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Organ Doses in Routine Radiographic Procedures

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School of Basic Health Sciences
Virginia Commonwealth University

This is to certify that the thesis prepared by *Yang Han* entitled *Organ Doses in Routine Radiographic Procedures* has been approved by his committee as satisfactory completion of the thesis requirement for the degree of Master of Science.

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7 Dec 1989

Date

Organ Doses in Routine Radiographic Procedures

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

By

Yang Han
B.S. Shanghai Jiao-Tong University. July, 1985

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December, 1989

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Lastly, I would like to thank my wife, family and classmates for their support and encouragement in my educational endeavors.

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List of Abbreviations

- AL — Aluminium
- AP — Anteroposterior
- C. Spine — Cervical Spine
- CT — Computed Tomography
- ESE — Exposure at Skin Entrance
- HVL — Half Value Layer
- keV — Kiloelectron Volts
- KUB — Kidney, Ureter and Bladder
- kVp — Kilovoltage Potential
- LAT — Lateral
- L. Spine — Lumbar Spine
- mAs — Milliamp Seconds
- MCV — Medical College of Virginia
- MeV — Million Electron Volts
- mrad — Millirad
- mR — Milliroentgen
- MSAD — Multiple Scan Average Dose
- PA — Posteroanterior
- R — Roentgen
- S.D. — Standard Deviation
- SID — Source-to-Image Distance
- TAR — Tissue-Air Ratio
- T. Spine — Thoracic Spine

Organ Doses in Routine Radiographic Procedures

Abstract

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

Yang Han

Virginia Commonwealth University, 1989

Major Director: Ding-Yu Fei, Ph. D.

There is general agreement that the extent of the risk from x-ray examination is related in some way to the radiation dose. As the dose increases, the likelihood of significant biological effects also increases. If a clear correlation between dose and effect is to be established, a convenient and reasonably accurate method of estimating patient's absorbed doses during common radiographic examinations will be highly needed. A simple method is developed in this project to determine the two important parameters – exposure at skin entrance (ESE) and half value layer (HVL), which is essential to get reasonably accurate estimates of absorbed doses. Then, the patient's absorbed doses in common x-ray examinations can be estimated using the computer program. The absorbed doses in 12 routine radiographic projections were calculated by the use of clinical data in MCV Hospital.

Chapter 1

Introduction

The origin of the x-ray machine can be traced to the discovery by Roentgen in 1895 that electrons striking surfaces within an electron tube at high speed generated a penetrating radiation, which he called x radiation. The radiation was detected accidentally when a paper screen washed with barium-platino-cyanide lit up brilliantly in a dark room in the vicinity of the electron tube, which was covered with a closely fitting mantle of thin black cardboard [Laws, 1977].

It was soon found that, because of their ability to penetrate matter, x rays could be used to produce pictures of interior of objects, and, over the years, x-ray machines were developed that could show the interior of objects in great detail. Our concern here is primarily with the use of x rays in examinations of the internal structure of the human body, that is, with photon energies less than 150 keV. Because x rays are so valuable in the diagnosis of disease and injury, they are used routinely in medical practice, and as a result they are responsible for most of the exposure of the public to ionizing radiation, outside of exposure due to the natural radiation background, which is radiation from naturally occurring radioactive materials and cosmic rays [Hale and Thomas, 1985].

The production of injury to living matter by ionizing radiation is the result of the transfer of large amounts of energy indiscriminately to individual molecules in the region through which the radiation passes. These large energy transfers cause disruptions of the molecular structure, and when the molecules affected are essential for the normal functioning of a cell, the cell in turn suffers injury or dies [Upton *et al.*, 1986]. Thus, the imparting of energy by ionizing radiation to living matter may be characterized in general as a harmful process, and the greater the energy imparted, the greater is the injury produced.

Because the transfer of energy plays the key role in the production of injury by ionizing radiation, all measurements and calculations to evaluate the hazard from ionizing particles have, as their initial object, the determination of the energy imparted by the ionizing particles to the region of concern. To talk quantitatively about energy imparted by radiation, we need to define the concept of radiation dose. Dose is the amount of energy per unit mass absorbed by tissues in our body when exposed to radiation. So, the biological effect of radiation is proportional in some way to the radiation dose.

We know that large doses of radiation can kill living cells. In radiation therapy, this effect is used as a treatment to deliberately kill cancer cells [Johns and Cunningham, 1983]. The effects on humans of low doses of radiation (less than 25 rad) similar to those delivered during common diagnostic x-ray examinations are not immediately noticeable. But during the last 30 years, much information has been amassed about the biological effects of radiation [Gofman and O'Connor, 1985]. Now we know the risks of common diagnostic x-ray examinations are small, and large

populations of individuals must be studied to observe the effects. Furthermore, radiation effects have a long latent period; for some effects, as long as 20 years may elapse between the radiation exposure and the appearance of the related disease [Hale and Thomas, 1985].

For radiation-safety considerations, the most radiosensitive organs in the body are active bone marrow (because of the risk of induction of leukemia), testes, ovaries, uterus (embryo), female breasts and thyroid [Rosenstein, 1976]. To evaluate the small, but still existent risks from radiographic examinations, we need information about the doses to these organs from typical examinations. The purpose of this project is to determine the doses delivered to these sensitive organs as a result of common radiographic procedures. The significance of this work will hopefully be the reduction of population doses from medical x-ray examinations as a result of a knowledge of radiation doses currently administered.

Chapter 2

Literature Review

2.1 Background Knowledge of X-Ray

2.1.1 X-Ray Production

X-ray are produced when electrons accelerated from the cathode strike the anode. Two processes contribute to x-ray production:

Bremsstrahlung

Characteristic x-ray production

Bremsstrahlung is the German word for "braking radiation". A moving electron gives off this radiation whenever it stops. When an electron is stopped by the nuclei in the anode, some of the electron is converted to x rays and most is converted to heat. At diagnostic energies about 99% of the electron energy is converted to heat and only 1% of the energy appears as x rays [Christensen *et al.*, 1978].

X-Ray Energies

Even though all electrons striking the anode have the same energy, the Bremsstrahlung process produces x rays with many different energies. Figure 2.1

presents a typical x-ray spectrum produced by Bremsstrahlung. The x-ray intensity is plotted against the x-ray energy.

Bremsstrahlung x rays range in energy from zero to a maximum energy equal to the energy of the bombarding electrons. X-ray production via the Bremsstrahlung process increases with increasing energy of the bombarding electron beam as well as increasing atomic number of the target. Most of the low energy photons cannot penetrate the wall of the x-ray tube. The straight line illustrates an x-ray spectrum produced at the anode. The curve illustrates the x-ray spectrum emitted from an x-ray tube.

Characteristic X Rays

Characteristic x rays are produced by transitions between electron orbits. The difference in the binding energies of the two orbits is released as an x-ray photon. Because these orbital energies are unique for each atom, the x rays are characteristic of the particular atoms. Figure 2.2 presents an x-ray spectrum obtained from the bombardment of a tungsten target.

Variation of X-Ray Output with mA

Changes in the number of electrons bombarding the anode (mA) changes only the number of x rays not the energy distribution (shape of x-ray spectrum) nor the maximum energy of x rays. Figure 2.3 illustrates the change in x-ray spectrum with mA.

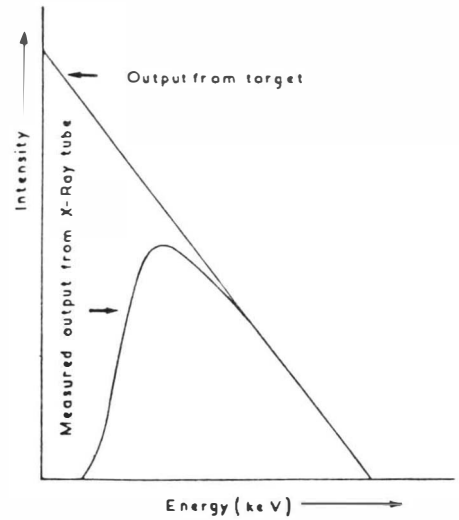


Figure 2.1: Energy spectrum of x rays produced by Bremsstrahlung [From Gifford, 1984]

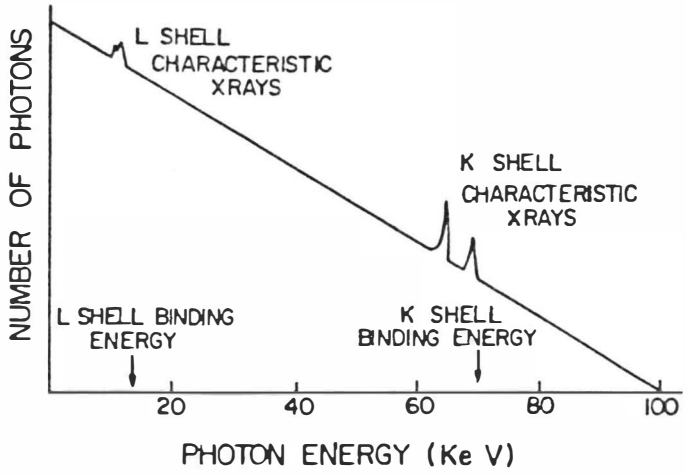


Figure 2.2: Energy spectrum produced by 100 keV electrons on tungsten [From Kelsey, 1985]

Variation of Intensity with kVp

Figure 2.4 illustrates the effect of changing the kVp on the intensity of the x rays emitted from the tube. As the kVp is increased, both the energy of the highest energy photons and the number of photons at all energies increase. Notice that very few of the x-ray photons in the beam have energies equal to the applied kVp.

Effective Filtration on the Beam

Figure 2.5 illustrates the effect of added filtration on the x-ray beam. The straight line indicates the x-ray spectrum produced at the anode. Most of the very low energy x rays are removed from the beam by the inherent filtration of the x-ray tube wall and collimator. Adding filtration reduces the number of photons at all energies but the lower energy photons are reduced proportionately more than higher energy photons. Most of the low energy photons contribute nothing to the diagnosis because they are absorbed in the body of the patient. By adding filtration, the penetrating ability of the x-ray beam is increased and patient dose is reduced. State and Federal regulations require at least 1.5 mm Al filtration for 70 kVp x-ray beams and at least 2.5 mm Al filtration for x-ray beam energies greater than 90 kVp [Kelsey, 1985].

2.1.2 X-Ray Interaction

The intensity of a monoenergetic x-ray beam passing through a layer of attenuating material depends on the thickness and type of material. If successive layers of attenuating material are added to the beam as shown schematically in figure 2.6,

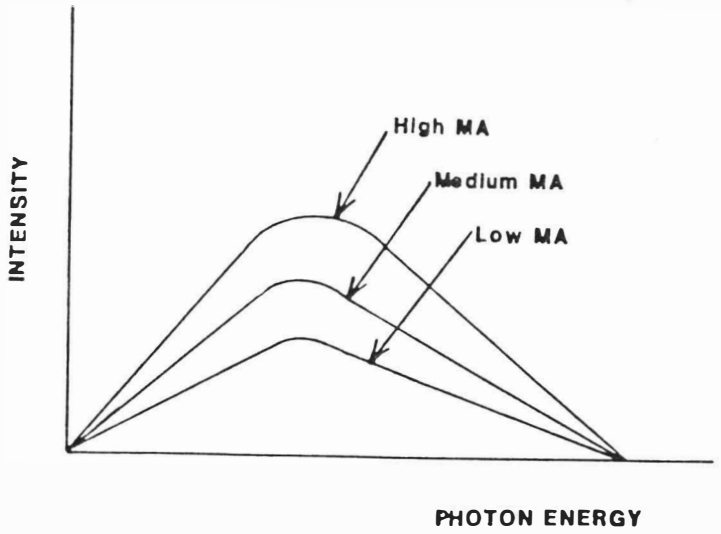


Figure 2.3: Variation of intensity with changes in mA [From Kelsey, 1985]

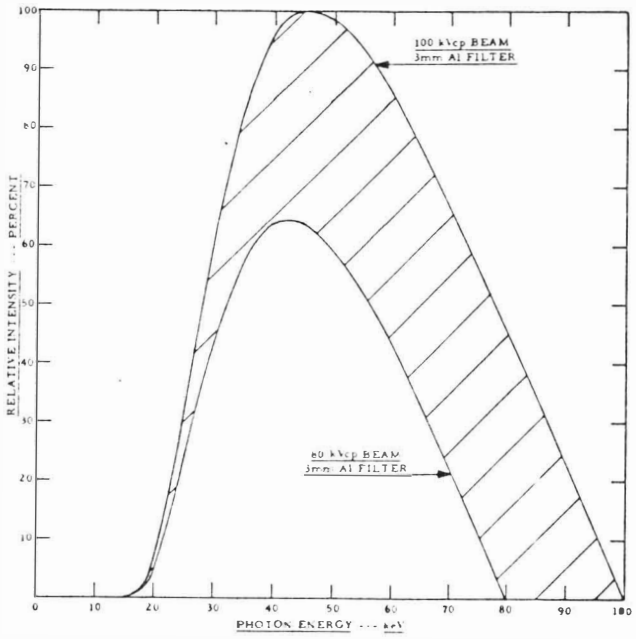


Figure 2.4: Effect of changing kVp on x-ray spectrum [From Stanton, 1969]

and the transmitted beam intensity change $\Delta I/I$ is a constant for a constant added thickness Δx. That is:

$$\Delta I = -I \cdot \mu \cdot \Delta x$$

Where ΔI is the change in intensity, I is the intensity, μ is the "linear attenuation coefficient" and Δx is the added thickness of material. The minus sign indicates a decrease in intensity. This equation can be integrated to give

$$I = I_0 \cdot e^{-\mu x}$$

The linear attenuation coefficient, μ, is measured in units of /cm. It gives the fractional reduction of x-ray intensity per cm of attenuating material. Figure 2.7 presents the transmitted intensity as a function of added thickness for a monoenergetic beam.

