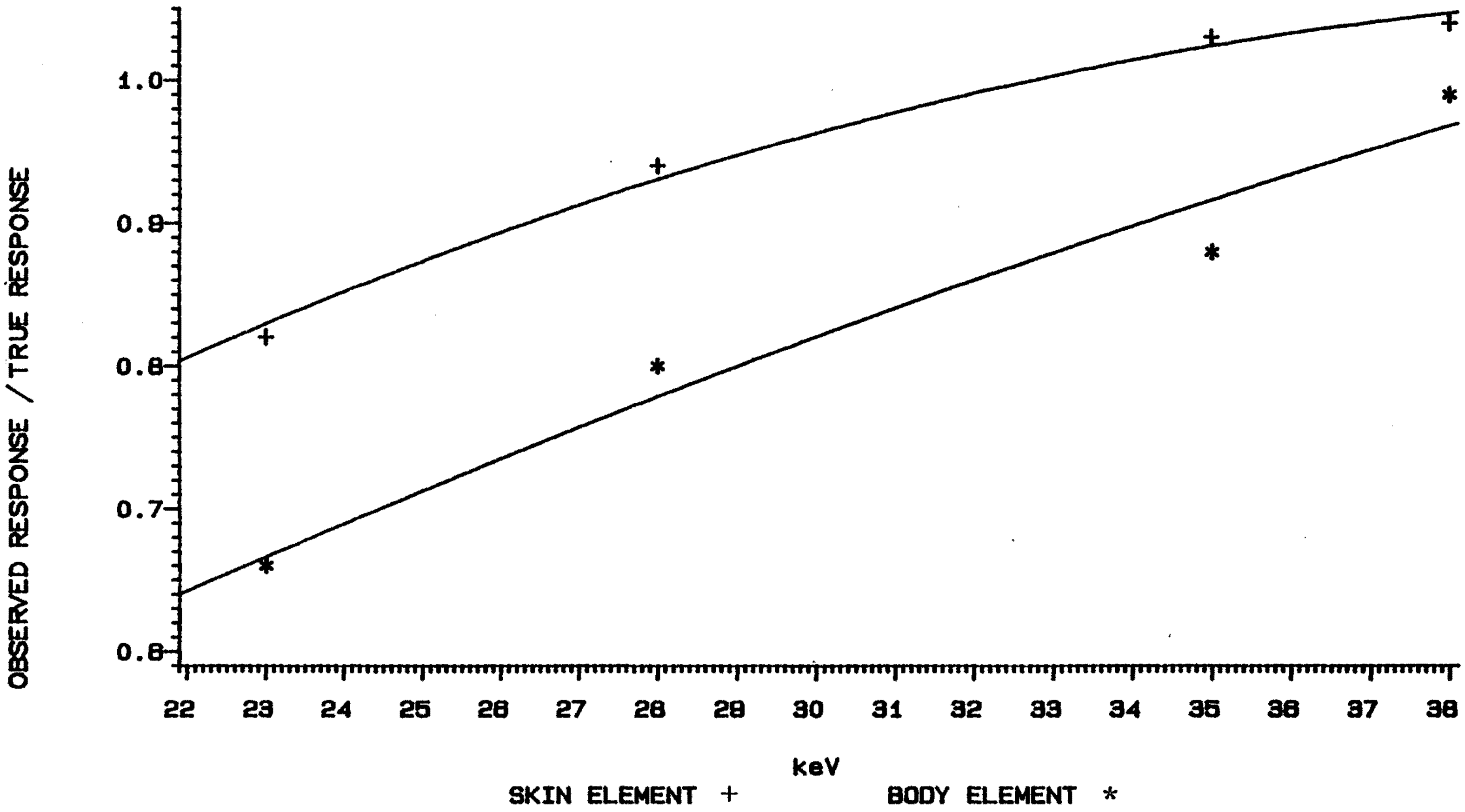
* average values of the previous projections

RADIOLOGIST	FRACTION OF WORKLOAD	ANNUAL EXPOSURE (mR)	$\bar{f}$ (mrad/mR)	ESTIMATED DOSE (mSv)	MEASURED DOSE (mSv)
A	75%	832	0.92	7.65	6.81
B	25%	277	0.92	2.55	2.60
C	20%	222	0.92	2.04	2.19

Since radiologists A, B, and C were not routinely involved in small animal fluoroscopy or large animal radiography, the estimated doses were based entirely on the small animal radiographic workload. The fraction of this workload assumed by each radiologist was determined from logbook records. The measured doses equivalent exhibit close agreement with the estimated doses equivalent.

Figure 1

X-RAY ENERGY RESPONSE OF THE PANASONIC UD-808 DOSIMETER

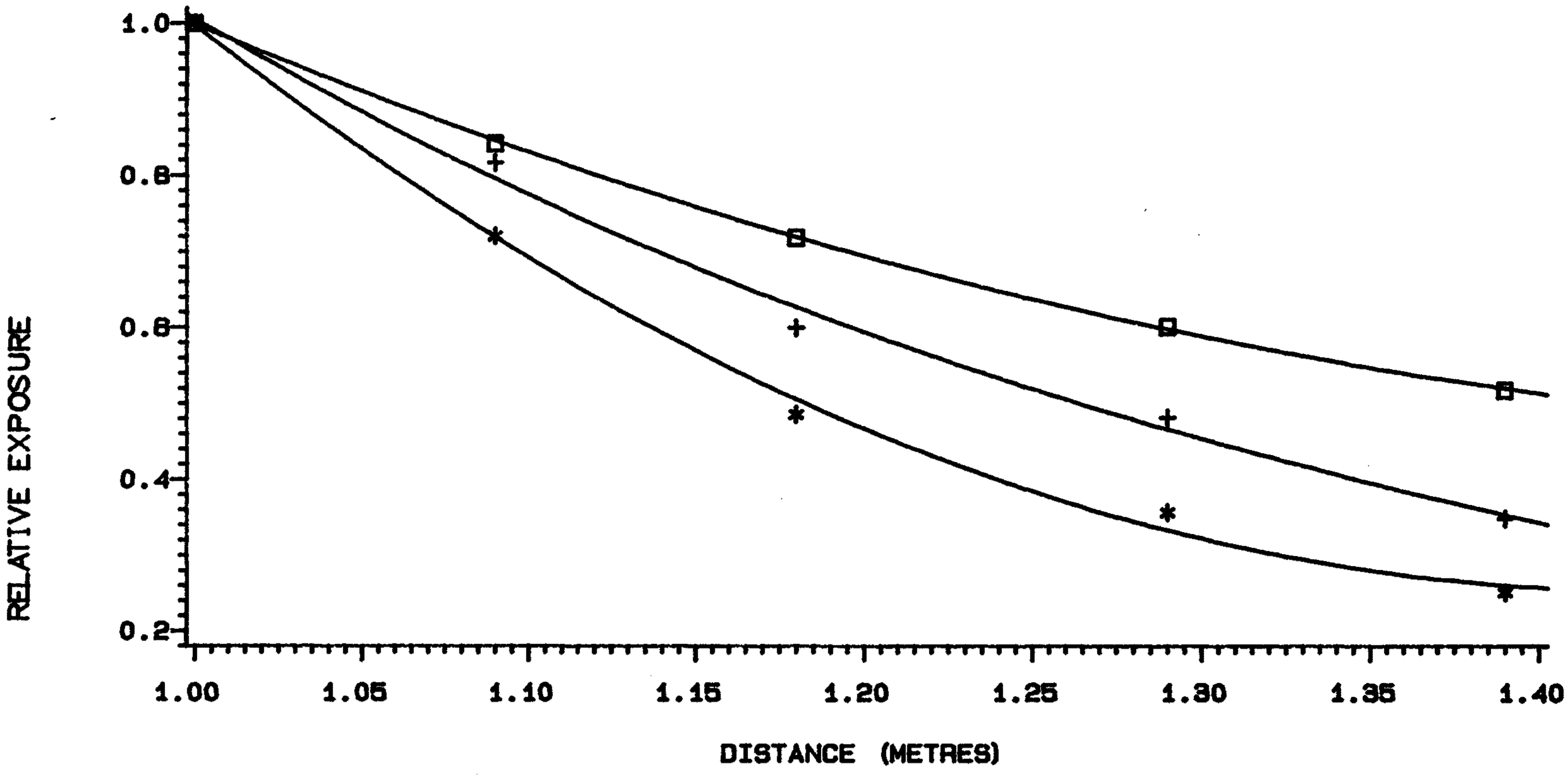


Calibration at the Ontario Ministry of Labour

60 kVp + 0.5 mm Al produced 23 keV effective x-ray energy
80 kVp + 1.0 mm Al produced 28 keV effective x-ray energy
100 kVp + 2.5 mm Al produced 35 keV effective x-ray energy
120 kVp + 2.5 mm Al produced 38 keV effective x-ray energy

Figure 2

EXPOSURE vs DISTANCE AT THE THYROID ELEVATION

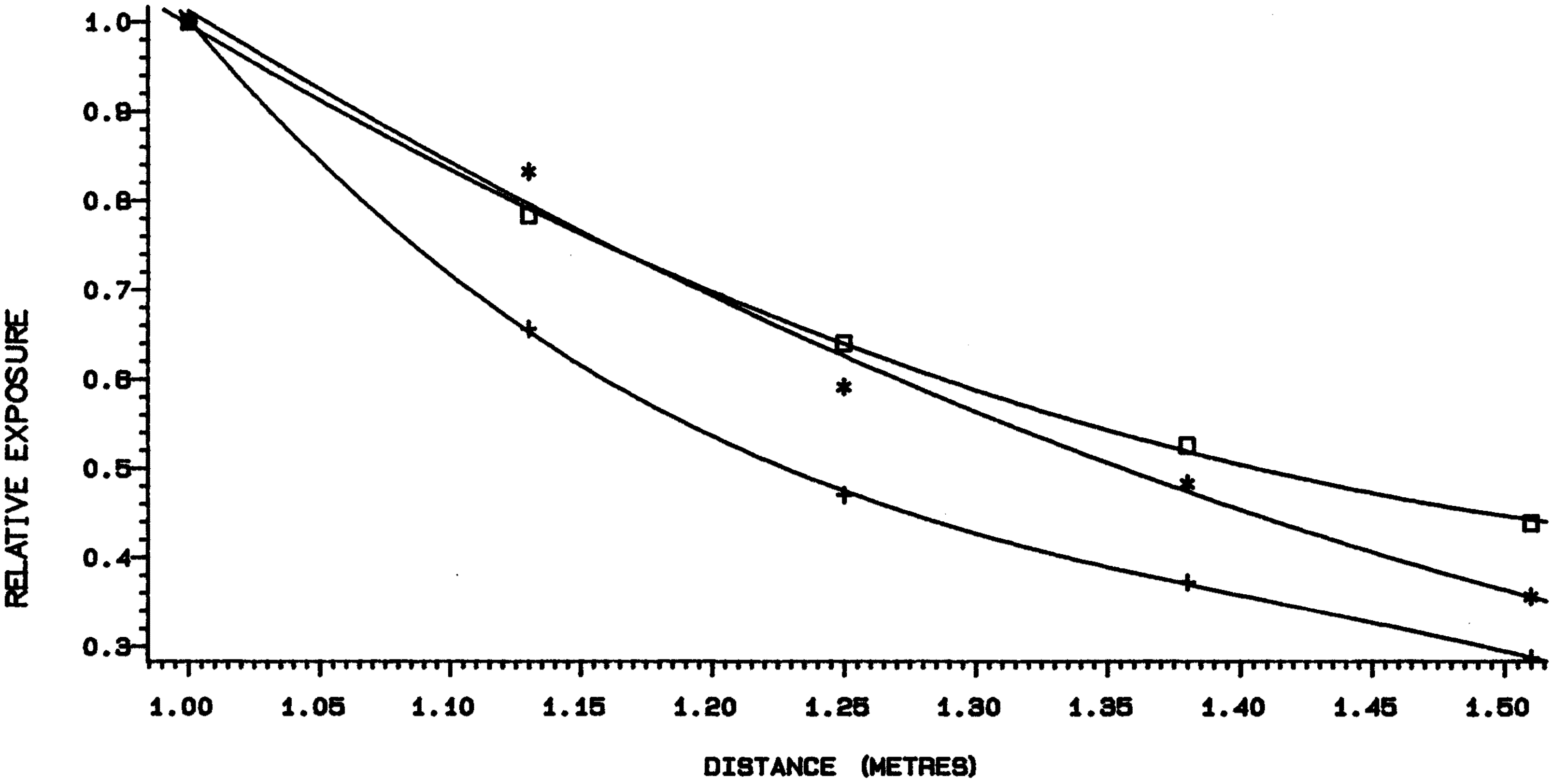


Inverse square law □ At 45 degrees * At 90 degrees +

Distance and exposure are normalized to a position
adjacent to the x-ray table opposite the patient.
Imagine that the attendant steps back from this position
at 45 degrees or at 90 degrees to the x-ray table.

