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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
11/14/2003	00	New document to establish the technical basis for the development of a generic document to use to perform dose reconstruction from occupationally related diagnostic X-ray procedures. First approved issue. Initiated by Judson L. Kenoyer.
12/08/2003	01	Revision that limits the use of this document to post 1970. Approved issue of Revision 01. Initiated by Judson L. Kenoyer
12/29/2003	02	Revision that includes information to re-instate the ability for the document to cover exposures pre-1970. Approved issue of Revision 02. Initiated by Judson L. Kenoyer
08/02/2005	03	Revision to add photofluorography use table and lumbar spine x-rays. Deleted footnote b and adjusted footnote references in Table 8. Approved issue of Revision 03. No retraining required. Initiated by Vernon E. Shockley and Ronald L. Kathren.
12/21/2005	03 PC-1	Approved page change revision. Page change initiated to incorporate recent direction from NIOSH to include DOL review comments on page 8. Deletes two obsolete paragraphs on page 8 in Section 1.0. Corrects table number reference on page 20 in Section 4.0. No sections were deleted. No retraining is required. Initiated by Vernon E. Shockley and Ronald L. Kathren. Signature on File 12/14/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 12/14/2005 Kate Kimpan, Projector Director Signature on File 12/21/2005 James W. Neton, Associate Director for Science
06/20/2011	04	Revision to add organ dose data from lordotic and oblique chest X-rays, chest fluoroscopy, thoracic and cervical spine X-rays, and skin doses for all procedures. Lists additional references in the Reference Section. Incorporates formal internal and NIOSH review comments. Also addresses an additional NIOSH comment. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Elyse M. Thomas.

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ACRONYMS AND ABBREVIATIONS

AP	anterior-posterior (X-ray projection)
AWE	Atomic Weapons Employer
C	coulomb (unit of charge)
cGy	centigray
cm	centimeter
DAP	dose area product
DCF	dose conversion factor
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
eq.	equivalent
ENSD	entrance skin dose
ESE	entrance skin exposure
EXSD	exit skin dose
Gy	gray (1 Gy = 1 J/kg)
H_E	Effective dose equivalent
HF	high frequency
HVL	half value layer
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
J	Joule (unit of energy)
$K_{a,i}$	incident air kerma (in air)
keV	kilo-electron volt
kVp	kilovolts peak
LAO	left anterior oblique (X-ray position)
LAT	lateral (X-ray projection)
LPO	left posterior oblique (X-ray position)
m	meter
mA	milliampere
mAs	milliampere-second
mGy	milligray
min	minute
mm	millimeter
mrad	millirad
mrem	millirem
NCRP	National Council on Radiation Protection and Measurements
NEXT	Nationwide Evaluation of X-Ray Trends
NIOSH	National Institute for Occupational Safety and Health
OBL	oblique (X-ray projection)

ORNL	Oak Ridge National Laboratory
PA	posterior-anterior (X-ray projection)
PFG	photofluorography
R	roentgen
RAO	right anterior oblique (X-ray position)
RPO	right posterior oblique (X-ray position)
RSD	remote skin dose
s	second
SID	source to image distance
SSD	source to skin distance
Sv	Sievert, unit of dose equivalent
TB	tuberculosis
TBD	technical basis document
TIB	technical information bulletin
U.S.C.	United States Code
VA	Veteran's Administration
§	section or sections

1.0 INTRODUCTION

Technical information bulletins (TIBs) are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

In this document, the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy (DOE) facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384l(5) and (12)].

2.0 OCCUPATIONAL MEDICAL X-RAY DOSE TO BE INCLUDED IN DOSE RECONSTRUCTION

The Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) requires the assignment of external dose from medical X-ray examinations performed for occupational health screening and required as a condition of employment. According to 42 CFR Part 81, external doses received from occupational X-ray screening procedures that were provided to the energy employee as a condition of employment must be included in dose reconstruction, while those performed for diagnostic or therapeutic reasons are excluded. Screening X-rays are systematic examinations performed on asymptomatic people without history, complaint, physical findings, or physician evaluation. Diagnostic X-rays are careful examinations of people who already have suspicious signs or symptoms of a potential condition performed after physician evaluation (NIOSH 2010). Therapeutic X-rays are used to treat cancer and other conditions, and not as an aid to diagnosing those conditions.

The purpose of this TIB is to describe medical X-ray dose reconstruction in general, and to provide organ dose equivalents that can be used complex-wide when site-specific information is specious or not available.

Many DOE/Atomic Weapon Employer (AWE) sites had their own medical clinics and equipment to perform medical X-ray screening of their workers. Sometimes, however, the DOE/AWE sites contracted with private physicians' offices, clinics, or local community hospitals to provide this service to workers (ORAUT 2011). A recent NIOSH interpretation of the EEOICPA statute is that the statute defines covered radiation as the radiation received by a covered employee at a covered facility during a covered period (NIOSH 2010). This interpretation affects how X-ray dose should be assigned if the X-rays were taken at a site or location that is not defined under the statute as a covered facility, such as offsite locations including private physicians' offices, clinics, or local community hospitals. Except in limited circumstances concerning residual radiation, only radiation that the employee received at a covered facility can be included in dose reconstruction.

3.0 TECHNICAL FACTORS AFFECTING MEDICAL X-RAY DOSE

A number of factors determine the dose to the worker from an X-ray procedure. These factors include the X-ray machine settings (typically called technique factors) used for the exposure, such as the kilovoltage (or the kilovolts peak, kVp), the beam current in milliamperes (mA), and time of exposure (seconds). Other factors that can affect the dose to the worker are the X-ray source-to-image distance (SID), where the X-ray source is defined as the focal spot or target of the X-ray tube, the amount of filtration in the machine, the size of the X-ray beam (collimation), the type of high-voltage generator, the type and speed of the film and screens, the film development procedure, the use of

grids, and the physical size of the worker. The effect of these factors on dose reconstruction is discussed in the following sections.

The dose to workers can be estimated with a reasonable degree of accuracy by several methods, depending on what is known about the specific X-ray machine used. Direct measurements of the X-ray beam itself can be used to determine dose to the worker from an X-ray procedure. Dose can also be determined using knowledge of the technique factors used on a given X-ray machine along with standard X-ray output tables in the open literature. Using either direct X-ray beam measurements or known technique factors obviates the need for detailed knowledge of some of the other factors that can affect dose. For example, the technique factors should include adjustments for the type and speed of the film and screens, film development, and use of grids. The uncertainty in the dose from many of these factors, including the uncertainty in the size of the worker, is discussed in Section 8.

3.1 KILOVOLTAGE, FILTRATION, AND TYPE OF HIGH-VOLTAGE GENERATOR

The maximum energy of the X-ray beam is determined by the voltage applied between the cathode and anode of the X-ray tube. Increasing the kilovoltage (kVp) will increase the maximum energy of the X-ray photons and, therefore, the ability of the X-ray photons to penetrate thicker body parts. Increasing the kVp will increase the beam output, defined as the quotient of the air kerma at a specified distance by the product of tube current and exposure time in units of Gy/mAs (ICRU 2005). Numerous empirical studies of beam output as a function of kVp over the years show that increasing the kVp will increase the beam output according to the 1.7 power of the kilovoltage for a given amount of filtration (Handloser and Love 1951; Trout, Kelley, and Cathey 1952; BRH 1970). In the absence of specific measurements or empirical data, this relationship can be used to determine or adjust the beam output as a result of changes in kilovoltage.

The X-rays from a medical X-ray machine are predominantly of bremsstrahlung origin and, therefore, exit the beam port with a spectrum of energies. It is difficult to know the precise energy spectrum of an X-ray beam from a particular X-ray machine, so in practice it is common to refer to the "beam quality" as a simple surrogate for detailed information about the energy spectrum (ICRU 1937). The beam quality is a measure of the ability of the beam to penetrate matter (also known as beam hardness), and is expressed in terms of the half value layer (HVL) of the beam in millimeters of aluminum. The beam quality and the HVL are primarily a function of the target material, kVp, and total filtration in the X-ray machine. Some knowledge of the beam quality is necessary for dose reconstruction. Ideally, machine-specific HVL measurements are available. Without actual HVL measurements, estimates of the HVL can be made with knowledge of the kVp and total filtration in the machine, which is the sum of the inherent filtration in the tube itself and any added filtration.

All X-ray tubes have inherent filtration, which includes the window, aperture, or port in the tube enclosure through which the X-ray beam passes or emerges from the X-ray tube. The tube housing is shielded to eliminate leakage radiation from the tube other than through the port. In medical X-ray machines used for radiographic imaging, the window or beam port through which the useful beam emerges is purposely made very thin, typically equivalent to 0.5 mm Al in attenuation, and so provides little beam hardening. It was recognized early that placing additional filters in the X-ray beam to preferentially absorb the lower energy X-rays in the spectrum while allowing the higher energy X-rays to pass through had the potential to reduce the skin dose to the individual being radiographed. For this reason, minimum filtration requirements for medical X-ray machines have been in existence for a long time.

Recommendations were made in 1937 by the International Committee for Radiological Units and Measurements (ICRU 1937), which specified aluminum filters for X-rays produced from 20 to 120 kVp. The 1936 recommendation of the U.S. Advisory Committee on X-Ray and Radium Protection,

the forerunner of the National Council on Radiation Protection and Measurements (NCRP), called for total filtration (permanently mounted) of 0.5 mm of Al equivalent for radiographic installations, and 1 mm Al equivalent for fluoroscopy (NBS 1936). Typical added filtration in the 1940s ranged from zero to 1 mm Al. In 1949, the National Bureau of Standards recommended 1 mm of Al added filtration for radiography of thick parts of the body such as the chest (NBS 1949). In 1955, the recommendation for medical radiographic machines called for 2.5 mm Al eq. total filtration (NBS 1955). The recommended total filtration remained at 2.5 mm in 1968 for medical radiographic machines operating above 70 kVp (NCRP 1968). For machines already in operation, these recommended filter thicknesses might not have been used for some time after the date of the recommendation. Since 1974, X-ray machine manufacturers have been required by law to include minimum amounts of filtration (21 CFR Part 1020). In this TIB, an HVL of 2.0 mm Al is assumed for determination of dose equivalent from chest fluoro, lumbar, thoracic, cervical spine, and pelvis X-rays, 2.5 mm Al for most other X-rays taken through 1985, and 4.0 mm Al for X-rays taken after 1985.