Half-Value Layer

The half-value layer (HVL) is defined as the amount of material which must be added to the x-ray beam to reduce the original intensity by a factor of two. It is one of the most important parameters about x-ray, because it presents the quality of the beam. The half-value layer can be expressed in terms of the attenuation coefficient as:

$$HVL = \frac{0.693}{\mu}$$

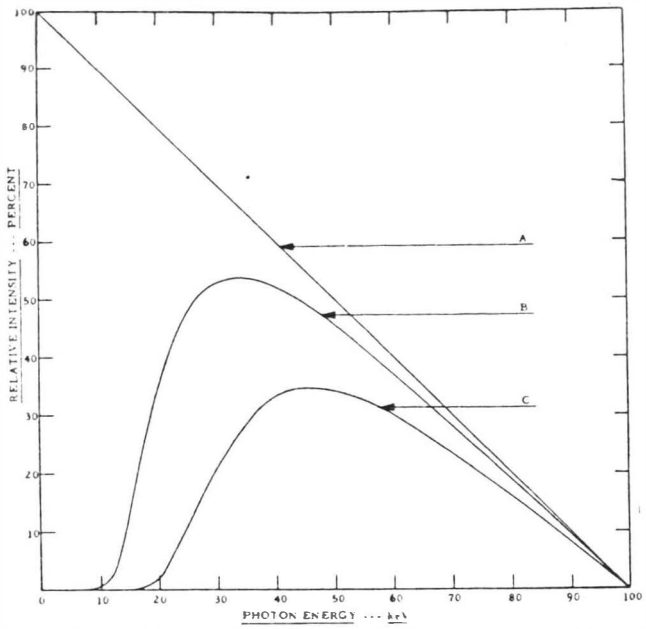


Figure 2.5: Effect of changing filtration on x-ray spectrum. A. As produced within the tube. B. In beam leaving tube, after traversing the inherent filtration of the tube and its housing. C. In beam reaching patient, after traversing both inherent filtration and external filter [From Stanton, 1969].

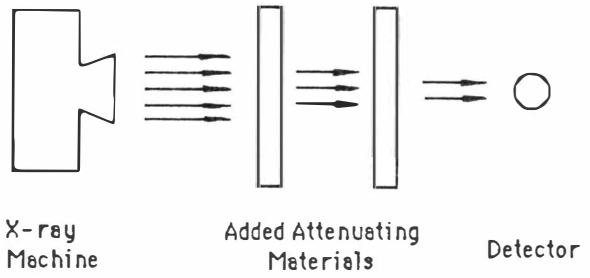


Figure 2.6: Simple attenuation experiment

First and Second Half-Value Layer

The half-value layer of an x-ray beam is defined as the amount of material required to attenuate the original intensity I_0 of the beam to one half its original value ($I_0/2$). The second half-value layer is defined as the amount of material required to reduce the beam intensity by an additional factor of two (to $I_0/4$). If all the x rays have the same energy, then the first and second HVL's are the same as shown in Figure 2.7.

The actual x-ray beam contains a mixture of x-ray energies, so the first and second HVL's will be different. That is because when an x-ray beam passes through the body, more low energy— "softer" x rays, are absorbed by body tissues than higher energy x rays. The penetrating ability of the beam increases as it passes through more tissue because relatively more of the lower energy photons are removed from the x-ray beam. The second half-value layer is always greater than the first half-value layer for diagnostic x-ray beams. Only with a monoenergetic beam are the first and second HVL's equal. Figure 2.8 presents a plot of intensity as a function of added material (AL) for a multienergetic x-ray beam.

Tissue Half-Value Layer

The half-value layer in tissue of most diagnostic x-ray beams is between 3 and 6 cm. This means that a change in patient thickness of 5 cm requires an mAs change by about a factor of two. With an average patient, only about a few percent of the incident x rays emerge from the patient [Wagner, 1985].

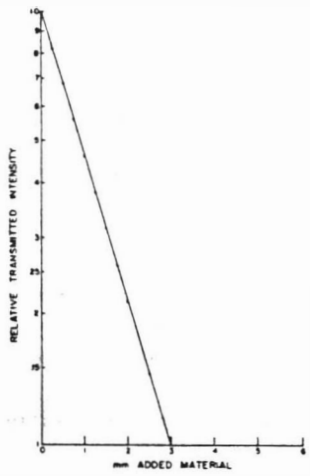


Figure 2.7: Transmitted intensity of a monoenergetic x-ray beam as a function of added thickness of aluminum [From Kelsey, 1985]

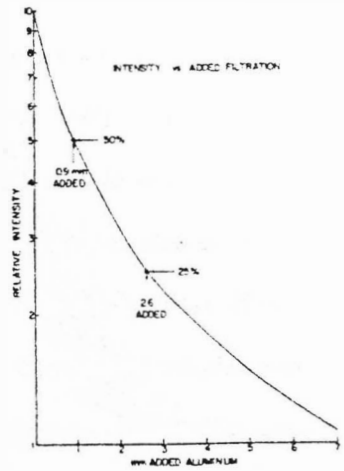


Figure 2.8: Transmitted intensity of a multi-energy x-ray beam as a function of added thickness of aluminum [From Stanton]

X-Ray Interactions in Matter

There are five ways in which x rays can interact with matter. They are:

Coherent Scattering

Photoelectric Interactions

Compton Scattering

Pair Production Interactions

Photodisintegration Interactions

The total attenuation coefficient μ_{total} is a combination of these interactions

$$\mu_{coh} + \mu_{pho} + \mu_{com} + \mu_{pair} + \mu_{dis}$$

μ_{pair} and μ_{dis} are zero below 1 MeV and so do not participate in the interactions at diagnostic energies [Johns and Cunningham, 1983].

Figure 2.9 and 2.10 give a qualitative demonstration of a Monte Carlo simulation of the random nature and widespread distribution of x-ray scattering in the phantom [Doi and Chan, 1980]. A narrow x-ray beam is incident normal to the phantom surface from top. An incident photon may have the first interaction along the central beam axis or may pass through the phantom. When the first interaction occurs, the location is indicated by a dot. If the effect is photoelectric, the photon is absorbed totally. If Compton or coherent scattering occurs, the scattered photon travels inside the phantom in a direction which is determined by the statistical nature of the scattering process. When the scattered photon undergoes a second interaction, the location is indicated by another dot. The scattering process is traced until all photon energy is absorbed by the phantom or the scattered photon escapes

the phantom.

Exposure and Absorbed Dose

X rays cause ionization as they pass through air. The number of ions created is dependent on the number and energy of x rays passing through it. Exposure is the amount of ionic charge created per unit mass of air by x rays. It is measured in units called roentgen (R). One roentgen of x rays produces over 2 billion ion pairs per cubic centimeter of exposed air at standard temperature and pressure.

Although exposure is an adequate quantification of diagnostic x rays emitted from a source, a more relevant measurement for biologic damage is the energy deposited in tissue through the interaction of ionizing radiations. Absorbed dose is the energy imparted to tissue per unit mass of tissue. It is measured in units of rad. One rad is strictly defined as the deposition of 0.01 joules of energy per kilogram of tissue.

Tissue-Air Ratio (TAR)

The right side of Figure 2.11 shows a beam of radiation incident on a phantom and the left side shows the same beam with the phantom removed. The tissue-air ratio (T_a) is the ratio of dose at X to the dose at X' and is represented by:

$$T_a(d, A_d, h\nu) = D_X / D_{X'}$$

It depends on the depth d below the surface of the phantom, the area A_d of the beam measured at depth d, and on the quality of the radiation, represented here by $h\nu$. The dependence on these variables is indicated by including them within

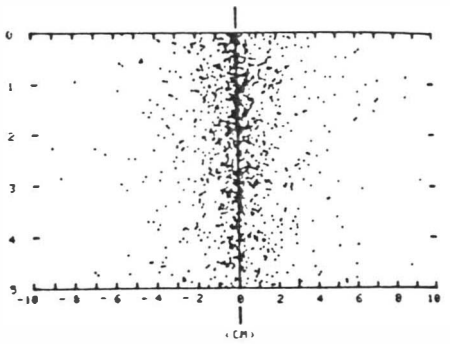


Figure 2.9: Lateral view of a 5-cm-thick,50% water/50% fat phantom. A narrow x-ray beam of 28.5 keV is incident normal to the phantom surface from the top. Dots represent interaction sites for 2,000 incident photons [From Doi and Chan, 1980].

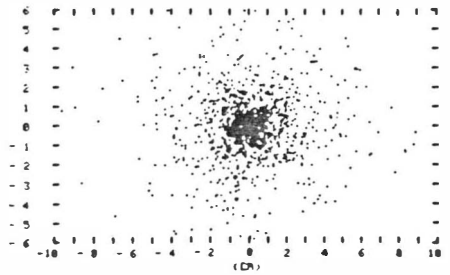


Figure 2.10: Top view of the phantom [From Doi and Chan, 1980]

parentheses after the symbol T_a.

The meaning of tissue-air ratio, as applied to a patient, is illustrated in Figure 2.12. Figure 2.12(a) shows a circular beam of radiation having cross-sectional area A_d at a distance F_a from the source. The beam is in air. After a given irradiation let the dose to a small mass of tissue on the axis be $D_{X'}$. The solid line contour in Figure 2.12(b) represents a patient in place being irradiated by the same beam. The depth of tissue overlying the axis is d and the dose at this point, D_X, may be calculated directly by the relation:

$$D_X = D_{X'} \cdot T_a(d, A_a, h\nu)$$

The tissue-air ratio is a very useful tool in describing dosimetric information. TARs are convenient because they are independent of the source-to-skin distance; therefore, one table is generally applicable to many examination geometries.

2.2 Estimation of Patient's Absorbed Dose

2.2.1 Estimation of Absorbed Dose in Radiographic Examination by Monte Carlo Simulation

When a patient is placed in a photon beam of known quality and quantity, the photons will be absorbed and scattered, and both the quality and quantity of the beam will be changed. Those x rays that give up all their energy are "absorbed" by the tissue and no longer exist. X rays that give up only part of their energy are diverted from their line of travel. These are referred to as scattered x rays. The deposition of energy by scattered radiation, therefore, can occur outside the primary

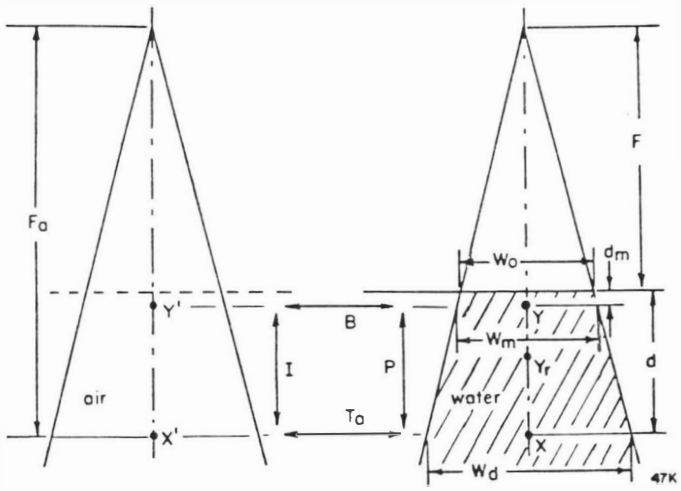


Figure 2.11: Diagram to illustrate the meaning of TAR [From Johns and Cunningham, 1983]

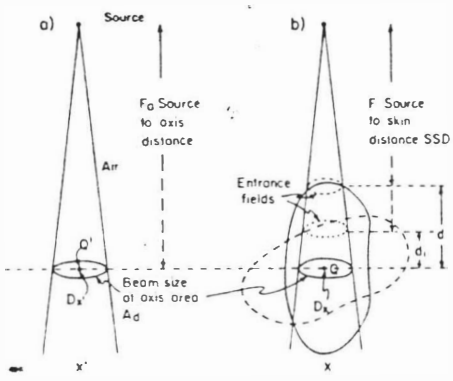


Figure 2.12: (a and b) Schematic diagram to illustrate the use of TAR in dose calculations [From Johns and Cunningham, 1983]

field of x rays. So, only a few percent of the x rays entering patient actually get through to make the image [Figure 2.13].