Figure 3

EXPOSURE vs DISTANCE AT THE GONAD ELEVATION



Inverse square law ☐ At 45 degrees * At 90 degrees +

Distance and exposure are normalized to a position adjacent to the x-ray table opposite the patient. Imagine that the attendant steps back from this position at 45 degrees or at 90 degrees to the x-ray table.

QUALITY CONTROL MEASUREMENTS

ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

X-RAY GENERATOR

Philips, Model DR3-T 1000
fixed unit for small animal radiography
150 kVp maximum, 500 mA maximum
three phase (3Φ)

X-RAY TUBE

Rotalix, serial 55769
rhenium alloyed, tungsten-molybdenum compound disc target
0.3 mm and 1.2 mm focal spots

inherent filtration:	2.0 mm Al
added filtration-dial:	1.0 mm Al
-or-	2.0 mm Al
-or-	0.1 mm Cu

APPENDIX 1

QC MEASUREMENT SUMMARY - PHILIPS 3ϕ, ROOM 636

1. Overload protection was confirmed at 80% of the rated exposure time.

2. The light field and the x-ray field were aligned within 2% of the source-image distance.

3. Timer accuracy within ± 10%:

Preset Time (s)	(ms)	Measured Time (ms)	Within ± 10%
1/10	100	100	Y
1/20	50	50	Y
1/30	33.3	40	N
1/40	25	25	Y
1/60	16.7	20	N
1/120	8.3	10	N

4. Coefficient of linearity of mA stations < 0.10:

kVp	mA	s	mAs	C.L.
75	50	0.20	10	0.04
75	100	0.10	10	0.09
75	200	0.05	10	0.13
75	300	0.30	10	

5. Kilovolts potential accurate within ± 5 kVp:

Preset kVp	Measured kVp	Within ± 5 kVp
60	56	Y
80	80	Y
100	104	Y
120	118	Y

6. Coefficient of variation for reproducibility of output < 0.05:

$$\frac{\sigma}{X} = 0.05$$

7. Half-value layer at 80 kVp > 2.5 mm Al equivalent:

measured HVL = 3.6 mm Al

8. Tube head leakage (X_ℓ) at one metre < 0.1% of the direct beam exposure (X_{db}) at one metre:

$$\frac{X_\ell}{X_{db}} = 0.028\%$$

PHILIPS 3Φ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

1. OVERLOAD PROTECTION

REF: Philips super Rotalix rating chart;
60 Hz, 9600 r.p.m., 1.2 mm focal spot;
6 and 12 pulse operation.

kV	mA	Rated Exposure Time (seconds)	80% Rated Time (seconds)	Machine Allowed Time (seconds)
100	100	17.0	13.6	6.0
100	200	3.0	2.4	2.0
100	300	1.0	0.8	0.62
100	500	0.16	0.13	0.066

Acceptance Limits

The x-ray overload protection circuit should indicate tube overload and prevent an exposure at about 80% of the x-ray tube rating and should function within 10% of that value (21).

2. LIGHT FIELD AND X-RAY FIELD CONGRUENCE

Technique: 60 kVp 100 mA 0.10 s 10 mAs
Field: 21 cm x 18 cm, S.I.D. = 91 cm
Radiograph dated 85 01 15

Misalignment is approximately one cm on each of the left, right, and bottom sides of the radiograph.

Acceptance Limits

The light field and x-ray field alignment should be within ± 2% of the source-image distance (21).

PHILIPS 3ϕ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

3. TIMER ACCURACY

Method: RMI timing test tool, serial 121A-26950
S.I.D. = 100 cm
Radiographs dated 85 01 03

kVp	mA	Preset Time (s)	Preset Time (ms)	Measured Time (ms)	Within ± 10%
78	100	0.1	100	100	Y
78	200	1/20	50	50	Y
78	300	1/30	33.3	40	N
78	500	1/40	25	25	Y
78	500	1/60	16.7	20	N
78	500	1/120	8.3	10	N

Acceptance Limits

Timer accuracy should be within ± 10% (20).

PHILIPS 3ϕ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

4. COEFFICIENT OF LINEARITY OF mA STATIONS

75 kVp 35 cm^3 ion chamber S.I.D. = 100 cm

Station 1: 50 mA 0.2 s 10 mAs

X_i 45 47 46 47 49 48 48 48 44 48 mR

$$\bar{X} = \frac{\Sigma X_i}{n} = \frac{470}{10} = 47.0 \text{ mR}$$

$$X_1 = \frac{\bar{X}}{\text{mAs}} = \frac{47.0}{10} = 4.70 \text{ mR/mAs}$$

Station 2: 100 mA 0.10 s 10 mAs

X_i 49 52 53 54 52 50 52 52 51 46 mR

$$\bar{X} = \frac{\Sigma X_i}{n} = \frac{511}{10} = 51.1 \text{ mR}$$

$$X_2 = \frac{\bar{X}}{\text{mAs}} = \frac{51.1}{10} = 5.11 \text{ mR/mAs}$$

Station 3: 200 mA 0.05 s 10 mAs

X_i 46 45 42 40 42 40 42 46 42 41 mR

$$\bar{X} = \frac{\Sigma X_i}{n} = \frac{426}{10} = 42.6 \text{ mR}$$

$$X_3 = \frac{\bar{X}}{\text{mAs}} = \frac{42.6}{10} = 4.26 \text{ mR/mAs}$$

PHILIPS 3ϕ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

Station 4: 300 mA 0.03 s 10 mAs

X_i 56 55 51 56 56 56 57 55 56 56 mR

$$\bar{X} = \frac{\Sigma X_i}{n} = \frac{554}{10} = 55.4 \text{ mR}$$

$$X_4 = \frac{\bar{X}}{\text{mAs}} = \frac{55.4}{10} = 5.54 \text{ mR/mAs}$$

The coefficient of linearity for consecutive mA stations:

Stations 1 and 2

$$\frac{|X_1 - X_2|}{X_1 + X_2} = \frac{|4.70 - 5.11|}{4.70 + 5.11} = \frac{0.41}{9.81} = 0.04$$

Stations 2 and 3

$$\frac{|X_2 - X_3|}{X_2 + X_3} = \frac{|5.11 - 4.26|}{5.11 + 4.26} = \frac{0.85}{9.37} = 0.09$$

Stations 3 and 4

$$\frac{|X_3 - X_4|}{X_3 + X_4} = \frac{|4.26 - 5.54|}{4.26 + 5.54} = \frac{1.28}{9.80} = 0.13$$

Acceptance Limit

The coefficient of linearity between adjacent mA stations is satisfactory if it is less than or equal to 0.10 (21).

PHILIPS 3ϕ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

5. ACCURACY OF kVp

Method: Wisconsin test cassette, serial 101-2619
S.I.D. = 100 cm
Radiograph dated 85 01 03

kVp	mA	s	mAs	3ϕ Match Step	Measured kVp
60	300	0.26	78	4.0	56
80	300	0.16	48	6.0	80
100	300	1/30	10	7.6	104
120	300	1/60	5	5.6	118

Acceptance Limits

The kVp station should be within ± 5 kVp.

6. REPRODUCIBILITY OF OUTPUT

Technique: 75 kVp 25 mA 0.16 s S.I.D. = 100 cm

35 cm^3 ion chamber

X_i 22.3 20.0 19.5 20.0 19.8 21.1 19.2 19.8 20.5 18.3 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{200.5}{10} = 20.05$$

$$\sigma^2 = \frac{1}{n-1}\,\Sigma(X_i-\overline{X})^2 = 1.177 \quad \text{which implies} \quad \sigma = 1.08$$

$$\frac{\sigma}{\overline{X}} = \frac{1.08}{20.05} = 0.05$$

Acceptance Limit

The coefficient of variation should be less than 0.05 (21).

PHILIPS 3ϕ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

7. HALF-VALUE LAYER

Technique: 80 kVp 300 mA 0.2 s 60 mAs

Method:
source-detector distance = 86 cm
source-filter distance = 43 cm
total filtration = 4.0 mm Al
detector: 35 cm^3 ion chamber

Added Filtration mm Al	Exposure X mR	ln X
0	292	5.677
0.1	287	5.659
0.2	277	5.624
0.5	262	5.568
1.0	242	5.488
1.5	221	5.401
2.0	201	5.305
2.5	181	5.200
3.0	161	5.082
3.5	151	5.018
4.0	136	4.912

The natural logarithm of the exposure expressed as a function of filtration is:

$$\ln X = -0.190\,f + 5.674 \quad \text{which implies} \quad f = \frac{5.674 - \ln X}{0.190}$$

$$f = 1\ \text{HVL} = \frac{5.674 - \ln(292/2)}{0.190} = 3.6\ \text{mm Al}$$

Acceptance Limit

At 80 kVp, the minimum filtration required is equivalent to 2.5 mm Al (20).

PHILIPS 3ϕ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

8. TUBE HEAD LEAKAGE

Technique: 80 kVp 200 mA 0.12 s 24 mAs

Method: exposed the 35 cm^3 ion chamber to the direct beam at 86 cm

exposed the 350 cm^3 ion chamber at one meter from the tube head, perpendicular to the direction of the direct beam; collimator closed.

	X_1	X_2	X_3	$\bar{X}$	
Direct Beam at 86 cm:	130	130	130	130	mR
Direct Beam at 100 cm:	96	96	96	96	mR
Leakage at 100 cm:	0.031	0.025	0.025	0.027	mR

The leakage radiation at one metre is expressed as a fraction of the direct beam exposure at the same distance:

$$\frac{X_\ell}{X_{db}} = \frac{0.027}{96} = 2.8 \times 10^{-4} = 0.028\%$$

Acceptance Limit

The leakage at one metre should be less than 0.1% of the direct beam exposure at one metre (20).