The relationship of beam output to kVp and to filtration is complex, to some extent machine-specific, and best determined empirically. However, in the absence of empirical data for a specific machine, adequate contemporary empirical and theoretical data exist on which to determine the machine output with a reasonable degree of certainty. For a given mAs setting on a machine, additional filtration generally reduces the air kerma in an exponential manner. For a typical single-phase X-ray machine operating in the range of 80 to 100 kVp, each additional millimeter of Al filtration will effect a reduction of about 40% in the air kerma (Trout, Kelley, and Cathey 1952; Taylor 1957). Thus, the approximate reduction in air kerma afforded by any thickness of Al filtration can be determined by the following exponential equation:

$$I = I_o e^{-0.4t}$$

or

$$\ln (I/I_0) = - 0.4\ t$$

where t is the thickness of Al in millimeters, and I and I_0 are air kerma with and without the filter, respectively. In the absence of specific measurements or empirical data, this correction can be applied to determine the effect of filtration on air kerma.

The effects of filtration and kVp tend to offset one another; the addition of filtration reduces the air kerma per milliampere-seconds, while increasing the kVp increases the air kerma per milliampere-seconds. Higher kVp radiographic techniques typically require fewer milliampere-seconds per radiograph, and will result in lower entrance skin dose, but might increase dose to organs at greater depths in the body.

High-voltage X-ray generators used for medical radiography since the 1940s are of three basic types: single-phase full-wave-rectified, typical of virtually all medical radiographic units used through the mid-1980s; three-phase; and high-frequency (HF). A single-phase full-wave-rectified generator produces 120 half sinusoidal pulses of X-rays per second, each with a duration of 1/120 second, with a 100% fluctuation in the voltage. A three-phase generator uses three single phase voltage lines, each slightly out of phase with the others, producing a more constant (i.e., less fluctuating) voltage (Selman 1965, p. 214), therefore producing a greater beam output (approximately 20%) as compared with a single-phase full-wave-rectified machine operating at the same kVp and mAs. Three-phase generators were primarily installed in hospitals because they were expensive and required three-phase wiring. An HF generator is the most modern type, and produces a voltage waveform with very little fluctuation (2%) in voltage to the X-ray tube (Amman 1991, p. 240). Three-phase and HF machines did not become commonplace until the 1980s and 1990s. For dose reconstruction and in

the absence of evidence to the contrary, X-ray machines will be assumed to be single-phase full-wave-rectified.

3.2 CURRENT AND EXPOSURE TIME

The *current* in an X-ray tube refers to the number of electrons accelerated across the evacuated volume of the X-ray tube, flowing from the cathode to the anode. For a given kilovoltage, the number of X-ray photons and the air kerma will be directly proportional to the X-ray tube current. *Exposure time* refers to the time the beam was on or that the machine was producing X-rays. As with the tube current, the number of X-ray photons and the air kerma will be directly proportional to the exposure time for a given kilovoltage. The exposure needed for a radiograph is typically specified in terms of mAs, the product of X-ray tube current, and the exposure time. All other factors being equal (e.g., kVp, filtration, development, film/screen combination), air kerma is proportional to the mAs.

To avoid or minimize image blurring from involuntary organ motion such as the beating heart, exposure time is minimized, and the current proportionately increased to obtain the desired amount of radiation for a properly exposed radiograph. Earlier medical X-ray machines were equipped with mechanical timers whose accuracy was not as good as the accuracy of the electronic timers used on later machines. Gross bias errors in timer accuracy are unlikely in that these would have resulted in over- or underexposure of the radiograph and, thus, would have been quickly detected and corrected. Small random errors in the timers might not have been visible on radiographs, but might have produced uncertainties of perhaps ±20% in the air kerma.

3.3 DISTANCE

X-ray beam output is a function of distance from the source of X-rays in the tube, approximating the inverse square law at large distances (i.e., more than a few tens of centimeters) from the tube. Radiographic chest radiographs are taken at a standard SID of 72 in. (183 cm) between the source and the plane of the film. Most other radiographs are taken at a standard SID of 36 in. to 40 in. (102 cm). The distance between the source and the worker's body, expressed as the source-to-skin distance (SSD), is smaller than the SID because the worker is positioned between the source and the film cassette.

The air kerma at the point where the X-ray beam enters the body, known as the incident air kerma ($K_{a,i}$) (ICRU 2005) is a reference point for determining organ dose. The $K_{a,i}$ depends on the SID for the X-ray procedure, the body thickness of the person being radiographed, and the thickness of the cassette/film holder. While the size of the worker clearly affects the $K_{a,i}$, individual measurements (such as chest thickness) or individual technique factor settings (kVp, mA, and time) were rarely recorded at the time each X-ray was performed on a given worker. This is true not only at DOE/AWE sites, but also at any other clinical facility for the same period. As a result, and because the organ dose conversion factors in International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982) are based on standard body dimensions (Cahoon 1961; Wochos, Detorie, and Cameron 1979; Kereiakes and Rosenstein 1980), dose reconstruction must be performed assuming the standard body dimensions.

Table 1 provides the standard SIDs for the more commonly performed X-ray screening procedures and the commonly accepted body part thicknesses involved. Table 1 also provides the calculated SSDs used in dose reconstruction, assuming a standard 5 cm between the point where the X-ray beam exits the body and the plane of the film to account for the thickness of the cassette and/or cassette holder (Kereiakes and Rosenstein 1980, p. 189).

Table 1. Standard body dimensions, SIDs, and SSDs used for dose reconstruction.

Procedure	Projection	Part thickness (cm)[a]	Standard SID (in/cm)	Calculated SSD[b] (cm)
Chest	PA (PFG)	23	40/102	74
	PA	23	72/183	155
	LAT	34	72/183	144
	OBL	34	72/183	144
	AP Lordotic	23	72/183	155
Lumbar spine	AP and spot	23	40/102	74
	LAT and spot	34	40/102	63
Thoracic spine	AP	23	40/102	74
	LAT	34	40/102	63
	OBL	34	40/102	63
Cervical spine	AP	15	40/102	82
	LAT	15	72/183[c]	153[d]
	OBL	15	40/102	82
Pelvis	AP	23	40/102	74

a. The chest and abdomen are assumed to be 23 cm thick and 34 cm wide. The neck is assumed to be 15 cm thick and 15 cm wide.
b. The SSD = SID – Part thickness – 5 cm. A 5 cm gap between the worker and the plane of the film is included to account for the thickness of the cassette and/or cassette holder.
c. The 72-in. SID is used for the LAT cervical spine to reduce magnification.
d. The SSD for the LAT cervical spine = 183 cm – 15 cm – 5 cm – 10 cm = 153 cm. The 10 cm accounts for the fact that during the LAT cervical spine, the shoulder is up against the cassette holder, and so the side of the neck is not actually in contact with the cassette holder, affecting the SSD calculation.

3.4 COLLIMATION

Collimation refers to the limitation of the size of the X-ray beam. In the early years following the discovery of X-rays, the philosophy was to use a fairly large aperture (i.e., limited collimation) to ensure that the entire area of clinical interest was included in the radiograph. As a result of radiation

protection concerns, beams began to be better collimated, limiting the area of the body exposed and minimizing the dose to organs outside the beam. Limiting the size of the X-ray beam had a beneficial effect on the image quality, because there was less scatter produced when smaller volumes of tissue were exposed. Without collimation, organs normally outside of the primary beam are exposed to the primary beam. Figure 1 (from Price 1958) illustrates how poor collimation can unnecessarily irradiate organs outside the area actually imaged on the film.

Beam limiting cones were widely used for radiography from the 1940s to the 1960s (Cahoon 1961, p. 68). The cones produced circular beams, and were gradually replaced by variable aperture collimators that produced rectangular beams that more efficiently corresponded to the rectangular shape of the film (Cahoon 1961, p. 70). By the early 1960s, techniques were being modified to incorporate better methods of collimation. The NCRP, in Report 33 (NCRP 1968), updated its guidance on medical X-ray protection, including guidance for restriction of the X-ray beam to the area of clinical interest. While many DOE facilities had probably already incorporated the beam limitation guidance in NCRP Report 33, some smaller facilities might not have incorporated it into their practices for several years.

Wochos, Detorie, and Cameron (1979) analyzed the 1972-1975 Nationwide Evaluation of X-Ray Trends (NEXT) data and found that at some facilities, primarily internal medicine and general practitioners, the beam area-to-film area ratio could be as high as 2.0, but noted that this ratio was significantly lower at hospitals and radiology facilities where more X-rays were done and personnel performing them were generally better trained. For dose reconstruction, it will be assumed that

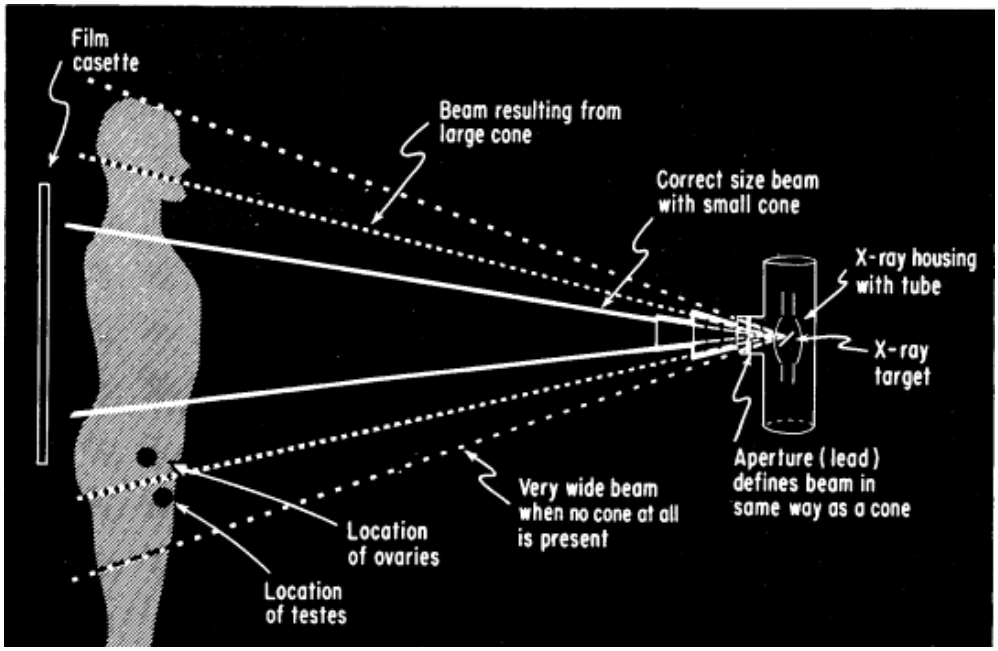

Figure 1. Diagram of poor collimation. From Price (1958).