Here, we are concerned with the absorbed doses received by sensitive organs in the patient. Since it is almost impossible to measure this directly, it must be calculated. Monte Carlo calculation is by far the most successful method for the simulation of the stochastic process of particle transport in a scattering medium because individual interactions can be recorded and multiple-scattering events can be traced [Chan and Doi, 1984][Chan and Doi, 1985].

Monte Carlo radiation transport technique simulates and records stochastically the energy deposition of x-ray photons as they undergo physical interactions in a mathematically described anthropomorphic phantom. This is accomplished by following the radiation transport of the energy of the incident photons using distributions known in radiation physics and recording the resulting energy depositions at the sites of interaction [Chan and Doi, 1983]. The scattering properties of a given medium (e.g., tissue) are calculated by equations that are known to describe accurately the physical scattering processes in the medium. Stochastic processes are simulated by probability density functions and an algorithm that generates randomly distributed numbers. When the technique is applied to simulate the interaction of diagnostic x rays in human tissue, the physical processes treated are the photoelectric effect and Compton scattering [Rosenstein, 1976].

The anthropomorphic phantom represents a reference human and is heterogeneous [Figure 2.14 and 2.15]. It consists of skeletal, lung, and tissue regions with corresponding compositions and densities. The important human organs are math-

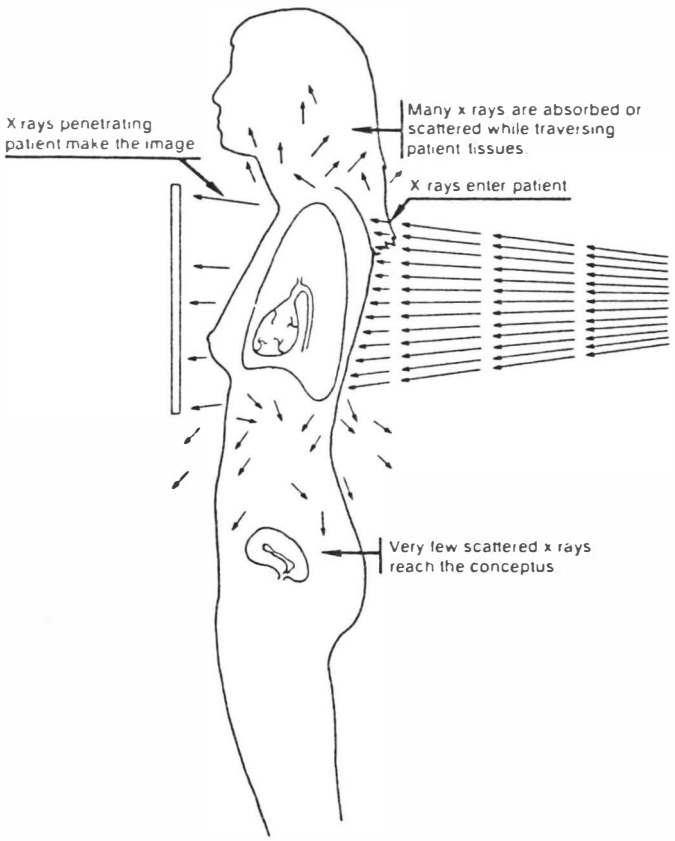


Figure 2.13: Diagram to illustrate the x-ray examination [From Wagner, 1985]

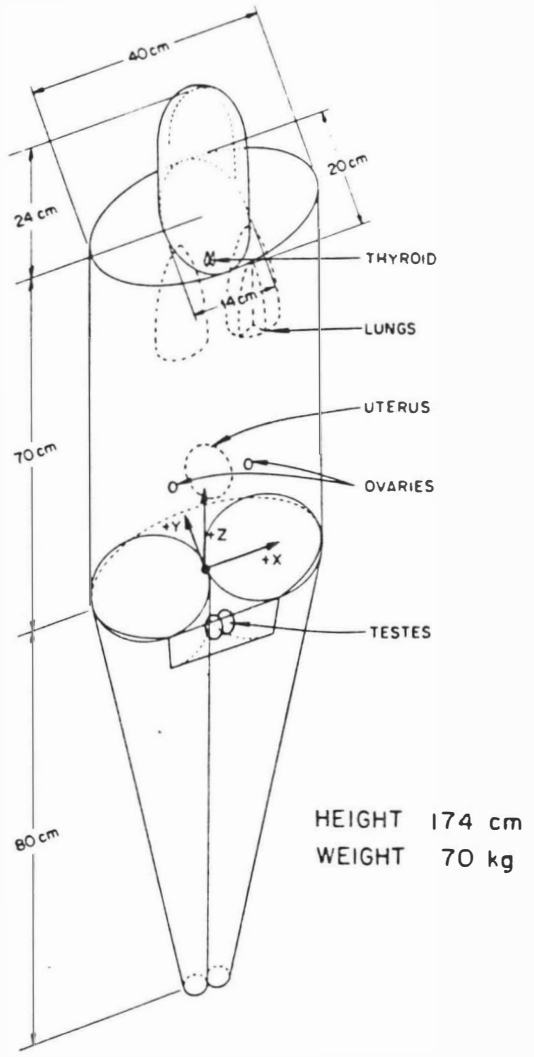


Figure 2.14: The adult reference patient [From Rosenstein, 1976]

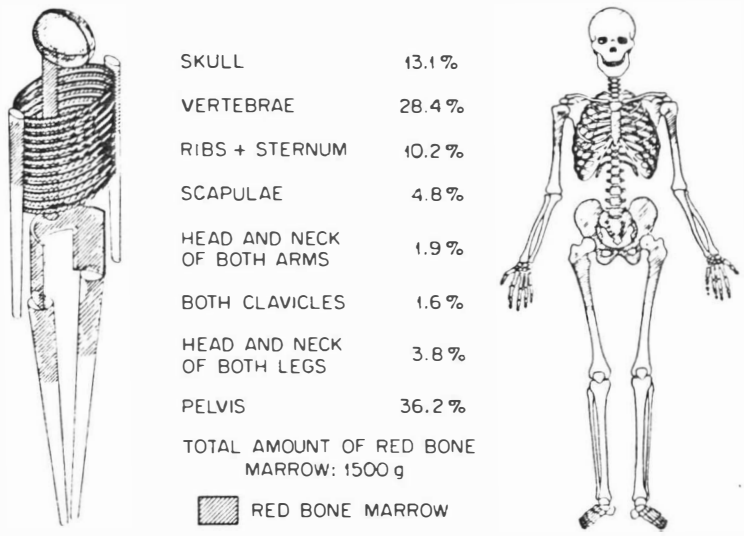


Figure 2.15: Idealized model of the skeleton for computer calculation (left) and a more realistic representation (right) with percentages of red bone marrow found in the shaded portions of the bones. The clavicles and scapulae for the model are not shown in the figure, but are included in the calculation [From Rosenstein, 1976].

ematically formulated within the phantom and are the interaction sites of interest. Energy depositions are accumulated at these sites. The average absorbed dose in the organ of interest is obtained directly by dividing the accumulated energy by the mass of the organ. The basic data are obtained in terms of the tissue-air ratio, which is the average absorbed dose in the organ per unit exposure (free-in-air) at the organ reference plane.

The details of the Monte Carlo technique and the phantom, as applied generally with diagnostic x-ray photon energies, can be found in [Chan and Doi, 1983] and [Rosenstein, 1976].

2.2.2 Estimation of Absorbed Dose in CT Examination

Doses in Computed Tomography (CT) examinations are important since their levels could be high depending on the operation conditions. Newer CT systems can operate at high mAs and have narrow scanning slice available. Very high doses can be produced by the use of these capabilities. Therefore, it is important for practitioners to be aware of the doses associated with their CT techniques.

Because of narrowly collimated x-ray beams, the variety of scanning motions, the number of scans in the procedure and different operating conditions, the method for describing the CT doses is quite different from that for estimating the radiographic doses. Figure 2.16 and 2.17 show the complexity of the dose distributions resulting from a single CT scan. In Figure 2.16, the shaded region indicates the portion of a cylindrical dosimetry phantom, subjected to direct irradiation by the moving, narrowly collimated x-ray beam during a CT scan. The line labeled

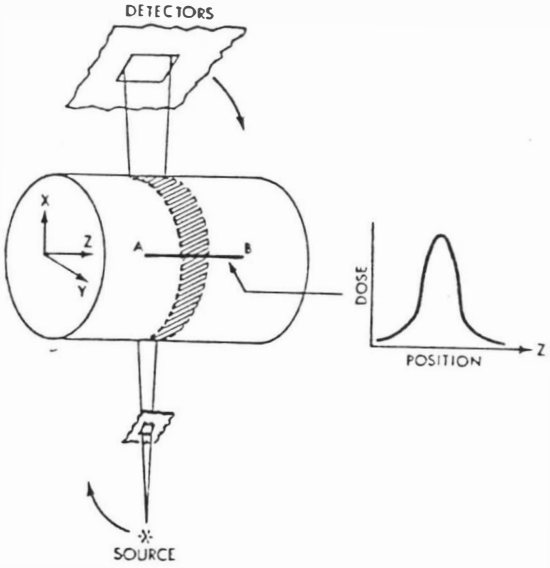


Figure 2.16: Illustration of CT system geometry, coordinate system used, and typical dose distribution of a single scan of CT system [From Shope *et al.*, 1981]

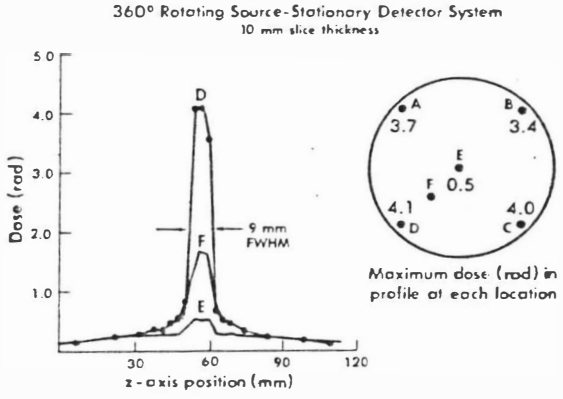


Figure 2.17: Dose profiles and maximum doses measured in profiles [From Shope *et al.*, 1981]

AB on the cylinder parallel to the z axis is an example of a line along which the dose profile could be measured as a function of position. In Figure 2.17, the letters indicate the locations, with respect to the phantom cross sections shown at right, where profile shown on the left is measured.

In practice, few diagnostic CT procedures consist of only one scan. Clinically, most CT procedures consist of a series of scans separated by distances on the order of the selected slice thickness. Figure 2.18 shows the dose profiles resulting from multiple scan series. The single scan profile, labeled with the number 1, is a typical profile which would be measured on or near the surface of a phantom in a scan procedure having a slice thickness T as specified by the CT manufacturer. The multiple scan profiles are formed by superposition and summation of the single scan profiles contributing to the multiple scan procedure. As the number of single scans is increased, the average dose of the multiple scan dose profile reaches a limiting value. This value is reached when the first and last scans of the series are sufficiently separated from the central scan of the series so that they don't contribute any significant dose to the region of central scan. Shope [Shope *et al.*, 1981] defines it as the multiple scan average dose (MSAD) for a multiple scan dose profile, denoted by M. It is given by the equation:

$$M_{N,I} = (1/I) \int_{-I/2}^{I/2} D_{N,I}(Z) dz$$

where $D_{N,I}(Z)$ is the dose as a function of position (X,Y constant) for a multiple scan dose profile consisting of N scans separated by a constant distance of I [see Figure 2.19(b)]. It is a proper estimation of the doses delivered in CT procedures

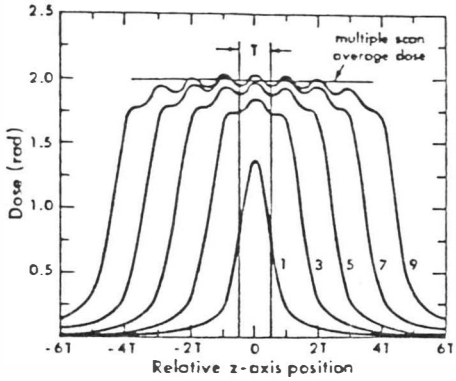


Figure 2.18: Simulated dose profiles for multiple scan series consisting of 1, 3, 5, 7, or 9 scans [From Shope *et al.*, 1981].