PHILIPS 3Φ, ROOM 636 RADIOLOGY O.V.C. JANUARY 1985

9. OUTPUT vs kVp

Method: measured the free air exposure in the direct beam at 100 cm

total filtration = 4.0 mm Al, 1.2 mm focal spot

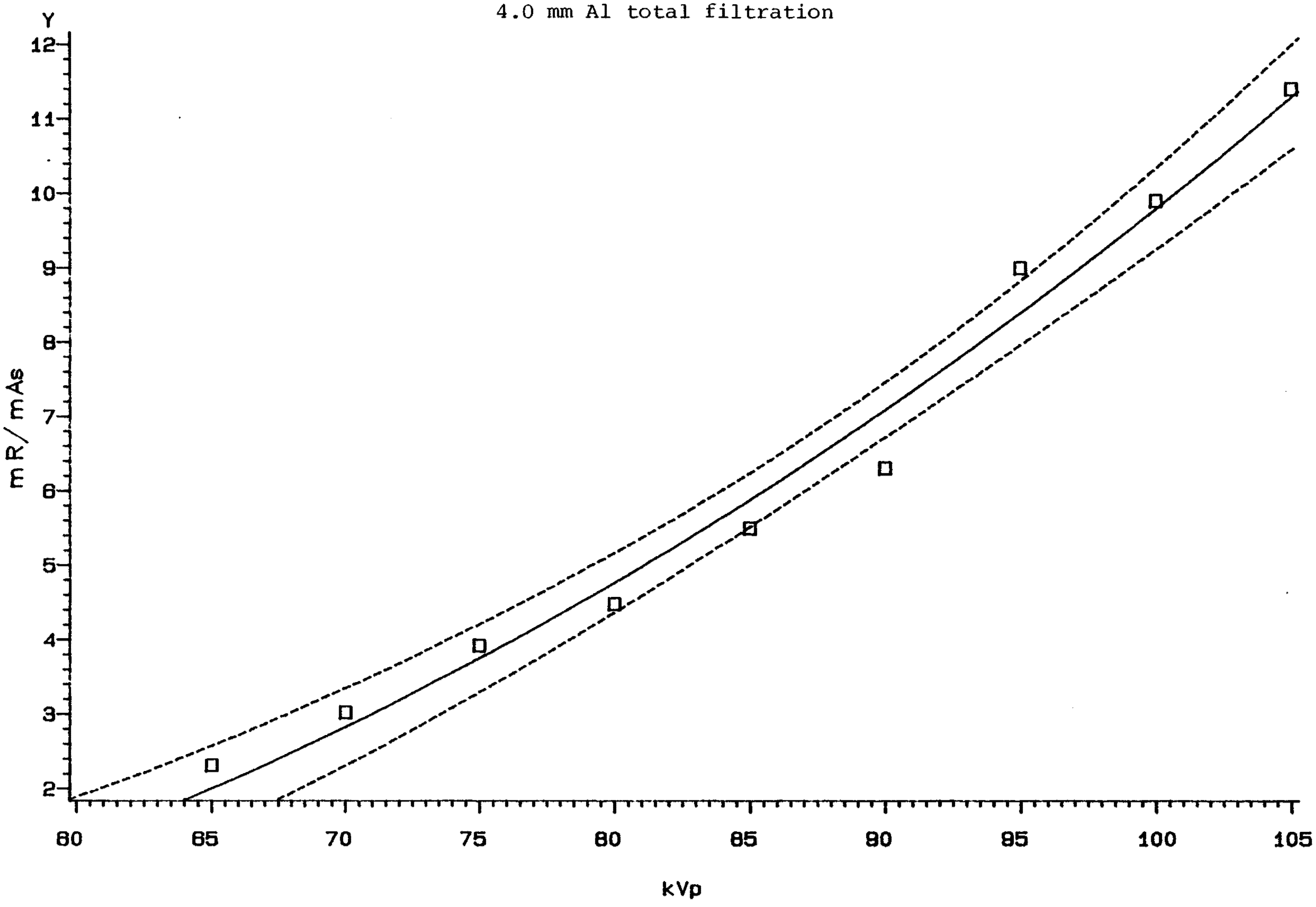
Recall: $\frac{\sigma}{\overline{X}} = 0.05$ thus $2\sigma = 0.10\ \overline{X}$ for 95.5% confidence

kVp	mA	s	mAs	$\overline{X} \pm 2\sigma$ (mR)	mR/mAs
65	500	0.10	50	115 ± 11	2.31 ± 0.22
70	500	0.10	50	151 ± 15	3.02 ± 0.30
75	500	0.10	50	196 ± 20	3.92 ± 0.40
80	500	0.10	50	224 ± 22	4.48 ± 0.44
85	500	0.05	25	137 ± 14	5.50 ± 0.56
90	500	0.05	25	158 ± 16	6.31 ± 0.64
95	100	0.10	10	90 ± 9	9.00 ± 0.90
100	100	0.10	10	99 ± 10	9.90 ± 1.00
105	100	0.10	10	114 ± 11	11.40 ± 1.10

The Philips 3Φ output (mR/mAs at 100 cm) is shown as a function of kVp in the accompanying figure.

PHILIPS 3ϕ OUTPUT AT 100 CM
(95% confidence limits shown)

4.0 mm Al total filtration



QUALITY CONTROL MEASUREMENTS

ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

X-RAY GENERATOR

York, Model 325
fixed unit for small animal radiography
120 kVp maximum, 300 mA maximum
single phase (1ɸ)

X-RAY TUBE

Machlett, Model 42-R
tungsten target, 2 mm focal spot

inherent filtration:	0.5 mm Al at 70 kVp
added filtration:	2.0 mm Al removable plate

APPENDIX 1

QC MEASUREMENT SUMMARY - YORK 1ϕ, ROOM 633

1. Overload protection was not confirmed (tube rating chart unavailable).

2. The light field and the x-ray field were aligned within 2% of the source-image distance.

3. Timer accuracy within ± 10%:

Preset Time (s)	(ms)	Measured Time (ms)	Within ± 10%
0.1	100	95	Y
1/20	50	40	N
1/30	33.3	35	Y
1/12	83.3	75	Y
1/15	66.7	70	Y
1/60	16.7	10	N

4. Coefficient of linearity of mA stations < 0.10:

kVp	mA	s	mAs	C.L.
65	100	0.2	20	0.03
65	200	0.1	20	0.03
65	300	0.06	20	

5. Kilovolts potential accurate within ± 5 kVp:

Preset kVp	Measured kVp	Within ± 5 kVp
60	56.5	Y
70	71.5	Y
80	84.5	Y
100	109.0	N
120	129.5	N

6. Coefficient of variation for reproducibility of output < 0.05:

$$\frac{\sigma}{\bar{X}} = 0.05$$

7. Half-value layer at 80 kVp > 2.5 mm Al equivalent:

measured HVL = 3.5 mm Al

8. Tube head leakage (X_ℓ) at one metre < 0.1% of the direct beam exposure (X_{db}) at one metre:

$$\frac{X_\ell}{X_{db}} = 0.015\%$$

YORK 10, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

1. OVERLOAD PROTECTION

Tube rating chart unavailable.

2. LIGHT FIELD AND X-RAY FIELD CONGRUENCE

Technique: 60 kVp 300 mA 1/30 s 10 mAs
Field: 23 cm x 27 cm, S.I.D. = 86 cm
Radiograph dated 85 01 19

Misalignment is approximately one cm beyond the light field at the top, about one cm within the light field at the bottom, and about one cm within the light field on the right.

Acceptance Limits

The light field and x-ray field alignment should be within ± 2% of the source-image distance (21).

YORK 10, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

3. TIMER ACCURACY

Method: RMI timing test tool, serial 121A-26950
S.I.D. = 100 cm
Radiographs dated 85 01 19

kVp	mA	Preset Time (s)	Preset Time (ms)	Measured Time (ms)	Within ± 10%
80	100	0.1	100	95	Y
80	200	1/20	50	40	N
80	300	1/30	33.3	35	Y
80	300	1/12	83.3	75	Y
80	300	1/15	66.7	70	Y
80	300	1/60	16.7	10	N

Acceptance Limits

Timer accuracy should be within ± 10% (20).

YORK 10, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

4. COEFFICIENT OF LINEARITY OF mA STATIONS

65 kVp 35 cm^3 ion chamber S.D.D. = 100 cm

Station 1: 100 mA 0.20 s 20 mAs

X_i 29.5 28.0 30.0 30.0 30.0 30.0 29.5 28.5 29.5 29.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{294.0}{10} = 29.4 \text{ mR}$$

$$X_1 = \frac{\overline{X}}{\text{mAs}} = \frac{29.4}{20} = 1.47 \text{ mR/mAs}$$

Station 2: 200 mA 0.10 s 20 mAs

X_i 27.5 28.0 27.0 28.0 28.0 26.5 28.0 28.0 26.0 28.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{275.0}{10} = 2.75 \text{ mR}$$

$$X_2 = \frac{\overline{X}}{\text{mAs}} = \frac{2.75}{20} = 1.38 \text{ mR/mAs}$$

Station 3: 300 mA 1/15 s 20 mAs

X_i 26.0 27.0 26.5 26.0 27.0 26.0 25.0 26.5 25.5 25.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{260.5}{10} = 26.05 \text{ mR}$$

$$X_3 = \frac{\overline{X}}{\text{mAs}} = \frac{26.05}{20} = 1.30 \text{ mR/mAs}$$

YORK 10, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

The coefficient of linearity for consecutive mA stations:

Stations 1 and 2

$$\frac{|X_1 - X_2|}{X_1 + X_2} = \frac{1.47 - 1.38}{1.47 + 1.38} = \frac{0.09}{2.85} = 0.03$$

Stations 2 and 3

$$\frac{|X_2 - X_3|}{X_2 + X_3} = \frac{1.38 - 1.30}{1.38 + 1.30} = \frac{0.08}{2.68} = 0.03$$

Acceptance Limit

The coefficient of linearity between adjacent mA stations is satisfactory if it is less than or equal to 0.10 (21).

YORK 1ϕ, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

5. ACCURACY OF kVp

Method: Wisconsin test cassette, serial 101-2619
S.I.D. = 100 cm
Radiographs dated 85 01 29, 85 02 14

kVp	mA	s	mAs	1ϕ Match Step	Measured kVp
60	300	0.6	180	3.7	56.5
70	300	0.6	180	8.2	71.5
80	300	0.4	120	6.8	84.5
100	300	0.10	30	7.7	109.0
120	300	1/15	20	7.6	129.5

Acceptance Limits

The kVp station should be within ± 5 kVp.

6. REPRODUCIBILITY OF OUTPUT

Technique: 70 kVp 300 mA 0.10 s 30 mAs S.D.D. = 91 cm

$35\ \mathrm{cm}^3$ ion chamber

X_i 48 52 44 50 46 49 47 48 49 47 mR

$$\bar{X} = \frac{\Sigma X_i}{n} = \frac{480}{10} = 48 \text{ mR}$$

$$\sigma^2 = \frac{1}{n-1}\Sigma(X_i-\bar{X})^2 = 4.89 \quad \text{which implies} \quad \sigma = 2.21$$

$$\frac{\sigma}{\bar{X}} = \frac{2.21}{48} = 0.05$$

Acceptance Limit

The coefficient of variation should be less than 0.05 (21).

YORK 10, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

7. HALF-VALUE LAYER

Technique: 80 kVp 300 mA 0.20 s 60 mAs

Method: source-detector distance = 90 cm
source-filter distance = 45 cm
total filtration = 2.5 mm Al
detector: 35 cm^3 ion chamber

Added Filtration mm Al	Exposure X mR	ln X
0	277	5.625
0.1	269	5.594
0.2	267	5.586
0.5	248	5.513
1.0	225	5.416
1.5	197	5.281
2.0	182	5.204
2.5	167	5.120
3.0	152	5.022
3.5	143	4.965
4.0	131	4.873

The natural logarithm of the exposure expressed as a function of filtration is:

$$\ln X = -0.190 f + 5.606 \quad \text{which implies} \quad f = \frac{5.606 - \ln X}{0.190}$$

$$f = 1 \text{ HVL} = \frac{5.606 - \ln (277/2)}{0.190} = 3.5 \text{ mm Al}$$

Acceptance Limit

At 80 kVp, the minimum filtration required is equivalent to 2.5 mm Al (20).