radiographs taken before approximately 1970 were poorly collimated compared with radiographs taken after 1970. If actual dose measurements or inspection of the radiographs from a particular site indicate that collimation was used before 1970, the site-specific evidence can be used in the development of organ doses in that site's Site Profile. However, in the absence of information to the contrary with respect to collimation before 1970, a beam area-to-film area ratio of 2.0 is assumed for dose reconstruction through 1970. This ratio would be achieved by exposure of an additional 3 in. in all directions around a 14-in. × 17-in. radiographic film.

An assumption of poor collimation of radiographs through 1970 might necessitate the use of dose conversion factors (DCFs) from ICRP Publication 34 (ICRP 1982) other than those for the intended examination, because ICRP Publication 34 DCFs are based on properly collimated beams. This is discussed in more detail in Section 5.2 of this TIB.

3.5 SCREENS, GRIDS, AND OTHER FACTORS

A number of other factors affects the X-ray exposure required to obtain a usable radiographic image and, therefore, has the potential to affect the dose to the worker. However, detailed knowledge of these factors is usually unnecessary for dose reconstruction if beam measurements are available or if the machine technical factors of kilovoltage (kVp), time (s), and current (mA) are known along with the amount of primary beam filtration.

The exposure needed for a suitable radiographic image is a function of film/screen combination speed and development. Underdevelopment of films requires additional exposure to achieve satisfactory film density. Intensifying screens are used in the cassette to convert the radiation efficiently to light photons that subsequently expose the film. Because film is more sensitive to light photons than to X-ray photons, using screens and film in combination can reduce the amount of radiation needed to produce an image. Film and screen speeds have increased dramatically since the 1940s and are one of the reasons that dose per X-ray procedure generally shows a downward trend over this period.

Grids are devices that are used in front of the film cassette to absorb scattered radiation before it reaches the film. The grid itself is comprised of very thin lead strips placed such that the diverging X-ray photons will pass between the strips. The strips will absorb radiation that is scattered at large

angles. Grids are typically used to radiograph thick body parts such as the abdomen, lumbar spine and, in recent times, the chest. The Potter Bucky diaphragm (also known as a Bucky grid) vibrates back and forth rapidly during the exposure, which minimizes the chance of the strips appearing on the film image. In any case, the above are all factored into the technique factors (i.e., kVp, mA, and time) used to produce images and, therefore, detailed knowledge of them is not always of importance in dose reconstruction.

The effect of various technical factors on radiation output is listed in Table 2.

Table 2. Relationship of technical factors to X-ray beam output.

Parameter	Units	Relationship to X-ray beam output
kilovoltage	kV	Air kerma proportional to 1.7 power of kVp
Tube current	mA	Air kerma proportional to tube current
Exposure time	sec	Air kerma proportional to exposure time
Filtration	mm Al	Air kerma decreases by ~40% for each additional mm Al added to the beam
Distance	cm or in.	Air kerma decreases by inverse square relationship ($1/d^2$)

4.0 DETERMINING INCIDENT AIR KERMA

One of the essential parameters used to determine organ dose equivalent is the incident air kerma, $K_{a,i}$ (ICRU 2005), which is the air kerma from the primary beam on the central X-ray beam axis at the SSD (i.e., at the skin-entrance plane). Only the primary radiation incident on the skin and not the backscattered radiation is included in the definition of $K_{a,i}$ (ICRU 2005, p. 28). The incident air kerma can be determined from actual X-ray beam measurements, knowledge of technical factors for the X-ray machine in question, or by using air kerma values from the literature and correcting to the SSD of interest. Each of these is discussed in the following sections. Before the quantity "exposure" became obsolete (ICRU 2005), the entrance skin exposure (ESE) was used to describe essentially the same quantity as incident air kerma.

4.1 USING BEAM MEASUREMENTS

Use of actual X-ray beam measurements is the simplest and most direct means of determining the incident air kerma, and is most likely to provide the most accurate estimates of organ dose equivalent from a given machine. Unfortunately, X-ray beam measurements are often unavailable, particularly before about 1980. Because actual measurements are the preferred method for determining incident air kerma, every effort to determine if such measurements have been made is justifiable. Beam measurements are typically quantified in units of roentgens (R) (now obsolete), coulombs per kilogram (C/kg), or Gray (Gy). Measurements with R-meters and ionization chambers, if properly performed, are reliable and have a low degree of uncertainty. In general, the uncertainty of properly performed measurements in the energy region of interest should not exceed +2% of the measured value (Kathren and Larson 1969).

Beam measurements in units of R must be converted to incident air kerma. Using the inverse square relationship listed in Table 2 and the standard SSDs from Table 1, the air kerma at any point on the central axis of the X-ray beam can be converted to the incident air kerma.

$$K_{a,i} = (R)(2.58E\text{-}4\ C/kg\ R^{-1})(33.97\ J/C)(100\ cGy/Gy)(1Gy/1J\ kg^{-1}) \quad (1)$$

where

$K_{a,i}$ is the incident air kerma to be used in organ dose calculations in units of cGy in air;
R is the exposure in roentgens at the skin entrance plane (i.e., ESE)
2.58E-4 C/kg R^{-1} is the conversion factor from R to C/kg

33.97J/C is the amount of energy required to ionize air

4.2 USING TECHNICAL FACTORS

In the absence of suitable beam measurements, the incident air kerma can be determined using machine-specific technical factors for a given X-ray examination and projection, and for an individual with the same dimensions as those listed in Table 1. The technical factors are used with published X-ray output data that provide air kerma per mAs as a function of kVp, filtration (or HVL), and distance to determine the incident air kerma. X-ray beam output data are available from a number of publications, including NCRP Report 102 (NCRP 1997) and ICRP Publication 34 (ICRP 1982). Table B-3 in NCRP Report 102 (p. 99) provides average air kerma rates for medical X-ray equipment operating at various kVp with 2.5-mm Al eq. filtration at distances from 30 to 182 cm from the source. As an alternative, Figure B.1 in NCRP Report No. 102 (p. 109) and Figure A1 in ICRP Publication 34 (p. 76) provide graphical representations of air kerma at 100 cm for various values of kVp and filter thickness greater than 2.5 mm Al eq. Using these tables or graphs, a reasonable estimate of incident air kerma can be obtained with knowledge of the mAs and the SSDs from Table 1.

4.3 USING PUBLISHED VALUES FROM MEDICAL LITERATURE

If both machine specific beam measurements and machine-specific technical factors are unknown or unreliable, values of incident air kerma from the general medical literature of the time can be used. These incident air kerma values are listed in Table 3. Published incident air kerma values are values from measurements reported in the literature for similar X-ray machines and X-ray procedures and for similar periods. Published incident air kerma values are used to calculate many of the organ dose equivalents published in this TIB, with a few exceptions where measured doses taken directly from medical literature are used. More detail about some of the incident air kerma values is provided in the sections on X-ray procedures.

Table 3. Published incident air kerma values by procedure and period.

		Through 1970		1971–1985		Post 1985	
Procedure	Projection	HVL (mm Al eq.)	Incident air kerma (cGy)	HVL (mm Al eq.)	Incident air kerma (cGy)	HVL (mm Al eq.)	Incident air kerma (cGy)
Chest	PFG	2.5	2.27[a]	---[b]	---[b]	---[b]	---[b]
	PA	2.5	0.20[c]	2.5	0.10	4.0	0.05
	LAT	2.5	0.50[c]	2.5	0.25	4.0	0.13
	OBL	2.5	0.50	2.5	0.25	4.0	0.13
	AP lordotic	2.5	0.20	2.5	0.10	4.0	0.05
	Fluoro (PA)	2.5	2.50[d]	---[b]	---[b]	---[b]	---[b]
Lumbar spine	AP and spot	2.0	1.44[e]	2.5	0.91[f]	---[b]	---[b]
	LAT and spot	2.0	3.79[e]	2.5	3.48[f]	---[b]	---[b]
Thoracic spine	AP	2.0	0.985[e]	---[b]	---[b]	---[b]	---[b]
	LAT	2.0	2.20[e]	---[b]	---[b]	---[b]	---[b]
	OBL	2.0	2.20	---[b]	---[b]	---[b]	---[b]
Cervical spine	AP	2.0	0.432[g]	---[b]	---[b]	---[b]	---[b]
	OBL	2.0	0.432[g]	---[b]	---[b]	---[b]	---[b]
	LAT	2.0	0.261[g]	---[b]	---[b]	---[b]	---[b]
Pelvis	AP	2.0	1.52[e]	---[b]	---[b]	---[b]	---[b]

a. Incident Air Kerma of 2.00 cGy is for stereo (two-exposure) PFG (Kirklin et al. ca. 1969; Rising and Soldat 1959).
b. Procedure not used for screening in this period.
c. From Stanford and Vance (1955, p. 270).
d. Fluoro dose based on 5 R/min for 30 sec, with an HVL of 2.0 mm Al eq.
e. From Lincoln and Gupton (1958, pp. 212-213) and Equation 1 or 6 in this TIB.
f. From Kereiakes and Rosenstein (1980, p. 213).
g. Braestrup and Wycoff (1958, pp. 140-141).