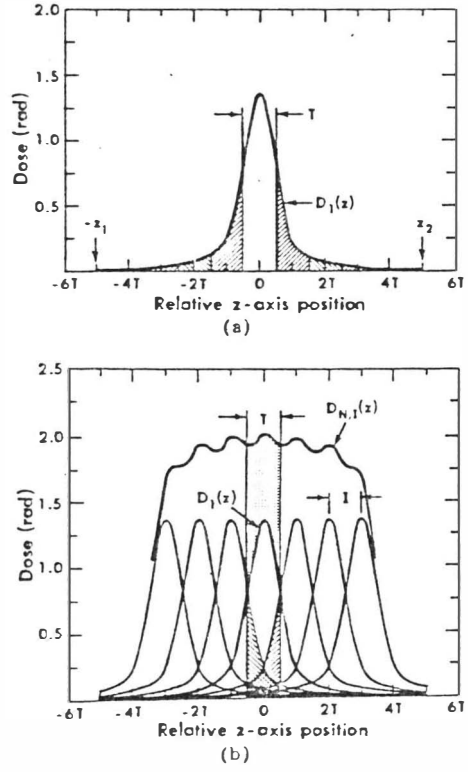


Figure 2.19: (a) Simulated dose profile $D_1(Z)$ for a single scan with slice thickness T. (b) Simulated dose profile $D_{N,I}(Z)$ from summation of 7 scans separated by a distance I equal to the slice thickness T [From Shope *et al.*, 1981].

consisting of multiple scans. Instead of measuring MSAD, Shope [Shope *et al.*, 1981] proposed a convenient way of predicting it using the dose descriptor — the computed tomography dose index (CTDI), which is denoted as C and defined by

$$C = (1/T)\int_{-\infty}^{\infty} D_1(Z)dz$$

where $D_1(Z)$ is the dose as a function of position along the Z axis for a single scan dose profile at a given point (x,y). T is the slice thickness [see Figure 2.19(a)].

Mathematically and experimentally, Shope *et al.* proved the relation between MSAD and CTDI:

$$C = M_{N,T}$$

The above equation is valid when the series consists of a large number of scans (greater than 8) separated by the slice thickness. It is very useful because the CTDI determined from single scan dose profile can be used to predict the dose in the central region of a multiple scan procedure.

Since a pencil-shaped ionization chamber (pencil chamber) can effectively average the radiation incident along its length [Suzuki, 1978], CTDI can be easily measured using a pencil chamber to get quick, reliable estimates of the radiation dose from CT procedures consisting of a series of adjacent scans.

Chapter 3

Materials and Methods

3.1 Estimating the Absorbed Dose in Radiographic Examination

In this project, a computer program provided by the Center for Devices and Radiological Health is used to estimate the absorbed doses to several tissues of a reference patient for a specified x-ray projection using tissue-air ratios generated previously by a Monte Carlo technique [Rosenstein, 1976][Peterson and Rosenstein, 1989]. The program is written in VAX-FORTRAN and uses formatted and unformatted direct access sequential data files. All subroutines used by the program are also in VAX-FORTRAN. A system flow diagram for the computer program is shown in Figure 3.1.

The program was originally developed for radiographic projections and its principal application has been to radiography. A variety of output tables which list the tissue doses for a projection can be selected by the user. The tissues included are the lungs, active bone marrow, ovaries, testes, thyroid, uterus, total trunk (excluding skeletal and lung tissues), female breasts. Also, many common radiographic projections can be specified in the program by projection code.

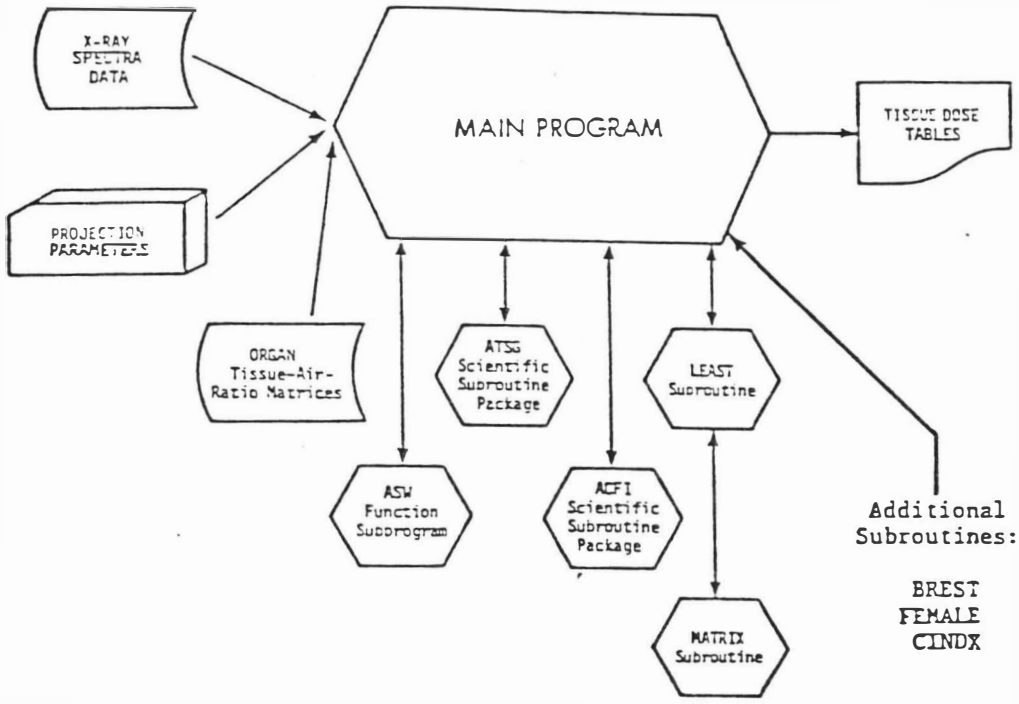


Figure 3.1: The flow diagram of computer program [From Peterson, 1989]

The data required to apply the computer program to estimate absorbed dose to those tissues are:

Projection and view (limited to anteroposterior (AP), posteroanterior (PA), and lateral)

X-ray field size at image receptor

X-ray field location relative to anatomical landmarks

Exposure (free-in-air) at skin entrance (ESE)

Beam quality (kVp and HVL)

Source-to-image receptor distance (SID)

Among these parameters, only ESE and HVL values are not readily available at the x-ray examinations. So they need to be determined before running the computer program.

3.2 Measuring the Phantom Dose in CT Head Scan Procedure

A CT unit, GE 9800 in MCV Hospital, was involved in the study. Data were collected using a standard dosimetry head phantom and a MDH model 10x5-10.3 CT pencil chamber connected with a MDH model 1015 x-ray monitor. The phantom has several holes parallel to the axis of CT scan rotation to allow the positioning of the pencil chamber at the center of the phantom and at four sites 1 cm inside the surface of the phantom. The focus of the study is to evaluate the effect of changes in technical parameters on the phantom doses in standard CT head procedures.

As previously described [Gagne *et al.*, 1983], MSAD can be computed using

the chamber reading in a single scan as:

$$MSAD = (f \cdot C \cdot M \cdot L)/T \tag{3.1}$$

where f is R-rad conversion factor, which is 0.78 (rad/R) since a 70 keV effective energy of CT x-ray beam is assumed [Gagne *et al.*, 1983]; C is chamber calibration factor, which is 2 in the study; M is chamber reading (R); L is chamber length, which is 100 mm; T is slice thickness (mm).

Chapter 4

Results

4.1 Absorbed Doses in Common Radiographic Examinations

4.1.1 Determining ESE and HVL

As stated previously, ESE and HVL need to be determined before doses could be estimated using the computer program. The most reliable procedure for determining ESE and HVL is to physically measure these values of each x-ray machine for each examination technique used. However, this is normally impractical in a busy clinical setting. And for the quality control purpose, generally only one technique (usually at 80 kVp, 40 inches) of each x-ray machine is checked for output and HVL. So it would be very helpful that if one knows variability in ESE and HVL as a function of other known parameters, then the ESE and HVL for any set of technique factors can be calculated using the single test technique.

Determining ESE

McGuire [McGuire, 1986] proposes a equation to estimate exposures for other technique factors from a single test exposure technique:

$$mR_0 = mR_t \cdot CF \cdot \frac{mAs_0}{mAs_t} \cdot \left(\frac{dist_t}{dist_0}\right)^2$$

where mAs_t, mR_t and $dist_t$ are parameters used and acquired in test exposure; mR_0 is estimated exposure at other parameters mAs_0 and $dist_0$ (mR_0 can be considered to be ESE if the other parameters are properly input for this purpose); CF is correction factor depending on the filtration of the machine and kVp.

Computation of this equation is straightforward except for determination of CF. Finding this parameter (and hence ESE) for other techniques from a single test exposure involves a two-step process with each step possibly involving a two-way interpolation of data between curves. This is somewhat complex and tedious if done by hand.

Glaze [Glaze *et al.*, 1982] describes a method using a single test exposure for calculating patient ESE and fetal dose for common radiographic examinations. A very simple relation between output intensity and kVp is established for 3-phase x-ray machines as:

$$N = A \cdot (k)^2$$

where N and k are the output intensity and kVp respectively, A is a constant depending on the filtration of the machine.

To investigate the relation between output intensity and kVp in a general clinical setting, the data from routine quality control survey for eight 3-phase x -

ray machines in McGuire Veterans Administration (V.A.) Hospital were analysed. The output intensity is plotted against the square of kVp [Figure 4.1 and 4.2]. The solid lines are fitted by means of linear least-square method and all the correlation coefficients are greater than 0.99. According to these plots, it could be assumed that the fitting lines are intercepted with the origin. So, one could assume mR is proportional to the square of kVp. That is:

$$\frac{mR_1}{mR_2} = \left(\frac{kVp_1}{kVp_2}\right)^2$$

if the other parameters (mAs, $dist$) are kept the same.

Our data verify Glaze's equation. Also, radiological physics textbooks [Meredith and Massey, 1972] [Christensen *et al.*, 1978] report that output intensity varies according to kVp^2. So, the conclusion is in agreement with this rule of thumb. Then correction factor (CF) in McGuire's equation could be simplified as $(kVp_0/kVp_t)^2$. ESE can be easily calculated using the following equation :

$$mR_0 = mR_t \left(\frac{kVp_0}{kVp_t}\right)^2 \frac{mAs_0}{mAs_t} \left(\frac{dist_t}{dist_0}\right)^2 \qquad (4.1)$$

where as stated previously, kVp_t, mAs_t, mR_t, and $dist_t$ are parameters used and acquired in test exposure; mR_0 is estimated exposure at other parameters kVp_0, mAs_0 and $dist_0$.