YORK 10, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

8. TUBE HEAD LEAKAGE

Technique: 80 kVp 200 mA 1/5 s 40 mAs

Method: exposed the 35 cm^3 ion chamber to the direct beam at 100 cm.

exposed the 350 cm^3 ion chamber at one metre from the tube head, perpendicular to the direction of the direct beam; collimator closed.

	X_1	X_2	X_3	$\bar{X}$	
Direct Beam at 100 cm:	110	112	108	110	mR
Leakage at 100 cm:	0.015	0.016	0.017	0.016	mR

The leakage radiation at one metre is expressed as a fraction of the direct beam exposure at the same distance:

$$\frac{X_\ell}{X_{db}} = \frac{0.016}{110} = 1.5 \times 10^{-4} = 0.015\%$$

Acceptance Limit

The leakage at one metre should be less than 0.1% of the direct beam exposure at one metre (20).

YORK 1ϕ, ROOM 633 RADIOLOGY O.V.C. JANUARY 1985

9. OUTPUT vs kVp

Method: measured the free air exposure in the direct beam at 91 cm

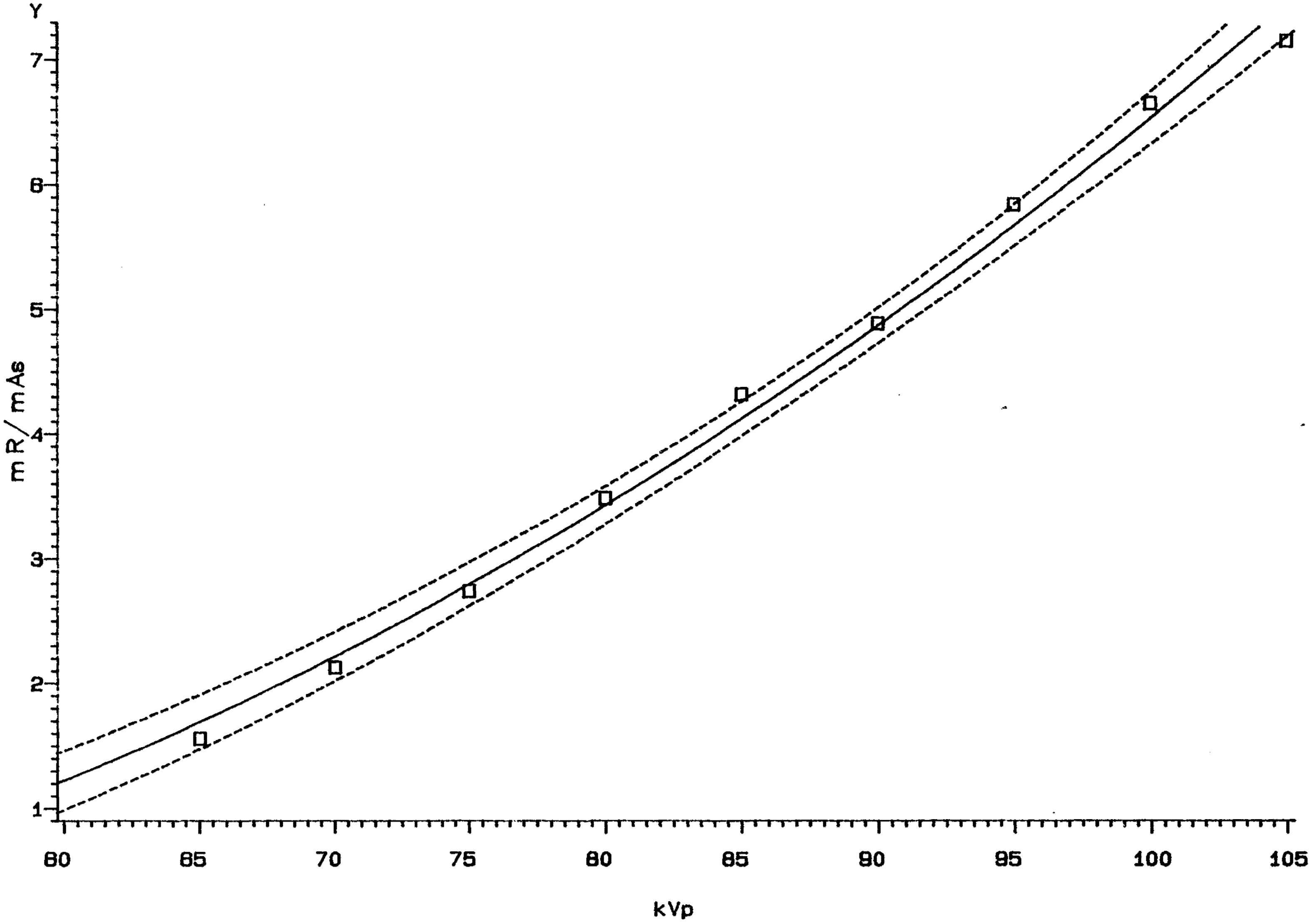
total filtration = 2.5 mm Al

Recall: $\frac{\sigma}{\bar{X}} = 0.05$ thus $2\sigma = 0.10\,\bar{X}$ for 95.5% confidence

kVp	mA	s	mAs	$\bar{X} \pm 2\sigma$ (mR)	mR/mAs
65	300	1/5	60	93 ± 9	1.56 ± 0.15
70	300	1/5	60	128 ± 13	2.13 ± 0.22
75	300	1/5	60	164 ± 16	2.74 ± 0.27
80	300	1/5	60	210 ± 21	3.49 ± 0.35
85	300	1/12	25	108 ± 11	4.32 ± 0.44
90	300	1/12	25	122 ± 12	4.89 ± 0.48
95	300	1/12	25	146 ± 15	5.84 ± 0.60
100	200	1/10	20	133 ± 13	6.65 ± 0.65
105	200	1/10	20	143 ± 14	7.15 ± 0.70

The York 1ϕ output (mR/mAs at 91 cm) is shown as a function of kVp in the accompanying figure.

YORK 1ϕ OUTPUT AT 91 CM
(95% confidence limits shown)
2.5 mm Al total filtration



QUALITY CONTROL MEASUREMENTS

ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

X-RAY GENERATOR

Picker, Model GX 1050, serial 298
fixed unit for large animal radiography
150 kVp maximum, 700 mA maximum
three phase (3Φ)

X-RAY TUBE

Picker Dunlee, Model PX 1402-EQ, serial 12748BJ 2175-0
tungsten target at 17°
2 mm focal spot
inherent filtration: 0.5 mm Al
added filtration: 2.0 mm Al

APPENDIX 1

QC MEASUREMENT SUMMARY - PICKER 3ϕ, ROOM 512

1. Overload protection was generally confirmed at less than 80% of the rated exposure time.

2. The light field and the x-ray field were aligned within ± 2% of the source-image distance.

3. Timer accuracy within ± 10%:

Preset Time (s)	(ms)	Measured Time (ms)	Within ± 10%
0.011	11	10	Y
0.022	22	20	Y
0.030	30	25	N
0.050	50	45	Y
0.100	100	100	Y
0.200	200	200	Y

4. Coefficient of linearity of mA stations < 0.10:

kVp	mA	s	mAs	C.L.
75	50	0.20	10	
				0.03
75	100	0.10	10	
				0.03
75	200	0.50	10	
				0.04
75	300	0.30	10	

5. Kilovolts potential accurate within ± 5 kVp:

Preset kVp	Measured kVp	Within ± 5 kVp
60	63.6	Y
80	82.6	Y
100	98.5	Y
120	109.0	N

6. Coefficient of variation for reproducibility of output < 0.05:

$$\frac{\sigma}{\bar{X}} = 0.02$$

7. Half-value layer at 80 kVp > 2.5 mm Al equivalent:

measured HVL = 3.1 mm Al

8. Tube head leakage (X_ℓ) at one metre < 0.1% of the direct beam exposure (X_{db}) at one metre:

$$\frac{X_\ell}{X_{db}} = 0.027\%$$

PICKER 3ϕ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

1. OVERLOAD PROTECTION

REF: Picker Dunlee radiographic rating charts;
180 Hz, three phase, 2.0 mm focal spot, high speed.

kV	mA	Rated Exposure Time (seconds)	80% Rated Time (seconds)	Machine Allowed Time (seconds)
100	700	1.1	0.8	1.0
100	600	1.5	1.2	1.0
100	500	2.0	1.6	2.0
100	400	3.0	2.4	4.0
100	300	4.0	3.2	6.0
100	200	7.5	6.0	6.0
100	150	13.0	10.4	6.0
100	100	18.0	14.4	6.0

Acceptance Limits

The x-ray overload protection circuit should indicate tube overload and prevent an exposure at about 80% of the x-ray tube rating and should function within 10% of that value (21).

2. LIGHT FIELD AND X-RAY FIELD CONGRUENCE

Technique: 60 kVp 700 mA 0.017 s 11.9 mAs
Field: 21 cm x 20 cm, S.I.D. = 100 cm
Radiograph dated 85 01 29

Misalignment is approximately 0.5 cm to the right, on both the left and right sides of the radiograph.

Acceptance Limits

The light field and x-ray field alignment should be within ± 2% of the source-image distance (21).

PICKER 3φ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

3. TIMER ACCURACY

Method: RMI timing test tool, serial 121A-26950
S.I.D. = 100 cm
Radiographs dated 85 01 29

		Preset Time		Measured	
kVp	mA	(s)	(ms)	Time (ms)	Within ± 10%
70	700	0.011	11	10	Y
70	700	0.022	22	20	Y
70	700	0.030	30	25	N
70	100	0.050	50	45	Y
70	100	0.100	100	100	Y
70	50	0.200	200	200	Y

Acceptance Limits

Timer accuracy should be within ± 10% (20).

PICKER 3ϕ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

4. COEFFICIENT OF LINEARITY OF mA STATIONS

75 kVp 35 cm^3 ion chamber S.D.D. = 94 cm

Station 1: 50 mA 0.20 s 10 mAs

X_i 51 51 51 51 54 54 51 54 51 51 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{519}{10} = 51.9 \text{ mR}$$

$$X_1 = \frac{\overline{X}}{\text{mAs}} = \frac{51.9}{10} = 5.19 \text{ mR/mAs}$$

Station 2: 100 mA 0.10 s 10 mAs

X_i 56 52 55 53 53 55 56 56 55 56 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{547}{10} = 54.7 \text{ mR}$$

$$X_2 = \frac{\overline{X}}{\text{mAs}} = \frac{54.7}{10} = 5.47 \text{ mR/mAs}$$

Station 3: 200 mA 0.05 s 10 mAs

X_i 55 54 54 54 54 56 54 54 55 54 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{544}{10} = 54.4 \text{ mR}$$

$$X_3 = \frac{\overline{X}}{\text{mAs}} = \frac{54.4}{10} = 5.44 \text{ mR/mAs}$$

PICKER 3ϕ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

Station 4: 300 mA 0.033 s 10 mAs

X_i 51 51 51 51 51 51 50 50 50 50 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{506}{10} = 50.6 \text{ mR}$$

$$X_4 = \frac{\overline{X}}{\text{mAs}} = \frac{50.6}{10} = 5.06 \text{ mR/mAs}$$

The coefficient of linearity for consecutive mA stations:

Stations 1 and 2

$$\frac{|X_1 - X_2|}{X_1 + X_2} = \frac{|5.19 - 5.47|}{5.19 + 5.47} = \frac{0.28}{10.66} = 0.03$$

Stations 2 and 3

$$\frac{|X_2 - X_3|}{X_2 + X_3} = \frac{|5.47 - 5.44|}{5.47 + 5.44} = 0.03$$

Stations 3 and 4

$$\frac{|X_3 - X_4|}{X_3 + X_4} = \frac{|5.44 - 5.06|}{5.44 + 5.06} = \frac{0.38}{10.50} = 0.04$$

Acceptance Limit

The coefficient of linearity between adjacent mA stations is satisfactory if it is less than or equal to 0.10 (21).