5.0 DETERMINING DOSE EQUIVALENT TO ORGANS OTHER THAN SKIN

The methodology of ICRP Publication 34 (ICRP 1982) is used to estimate many organ dose equivalents. This methodology is based on Monte Carlo calculations for a reference adult defined in Kereiakes and Rosenstein (1980, Table 94 and Figures 2 and 3) that appear to be more representative of the human body than the simple nonstandardized phantoms used in the 1950s for early studies on gonad dose to the population (Lincoln and Gupton 1958; Laughlin et al 1957; Billings, Norman, and Greenfield 1957). In ICRP Publication 34 methodology, organ dose is obtained as the product of entrance kerma and a DCF selected from Tables A2 to A8. Entrance kerma is defined in ICRP Publication 34 as "air kerma in air without backscatter." For consistency in this TIB, the term incident air kerma ($K_{a,i}$) from ICRU (2005) will be used:

$$ODE = (K_{a,i})(DCF)(1cSv/cGy) \quad (2)$$

where

ODE is the organ dose equivalent in rem

$K_{a,i}$ is the incident air kerma in cGy

DCF is the selected dose conversion factor

1 cSv/cGy is the conversion from absorbed dose to dose equivalent for X-ray photons. 1 cSv = 1 rem

Selection of the appropriate DCF from Tables A2 to A8 in ICRP Publication 34 (ICRP 1982) requires knowledge of the X-ray projection, the organ, and the X-ray beam quality expressed in terms of the HVL in millimeters of aluminum. If the kVp and total filtration are known, HVLs can be estimated from the data given in Tables A16 and A17 of ICRP Publication 34 (p. 77) or Table B.2 in NCRP Report 102 (NCRP 1997, p. 98).

5.1 SUBSTITUTE DCFS FOR ORGANS NOT LISTED IN ICRP PUBLICATION 34

Tables A2 to A8 in ICRP Publication 34 (ICRP 1982) do not include all the organs that correspond to the likely primary cancer site locations used in the Interactive RadioEpidemiological Program (IREP) computer program, which is used in dose reconstruction. Therefore, a substitute DCF must be selected for organs for which there is no corresponding DCF in ICRP Publication 34. For a properly collimated beam, the substitute DCF is usually selected according to anatomical proximity, with due consideration to other factors such as whether one or both organs are inside or outside the primary beam, organ depth, characteristics of overlying tissue, etc. Figure 2 illustrates the relationships between the locations of organs.

For properly collimated beams in general for chest, thoracic, and cervical spine X-rays, the DCF for lung is used for other organs in the thoracic or upper abdominal cavity (i.e., thymus, esophagus, stomach, and liver/gall bladder/spleen). Because an appreciable fraction of the skeleton is in the trunk, in particular the trabecular bone, which has a large surface-to-volume ratio, and the sternum, which is a primary location of the red marrow in the adult, the DCF for the lung is used to determine the dose to bone surfaces for chest, thoracic, and cervical spine X-rays. When the lung DCF is used as a substitute for other organs, the higher of the male or female lung DCF is used to determine the dose to these other organs for employees of both genders. Using the same logic, the DCF for the ovary is used as a substitute to determine the dose to organs in the lower abdomen such as the urinary bladder, prostate, and colon/rectum, regardless of employee gender. For the lumbar spine and pelvis, the DCF for the ovary is used as a substitute to determine the dose to the liver, gall

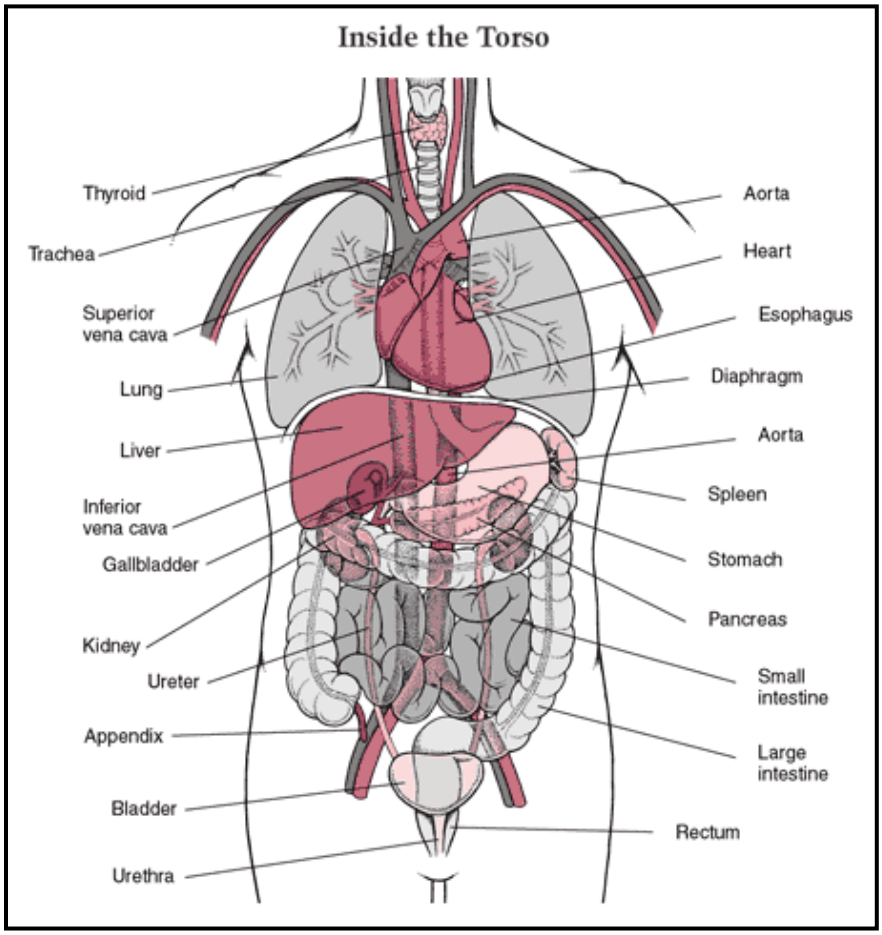

Figure 2. Diagram of the torso. Source: http://www.merck.com/mrkshared/mmanuel_home/illus/1i1.jsp (Beers 2003, Section 1, Chapter 1).

bladder, spleen, urinary bladder, prostate, colon, rectum, stomach, bone surfaces (in the spine and pelvis), and the remainder organs regardless of employee gender.

The thyroid DCF is usually selected as the substitute to determine the dose to the eye/brain. However, one important exception to this generality is made for determining eye/brain dose from photofluorography (PFG) examinations of the chest. Because of the shorter SID used in PFG (40 in.) compared with radiographic chests (72 in.), the thyroid is most likely to be in the primary beam for PFG, while the eye/brain is most likely to be outside the primary beam of PFG. A better choice of a substitute DCF for the dose to the eye/brain for PFG is then one where the thyroid (as a substitute for the eye/brain) is just outside the primary beam. The larger of the DCF for the posterior-anterior (PA) or lateral (LAT) skull or lungs for PA chest were selected as substitutes since the thyroid is just outside a properly collimated primary beam in those projections. Other exceptions to the general relationship listed in Table 4 are footnoted.

5.2 SUBSTITUTE DCFS FOR POOR COLLIMATION

Without good collimation, organs normally outside the primary beam are exposed to the primary beam. This necessitates the use of DCFs from ICRP Publication 34 (ICRP 1982) other than those for the intended procedure, because Publication 34 assumes properly collimated beams. For example, the thyroid is normally assumed to be outside the properly collimated beam of a PA chest projection (DCF = 32 mGy Gy^{-1} for HVL of 2.5 mm Al). However, a poorly collimated PA chest beam that is

about 2.0 times the size of the film must be assumed to include the thyroid in the primary beam. The dose to the thyroid can then be reasonably estimated by using a DCF for a projection in which the thyroid is clearly in the primary beam, such as the anterior-posterior (AP) cervical spine projection (DCF = 868 mGy Gy-1 for HVL of 2.5 mm Al). However, the thyroid is near the exit surface of the X-ray beam during a PA chest projection and near the entrance surface of the beam during an AP

Table 4. Organs without ICRP Publication 34 DCFs and their substitutes.[a]

IREP organ	ICRP 34 substitute DCF
Thymus Esophagus	Lung
Stomach Bone surface Liver/gall bladder/spleen Remainder organs	Lung[b] or ovary
Urinary bladder Colon/rectum, prostate	Ovary
Eye/brain	Thyroid[c]

a. Applies to most properly collimated radiographic procedures.
b. The lung is not used as the substitute DCF for these organs for the pelvis or lumbar spine. Refer to Table 5-2 in ICRP Publication 34.
c. The PA and/or LAT skull, or the PA chest DCF, whichever is larger, is used to determine the dose to the eye/brain resulting from the PFG chest.

cervical spine projection. A simple depth dose correction can be applied to the AP cervical spine DCF to account for the additional tissue attenuation in the neck when the thyroid is in the primary beam (as it is during an AP cervical spine projection), but nearer the exit surface of the beam (as it is during the PA chest projection). Depth dose factors from Table B.8 of NCRP Report 102 (NCRP 1997) are used to make this correction. The resulting modified DCF for the thyroid for poorly collimated beams is 174 mGy Gy-1 assuming the thyroid is approximately 10 cm below the surface of the back of the neck, and using a depth dose factor of 0.2 for 2.5 mm Al HVL from Table B.8 of NCRP Report 102: 868 mGy Gy-1 × 0.2 = 174 mGy Gy-1.

The substitute DCFs selected to determine dose to unnecessarily exposed organs as a result of poor collimation are presented in Tables 5 and 6. They are further discussed in the sections that describe the various screening procedures and projections. Note that only substitute DCFs are shown in this table. A complete table of DCFs is in Attachment A, Table A-14.