Determining HVL

To characterize the change in HVL with change in kVp, a calibrated MDH model 10X5-6 ionization chamber was used in conjunction with an MDH model

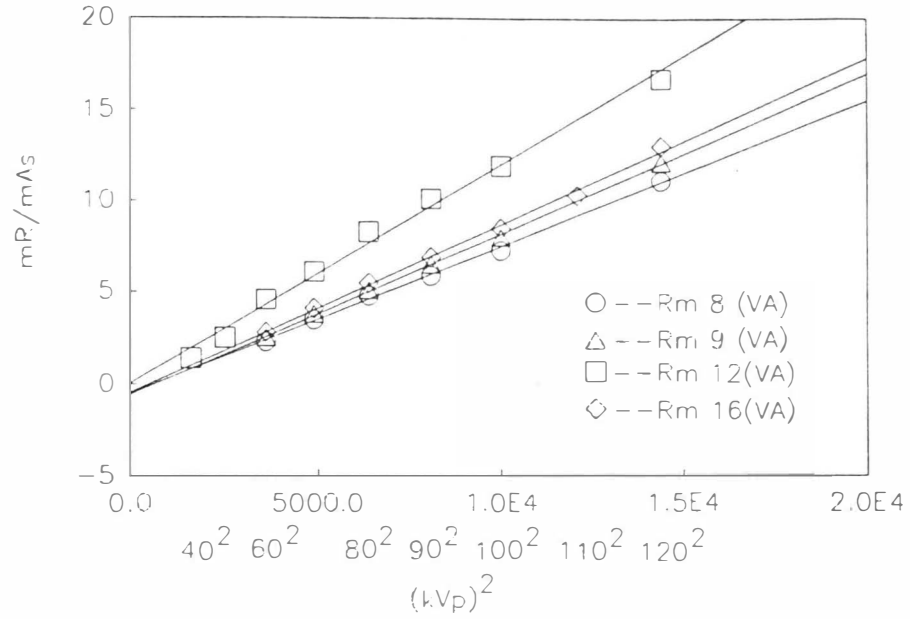


Figure 4.1: Relation between output intensity and kVp (1)

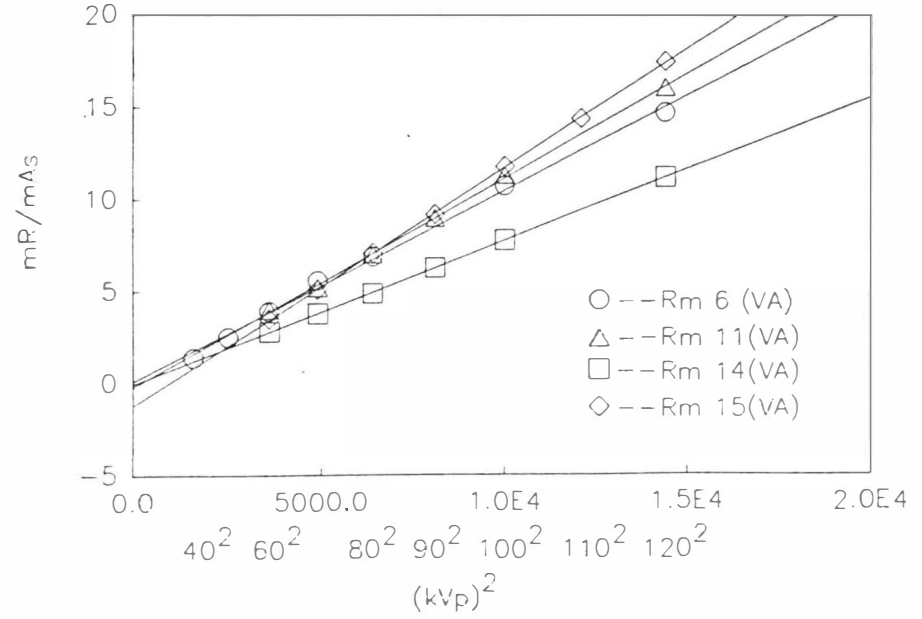


Figure 4.2: Relation between output intensity and kVp (2)

1015 x-ray monitor to measure exposures with different added thickness of Al plates in 10-kVp increments from 60 kVp to 120 kVp (except 110kVp) for four 3-phase x-ray machines in MCV and V.A. Hospitals. The accuracy of this chamber is better than ±5% in this energy range. The HVL data are shown in Table 4.1. Then HVL is plotted as a function of kVp [Figure 4.3]. The lines are fitted using the linear least-square regression and all the correlation coefficients are greater than 0.99.

With the slopes of 0.0329, 0.0359, 0.0311 and 0.0337 respectively, these lines are found to be paralleled well among each other, so a simple relation between HVL and kVp could be assumed using the average slope of the four:

$$HVL = 0.033 \cdot kVp + B \tag{4.2}$$

where B is a constant for each individual x-ray machine. Comparison of experimental points and the lines obtained using the equation shows maximum separations of ±6%. So if one pair of data of HVL and kVp is known (usually near 80 kVp in the quality control survey), other values of HVL at different kVp could be estimated by this equation.

With Equation 4.1 and 4.2 provided above, the ESE and HVL for any set of technique factors can be calculated using the single test technique which usually can be found in x-ray machine survey report. Then the computer program can be applied to estimate the absorbed doses to different organs.

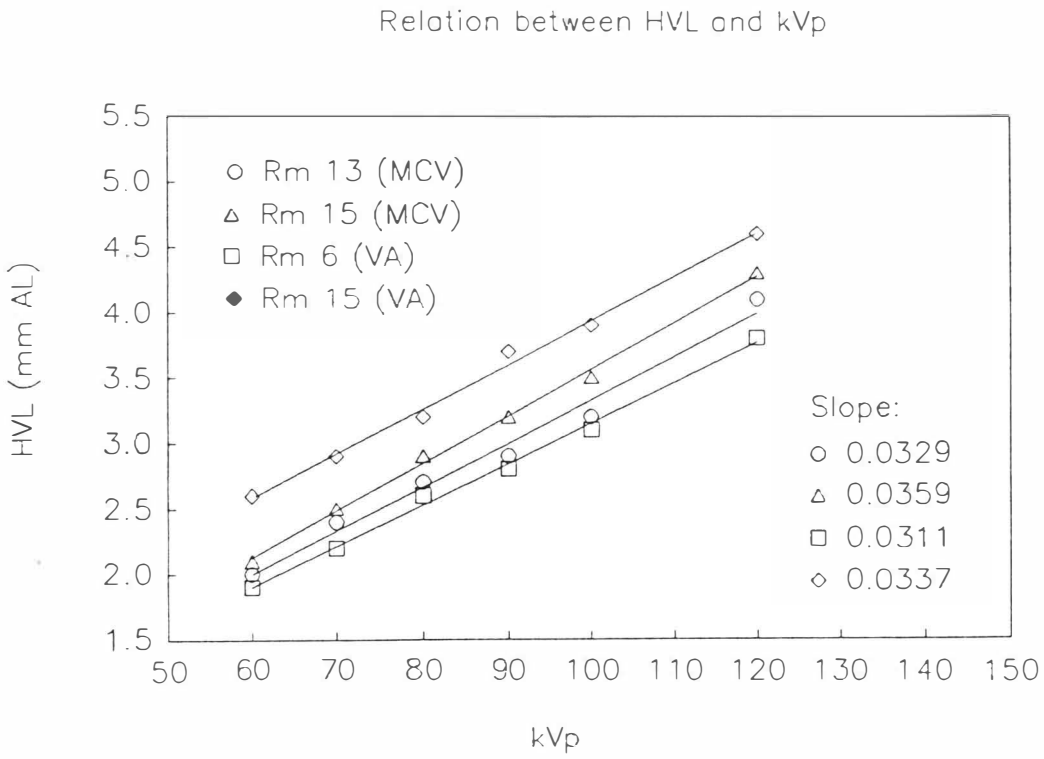


Figure 4.3: Relation between HVL and kVp

4.1.2 Doses in Common X-Ray Examinations

According to our limited measurements of 20 patients, 80% of them were found to have a body thickness (AP) of between 16 and 24 cm, and 20% over 24 cm. It is in agreement with Maillie's study [Maillie, 1982], in which he found that 85% of the patients have a AP thickness of between 15 and 25 cm. So, in this study, by observation, patient who has a AP dimension of between 16 and 19 cm is considered small; a AP dimension of between 19 and 24 cm is medium and a AP dimension of over 24 cm is large. Compared with large-sized patients, small and medium-sized patients are much closer to the reference adult model used in the computing (20 cm AP dimension, 174 cm and 70 kg). The computer program may not be applicable to large-sized patients because some large patients could have a AP thickness of over 28 cm, which varies significantly from the computing model. Therefore, only doses to small and medium-sized patients are estimated using the computer program. Also, the errors caused by the differences of thickness between the computing model and actual patients could be cancelled out to some extent by including both small and medium-sized patients in calculating the average doses to average-sized patients.

The technical parameters and absorbed doses to different organs for 12 common radiographic examinations in MCV Hospital are shown in Appendix A. The techniques used for large-sized patients are also listed to show how large mAs (thus the exposure) could be. All the machines involved in the study are 3-phase machines. The technical parameters (except ESE and HVL) were recorded at x-ray examinations for clinical adult patients in MCV Hospital where the x-ray machine

survey data are available (see Appendix B). After calculating the ESE and HVL for each examination in specific x-ray room using Equation 4.1, 4.2 and the corresponding data from the survey report in Appendix B, the absorbed doses are computed. In calculating the ESE, an AP dimension of 20 cm and an lateral dimension of 34.4 cm are assumed. Also, 5 cm is allowed between the table top (or cassette holder) and the image receptor plane [Rosenstein, 1976].

Currently, most of the x-ray machines are operated with phototimers and don't give the readings of actual mAs during the examinations. Since the use of the computer program for estimating the absorbed doses requires the value of mAs in each examination for calculating ESE, the majority of the data in the study were recorded in Room 15 which has a x-ray machine of Rapido 400 (Picker International) with after-shot mAs reading.

Table 4.2 and 4.3 show the average absorbed doses to the average-sized reference patient in 12 routine radiographic procedures in MCV Hospital.

According to the tables, the most significant average doses to different organs are shown below:

lungs — T. Spine (LAT) examinations (218 mrad for man and 228 mrad for woman);

Active Bone Marrow — L. Spine (LAT) examinations (70 mrad for man and 74 mrad for woman);

Thyroid — C. Spine (AP) examinations (193 mrad for man and 196 mrad for woman);

Testes — Femur (AP) examinations (210 mrad);

Breasts — T. Spine (AP) examinations (322 mrad);

Ovaries — L. Spine (LAT) and L. Spine (AP) examinations (146 mrad and 137 mrad);

Uterus — L. Spine (AP), KUB (AP) and Pelvis (AP) examinations (158 mrad, 151 mrad and 144 mrad respectively).

4.2 Phantom Doses in CT Head Scan Procedures

The data are grouped in Table 4.4 to 4.10 in order to evaluate the effect on phantom dose of changes in technical parameters of CT scan. In the study, CT construction matrix is always 512 and field of view is 25 cm. MSAD is calculated using Equation 3.1.

The results show that surface doses (Position B to E) are almost the same as the center doses (Position A); There is no significant changes in doses with changes in slice thickness (except 1.5 mm slice which is rarely used in CT scan); As expected, doses have linear relation with either mA (except 10 mA which has no clinical meaning) or time of scan; CT resolution doesn't have effect on dose. There is no simple relation between kVp and MSAD.

Room No.	kVp					
	60	70	80	90	100	120
13 (MCV)	2.0	2.4	2.7	2.9	3.2	4.1
15 (MCV)	2.1	2.5	2.9	3.2	3.5	4.3
6 (VA)	1.9	2.2	2.6	2.8	3.1	3.8
15 (VA)	2.6	2.9	3.2	3.7	3.9	4.6

Table 4.1:: HVL (mm) at different kVp

Exam (View)	Sex	No.of Pat.	Average Absorbed Dose (mrad) (S.D.)							
			Lungs	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
Chest (PA)	M	14	16 (3.9)	4.6 (1.1)	1.5 (0.4)	5.3 (1.2)	(+)			
	F	13	15 (3.5)	3.7 (0.8)	1.5 (0.3)	4.2 (0.9)		2.5 (0.6)	0.1 (0.0)	0.1 (0.0)
Chest (LAT)	M	12	18 (6.8)	4.6 (1.7)	9.5 (3.6)	6.9 (2.6)	(+)			
	F	11	20 (4.6)	3.4 (0.8)	8.9 (2.1)	5.5 (1.3)		(a)	0.1 (0.0)	0.1 (0.0)
L. Spine (AP)	M	10	46 (29)	26 (13)	0.2 (0.1)	91 (47)	2.6 (1.5)			
	F	9	49 (17)	23 (13)	0.2 (0.1)	91 (31)		(a)	137 (48)	158 (76)
L. Spine (LAT)	M	8	33 (17)	70 (23)	0.3 (0.1)	149 (64)	2.3 (1.0)			
	F	9	41 (16)	74 (29)	0.3 (0.1)	159 (60)		(a)	146 (57)	97 (38)
C. Spine (AP)	M	9	4.3 (1.1)	3.8 (0.9)	193 (47)	4.9 (1.2)	(+)			
	F	10	4.7 (1.0)	4.0 (1.0)	196 (55)	5.1 (1.2)		(a)	(+)	(+)
C. Spine (LAT)	M	10	4.8 (1.4)	4.4 (1.2)	11 (5.3)	3.4 (0.9)	(+)			
	F	8	6.5 (2.6)	6.1 (2.6)	14 (5.7)	4.7 (2.0)		(a)	(+)	(+)

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes

Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad

(a): Not calculated, however breasts are near or partially in x-ray field.