PICKER 3Φ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

5. ACCURACY OF kVp

Method: Wisconsin test cassette, serial 101-2619
S.I.D. = 94 cm
Radiograph dated 85 01 29

kVp	mA	s	mAs	3Φ Match Step	Measured kVp
60	300	0.33	99	6.5	63.6
80	300	0.13	39	6.8	82.6
100	300	0.03	9	6.0	98.5
120	300	0.017	5	3.4	109.0

Acceptance Limits

The kVp station should be within ± 5 kVp.

6. REPRODUCIBILITY OF OUTPUT

Technique: 80 kVp 700 mA 0.10 s 70 mAs

35 cm^3 ion chamber S.D.D. = 94 cm

X_i 460 460 460 460 440 450 440 450 450 450 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{4520}{10} = 452$$

$$\sigma^2 = \frac{1}{n-1}\Sigma(X_i-\overline{X})^2 = 62.4 \text{ which implies } \sigma = 7.9$$

$$\frac{\sigma}{\overline{X}} = \frac{7.9}{452} = 0.02$$

Acceptance Limit

The coefficient of variation should be less than 0.05 (21).

PICKER 3ϕ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

7. HALF-VALUE LAYER

Technique: 80 kVp 300 mA 0.20 s 60 mAs

Method:
source-detector distance = 94 cm
source-filter distance = 47 cm
total filtration = 2.5 mm Al
detector: 35 cm^3 ion chamber

Added Filtration mm Al	Exposure X mR	ln X
0	387	5.959
0.1	367	5.905
0.5	336	5.818
1.0	295	5.689
1.5	270	5.599
2.0	234	5.457
2.5	214	5.366
3.0	194	5.266
3.5	181	5.201
4.0	168	5.125

The natural logarithm of the exposure expressed as a function of filtration is:

$$\ln X = -0.210\, f + 5.918 \quad \text{which implies} \quad f = \frac{5.918 - \ln X}{0.210}$$

$$f = 1\ \text{HVL} = \frac{5.918 - \ln (387/2)}{0.210} = 3.1\ \text{mm Al}$$

Acceptance Limit

At 80 kVp, the minimum filtration required is equivalent to 2.5 mm Al (20).

PICKER 3ϕ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

8. TUBE HEAD LEAKAGE

Technique: 80 kVp 700 mA 0.30 s 21 mAs

Method: exposed the 35 cm^3 ion chamber to the direct beam at 91 cm, field 13 cm x 18 cm

exposed the 350 cm^3 ion chamber at one meter from the tube head, perpendicular to the direction of the direct beam; collimator closed.

	X_1	X_2	X_3	$\overline{X}$	
Direct Beam at 91 cm:	120	120	122	120.6	mR
Direct Beam at 100 cm:	99	99	101	99.6	mR
Leakage at 100 cm:	0.030	0.025	0.027	0.027	mR

The leakage radiation at one metre is expressed as a fraction of the direct beam exposure at the same distance:

$$\frac{X_\ell}{X_{db}} = \frac{0.027}{99.6} = 2.7 \times 10^{-4} = 0.027\%$$

Acceptance Limit

The leakage at one metre should be less than 0.1% of the direct beam exposure at one metre (20).

PICKER 3ϕ, ROOM 512 RADIOLOGY O.V.C. JANUARY 1985

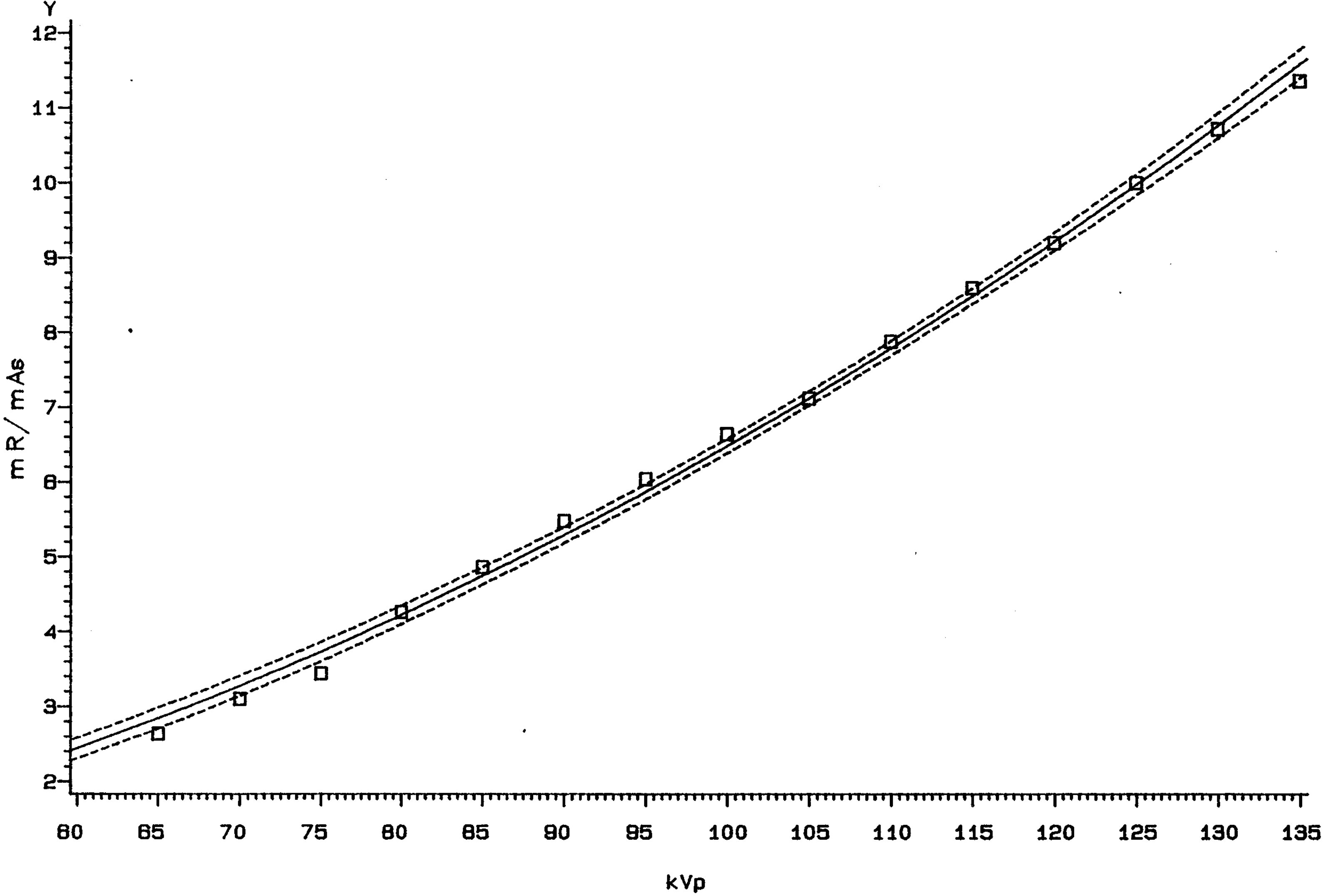
9. OUTPUT vs kVp

Method: measured the free air exposure in the direct beam at 100 cm
total filtration = 2.5 mm Al, 2 mm focal spot

Recall: $\frac{\sigma}{\overline{X}} = 0.02$ thus $2\sigma = 0.04\,\overline{X}$ for 95.5% confidence

kVp	mA	s	mAs	$\overline{X} \pm 2\sigma$ (mR)	mR/mAs
65	500	0.10	50	132 ± 5	2.64 ± 0.10
70	500	0.10	50	155 ± 6	3.10 ± 0.12
75	500	0.10	50	172 ± 7	3.44 ± 0.14
80	500	0.10	50	213 ± 8	4.26 ± 0.16
85	500	0.10	50	243 ± 10	4.86 ± 0.20
90	500	0.05	25	137 ± 5	5.48 ± 0.22
95	500	0.05	25	151 ± 6	6.04 ± 0.24
100	500	0.05	25	166 ± 7	6.64 ± 0.26
105	500	0.05	25	178 ± 7	7.12 ± 0.28
110	500	0.05	25	197 ± 8	7.88 ± 0.32
115	500	0.05	25	215 ± 9	8.60 ± 0.34
120	500	0.05	25	230 ± 9	9.20 ± 0.37
125	500	0.05	25	250 ± 10	10.00 ± 0.40
130	500	0.05	25	268 ± 11	10.72 ± 0.43
135	500	0.05	25	284 ± 11	11.36 ± 0.45

The Picker 3ϕ output (mR/mAs at 100 cm) is shown as a function of kVp in the accompanying figure.



PICKER 3ϕ OUTPUT AT 100 CM
(95% confidence limits shown)
2.5 mm Al total filtration

QUALITY CONTROL MEASUREMENTS

ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

X-RAY GENERATOR

Philips Medio-30, serial XC 2031/00
mobile unit for large animal radiography
125 kVp maximum, 300 mA maximum
single phase (1ϕ)

X-RAY TUBE

Rotalix, serial XF 3010/00
1 mm and 2 mm focal spots
total filtration = 2.5 mm Al

APPENDIX 1

QC MEASUREMENT SUMMARY - PHILIPS MEDIO-30, 1ϕ, ROOM 512

1. Overload protection was not confirmed (tube rating chart unavailable).

2. The light field and the x-ray field were aligned within ± 2% of the source-image distance.

3. Timer accuracy within ± 10%:

Preset Time (s)	(ms)	Measured Time (ms)	Within ± 10%
1.0	1000	930	Y
0.5	500	450	Y
0.25	250	235	Y
0.20	200	185	Y
0.10	100	80	N
0.05	50	40	N

4. Coefficient of linearity of mA stations < 0.10:

kVp	mA	s	mAs	C.L.
62	100	0.10	10	0.03
62	150	0.08	12	0.07
62	200	0.05	10	0.10
62	300	0.04	12	

5. Kilovolts potential accurate within ± 5 kVp:

Preset kVp	Measured kVp	Within ± 5 kVp
62	64.0	Y
80	79.0	Y
102	97.5	Y
120	112.5	N

6. Coefficient of variation for reproducibility of output < 0.05:

$$\frac{\sigma}{\bar{X}} = 0.01$$

7. Half-value layer at 80 kVp > 2.5 mm Al equivalent:

measured HVL = 3.3 mm Al

8. Tube head leakage (X_ℓ) at one metre < 0.1% of the direct beam exposure (X_{db}) at one metre:

$$\frac{X_\ell}{X_{db}} = 0.017\%$$

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

1. OVERLOAD PROTECTION

Tube Rating Chart unavailable.