6.0 DETERMINING DOSE EQUIVALENT TO SKIN

The dose equivalent to the skin surface in the primary beam can be calculated with the following equation:

$$D_{(\text{skin surface})} = (D_{air})\,(\mu_{en}/\rho)_{\text{muscle}}\,(\mu_{en}/\rho)_{air}^{-1}\,(BSF)(1cSv/cGy) \quad (3)$$

where:

$D_{(\text{skin surface})}$ is the dose equivalent at the skin surface or the entrance skin dose equivalent (ENSD)

D_{air} = Incident air kerma in cGy

The ratio $(\mu_{en}/\rho)_{\text{muscle}}\,(\mu_{en}/\rho)_{air}^{-1}$ = 1.04 – 1.07 for the 40- to 140-kVp range, usually ignored (Wall, Harrison, and Spiers 1988)

BSF is the backscatter factor from Table B.8 in NCRP Report 102 (NCRP 1997, p. 103), which provides BSF for different beam qualities and field sizes

1 cSv/cGy is the conversion from absorbed dose to dose equivalent for X-ray photons. 1 cSv = 1 rem

Table 5. Substitute DCFs for poorly collimated chest beams through 1970.[a,b]

Organ of interest	PFG (2.5 mm Al HVL)	Chest fluoro (2.0 mm Al HVL)	PA chest through 1970 (2.5 mm Al HVL)	LAT/OBL chest through 1970 (2.5 mm Al HVL)	AP lordotic chest through 1970 (2.5 mm Al HVL)
Thyroid	DCF for AP C-spine corrected for depth by 0.2.	DCF for AP C-spine corrected for depth by 0.2.	DCF for AP C-spine corrected for depth by 0.2	DCF for lat skull	DCF for AP C-spine
Eye/brain	DCF for thyroid	DCF for thyroid	DCF for thyroid	DCF for thyroid for lat skull	DCF for AP C-spine
Ovaries	N/A		N/A	N/A	DCF for AP abdomen
Liver, gall bladder, spleen					
Urinary bladder/prostate	N/A		N/A	N/A	DCF for AP abdomen
Colon/rectum	N/A		N/A	N/A	DCF for AP abdomen
Testes	N/A		N/A	N/A	DCF for AP abdomen
Lungs male					
Lungs female					
Thymus					
Esophagus					
Stomach					
Bone surfaces					
Remainder					
Breast					
Uterus	N/A		N/A	N/A	DCF for AP abdomen
Bone marrow male					
Bone marrow female					

a. Only substitute DCFs are shown in this table. A complete table of DCFs is in Attachment A, Table A-14.
b. N/A means that a measured dose from literature is used rather than a DCF.

Table 6. Substitute DCFs for poorly collimated spine and pelvis beams through 1970 (2.0 mm Al HVL).[a,b]

Organ of interest	AP lumbar spine	LAT lumbar spine	AP pelvis	AP thoracic spine	LAT/OBL thoracic spine	AP/OBL cervical spine	LAT cervical spine
Thyroid					DCF for LAT C-spine		
Eye/brain				10% of thyroid DCF[d]	DCF for thyroid		
Ovaries	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Liver, gall bladder,	DCF for	DCF for	DCF for				

spleen	ovary	ovary	ovary				
Urinary Bladder/prostate	DCF for ovary	DCF for ovary	DCF for ovary	DCF for ovary	DCF for ovary	N/A	N/A
Colon/rectum	DCF for ovary	DCF for ovary	DCF for ovary	DCF for ovary	DCF for ovary	N/A	N/A
Testes	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lungs male							
Lungs female							
Thymus							
Esophagus							
Stomach	DCF for ovary	DCF for ovary	DCF for ovary				
Bone surfaces	DCF for ovary	DCF for ovary	DCF for ovary				
Remainder	DCF for ovary	DCF for ovary	DCF for ovary				
Breast	N/A[c]	N/A[c]	N/A[c]			DCF for lung	DCF for lung
Uterus						N/A	N/A
Bone marrow male							
Bone marrow female							

a. Only substitute DCFs are shown in this table. A complete table of DCFs is in Attachment A, Table A-14.
b. N/A means that a measured dose from literature is used rather than a DCF.
c. Used method from Huda and Bissessur (1990).
d. See section 7.6 on thoracic spine, and Kereiakes and Rosenstein 1980, p. 205.

6.1 ENTRANCE SKIN DOSE EQUIVALENT

The entrance skin dose equivalent calculated using Equation 3 is the starting point for determining other skin dose equivalents. The ENSD is assigned to areas of skin in the primary beam on the beam entrance side of the body for a particular radiographic projection. Because the area of skin in the primary beam varies with the type of radiographic procedure, the projection, and collimation, standard areas of skin were defined for use in dose reconstruction. These standard areas are listed in Tables A-1 to A-6 of Attachment A, along with areas of skin that are assigned the ENSD for various procedures, projections, and periods.

6.2 EXIT SKIN DOSE EQUIVALENT

The exit skin dose (EXSD) equivalent is the dose equivalent to areas of skin where the X-ray beam exits the body. The EXSD is determined by dividing the ENSD by an absorption factor from Table B.7 in NCRP Report 102 (NCRP 1997, p. 102) to account for attenuation in the body. The selection of absorption factor depends on the beam quality and the thickness (in centimeters) of overlying tissue. In this TIB, the standard body dimensions from Table 1 are used with the assumed beam qualities (2.0, 2.5, and 4.0 mm Al HVL). The absorption factor is decreased by 10% to allow for differences between the tabulated values and actual values, as specified in the footnote to Table B.7 in NCRP Report 102. The areas of skin that are assigned the EXSD for various procedures and projections are listed in Tables A-1 to A-6 of Attachment A for various procedures, projections, and periods.

$$EXSD = (ENSD)(0.9\ AF)^{-1} \quad (4)$$

where:

EXSD is the exit skin dose

ENSD is the entrance skin dose
0.9 is an uncertainty factor in the tabulated AF
AF is the absorption factor selected from Table B.7 in NCRP Report 102 (NCRP 1997, p. 102)

6.3 SKIN OUTSIDE BUT NEAR PRIMARY BEAM

Entrance and exit dose equivalent to portions of the skin outside but near the beam are assumed to be 10% of the doses in the neighboring region inside the beam. This is based on the finding that the dose to the testes is 10% of the central beam dose when the testes are just outside the beam (Kereiakes and Rosenstein 1980, p. 205). The areas of skin that are assigned the 10% of the ENSD or the EXSD are listed in Tables A-1 to A-6 of Attachment A for various procedures, projections, and periods.

6.4 REMOTE SKIN DOSE EQUIVALENT

The dose equivalent to areas of skin that are remotely located from the primary beam (entrance or exit) is estimated from the scatter that would be the sole source of irradiation to those areas of skin. The dose equivalent to these areas is called the remote skin dose (RSD) in this TIB. The RSD is estimated using the following equation:

$$RSD = (ENSD)\ (Average\ Depth\ Dose)\ (1.1)\ (0.0005)\ (1/r^2) \quad (5)$$

where:

ENSD is the entrance skin dose equivalent from the primary beam calculated from Equation 3,

The average depth dose is the fraction of the ENSD at a point at the mid-plane of the body from Table B.8 in NCRP Report 102 (NCRP 1997, p. 103)

The factor 1.1 accounts for differences between the SSD of 60 cm assumed in Table B.8 and other SSDs specified in the title of Table B.8 (NCRP 1997, p. 103)

The factor 0.0005 is the ratio of scattered to incident exposure at 1 m from a 70-kVp primary beam that scatters 90° from the path of the incident X-ray beam from Table B-2 in NCRP Report 49 (NCRP 1976, p. 59)

The factor $1/r^2$ is a correction for the distance between the center of the primary beam to the remote skin area of interest. The distance is based on the reference adult worker defined in Kereiakes and Rosenstein (1980, Table 94 and Figures 2 and 3).

The areas of skin that are assigned the RSD for various procedures and projections are listed in Tables A-1 to A-6 of Attachment A.

7.0 TYPES AND FREQUENCY OF X-RAY SCREENING

There is some variability from site to site as to which standard projections were included in screening protocols and how frequently they were performed, depending on physician or radiologist preference. The standard screening protocols for workers or small subsets of workers should be addressed in each Occupational Medical Dose technical basis document (TBD) for a particular DOE or AWE site. X-ray projections requested by the physician on a case-by-case basis in addition to the screening protocol fall into the diagnostic category (i.e., not screening) and should not be included in dose reconstruction in compliance with 42 CFR Part 81, with a few exceptions described in the sections below.

The incidence of technically deficient films necessitating retakes is not known, but it is likely to have been very small, probably no more than a few percent. Trout et al. (1973) in their analysis of the rejection rate of chest radiographs obtained during the Coal Mine "Black Lung" program reported an average rejection rate of 3% among 67,000 radiographs. This low rejection rate occurred in a program that had fairly high standards of training for the radiologists interpreting the images in addition to standards for the image quality of the films. It is doubtful that the retake rate in the DOE complex would have been higher than this when the standards for the film readers and image quality were not formally in place in the DOE complex. Goldman and Beech (1979, p. 44) report that only about 3.64% of the examinations performed at the Baltimore Public Health Service Hospital involved a retake.

In the DOE complex, Los Alamos National Laboratory reported a retake rate of 2.2% in 1998 (Antonsen 1998, p. 26); Lawrence Berkeley National Laboratory reported a retake rate of 0% in 1991 (Thomas 1991a, p. 3); no retake program was in place at Lawrence Livermore National Laboratory in 1991 (Thomas 1991b, p. 4) or at Brookhaven National Laboratory in 1994 (Bernacki 1994, pp.13-14). The data cited above do not support the automatic inclusion of retakes as an additional source of exposure to each worker, but if dose reconstructors encounter records of retakes in individual claim file records, the dose from them should be included.