(b): Dose is negligible -- x-ray field completely outside of breast region.

Table 4.2:: Average absorbed doses in common radiographic examinations (1)

Exam (View)	Sex	No.of Pat.	Average Absorbed Dose (mrad) (S.D.)							
			Lungs	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
T. Spine (AP)	M	7	167 (45)	17 (4.6)	46 (12)	49 (13)	(+)			
	F	5	125 (40)	14 (4.4)	46 (15)	39 (13)		322 (103)	0.5 (0.2)	0.4 (0.1)
T. Spine (LAT)	M	7	218 (122)	39 (22)	11 (5.9)	77 (43)	(+)			
	F	6	228 (105)	29 (13)	9.8 (4.6)	59 (27)		(a)	0.4 (0.2)	0.4 (0.2)
KUB (AP)	M	12	6.6 (2.4)	21 (7.6)	0.1 (0.05)	79 (30)	9.4 (3.4)			
	F	11	6.4 (2.7)	21 (9.3)	0.1 (0.05)	73 (30)		(b)	112 (46)	151 (62)
Pelvis (AP)	M	11	0.4 (0.1)	17 (5.7)	(+)	70 (20)	37 (11)			
	F	8	0.5 (0.2)	18 (7.1)	(+)	73 (29)		(b)	107 (41)	144 (56)
Femur (AP)	M	5	(+)	1.7 (0.6)	(+)	5.7 (1.9)	210 (69)			
	F	10	(+)	1.6 (0.6)	(+)	4.9 (2.3)		(b)	1.4 (0.7)	2.0 (1.0)
Shoulder (AP)	M	7	22 (5.3)	2.6 (0.5)	5.4 (2.2)	6.5 (1.4)	(+)			
	F	8	17 (4.0)	2.3 (0.5)	6.7 (2.2)	5.4 (1.1)		(a)	(+)	(+)

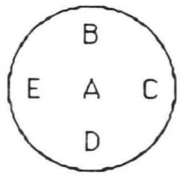
ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad

(a): Not calculated, however breasts are near or partially in x-ray field.

(b): Dose is negligible -- x-ray field completely outside of breast region.

Table 4.3:: Average absorbed doses in common radiographic examinations (2)

Position	Reading (R)	MSAD (rad)
A	0.317	4.95
B	0.358	5.58
C	0.324	5.05
D	0.309	4.82
E	0.314	4.90
Average MSAD for Position B-E		5.09



Mode of Scan: Normal;
Slice Thickness: 10 (mm);
Resolution: Tissue;
kVp: 120; mA: 170; Time: 2 (s)

Table 4.4:: Effect of changing position on MSAD

Slice Thickness (mm)	Reading (R)	MSAD (rad)
1.5	0.054	5.62
3.0	0.098	5.10
5.0	0.159	4.96
10.0	0.317	4.95

Position: A; Mode of Scan: Normal; Resolution: Tissue;
kVp: 120; mA: 170; Time: 2 (s)

Table 4.5:: Effect of changing slice thickness on MSAD

mA	Reading (R)	MSAD (rad)
10	0.002	0.03
40	0.072	1.12
100	0.184	2.87
170	0.317	4.95
200	0.357	5.57

Position: A; Mode of Scan: Normal;
Slice Thickness: 10 (mm); Resolution: Tissue;
kVp: 120; Time: 2 (s)

Table 4.6:: Effect of changing mA on MSAD

Resolution	Reading (R)	MSAD (rad)
Tissue	0.317	4.95
Standard	0.314	4.90
Detail	0.314	4.90
Bone	0.310	4.84

Position: A; Mode of Scan: Normal; Time: 2 (s);
Slice Thickness: 10 (mm); kVp: 120; mA: 170

Table 4.7:: Effect of changing resolution on MSAD

Mode of Scan	Time (s)	Reading (R)	MSAD (rad)
Half	1.2	0.189	2.95
Normal	2.0	0.317	4.95
Overscan	2.3	0.366	5.71

Position: A; Slice Thickness: 10 (mm);
Resolution: Tissue; kVp: 120; mA: 170

Table 4.8:: Effect of changing mode of scan on MSAD

Time (s)	Reading (R)	MSAD (rad)
2	0.317	4.95
4	0.627	9.78

Position: A; Mode of Scan: Normal;
Slice Thickness: 10 (mm); Resolution: Tissue;
kVp: 120; mA: 170

Table 4.9:: Effect of changing time on MSAD

kVp	Reading (R)	MSAD (rad)
80	0.114	1.78
120	0.317	4.95

Position: A; Mode of Scan: Normal;
Slice Thickness: 10 (mm); Resolution: Tissue;
mA: 170; Time: 2 (s)

Table 4.10:: Effect of changing kVp on MSAD

Chapter 5

Discussion

X-ray images of acceptable diagnostic quality should be obtained with minimum radiation exposure to patients. To distinguish between necessary and unnecessary exposure, at least four x-ray exposure guidelines currently exist in the United States. They are Illinois Patient Exposure Limits (IPEL)[Neuweg, 1980], Vermont Entrance Skin Exposure Criteria (VESEC)[State of Vermont Regulations, 1977], Federal Entrance Skin Exposure Guides (FESEG)[Martin *et al.*, 1977] and Conference of Radiation Control Program Directors Patient Exposure Guides (CRCPDPEG)[Task Force on Quality Assurance, 1981]. Three of them (VESEC, FESEG and CRCPDPEG) give the limits of ESE (free-in-air) for some common x-ray examinations of average adult patients. In Table 5.1, the average ESE of average patients (including men and women) in this project are compared with the limits of the guidelines for several common projections. It shows that ESEs in MCV Hospital are within the range. So, the techniques used in MCV Hospital for common x-ray examinations are appropriate.

As public awareness of medical applications of radiation grows, information on radiation doses and the possible effects of radiation exposure is increasingly being

demanded. There is general agreement that the extent of the risk is related in some way to the amount of exposure to radiation although at the present time there is no epidemiological evidence to establish the exact relationship, especially at the low exposure levels presently used in most diagnostic examinations. As the exposure to radiation increases, the likelihood of significant biological effects also increases. However, if a clear correlation between radiation dose and effect is to be established, a reasonably accurate method of estimating absorbed dose to the patient during a radiographic examination will be highly needed, because it is very important for monitoring of the procedure and for the evaluation of the risks from the ionizing radiation.

The individual patient's absorbed dose is influenced by several factors: his body size and constitution, the performance of the equipment used, the training of the personnel and the method of the examination. The effect of patient's body size and constitution can be easily seen in the clinical data (Appendix A). For example, a large patient can have more than 10 times mAs (thus the exposure) of a small patient. Even for patients with similar size, doses can still vary widely. Until there is a better anthropomorphic patient model of the proper tissue equivalency and of varying sizes, this kind of error can only be minimized by large number of patient data. Also, because of the wide range of technical parameters (output intensity, beam quality) among radiographic units, it is essential they are measured for any unit for which a reasonable estimate of patient dose is to be made. The advantage of the method for estimating dose described here is that, by the use of two simple equations, a single output intensity value and a single HVL value which should be

readily available from the facility's most recent radiation control survey, the two important parameters of ESE and HVL can be determined for each radiographic examination to estimate the patient's absorbed doses using the existing computer program. So, this method takes the effect of individual machine's performance partially into consideration by using an actual exposure and HVL from the unit as a reference point. And the error introduced by using those two equations is small in comparison with other factors in the procedures of estimation, such as variability of patient size.

There are several factors in radiographic diagnostic procedures which are not addressed by the standard reference model used to calculate organ doses. These are the different patient sizes, constitution and the effect of barium. They need to be further investigated. Also, more patients' data, especially the actual patient thickness, and technical parameters from different x-ray machines are needed for next-step study of patient's absorbed doses in common radiographic examinations.

Examination	VESEC (mR)	FESEG (mR)	CRCPDPEG (mR)	ESE in MCV (mR)
Chest (PA)	30	30	——	26
KUB (AP)	750	750	400 - 775	467
L.Spine(AP)	1000	1000	475 - 1000	666
C.Spine(AP)	250	250	100 - 300	240
T.Spine(AP)	900	900	——	424

VESEC: Vermont Entrance Skin Exposure Criteria

FESEG: Federal Entrance Skin Exposure Guides

CRCPDPEG: Conference of Radiation Control Program Directors Patient Exposure Guides

Table 5.1:: Comparison of average ESE in this study with the limits of the guidelines

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Appendix A – Experimental Data

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Chest (PA)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	15	M	M	130	3	14x17	72	23	4.63	13	4.0	1.5	4.6	+			
2	15	M	M	130	4	17x14	72	31	4.63	18	5.1	1.2	5.8	+			
3	15	M	M	130	3	14x17	72	23	4.63	13	4.0	1.5	4.6	+			
4	15	M	M	130	3	14x17	72	23	4.63	13	4.0	1.5	4.6	+			
5	1(NC)	M	M	125	3	14x17	72	17	4.46	9.7	2.9	1.1	3.4	+			
6	12	M	M	130	4	14x17	72	32	4.69	19	5.7	2.2	6.5	+			
7	1(NC)	M	M	125	3	14x17	72	17	4.46	9.7	2.9	1.1	3.4	+			
8	15	M	M	130	4	17x14	72	31	4.63	18	5.1	1.2	5.8	+			
9	15	M	M	130	4	14x17	72	31	4.63	18	5.4	2.1	6.3	+			
10	15	M	M	130	4	14x17	72	31	4.63	18	5.4	2.1	6.3	+			
11	15	M	M	130	3	17x14	72	23	4.63	14	3.8	0.9	4.3	+			
12	15	M	S	130	3	14x17	72	23	4.63	13	4.0	1.5	4.6	+			
13	15	M	M	130	4	14x17	72	31	4.63	18	5.4	2.1	6.3	+			
14	15	M	M	130	5	17x14	72	39	4.63	23	6.5	1.5	7.3	+			
1	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
2	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
3	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
4	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
5	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
6	12	F	S	130	2	14x17	72	16	4.69	9.9	2.4	1.1	2.8		1.6	0.1	0.1
7	15	F	M	130	3	17x14	72	23	4.63	14	3.2	0.9	3.7		2.3	0.1	0.1
8	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
9	15	F	M	130	4	14x17	72	31	4.63	19	4.6	2.1	5.3		3.1	0.1	0.1
10	15	F	M	130	4	14x17	72	31	4.63	19	4.6	2.1	5.3		3.1	0.1	0.1
11	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1
12	15	F	M	130	5	17x14	72	39	4.63	24	5.5	1.5	6.2		3.9	0.1	0.1
13	15	F	M	130	3	14x17	72	23	4.63	14	3.4	1.5	3.9		2.3	0.1	0.1

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.1:: Doses in chest (PA) examination

Chest (LAT)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	15	M	M	130	5	14x17	72	47	4.63	13	3.3	6.9	5.0	(+)			
2	15	M	M	130	7	14x17	72	66	4.63	18	4.6	9.7	7.1	(+)			
3	15	M	S	130	4	14x17	72	38	4.63	11	2.7	5.6	4.1	(+)			
4	15	M	M	130	7	14x17	72	66	4.63	18	4.6	9.7	7.1	(+)			
5	15	M	M	130	6	14x17	72	59	4.69	17	4.2	8.7	6.4	(+)			
6	1(NC)	M	M	125	6	14x17	72	40	4.46	11	2.7	5.8	4.2	(+)			
7	15	M	M	130	11	14x17	72	104	4.63	29	7.3	15	11	(+)			
8	15	M	S	130	4	14x17	72	38	4.63	11	2.7	5.6	4.1	(+)			
9	15	M	S	130	5	14x17	72	47	4.63	13	3.3	6.9	5.0	(+)			
10	15	M	L	130	17	14x17	72										
11	15	M	M	130	10	14x17	72	94	4.63	26	6.6	14	10	(+)			
12	15	M	M	130	8	14x17	72	75	4.63	21	5.3	11	8.0	(+)			
13	15	M	M	130	11	14x17	72	104	4.63	29	7.3	15	11	(+)			
1	15	F	M	130	7	14x17	72	66	4.63	21	3.7	9.7	6.0		(a)	0.1	0.1
2	15	F	M	130	5	14x17	72	47	4.63	15	2.6	6.9	4.3		(a)	0.1	0.1
3	15	F	M	130	6	14x17	72	57	4.63	18	3.0	8.4	5.2		(a)	0.1	0.1
4	15	F	M	130	5	14x17	72	47	4.63	15	2.6	6.9	4.3		(a)	0.1	0.1
5	12	F	S	130	4	14x17	72	39	4.69	13	2.2	5.8	3.6		(a)	0.1	0.1
6	15	F	S	130	5	14x17	72	47	4.63	15	2.6	6.9	4.3		(a)	0.1	0.1
7	15	F	M	130	9	14x17	72	85	4.63	27	4.8	12	7.7		(a)	0.2	0.1
8	15	F	L	130	22	14x17	72										
9	15	F	M	130	8	14x17	72	75	4.63	24	4.2	11	6.8		(a)	0.1	0.1
10	15	F	M	130	7	14x17	72	66	4.63	21	3.7	9.7	6.0		(a)	0.1	0.1
11	15	F	M	130	8	14x17	72	75	4.63	24	4.2	11	6.8		(a)	0.1	0.1
12	15	F	L	130	18	14x17	72										
13	15	F	M	130	7	14x17	72	66	4.63	21	3.7	9.7	6.0		(a)	0.1	0.1