2. LIGHT FIELD AND X-RAY FIELD CONGRUENCE

Technique: 62 kVp 300 mA 0.4 s 120 mAs
Field: 27 cm x 23 cm, S.I.D. = 100 cm
Radiograph dated 85 02 23

Misalignment is approximately one cm to the right on both the left and right sides, and approximately one cm up on the bottom side.

Acceptance Limits

The light field and x-ray field alignment should be within ± 2% of the source-image distance (21).

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

3. TIMER ACCURACY

Method: RMI timing test tool, serial 121A-26950
S.I.D. = 100 cm
Radiographs dated 85 02 23

kVp	mA	Preset Time (s)	Preset Time (ms)	Measured Time (ms)	Within ± 10%
62	300	1.0	1000	930	Y
62	300	0.5	500	450	Y
62	300	0.25	250	235	Y
62	300	0.20	200	185	Y
62	300	0.10	100	80	N
62	300	0.05	50	40	N

Acceptance Limits

Timer accuracy should be within ± 10% (20).

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

4. COEFFICIENT OF LINEARITY OF mA STATIONS

62 kVp 35 cm^3 ion chamber S.D.D. = 98 cm

Station 1: 100 mA 0.10 s 10 mAs

X_i 12.5 13.0 13.0 13.0 13.0 13.0 13.0 13.0 13.0 13.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{129.5}{10} = 12.95 \text{ mR}$$

$$X_1 = \frac{\overline{X}}{\text{mAs}} = \frac{12.95}{10} = 1.295 \text{ mR/mAs}$$

Station 2: 150 mA 0.08 s 12 mAs

X_i 16.5 17.0 16.5 16.5 17.0 16.5 16.5 16.5 17.0 16.5 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{166.5}{10} = 16.65 \text{ mR}$$

$$X_2 = \frac{\overline{X}}{\text{mAs}} = \frac{16.65}{12} = 1.390 \text{ mR/mAs}$$

Station 3: 200 mA 0.05 s 10 mAs

X_i 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 12.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{120}{10} = 12.0 \text{ mR}$$

$$X_3 = \frac{\overline{X}}{\text{mAs}} = \frac{12.0}{10} = 1.200 \text{ mR/mAs}$$

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

Station 4: 300 mA 0.04 s 12 mAs

X_i 11.5 12.0 11.5 12.0 12.0 12.0 12.0 12.0 11.5 12.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{118.5}{10} = 11.85 \text{ mR}$$

$$X_4 = \frac{\overline{X}}{\text{mAs}} = \frac{11.85}{12} = 0.987 \text{ mR/mAs}$$

The coefficient of linearity for consecutive mA stations:

Stations 1 and 2

$$\frac{|X_1 - X_2|}{X_1 + X_2} = \frac{|1.295 - 1.390|}{1.295 + 1.390} = \frac{0.095}{2.685} = 0.03$$

Stations 2 and 3

$$\frac{|X_2 - X_3|}{X_2 + X_3} = \frac{|1.390 - 1.200|}{1.390 + 1.200} = \frac{0.190}{2.590} = 0.07$$

Stations 3 and 4

$$\frac{|X_3 - X_4|}{X_3 + X_4} = \frac{|0.987 - 1.200|}{0.987 + 1.200} = \frac{0.213}{2.187} = 0.10$$

Acceptance Limit

The coefficient of linearity between adjacent mA stations is satisfactory if it is less than or equal to 0.10 (21).

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

5. ACCURACY OF kVp

Method: Wisconsin test cassette, serial 101-2619
S.I.D. = 100 cm
Radiograph dated 85 02 23

kVp	mA	s	mAs	1ϕ Match Step	Measured kVp
62	300	0.50	150	5.0	64.0
80	300	0.32	96	4.5	79.0
102	200	0.10	20	5.0	97.5
120	200	0.05	10	4.0	112.5

Acceptance Limits

The kVp station should be within ± 5 kVp.

6. REPRODUCIBILITY OF OUTPUT

Technique: 66 kVp 300 mA 0.05 s 15 mAs

S.D.D. = 100 cm

35 cm^3 ion chamber

X_i 22.0 21.5 22.0 21.5 21.5 21.5 21.5 21.5 21.5 21.5 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{216}{10} = 21.6$$

$$\sigma^2 = \frac{1}{n-1} \Sigma(X_i-\overline{X})^2 = 0.04 \quad \text{which implies} \quad \sigma = 0.21$$

$$\frac{\sigma}{\overline{X}} = \frac{0.21}{21.6} = 0.01$$

Acceptance Limit

The coefficient of variation should be less than 0.05 (21).

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

7. HALF-VALUE LAYER

Technique: 80 kVp 200 mA 0.5 s 100 mAs

Method:
source-detector distance = 100 cm
source-filter distance = 50 cm
total filtration = 2.5 mm Al
detector: 35 cm^3 ion chamber

Added Filtration mm Al	Exposure X mR	ln X
0	224	5.413
0.1	214	5.368
0.2	209	5.344
0.5	194	5.270
1.0	174	5.162
1.5	154	5.040
2.0	140	4.939
2.5	128	4.849
3.0	120	4.784
3.5	108	4.679
4.0	100	4.605

The natural logarithm of the exposure expressed as a function of filtration is:

$$\ln X = -0.201\, f + 5.376 \quad \text{which implies} \quad f = \frac{5.376 - \ln X}{0.201}$$

$$f = 1\ \text{HVL} = \frac{5.376 - \ln(224/2)}{0.201} = 3.3\ \text{mm Al}$$

Acceptance Limit

At 80 kVp, the minimum filtration required is equivalent to 2.5 mm Al (20).

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

8. TUBE HEAD LEAKAGE

Technique: 82 kVp 200 mA 0.5 s 100 mAs

Method: exposed the 35 cm^3 ion chamber to the direct beam at 100 cm

exposed the 350 cm^3 ion chamber at 100 cm from the tube head, perpendicular to the direction of the direct beam; collimator closed.

Direct Beam at 100 cm: $X_{db} = 229$ mR

Leakage at 100 cm: $X_{\ell} = 0.04$ mR

The leakage radiation at one metre is expressed as a fraction of the direct beam exposure at the same distance:

$$\frac{X_{\ell}}{X_{db}} = \frac{0.04}{229} = 1.74 \times 10^{-4} = 0.017\%$$

Acceptance Limit

The leakage at one metre should be less than 0.1% of the direct beam exposure at one metre (20).

PHILIPS MEDIO-30, 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

9. OUTPUT vs kVp

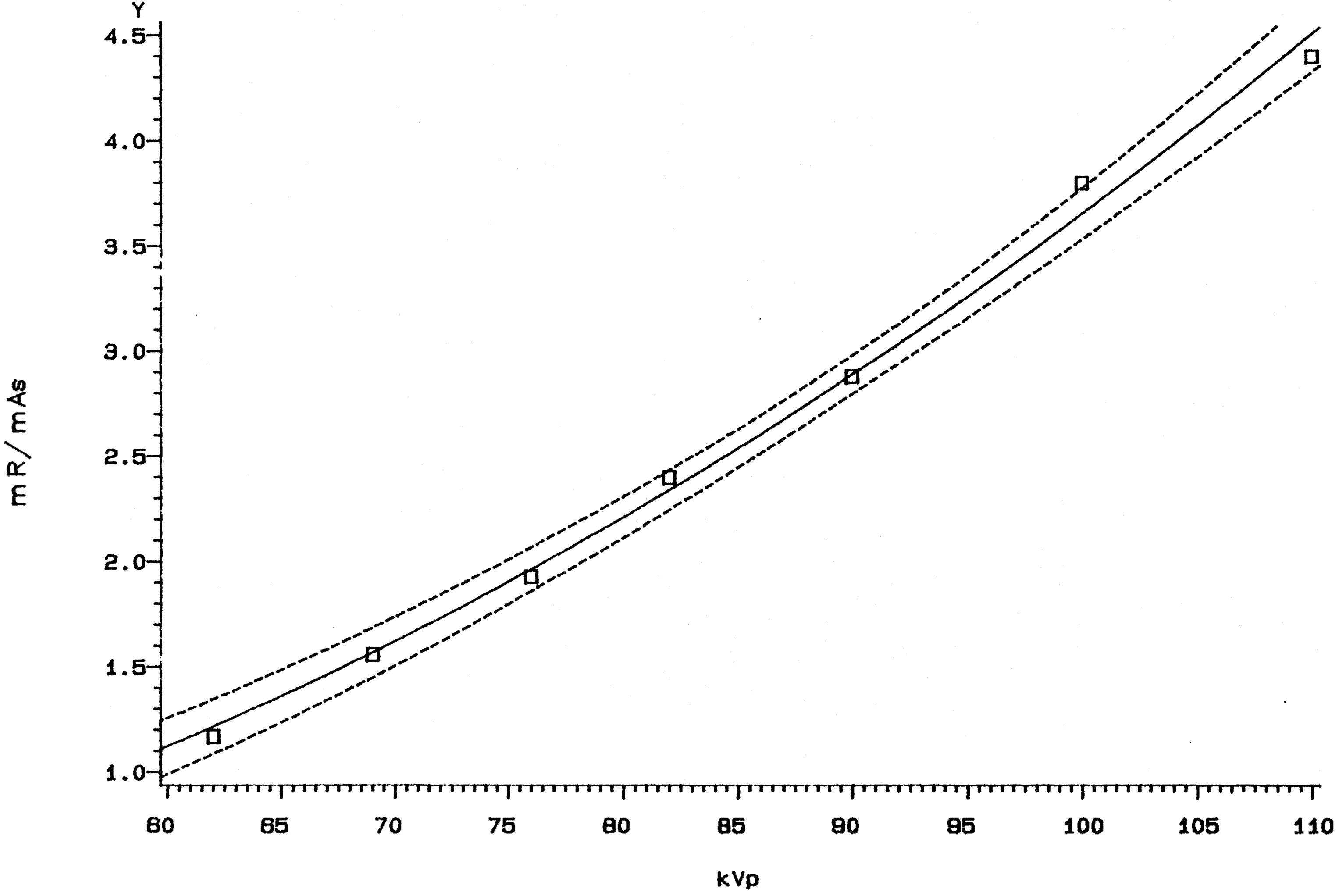
Method: measured the free air exposure in the direct beam at 100 cm

total filtration = 2.5 mm Al, 2 mm focal spot

Recall: $\frac{\sigma}{\overline{X}} = 0.01$ thus $2\sigma = 0.02\ \overline{X}$ for 95.5% confidence

kVp	mA	s	mAs	$\overline{X} \pm 2\sigma$ (mR)	mR/mAs
62	300	0.32	96	112 ± 2	1.17 ± 0.02
69	300	0.32	96	150 ± 3	1.56 ± 0.03
76	300	0.32	96	185 ± 4	1.93 ± 0.04
82	200	0.25	50	120 ± 2	2.40 ± 0.04
90	200	0.25	50	144 ± 3	2.88 ± 0.06
100	100	0.25	25	95 ± 2	3.80 ± 0.08
110	100	0.25	25	110 ± 2	4.40 ± 0.08

The Philips Medio-30, 1ϕ output (mR/mAs at 100 cm) is shown as a function of kVp in the accompanying figure.



PHILIPS MEDIO-30 1ϕ OUTPUT AT 100 CM
(95% confidence limits shown)
2.5 mm Al total filtration

QUALITY CONTROL MEASUREMENTS

ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

X-RAY GENERATOR

Fischer, Model FP-350, Serial 7904065
mobile unit for large animal radiography
100 kVp maximum, 35 mA maximum
single phase (1ϕ), half-wave rectified.