7.1 RADIOGRAPHIC CHEST

The most commonly performed X-ray screening examination or procedure is the conventional radiographic chest, which was used in the DOE/AWE complex to screen for diseases of the lungs and heart, primarily tuberculosis (TB) and occupational lung diseases like asbestosis (Wirth 1951; Cantril 1951). The PA chest projection was standard (Merrill 1949, p. 497), and sometimes accompanied by the LAT chest projection. The LAT chest was almost always a left LAT, performed with the left side of the body towards the film, to image the heart and the aorta (Merrill 1949, p. 507). Both of these projections were made on 14-in. × 17-in. film at a standard source to image distance of 72 in. (Merrill 1949, p. 497). The PA chest was occasionally performed in stereo, meaning that exposures were made on two separate films, using slightly different X-ray tube angles, and viewed at the same time with a stereoscope (Selman 1965, p. 337). The significance of the word *stereo* for dose reconstruction is that two exposures were made and, therefore, organ doses should be doubled when dose reconstructors find claim file records in which stereo projections were obtained. In the complete absence of information about a site's chest X-ray screening protocol and standard projections (including the lack of X-ray records in the claim files), a preemployment, annual, and termination PA radiographic chest X-ray should be assumed for workers for screening (Wirth 1951, p. 28).

The oblique (OBL) chest projection is usually considered an additional projection because it is used to help a physician diagnose suspicious areas found on the PA or LAT chest projection. It is not typically performed on all workers as part of a screening protocol. However, there is evidence that OBL projections increase the diagnostic accuracy of asbestosis and, therefore, could have been included as a standard screening projection for asbestos workers (Baker and Greene 1982). The OBL chest projection is usually performed with the individual's right or left anterior chest closest to the film, and referred to as the right anterior oblique (RAO) or left anterior oblique (LAO), respectively. The X-ray beam still enters the individual's body from the back and exits the front (i.e., PA). Doses from the OBL chest projection should be included in dose reconstructions for asbestos workers if they are listed in the worker's claim file as having been performed. If only one OBL chest projection was performed, dose reconstructors should assume that it was the RAO chest.

The OBL chest projection uses essentially the same technical factors as those used for the LAT chest projection, because the body part thickness is approximately the same for the two projections. When organ doses for the OBL projection are not specified in TBDs, they can be assumed to be the same as those from the LAT projection, with the exception of skin, which will be different from those of the

LAT chest projection because of the beam entering on the left side of the body (for the RAO) rather than the right side (for the LAT).

The lordotic chest projection (also known as the Lindblom position) was another additional projection requested by physicians to better visualize the apices (i.e., the uppermost portion) of the lungs (Merrill 1949, p. 513), a common location for TB. The lordotic projection was most commonly performed AP, where the individual faced the X-ray tube and leaned backwards from the waist toward the cassette for the exposure (Merrill 1949, p. 513). It would not have been performed routinely on all workers as a standard screening projection. This is evidenced by the fact that at the Hanford Site, the number of lordotic chest projections is only 2% of the number of PA chest projections performed in the 10-year period from 1946 to 1956 (Kirklin 1969). Because active TB was a cause for rejection of a potential worker (i.e., not hiring) (Cantril 1951), and the lordotic projection might have been necessary to diagnose active TB, the dose from lordotic X-rays in the preemployment examination should be included in dose reconstruction. In the periodic screening examinations performed on workers after hire, the lordotic projection *can* be considered a diagnostic projection in accordance with the definition of screening, and not included in dose reconstruction. Organ doses from the lordotic chest projection are not provided after 1985 because it is unlikely to have been performed after that time with the increasing use of computed tomography scans.

The incident air kerma values used to determine organ dose equivalents in this TIB are listed in Table 3. The incident air kerma for a LAT chest X-ray is assumed to be 2.5 times that of a PA chest in this TIB, a conservative value based on measurements from Hanford (Kirklin et al. ca. 1969) where a factor of 1.94 was observed, and other measurements that suggest the ratio of incident air kerma from LAT and PA chest radiographs could have been somewhat greater than that (Stanford and Vance 1955, p. 270).

The DCF for the female lung is higher than that for the male lung for all chest projections except the lordotic projection. The male lung DCF is higher than the female lung DCF for the lordotic chest projection (performed AP). Since the higher of the two lung DCFs is used to determine the dose to the other organs in the chest cavity (see section 5.1), the female lung DCF is used to determine the dose to the esophagus, stomach, liver/gall bladder/spleen, bone surfaces, and remainder for all chest projections except the lordotic projection, and the male lung DCF is used to determine the dose to these organs for the lordotic projection.

The organ dose equivalents from all chest projections are in Tables A-7 to A-9 in Attachment A.

7.2 PHOTOFLUOROGRAPHIC CHEST

PFG, also known as mass miniature radiography, was used for mass chest screenings for TB starting around 1940 (Birkelo et al. 1947). PFG was a mass chest screening technique most suitable to large populations because it was time-efficient and cost-effective (American Trudeau Society 1957, p. 3). Some of the screening chest X-rays with DOE and its predecessor organizations occurred with PFG. Photofluorography should not be confused with fluoroscopy, which is discussed in Section 7.3.

PFG differed from conventional chest radiography on 14-in. × 17-in. film in that the X-ray image was miniaturized with a camera lens or mirror optics system to expose 35-mm film, 70-mm film, 4-in. × 5-in. film, or 4-in. × 10–in. film for stereo views (two exposures) (Laughlin et al. 1957; Birkelo et al. 1947). The worker was positioned in the same manner as for a conventional radiographic chest X-ray, that is, PA. Most PFG equipment was portable, semiportable, or installed in the limited space provided by a mobile bus (Van Allen 1951, p. 832). A diagram of PFG is provided in Figure 3, and a photograph of a General Electric PFG machine is provided in Figure 4.

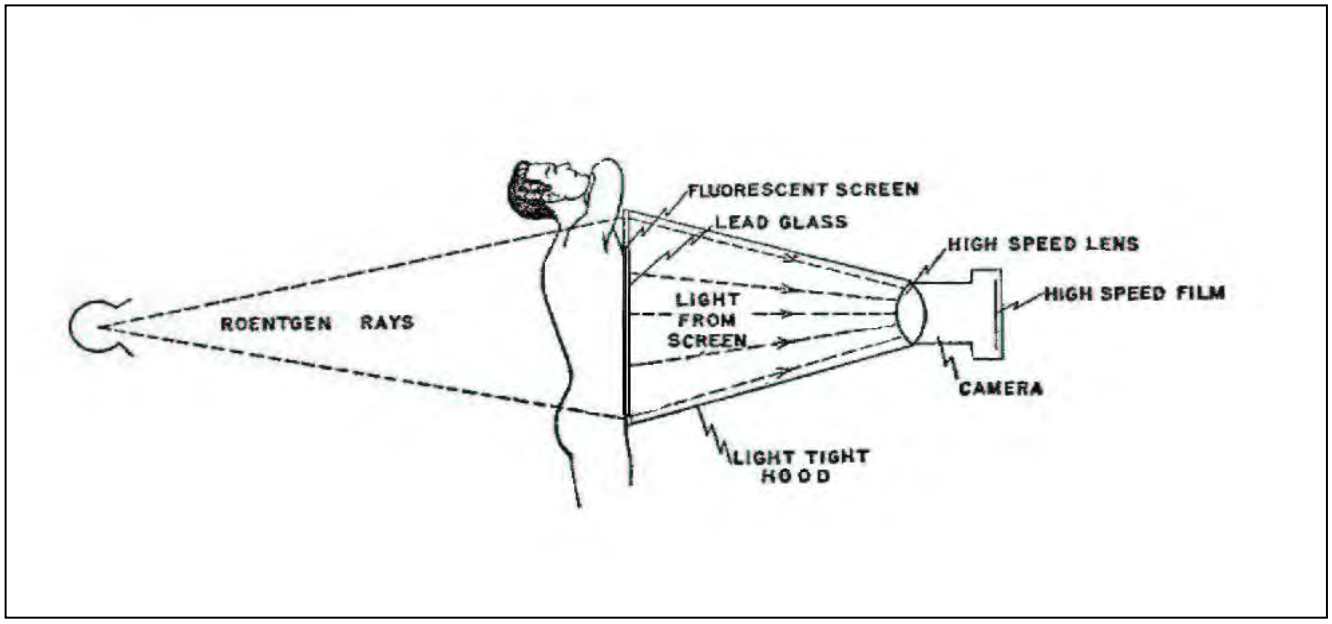

Figure 3. Essential components of a PFG unit. From Selman 1965, p. 353.

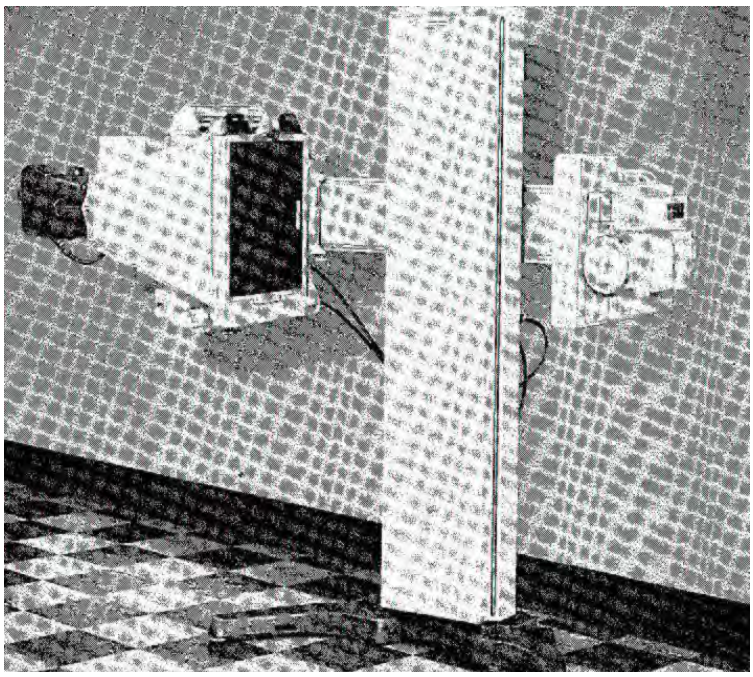

Figure 4. Typical General Electric PFG system. From GE 1963, p. 25.