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.2:: Doses in chest (LAT) examination

L. Spine (AP)																		
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose								
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	1(NC)	M	M	77	63	11x14	40	555	2.87	13	16	0.1	5.3	1.1			
2	15	M	L	75	306	14x17	40	3313	2.82	250	123	1.2	462	13			
3	1(NC)	M	M	77	80	11x14	40	761	2.87	18	22	0.2	73	1.5			
4	15	M	M	75	51	14x17	40	552	2.82	42	20	0.2	77	2.2			
5	15	M	M	75	33	14x17	40	357	2.82	27	13	0.1	50	1.4			
6	15	M	M	75	64	14x17	40	693	2.82	52	26	0.2	97	2.8			
7	15	M	M	75	139	14x17	40	1505	2.82	114	56	0.5	210	6.1			
8	15	M	L	75	295	14x17	40	3194	2.82	241	118	1.1	446	13			
9	15	M	L	77	200	14x17	40	2282	2.88	175	86	0.8	323	9.4			
10	15	M	M	75	48	14x17	40	520	2.82	39	19	0.2	73	2.1			
11	15	M	M	75	41	14x17	40	444	2.82	34	16	0.2	62	1.8			
12	15	M	M	77	56	14x17	40	639	2.88	51	29	0.3	93	3.1			
13	15	M	M	77	74	14x17	40	844	2.88	67	38	0.4	123	4.0			
1	15	F	M	75	75	14x17	40	812	2.82	61	30	0.3	113		(a)	169	223
2	15	F	L	82	87	14x17	40	1126	3.05	93	53	0.5	170		(a)	265	344
3	15	F	L	85	186	14x17	40	2587	3.15	219	127	1.2	398		(a)	624	810
4	15	F	M	75	27	14x17	40	292	2.82	22	11	0.1	41		(a)	61	80
5	15	F	L	82	287	14x17	40	3714	3.05	307	176	1.7	560		(a)	873	1133
6	15	F	L	75	180	14x17	40	1949	2.82	147	72	0.7	272		(a)	405	535
7	15	F	M	75	63	14x17	40	682	2.82	51	25	0.2	95		(a)	142	187
8	15	F	M	77	69	14x17	40	787	2.88	62	35	0.3	115		(a)	176	230
9	15	F	M	75	44	14x17	40	476	2.82	36	18	0.2	66		(a)	99	131
10	15	F	M	75	71	14x17	40	769	2.82	58	28	0.3	107		(a)	160	211
11	15	F	M	77	82	14x17	40	936	2.88	74	42	0.4	136		(a)	210	273
12	15	F	M	75	58	14x17	40	628	2.82	47	23	0.2	88		(a)	130	172
13	15	F	S	75	38	14x17	40	411	2.82	31	15	0.1	57		(a)	85	113

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.3:: Doses in L. spine (AP) examination

L. Spine (LAT)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	1(NC)	M	M	81	250	11x14	40	3760	3.00	24	75	0.2	153	1.7			
2	15	M	L	80	500	14x17	40	9500	2.98	139	252	1.2	554	10			
3	1(NC)	M	M	77	250	11x14	40	3397	2.87	21	65	0.2	135	1.4			
4	15	M	L	85	269	14x17	40	5770	3.15	89	162	0.7	348	6.5			
5	17	M	M	85	125	11x14	40	1584	5.37	18	60	0.2	92	1.6			
6	15	M	M	85	59	14x17	40	1266	3.15	19	35	0.2	76	1.4			
7	15	M	S	85	101	14x17	40	2166	3.15	33	61	0.3	131	2.4			
8	15	M	M	73	320	14x17	40	5063	2.75	64	106	0.5	271	3.9			
9	15	M	L	77	320	14x17	40	5633	2.88	80	145	0.7	321	5.7			
10	15	M	L	77	400	14x17	40	7041	2.88	100	181	0.8	402	7.2			
11	15	M	M	85	164	14x17	40	3518	3.15	54	99	0.5	212	4.0			
12	15	M	M	77	121	14x17	40	2130	2.88	30	55	0.3	122	2.2			
13																	
1	14	F	M	60	250	14x17	40	1873	3.38	28	48	0.2	114		(a)	95	62
2	15	F	L	75	400	14x17	40	6680	2.82	87	144	0.6	364		(a)	285	184
3	15	F	M	93	55	14x17	40	1412	3.41	23	43	0.2	89		(a)	84	56
4	15	F	M	95	115	14x17	40	3081	3.48	52	95	0.4	197		(a)	187	125
5	15	F	L	87	400	11x14	40	8988	3.21	62	193	0.6	382		(a)	315	192
6	15	F	M	85	94	14x17	40	2016	3.15	31	57	0.3	122		(a)	111	74
7	15	F	L	93	163	14x17	40	4185	3.41	69	127	0.6	265		(a)	249	166
8	15	F	M	85	157	14x17	40	3368	3.15	52	94	0.4	203		(a)	185	123
9	15	F	M	85	172	14x17	40	3689	3.15	57	103	0.5	222		(a)	203	135
10	15	F	M	93	146	14x17	40	3749	3.41	62	114	0.5	237		(a)	223	149
11	15	F	S	77	78	14x17	40	1373	2.88	20	35	0.2	78		(a)	69	46
12	15	F	M	85	134	14x17	40	2874	3.15	44	81	0.4	173		(a)	158	105
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.4:: Doses L. spine (LAT) examination

C. Spine (AP)

No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	16	M	S	70	30	10x12	50	164	3.35	4.5	3.5	150	4.4	(+)			
2	12	M	S	70	30	10x12	40	296	2.71	5.3	4.6	236	6.0	(+)			
3	15	M	M	70	27	10x12	40	255	2.65	4.5	3.9	201	5.0	(+)			
4	15	M	M	75	31	10x12	40	336	2.82	6.3	5.5	274	7.0	(+)			
5	15	M	M	70	19	10x12	40	179	2.65	3.1	2.7	141	3.5	(+)			
6	15	M	M	75	27	10x12	40	292	2.82	5.4	4.8	238	6.0	(+)			
7	15	M	M	70	21	10x12	40	198	2.65	3.5	3.0	156	3.9	(+)			
8	15	M	M	70	25	10x12	40	236	2.65	4.1	3.6	186	4.7	(+)			
9	15	M	S	75	18	10x12	40	195	2.82	3.4	3.0	154	3.9	(+)			
10																	
11																	
12																	
13																	
1	15	F	M	70	28	10x12	40	264	2.65	4.6	4.0	208	5.2		(a)	(+)	(+)
2	15	F	M	70	32	10x12	40	302	2.65	5.3	4.6	238	6.0		(a)	(+)	(+)
3	13	F	M	73	40	10x12	40	293	2.52	6.0	5.3	253	6.6		(a)	(+)	(+)
4	15	F	S	70	25	10x12	40	236	2.65	4.1	3.6	186	4.7		(a)	(+)	(+)
5	15	F	M	75	64	10x12	72	165	2.82	5.1	3.4	143	4.7		(a)	(+)	(+)
6	15	F	S	75	40	10x12	72	103	2.82	3.2	2.1	89	2.9		(a)	(+)	(+)
7	13	F	M	73	40	10x12	40	293	2.52	6.0	5.3	253	6.6		(a)	(+)	(+)
8	15	F	M	70	32	10x12	40	302	2.65	5.3	4.6	238	6.0		(a)	(+)	(+)
9	15	F	M	70	28	10x12	40	264	2.65	4.6	4.0	208	5.2		(a)	(+)	(+)
10	15	F	M	70	19	10x12	40	179	2.65	3.1	2.7	141	3.5		(a)	(+)	(+)
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.5:: Doses in C. spine (AP) examination

C. Spine (LAT)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	16	M	S	70	30	10x12	50	222	3.35	6.6	6.0	14	4.5	(+)			
2	12	M	S	70	30	10x12	50	229	2.71	5.7	5.1	12	4.0	(+)			
3	15	M	M	70	11	10x12	40	160	2.65	2.8	2.7	6.0	2.2	(+)			
4	15	M	M	70	50	11x14	72	137	2.65	6.7	4.8	22	3.9	(+)			
5	15	M	M	70	40	10x12	72	109	2.65	3.8	3.1	7.5	2.5	(+)			
6	15	M	M	75	12	10x12	40	200	2.82	3.7	3.6	8.0	2.8	(+)			
7	15	M	M	70	17	10x12	40	247	2.65	4.3	4.2	9.3	3.3	(+)			
8	15	M	S	70	14	10x12	40	204	2.65	3.6	3.5	7.7	2.7	(+)			
9	15	M	M	75	16	10x12	40	267	2.82	4.9	4.8	11	3.8	(+)			
10	15	M	M	70	24	10x12	40	349	2.65	6.1	6.0	13	4.7	(+)			
11																	
12																	
13																	
1	15	F	M	70	27	10x12	40	393	2.65	6.9	6.7	15	5.3		(a)	(+)	(+)
2	13	F	M	73	40	10x12	40	452	2.52	9.2	9.1	20	6.9		(a)	(+)	(+)
3	15	F	S	70	10	10x12	40	145	2.65	2.5	2.5	5.5	2.0		(a)	(+)	(+)
4	15	F	M	75	64	10x12	72	201	2.82	7.4	6.0	15	4.8		(a)	(+)	(+)
5	15	F	S	75	40	10x12	72	126	2.82	4.7	3.8	9.1	3.0		(a)	(+)	(+)
6	13	F	M	73	40	10x12	40	452	2.52	9.2	9.1	20	6.9		(a)	(+)	(+)
7	15	F	M	70	32	10x12	40	466	2.65	8.1	8.0	18	6.3		(a)	(+)	(+)
8	15	F	M	72	13	10x12	40	200	2.72	3.6	3.5	7.7	2.7		(a)	(+)	(+)
9																	
10																	
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.6:: Doses C. spine (LAT) examination

T. Spine (AP)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	15	M	M	75	51	14x17	40	552	2.82	217	22	59	64	(+)			
2	15	M	M	75	28	14x17	40	303	2.82	119	12	33	35	(+)			
3	15	M	S	75	48	14x17	40	520	2.82	204	20	56	60	(+)			
4	15	M	M	75	34	14x17	40	368	2.82	145	14	40	43	(+)			
5	15	M	M	75	24	14x17	40	260	2.82	102	10	28	30	(+)			
6	15	M	M	75	42	14x17	40	455	2.82	179	18	49	53	(+)			
7	15	M	M	75	47	14x17	40	509	2.82	200	20	55	59	(+)			
8	15	M	L	75	79	14x17	40	855	2.82	336	34	92	99	(+)			
9																	
10																	
11																	
12																	
13																	
1	15	F	L	75	85	14x17	40	920	2.82	271	31	99	85		698	1.1	0.9
2	15	F	L	80	90	14x17	40	1109	2.98	346	43	128	110		861	1.8	1.4
3	15	F	M	75	51	14x17	40	552	2.82	163	18	59	51		419	0.7	0.5
4	15	F	M	75	34	14x17	40	368	2.82	108	12	40	34		279	0.4	0.3
5	15	F	M	75	43	14x17	40	466	2.82	137	16	50	43		353	0.6	0.4
6	15	F	M	75	48	14x17	40	520	2.82	153	17	56	48		394	0.6	0.5
7	15	F	S	75	20	14x17	40	217	2.82	64	7.3	23	20		165	0.3	0.2
8																	
9																	
10																	
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.7:: Doses in T. spine (AP) examination