X-RAY TUBE

Fischer
inherent filtration = 2.0 mm Al at 100 kVp.

QC MEASUREMENT SUMMARY - FISCHER 1Φ, ROOM 512

1. Overload protection was not confirmed (tube rating chart unavailable).

2. The light field and the x-ray field were aligned within 2% of the source-image distance.

3. Timer accuracy within ± 10%:

Preset Time (ms)	Measured Time (ms)	Within ± 10%
50	No Exposure	
100	100	Y
200	200	Y
250	267	Y
300	300	Y
500	517	Y

4. Coefficient of linearity of mA stations < 0.10:

kVp	mA	s	mAs	C.L.

No data obtainable

5. Kilovolts potential accurate within ± 5 kVp:

Preset kVp	Measured kVp	Within ± 5 kVp
60	54.0	N
80	76.5	Y
100	89.5	N

6. Coefficient of variation for reproducibility of output < 0.05:

$$\frac{\sigma}{\bar{X}} = 0.04$$

7. Half-value layer at 100 kVp > 2.5 mm Al equivalent:

measured HVL = 3.3 mm Al

8. Tube head leakage (X_ℓ) at one metre < 0.1% of the direct beam exposure (X_{db}) at one metre:

$$\frac{X_\ell}{X_{db}} = 0.015\%$$

FISCHER 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

1. OVERLOAD PROTECTION

Tube rating chart unavailable.

Acceptance Limits

The x-ray overload protection circuit should indicate tube overload and prevent an exposure at about 80% of the x-ray tube rating and should function within 10% of that value (21).

2. LIGHT FIELD AND X-RAY FIELD CONGRUENCE

Technique: 60 kVp 35 mA 0.25 s 8.75 mAs
Field: 20 cm x 20 cm, S.I.D. = 100 cm
Radiograph dated 85 02 26

The x-ray field was smaller than the light field by:

0.5 cm along the left side
1.0 cm along the top side
1.5 cm along the right side
0.7 cm along the bottom side

Acceptance Limits

The light field and x-ray field alignment should be within ± 2% of the source-image distance (21).

FISCHER 10, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

3. TIMER ACCURACY

Method: RMI timing test tool, serial 121A-26950
S.I.D. = 81 cm
Radiographs dated 85 02 26

kVp	mA	Preset Time (ms)	Measured Time (ms)	Within ± 10%
80	20	50	no exposure	
80	20	100	100	Y
80	20	200	200	Y
90	15	250	267	Y
90	15	300	300	Y
90	15	500	500	Y

Acceptance Limits

Timer accuracy should be within ± 10% (20).

FISCHER 10, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

4. COEFFICIENT OF LINEARITY OF mA STATIONS

No data obtainable.

FISCHER 1Φ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

5. ACCURACY OF kVp

Method: Wisconsin test cassette, serial 101-2619
S.I.D. = 50 cm
Radiograph dated 85 02 26

kVp	mA	s	mAs	1Φ Match Step	True kVp
60	35	4	140	3.0	54.0
80	20	4	80	3.7	76.5
100	10	2	20	2.9	89.5

Acceptance Limits

The kVp station should be within ± 5 kVp.

6. REPRODUCIBILITY OF OUTPUT

Technique: 70 kVp 30 mA 0.2 s 6 mAs

35 cm^3 ion chamber S.I.D. = 90 cm

X_i 11.0 10.0 10.0 10.5 10.0 10.0 10.5 10.5 11.0 10.0 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = 10.35 \text{ mR}$$

$$\sigma^2 = \frac{1}{n-1} \Sigma (X_i - \overline{X})^2 = 0.17 \quad \text{which implies} \quad \sigma = 0.41$$

$$\frac{\sigma}{\overline{X}} = \frac{0.41}{10.35} = 0.04$$

Acceptance Limit

The coefficient of variation should be less than 0.05 (21).

FISCHER 10, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

7. HALF-VALUE LAYER

Technique: 100 kVp 10 mA 4.0 s 40 mAs

Method:
source-detector distance = 60 cm
source-filter distance = 30 cm
total filtration = 2.0 mm Al
detector: 35 cm^3 ion chamber

Added Filtration mm Al	Exposure X mR	ln X
0	290	5.670
0.1	280	5.635
0.2	275	5.617
0.5	260	5.561
1.0	228	5.429
1.5	205	5.323
2.0	190	5.247
2.5	162	5.088
3.0	153	5.030
3.5	140	4.942
4.0	131	4.875

The natural logarithm of the exposure expressed as a function of filtration is:

$$\ln X = -0.204 f + 5.650 \quad \text{which implies} \quad f = \frac{5.650 - \ln X}{0.204}$$

$$f = 1 \text{ HVL} = \frac{5.650 - \ln (290/2)}{0.204} = 3.3 \text{ mm Al}$$

Acceptance Limit

At 100 kVp, the minimum filtration required is equivalent to 2.5 mm Al (20).

FISCHER 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

8. TUBE HEAD LEAKAGE

Technique: 100 kVp 10 mA 1.0 s 10 mAs

Method: exposed the 35 cm^3 ion chamber to the direct beam at 100 cm

exposed the 350 cm^3 ion chamber at one meter from the tube head, perpendicular to the direction of the direct beam; collimator closed.

	X_1	X_2	X_3	$\overline{X}$	
Direct Beam at 100 cm:	26.5	27.0	25.5	26.3	mR
Leakage at 100 cm:	0.004	0.004	0.004	0.004	mR

The leakage radiation at one metre is expressed as a fraction of the direct beam exposure at the same distance:

$$\frac{X_\ell}{X_{db}} = \frac{0.004}{26.3} = 1.5 \times 10^{-4} = 0.015\%$$

Acceptance Limit

The leakage at one metre should be less than 0.1% of the direct beam exposure at one metre (20).

FISCHER 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

9. OUTPUT vs kVp

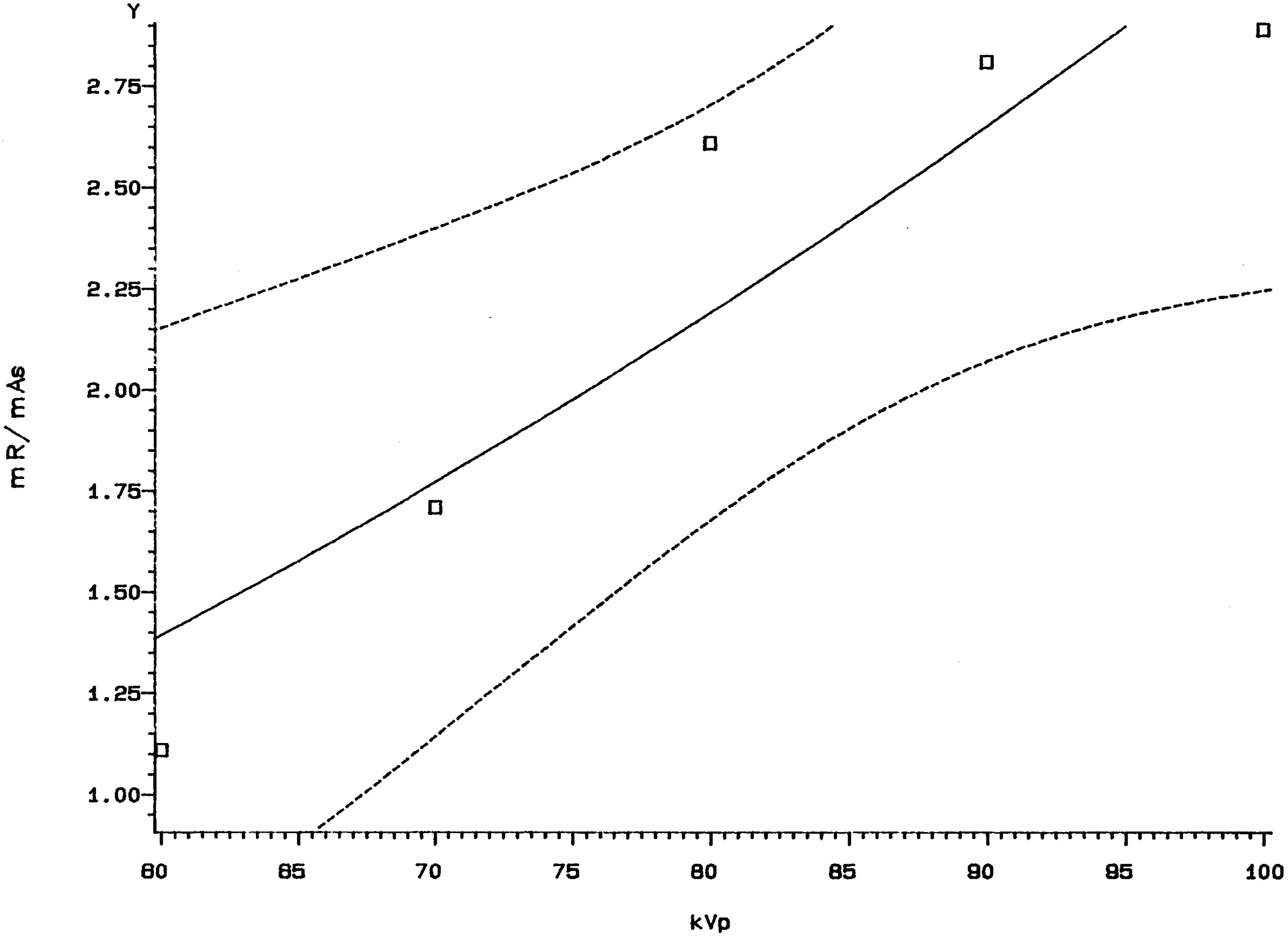
Method: measured the free air exposure in the direct beam at 90 cm

total filtration = 2.0 mm Al

Recall: $\frac{\sigma}{\bar{X}} = 0.04$ thus $2\sigma = 0.08\,\bar{X}$ for 95.5% confidence

kVp	mA	s	mAs	$\bar{X} \pm 2\sigma$ (mR)	mR/mAs
60	35	0.3	10.5	11.7 ± 0.9	1.11 ± 0.09
70	30	0.3	9.0	15.4 ± 1.2	1.71 ± 0.14
80	20	0.5	10.0	26.1 ± 2.1	2.61 ± 0.21
90	15	0.6	9.0	25.3 ± 2.0	2.81 ± 0.22
100	10	1.0	10.0	28.9 ± 2.3	2.89 ± 0.23

The Fischer 1ϕ output (mR/mAs at 90 cm) is shown as a function of kVp in the accompanying figure.



FISCHER 1ϕ OUTPUT AT 90 CM
(95% confidence limits shown)
2.0 mm Al total filtration

QUALITY CONTROL MEASUREMENTS

ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

X-RAY GENERATOR

Universal X-ray Products Inc.
mobile unit for large animal radiography
100 kVp maximum, 100 mA maximum
single phase (1ϕ)

X-RAY TUBE

Universal X-ray Products Inc.
CAT NO. UX 20H, serial 10086
0.8 mm and 1.8 mm focal spots, W target
inherent filtration = 2.0 mm Al in collimator
added filtration-dial: 1.0 mm Al
-or- 2.0 mm Al
-or- 0.1 mm Cu

QC MEASUREMENT SUMMARY - UNIVERSAL 1ϕ, ROOM 512

1. Overload protection was not confirmed (tube rating chart unavailable).

2. The light field and the x-ray field were aligned within 2% of the source-image distance.

3. Timer accuracy within ± 10%:

Preset Time (ms)	Measured Time (ms)	Within ± 10%
16.7	15	Y
33	25	N
50	45	Y
100	96	Y
200	195	Y
250	250	Y

4. Coefficient of linearity of mA stations < 0.10:

kVp	mA	s	mAs	C.L.
70	50	1/5	10	0.10
75	100	1/10	10	

5. Kilovolts potential accurate within ± 5 kVp:

Preset kVp	Measured kVp	Within ± 5 kVp
60	--	N
80	77.5	Y
100	95.5	Y

6. Coefficient of variation for reproducibility of output < 0.05:

$$\frac{\sigma}{\bar{X}} = 0.01$$

7. Half-value layer at 80 kVp > 2.5 mm Al equivalent:

measured HVL = 3.3 mm Al

8. Tube head leakage (X_ℓ) at one metre < 0.1% of the direct beam exposure (X_{db}) at one metre:

$$\frac{X_\ell}{X_{db}} = 0.032\%$$

UNIVERSAL 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

1. OVERLOAD PROTECTION

Tube rating chart unavailable.