PFG typically produces higher doses to workers than conventional chest radiography (Braestrup and Wyckoff 1958, p. 140; Laughlin et al. 1957; Moeller, Terrill, and Ingraham 1953). Moeller, Terrill, and Ingraham (p. 59) stated that the "largest single source of medical radiation exposure in the United States is the mass chest X-ray survey for tuberculosis." The resolution of PFG systems was not as good as conventional film screen systems; only 6 line/pairs per mm rather than about 9-10 line/pairs per mm (Goodwin, Quimby, and Morgan 1970, p. 108). In addition, the small size of the films made the images difficult to interpret. The higher dose and small film size with PFG, combined with lower resolution and perfection of the Mantoux skin test for TB screening, eventually led to PFG becoming obsolete, probably in the mid-1960s. By the mid-1970s, it was recommended that “Whenever

possible, Federal agencies should not use photofluorographic equipment to perform X-ray examinations" (EPA 1976, p. 13).

Typical operating parameters reported for 1950s PFG were 24 mAs at 83 kVp at a target-to-film distance of 36 in. (Braestrup and Wyckoff 1958, p. 143), and 30 mAs at 90 kVp with a target-to-film distance of 40 in. and 2.4 mm added filtration. Phantom measurements in the literature indicate an entrance skin dose (including backscatter) of about 0.5 cGy (Laughlin et al. 1957) to 1.53 cGy (Rising and Soldat 1959). The incident air kerma value for PFG was derived from the measured skin dose in Rising and Soldat (1959) and Equation 6 below.

The incident air kerma ($K_{a,i}$) corresponding to the published skin dose value is calculated by:

$$K_{ai} = (\text{ENSD rad})(\text{BSF})^{-1}\ (1\text{cGy rad}^{-1}) \quad (6)$$

where:

$K_{a,i}$ is the incident air kerma to be used in organ dose calculations in units of cGy in air;

ENSD is the entrance skin dose in rad [1.53 for PFG chest from Rising and Soldat (1959)

BSF is the backscatter factor from Table B.8 of NCRP Report 102 (NCRP 1997) (1.35 for 2.5 mm Al HVL)

As a result of the shorter SID of PFG compared with conventional radiographic machines, the beam for PFG is estimated to include the thyroid, thoracic organs, and liver/gall bladder/spleen, but not the eye/brain, gonads, urinary bladder/prostate, or colon/rectum.

PFG was commonly performed as a stereo procedure, which required two projections from slightly different angles. Therefore, the organ dose equivalents in this TIB assume a stereo exposure. Dose reconstructors must pay attention to the size of the film in the claim file records and, if the 4-in. × 10-in. film is noted to have been used, dose reconstructors should assume stereo projections and use the organ doses listed in Tables A-7 and A-8 in Attachment A. If the film size in the claim file records is 4-in. × 5-in., dose reconstructors should assume a single projection, and divide the organ doses listed in Tables A-7 and A-8 in half.

Because PFG was primarily a mass screening technique most suitable to large populations, and therefore unlikely to have occurred on a mass scale at AWE sites, PFG should not be assumed to have occurred at AWE sites unless there is evidence to the contrary.

Organ dose equivalents from PFG chest X-rays are in Tables A-7 and A-8 in Attachment A.

7.3 CHEST FLUOROSCOPY

Fluoroscopy, not to be confused with PFG, discussed in Section 7.2, involves real-time viewing of a fluorescent screen continuously activated by X-rays. This procedure was not generally amenable to mass examinations or preemployment screening of workers, and was not mentioned as a screening technique in a study to determine the most efficacious method for mass screening (Birkelo et al. 1947). In a report on chest X-rays, surveys, and radiation exposure, the American Trudeau Society (1957, p. 3) states,

> *Screening of groups by fluoroscopy should be strongly discouraged for several reasons: the results are not accurate for diagnostic purposes; there is no permanent film record of the examination; and the radiation exposure involved both for the subject and*

examiner is excessive. However, special fluoroscopic examination may be indicated for specific diagnostic purposes and for the determination of the dynamics of the chest.

Although chest fluoroscopy was not a standard preemployment or occupational screening procedure for the chest, there are indications that fluoroscopic chest examinations were conducted and required by at least two sites (Linde Ceramics and Battelle King Avenue) and it is possible that such examinations were also conducted elsewhere (ORAUT 2009 and 2010).

Given the era, the fluoroscopic equipment was most likely to have been "direct" or non-image-intensified fluoroscopy equipment, which is now considered obsolete. While incident air kerma rates for this type of equipment can be found in the literature, average fluoroscopy exposure times, especially for chest screening examinations, are not commonly found. However, a study of the incident air kerma rates, HVLs, and estimated fluoroscopy exposure times was conducted on non-image-intensified fluoroscopy equipment in the modern era in Albania (Marshall et al. 2001). In this study, the exposure time for chest fluoroscopy screening was estimated to be about 20 seconds, with an average incident air kerma rate of about 4 cGy/min, and an average HVL of about 2.3 mm Al. Therefore, chest fluoroscopy dose equivalents in this TIB are calculated using an incident air kerma rate of 5 cGy/min for 30 seconds of fluoroscopy time and assumed HVL of 2.0 mm Al based on the Marshall et al. data. For chest fluoroscopy, the X-ray field is assumed to include the thoracic organs and the liver/gall bladder/spleen, but not the thyroid, gonads, urinary bladder/prostate, or colon/rectum, because of the short SSD (approximately 40 cm). However, the beam size is estimated to be similar to the beam for a poorly collimated radiographic chest X-ray to account for the fact that the field in chest fluoroscopy is dynamic and could expose a larger area of the body than the short SSD would initially imply. A diagram of non-image-intensified fluoroscopy is provided in Figure 5, and doses for chest fluoroscopy are included in Tables A-7 and A-8 in Attachment A.

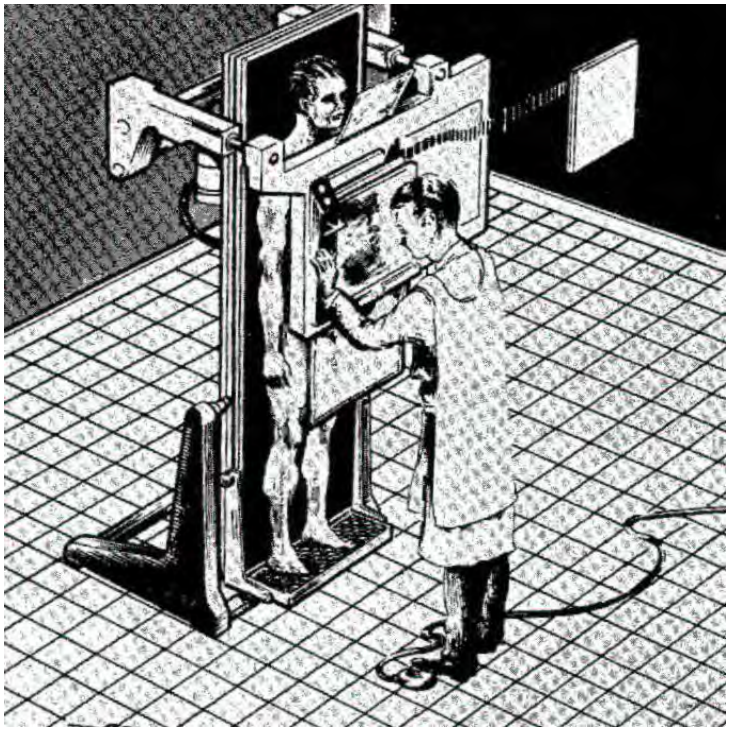

Figure 5. Diagram of non-image-intensified fluoroscopy. From Massey 1977, p. 90.

7.4 LUMBAR SPINE

Lumbar spine radiographs have been used since the 1930s to determine the presence of back problems or to predict future occurrence of back problems (La Rocca, and Macnab 1969, p. 383). At some DOE and AWE sites, lumbar spine radiographs were required for certain classes of workers (usually males) whose work could entail heavy labor. Typically, if lumbar spine radiography was used for screening, it was performed as part of the preemployment physical examination, and for many workers this might have been the only occasion on which lumbar spine radiographs were taken. However, the possibility of periodic lumbar spine examinations, including a physical examination at the termination of employment should not be precluded.

The number of lumbar spine projections per examination was likely to have varied from site to site, and should be documented in the TBD if they were performed. In a study of the number of lumbar spine projections performed to assess applicants for Veteran's Administration (VA) compensation for lumbar spine disease or injury, Eisenberg et al. (1980, p. 1073) found that on average, the number of lumbar spine projections performed at VA facilities was 4.2 per examination. In the absence of evidence to the contrary, a lumbar spine examination for screening should be assumed to consist of 4 projections: AP, LAT, LAT spot of L4-5, and AP spot. The organ dose equivalents for the individual projections are provided, however, if claim file records indicate fewer than four projections, dose reconstructors can determine the total dose equivalent accordingly. While both the AP and LAT spot projections were likely to have been made on smaller size film and with smaller beam sizes, it is assumed for dose reconstruction that these were made on full size 14-in. × 17-in. film.

Eventually, the preemployment lumbar spine radiographs were shown to have low predictive value for future lumbar spine disability (La Rocca and Macnab 1969, p. 387), and various groups recommended that lumbar spine radiographs be discontinued for screening (American Occupational Medical Association, 1979).

There are several good studies of measured doses to the skin and gonads from the lumbar spine examination that were conducted in the 1950s, because of the concern at that time about gonad dose to the population as a whole (Lincoln and Gupton 1958; Laughlin et al 1957; Billings, Norman, and Greenfield 1957). Measured skin doses with phantoms (i.e., including backscatter) in these studies ranged from 0.25 to 3.9 cGy for the AP lumbar spine projection, and from 0.5 to 12.4 cGy for the LAT lumbar spine projection, depending on whether the facility used a low (50-70) or high (90-120) kVp technique. In this TIB, the measured skin and gonad doses from Lincoln and Gupton (1958, Table VII) will be used because they appear to be in the middle of the range, and because several of their measurements were performed at DOE sites [Oak Ridge National Laboratory (ORNL) and the K-25 Plant].