T. Spine (LAT)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	15	M	M	70	250	14x17	40	3637	2.65	454	82	22	160	0.1			
2	15	M	M	65	57	14x17	40	715	2.49	84	15	4.0	30	(+)			
3	15	M	S	70	77	14x17	40	1120	2.65	140	25	6.9	49	(+)			
4	15	M	S	70	160	14x17	40	2328	2.65	290	52	14	102	(+)			
5	15	M	M	70	117	14x17	40	1702	2.65	212	38	10	75	(+)			
6	15	M	M	70	88	14x17	40	1280	2.65	160	29	7.8	56	(+)			
7	15	M	M	70	102	14x17	40	1484	2.65	185	33	9.1	65	(+)			
8	15	M	L	75	243	14x17	40	4058	2.82	532	97	27	186	0.1			
9																	
10																	
11																	
12																	
13																	
1	14	F	L	60	200	14x17	40	1498	3.38	256	33	12	66		(a)	0.4	0.5
2	14	F	L	80	200	11x14	40	2663	4.04	472	58	14	96		(a)	0.7	0.7
3	15	F	L	75	204	14x17	40	3407	2.82	514	65	22	133		(a)	0.8	0.9
4	15	F	M	70	83	14x17	40	1207	2.65	173	22	7.4	45		(a)	0.3	0.3
5	15	F	M	75	134	14x17	40	2238	2.82	338	43	15	87		(a)	0.5	0.6
6	15	F	M	70	101	14x17	40	1469	2.65	211	26	9.0	55		(a)	0.3	0.4
7	15	F	M	70	68	14x17	40	989	2.65	142	18	6.1	37		(a)	0.2	0.2
8	15	F	M	70	180	14x17	40	2618	2.65	375	47	16	98		(a)	0.6	0.6
9	15	F	S	70	61	14x17	40	887	2.65	127	16	5.4	33		(a)	0.2	0.2
10																	
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.8:: Doses in T. spine (LAT) examination

KUB (AP)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	14	M	M	75	80	14x17	40	607	3.88	9.6	31	0.1	110	14			
2	16	M	M	70	30	14x17	40	287	3.35	4.1	13	(+)	48	5.8			
3	12	M	S	80	20	14x17	40	258	3.04	3.8	13	(+)	42	5.3			
4	12	M	M	70	50	14x17	40	493	2.71	5.8	18	0.1	73	8.2			
5	15	M	M	75	70	14x17	40	758	2.82	9.3	29	0.1	115	13			
6	1(NC)	M	M	71	63	14x17	40	472	2.67	5.5	17	0.1	69	7.8			
7	14	M	L	70	113	14x17	40	747	3.71	11	37	0.1	132	16			
8	14	M	M	70	65	14x17	40	430	3.71	6.6	21	0.1	76	9.3			
9	14	M	M	90	32	14x17	40	350	4.37	7.4	26	0.1	71	10			
10	14	M	S	70	25	14x17	40	165	3.71	2.5	8.2	(+)	29	3.6			
11	15	M	M	75	62	14x17	40	671	2.82	8.3	26	0.1	102	12			
12	15	M	M	75	73	14x17	40	790	2.82	9.7	31	0.1	120	14			
13	15	M	M	75	53	14x17	40	574	2.82	7.1	22	0.1	87	10			
1	1(NC)	F	M	77	81	14x17	40	714	2.87	9.9	34	0.1	112		(b)	173	231
2	12	F	M	70	30	14x17	40	296	2.71	3.5	11	(+)	44		(b)	64	87
3	12	F	S	70	20	14x17	40	197	2.71	2.3	7.3	(+)	29		(b)	43	58
4	12	F	M	80	20	14x17	40	258	3.04	3.8	13	(+)	42		(b)	65	88
5	12	F	M	75	30	14x17	40	340	2.88	4.3	13	0.1	52		(b)	78	105
6	14	F	M	70	65	14x17	40	430	3.71	6.6	21	0.1	76		(b)	117	158
7	14	F	M	90	40	14x17	40	437	4.37	9.2	32	0.1	89		(b)	151	199
8	14	F	M	90	32	14x17	40	350	4.37	7.4	26	0.1	71		(b)	121	159
9	15	F	L	75	320	14x17	40	3465	2.82	43	134	0.5	525		(b)	776	1056
10	15	F	M	75	76	14x17	40	823	2.82	10	32	0.1	125		(b)	184	251
11	15	F	S	75	42	14x17	40	455	2.82	5.6	18	0.1	69		(b)	102	139
12	15	F	S	75	55	14x17	40	595	2.82	7.3	23	0.1	90		(b)	133	181
13	15	F	L	82	204	14x17	40	2640	3.05	39	132	0.5	431		(b)	672	898

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.9:: Doses in KUB (AP) examination

Pelvis (AP)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	1(NC)	M	M	77	40	17x14	40	352	2.87	0.4	16	(+)	58	31			
2	1(NC)	M	M	77	80	17x14	40	705	2.87	0.8	32	(+)	116	62			
3	15	M	S	75	37	17x14	40	401	2.82	0.4	15	(+)	64	34			
4	15	M	M	75	52	17x14	40	563	2.82	0.5	21	(+)	89	47			
5	15	M	M	72	40	17x14	40	399	2.72	0.4	15	(+)	62	32			
6	15	M	M	75	48	17x14	40	520	2.82	0.5	20	(+)	82	44			
7	15	M	M	75	39	17x14	40	422	2.82	0.4	16	(+)	67	35			
8	15	M	M	75	33	17x14	40	357	2.82	0.3	14	(+)	57	30			
9	15	M	S	75	28	17x14	40	303	2.82	0.3	11	(+)	48	25			
10	15	M	M	75	41	17x14	40	444	2.82	0.4	17	(+)	70	37			
11	15	M	M	75	31	17x14	40	336	2.82	0.3	13	(+)	53	28			
12	15	M	L	75	121	17x14	40	1310	2.82	1.2	49	0.1	206	109			
13																	
1	14	F	S	70	25	17x14	40	165	3.71	0.2	8.0	(+)	30		(b)	46	62
2	1(NC)	F	M	77	63	17x14	40	555	2.87	0.7	25	(+)	91		(b)	138	184
3	15	F	L	75	171	17x14	40	1851	2.82	1.8	70	0.1	294		(b)	425	576
4	15	F	S	75	38	17x14	40	411	2.82	0.4	16	(+)	65		(b)	94	128
5	15	F	S	75	75	17x14	40	812	2.82	0.8	31	0.1	129		(b)	187	253
6	15	F	S	75	36	17x14	40	390	2.82	0.4	15	(+)	62		(b)	90	121
7	15	F	M	75	42	17x14	40	455	2.82	0.4	17	(+)	72		(b)	105	142
8	15	F	M	75	34	17x14	40	368	2.82	0.4	14	(+)	58		(b)	85	114
9	15	F	M	75	44	17x14	40	476	2.82	0.5	18	(+)	75		(b)	109	148
10																	
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units : Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.10:: Doses in pelvis (AP) examination

Femur (AP)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	15	M	L	75	61	14x17	40	660	2.82	(+)	4.8	(+)	16	593			
2	15	M	M	75	14	14x17	40	152	2.82	(+)	1.1	(+)	3.7	137			
3	15	M	S	70	21	14x17	40	198	2.65	(+)	1.3	(+)	4.6	174			
4	15	M	M	75	27	14x17	40	292	2.82	(+)	2.1	(+)	7.1	262			
5	15	M	M	75	18	14x17	40	195	2.82	(+)	1.4	(+)	4.7	175			
6	15	M	M	75	31	14x17	40	336	2.82	(+)	2.4	(+)	8.2	302			
7																	
8																	
9																	
10																	
11																	
12																	
13																	
1	15	F	S	75	21	14x17	40	227	2.82	(+)	1.6	(+)	5.5		(b)	1.6	2.3
2	15	F	S	75	25	14x17	40	271	2.82	(+)	2.0	(+)	6.6		(b)	1.9	2.8
3	15	F	S	75	32	14x17	40	346	2.82	(+)	2.5	(+)	8.4		(b)	2.4	3.5
4	15	F	S	70	12	11x14	40	113	2.65	(+)	0.4	(+)	1.0		(b)	0.2	0.4
5	15	F	S	70	11	14x17	40	103	2.65	(+)	0.7	(+)	2.4		(b)	0.7	1.0
6	15	F	M	75	23	14x17	40	249	2.82	(+)	1.8	(+)	6.1		(b)	1.7	2.5
7	15	F	M	75	33	11x14	40	357	2.82	(+)	1.5	(+)	3.6		(b)	0.9	1.4
8	15	F	M	75	30	11x14	40	325	2.82	(+)	1.4	(+)	3.3		(b)	0.8	1.3
9	15	F	M	75	19	14x17	40	206	2.82	(+)	1.5	(+)	5.0		(b)	1.4	2.1
10	15	F	M	75	28	14x17	40	303	2.82	(+)	2.2	(+)	7.4		(b)	2.1	3.1
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.11:: Doses in femur (AP) examination

Shoulder (one, AP)																	
No.	Rm	Sex	Size	kVp	mAs	Film Size	SID	ESE	HVL	Dose							
										Lung	ABM	Thy.	T.T.	Tes.	Bre.	Ova.	Ute.
1	15	M	M	72	25	11x14	40	249	2.72	33	3.6	10	9.3	(+)			
2	15	M	M	75	16	10x12	40	173	2.82	18	2.2	3.9	5.5	(+)			
3	15	M	M	72	23	10x12	40	229	2.72	24	2.8	5.0	7.2	(+)			
4	15	M	S	75	14	11x14	40	152	2.82	20	2.3	6.6	5.8	(+)			
5	15	M	M	75	18	10x12	40	195	2.82	21	2.5	4.4	6.2	(+)			
6	15	M	S	75	17	10x12	40	184	2.82	19	2.4	4.1	5.9	(+)			
7	15	M	M	75	16	10x12	40	173	2.82	18	2.2	3.9	5.5	(+)			
8																	
9																	
10																	
11																	
12																	
13																	
1	13	F	M	70	20	10x12	40	135	2.42	11	1.6	3.2	3.6		(a)	(+)	(+)
2	15	F	M	75	16	11x14	40	173	2.82	17	2.2	7.5	5.3		(a)	(+)	(+)
3	15	F	M	75	32	10x12	40	268	2.82	21	2.9	6.0	6.9		(a)	(+)	(+)
4	15	F	M	75	20	10x12	40	167	2.82	13	1.8	3.7	4.3		(a)	(+)	(+)
5	15	F	M	75	19	11x14	40	206	2.82	21	2.6	8.9	6.3		(a)	(+)	(+)
6	15	F	S	75	14	11x14	40	152	2.82	15	1.9	6.6	4.7		(a)	(+)	(+)
7	15	F	M	75	18	11x14	40	195	2.82	20	2.5	8.4	6.0		(a)	(+)	(+)
8	15	F	M	75	19	11x14	40	206	2.82	21	2.6	8.9	6.3		(a)	(+)	(+)
9																	
10																	
11																	
12																	
13																	

ABM: Active Bone Marrow Thy.: Thyroid T.T.: Trunk Tissue Tes.: Testes
Bre.: Breasts Ova.: Ovaries Ute.: Uterus (+): < 0.05 mrad
(a): Not calculated, however breasts are near or partially in x-ray field.
(b): Dose is negligible -- x-ray field completely outside of breast region.
Units: Film Size (inchxinch), SID (inch), ESE (mR), HVL (mm), Dose (mrad).

Table A.12:: Doses in shoulder (one, AP) examination

Appendix B – MCV Hospital X-Ray Machine Survey Report

Room	mR/mAs (80 kVp, 40 Inches)	HVL (mm AL) (80 kVp)
2	6.76	2.95
10 #	7.34	3.04
12	7.34	3.04
13	4.77(78 kVp)	2.75
14	4.92	4.04
15	7.02	2.98
16	7.12	3.68
17	5.25 (90 kVp)	5.20
18	7.58	3.43
1 (E.D.) *	5.60	3.48
2 (E.D)	7.35	3.72
3 (E.D) ##	7.35	3.72
1 (N.C.) **	5.42	2.97
2 (N.C.)	7.70	3.25

* E.D. = Emergency Department

** N.C. = Nelson Clinic

\# Room 10 and 12 share a generator

Room 3 (E.D.) and 2 (E.D.) share a generator

Table B.1:: MCV Hospital x-ray machine survey report

Vita