2. LIGHT FIELD AND X-RAY FIELD CONGRUENCE

Technique: 62 kVp 100 mA 1/12 s 8.3 mAs
Field: 26 cm x 22 cm, S.I.D. = 100 cm
Radiograph dated 85 01 31

Misalignment was approximately one cm beyond the light field along the bottom side.

Acceptance Limits

The light field and x-ray field alignment should be within ± 2% of the source-image distance (21).

UNIVERSAL 1Φ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

3. TIMER ACCURACY

Method: RMI timing test tool, serial 121A-26950
S.I.D. = 91 cm
Radiographs dated 85 03 05

kVp	mA	Preset Time (ms)	Measured Time (ms)	Within ± 10%
80	100	16.7	15	Y
80	100	33	25	N
80	100	50	45	Y
80	100	100	96	Y
70	100	200	195	Y
70	100	250	250	Y

Acceptance Limits

Timer accuracy should be within ± 10% (20).

UNIVERSAL 10, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

4. COEFFICIENT OF LINEARITY OF mA STATIONS

70 kVp 35 cm^3 ion chamber S.D.D. = 91 cm

Station 1: 50 mA 1/5 s 10 mAs

X_i 27.0 27.0 26.5 27.0 27.0 26.5 27.0 26.5 26.5 26.5 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{267.5}{10} = 26.75 \text{ mR}$$

$$X_1 = \frac{\overline{X}}{\text{mAs}} = \frac{26.75}{10} = 2.67 \text{ mR/mAs}$$

Station 2: 100 mA 1/10 s 10 mAs

X_i 22.0 21.5 22.0 22.0 22.0 21.5 21.5 21.5 21.5 21.5 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{217.0}{10} = 21.7 \text{ mR}$$

$$X_2 = \frac{\overline{X}}{\text{mAs}} = \frac{21.7}{10} = 2.17 \text{ mR/mAs}$$

The coefficient of linearity for consecutive mA stations:

Stations 1 and 2

$$\frac{|X_1 - X_2|}{X_1 + X_2} = \frac{2.67 - 2.17}{2.67 + 2.17} = \frac{0.50}{4.84} = 0.10$$

Acceptance Limit

The coefficient of linearity between adjacent mA stations is satisfactory if it is less than or equal to 0.10 (21).

UNIVERSAL 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

5. ACCURACY OF kVp

Method: Wisconsin test cassette, serial 101-2619
S.I.D. = 91 cm
Radiograph dated 85 01 31

kVp	mA	s	mAs	1ϕ Match Step	Measured kVp
60	100	1.5	150	No Exposure	--
80	100	1.4	140	4.11	77.5
100	100	0.4	40	4.40	95.5

Acceptance Limits

The kVp station should be within ± 5 kVp.

6. REPRODUCIBILITY OF OUTPUT

Technique: 60 kVp 100 mA 1/5 s 20 mAs

35 cm^3 ion chamber S.I.D. = 91 cm

X_i 24.5 24.0 24.5 24.0 24.5 24.0 24.0 24.0 24.0 24.5 mR

$$\overline{X} = \frac{\Sigma X_i}{n} = \frac{242}{10} = 24.2 \text{ mR}$$

$$\sigma^2 = \frac{1}{n-1} \Sigma(X_i-\overline{X})^2 = 0.07 \quad \text{which implies} \quad \sigma = 0.26$$

$$\frac{\sigma}{\overline{X}} = \frac{0.26}{24.2} = 0.01$$

Acceptance Limit

The coefficient of variation should be less than 0.05 (21).

UNIVERSAL 1Φ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

7. HALF-VALUE LAYER

Technique: 80 kVp 100 mA 1/2 s 50 mAs

Method:
source-detector distance = 91 cm
source-filter distance = 45.5 cm
total filtration = 2.0 mm Al
detector: 35 cm^3 ion chamber

Added Filtration mm Al	Exposure X mR	ln X
0	226	5.421
0.1	216	5.375
0.2	211	5.352
0.5	197	5.283
1.0	181	5.198
1.5	159	5.069
2.0	147	4.990
2.5	133	4.890
3.0	118	4.771
3.5	110	4.700
4.0	102	4.625

The natural logarithm of the exposure expressed as a function of filtration is:

$$\ln X = -\,0.199\, f + 5.393 \quad \text{which implies} \quad f = \frac{5.393 - \ln X}{0.199}$$

$$f = 1\ \text{HVL} = \frac{5.393 - \ln(226/2)}{0.199} = 3.3\ \text{mm Al}$$

Acceptance Limit

At 80 kVp, the minimum filtration required is equivalent to 2.5 mm Al (20).

UNIVERSAL 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

8. TUBE HEAD LEAKAGE

Technique: 60 kVp 100 mA 1/5 s 20 mAs

Method: exposed the 35 cm^3 ion chamber to the direct beam at 96.5 cm

exposed the 350 cm^3 ion chamber at one meter from the tube head, perpendicular to the direction of the direct beam; collimator closed.

	X_1	X_2	X_3	$\overline{X}$	
Direct Beam at 96.5 cm:	23.5	23.5	23.5	23.5	mR
Direct Beam at 100 cm:	21.8	21.8	21.8	21.8	mR
Leakage at 100 cm:	0.007	0.007	0.007	0.007	mR

The leakage radiation at one metre is expressed as a fraction of the direct beam exposure at the same distance:

$$\frac{X_\ell}{X_{db}} = \frac{0.007}{21.8} = 3.2 \times 10^{-4} = 0.032\%$$

Acceptance Limit

The leakage at one metre should be less than 0.1% of the direct beam exposure at one metre (21).

UNIVERSAL 1ϕ, ROOM 512 RADIOLOGY O.V.C. FEBRUARY 1985

9. OUTPUT vs kVp

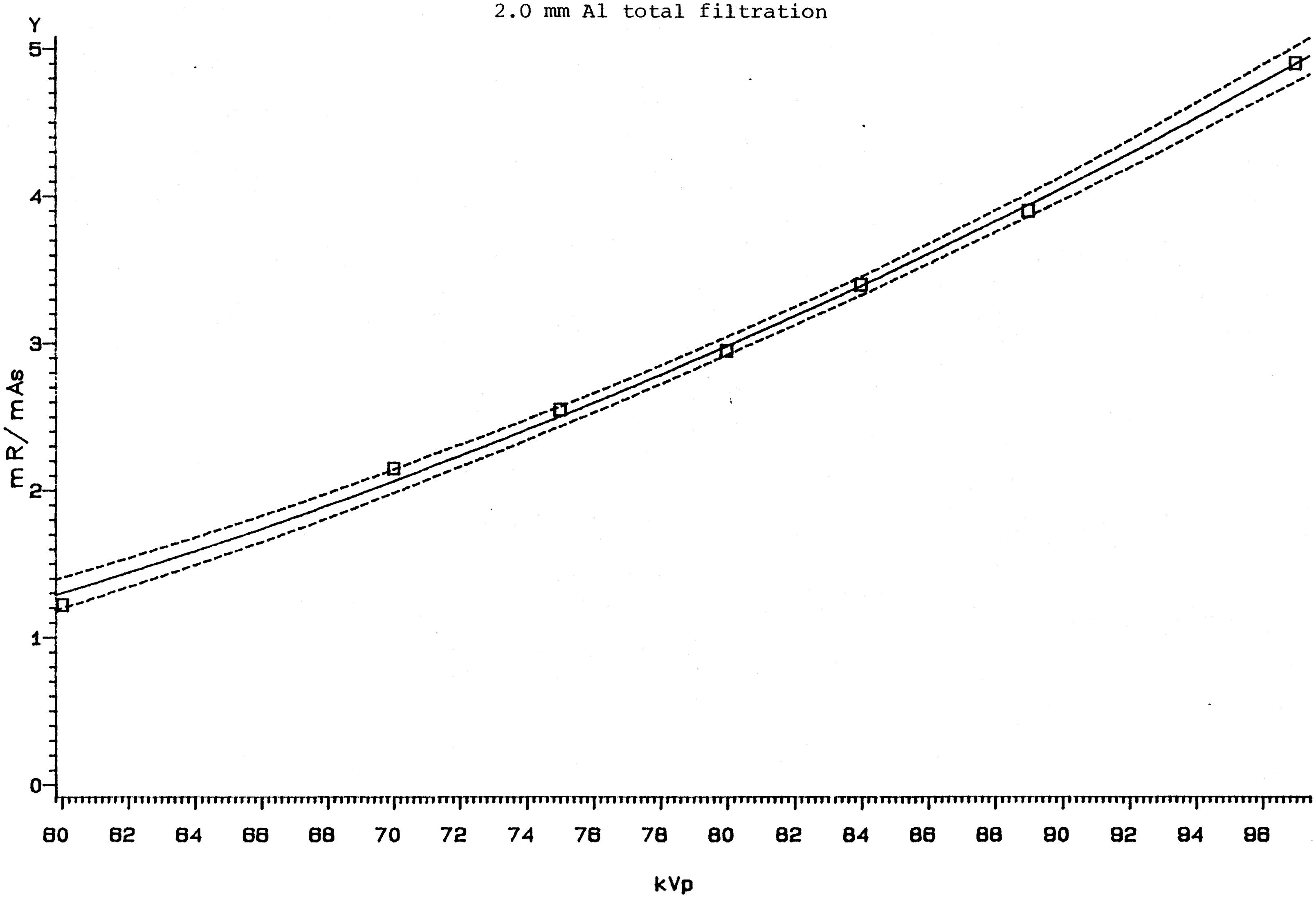
Method: measured the free air exposure in the direct beam at 91 cm

filtration = 2.0 mm Al

Recall: $\frac{\sigma}{\overline{X}} = 0.01$ thus $2\sigma = 0.02\ \overline{X}$ for 95.5% confidence

kVp	mA	s	mAs	$\overline{X} \pm 2\sigma$ (mR)	mR/mAs
60	100	1/5	20	24.5 ± 0.5	1.22 ± 0.02
70	100	1/5	20	43.0 ± 0.9	2.15 ± 0.04
75	100	1/5	20	51.0 ± 1.0	2.55 ± 0.05
80	100	1/5	20	59.0 ± 1.2	2.95 ± 0.06
84	100	1/5	20	68.0 ± 1.4	3.40 ± 0.07
89	100	1/5	20	78.0 ± 1.6	3.90 ± 0.08
97	100	1/10	10	49.0 ± 1.0	4.90 ± 0.10

The Universal 1ϕ output (mR/mAs at 91 cm) is shown as a function of kVp in the accompanying figure.



UNIVERSAL 1ϕ OUTPUT AT 91 CM
(95% confidence limits shown)
2.0 mm Al total filtration