The incident air kerma value for the lumbar spine projections through 1970 were derived from the average skin doses at ORNL listed in Lincoln and Gupton (1958, Table VII). The skin dose value for the AP lumbar spine is 1,900 mrad, measured with a phantom, and therefore includes backscatter. The incident air kerma is derived using Equation 6 above. The HVL of 2.0 was determined from the data in Lincoln and Gupton (1958, Tables VII and III). Table III shows that for a skin dose of 2,000 mrad, the kVp was 80 and the filter (assumed to be the added filter) was 1.0 mm Al. Assuming a total filtration of 1.5 mm Al eq., the HVL is 1.8, rounded to 2.0 mm Al at 80 kVp from Table B.2 in NCRP Report 102 (NCRP 1997, p. 98). The incident air kerma for the LAT lumbar spine projection was determined in the same way, resulting in an incident air kerma value of 3.79 cGy.

The ovary and testes doses for the poor collimation period before 1970 also come directly from Lincoln and Gupton (1958, Table VII), because they were measured with a phantom and include backscatter.

X-rays of the lumbar spine were performed AP, often on 14-in. × 17-in. film in the lengthwise direction, and using a 40–in. SID. Figure 6 is an approximately scaled diagram of the poorly and properly collimated beams in relation to abdominal organs for the AP lumbar spine, and helps to visualize the beam for the proper selection of DCFs. The DCF for the ovary from ICRP Publication 34 (ICRP 1982) is used to determine the dose to the liver/gall bladder/spleen, the urinary bladder/prostate, the colon/rectum, bone surfaces, stomach, and remainder organs because these organs are likely to be in the primary beam. The DCFs are summarized in Table 6.

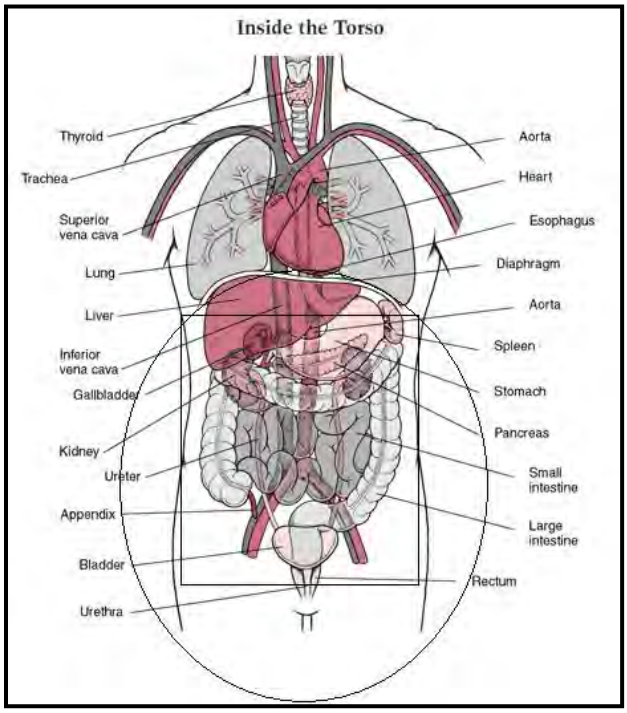

Figure 6. Beam areas in relation to body anatomy for the AP lumbar spine.

The incident air kerma value for the lumbar spine projections after 1970 comes directly from Kereiakes and Rosenstein (1980, p. 213). These data are contemporaneous and relevant for use in this period. Again, the DCF for the ovary from ICRP Publication 34 (ICRP 1982) is used to determine the dose to the liver/gall bladder/spleen, the urinary bladder/prostate, the colon/rectum, bone surfaces, stomach, and remainder organs because these organs are likely to be in the primary beam.

There is no DCF in ICRP Publication 34 (ICRP 1982) for the breast from lumbar spine projections. ICRP Publication 34 (p. 57) states that the DCF is "not computed but small compared with projections listed." Several methods of estimating breast dose equivalent have been used in some of the TBDs. In this TIB, a method described by Huda and Bissessur (1990) is used to determine the dose equivalent to the breast from the lumbar spine projections. Huda and Bissessur provide graphical representations of the effective dose equivalent (H_E) per unit entrance skin dose (backscatter included) as a function of kVp for 12 common radiographic procedures, and values of dose equivalent per unit dose area product (DAP). The data are a result of individual organ doses obtained using a Monte Carlo method for reference man as a function of kVp and X-ray beam filtration (Huda and Bissessur 1990 p. 998). Huda and Bissessur provide the fraction of the total H_E due to several organs, one of which is the breast. With knowledge of the DAP, and the fraction due to the breast dose, the H_E and the dose to the breast can be derived (Huda and Bissessur 1990, p. 1001). The dose to the breast from lumbar spine projections for both periods was determined using this method.

Organ dose equivalents from lumbar spine X-rays are in Tables A-10 and A-11 in Attachment A.

7.5 PELVIS

In 1932, skeletal fluorosis was discovered as an occupational disease in cryolite (natural fluoride of aluminum and sodium) workers in Copenhagen, Denmark (Grandjean 1982). Skeletal fluorosis exhibited a variety of radiologic patterns including increased bone density, calcification of ligaments, and periosteal changes (Chan-Yeung et al. 1983). During the early years of atomic weapons work, the Manhattan Engineering District and the U.S. Atomic Energy Commission sometimes required that X-rays of the pelvis be taken of personnel who worked with materials containing fluoride to detect bone changes due to fluorosis (Van Horn 1943; Osinski 1947).

X-rays of the pelvis were used in the 1940s for medical monitoring of workers with potential exposure to fluoride and fluoride compounds. It is assumed that by 1960 more specific and sensitive screening methods than spine and pelvis radiographs for fluorosis were available.

Workers in the atomic weapons complex who might have been exposed to fluoride and fluoride compounds include workers at the gaseous diffusion plants. In the absence of specific fluorosis monitoring programs documented by individual sites and described in TBDs for those sites, organ doses for pelvis, lumbar, thoracic, and cervical spine X-rays should be included in dose reconstructions for workers exposed to fluoride and fluoride compounds if the employees' records include evidence of these types of X-ray procedures.

Lincoln and Gupton (1958) measured skin and gonad doses (including backscatter) using a tissue-equivalent phantom for various examinations, including the AP pelvis. In this TIB, the measured skin and gonad doses from Lincoln and Gupton (1958, Table VII) will be used because they appear to be in the middle of the range, and because several of their measurements were performed at DOE sites (ORNL and K-25). An HVL of 2 mm Al is assumed based on the data in Lincoln and Gupton. The incident air kerma is derived using Equation 6 above, resulting in an incident air kerma value for the pelvis of 1.52 cGy.

X-rays of the pelvis were performed AP, often on 14-in. × 17-in. film placed in the crosswise direction, and using a 40–in. SID. Figure 7 is an approximately scaled diagram of the poorly and properly collimated beams in relation to abdominal organs for the AP pelvis, and helps to visualize the beam for the proper selection of DCFs. The DCF for the ovary from ICRP Publication 34 (ICRP 1982) is used to determine the dose to the liver/gall bladder/spleen, the urinary bladder/prostate, the colon/rectum, stomach, bone surfaces, and remainder organs because these organs are likely to be in the primary beam. The DCFs are summarized in Table 6.

There is no DCF in ICRP Publication 34 (ICRP 1982) for the breast from the AP pelvis. ICRP Publication 34 (p. 57) states that the DCF is "not computed but small compared with projections listed." The method described by Huda and Bissessur (1990) in Section 7.4 is used to determine the dose to the breast from the AP pelvis.

Organ dose equivalents from pelvis X-rays are in Tables A-10 and A-11 in Attachment A.

7.6 THORACIC AND CERVICAL SPINE

X-rays of the thoracic spine (also called dorsal spine) or cervical spine were used in the 1940s for medical monitoring of workers with potential exposure to fluoride and fluoride compounds similar to the X-rays of the pelvis described in Section 7.5. Organ dose equivalents for thoracic and cervical spine X-rays should, therefore, be included in dose reconstructions for workers exposed to fluoride and fluoride compounds if the employees' records include evidence of these types of X-ray procedures.

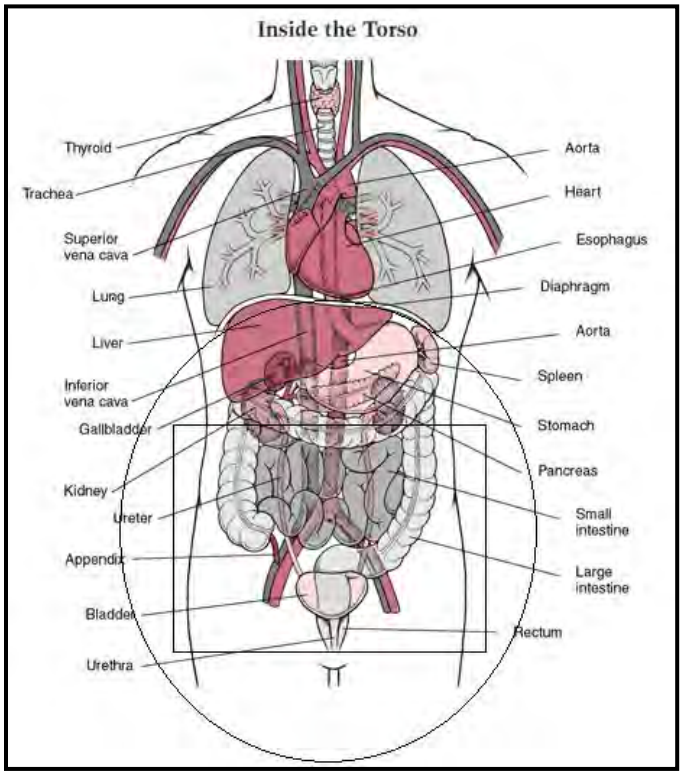

Figure 7. Beam areas in relation to body anatomy for the AP pelvis.

Routine protocols for thoracic and cervical spine X-rays are listed in Table 7. While it is possible that fewer exposures were made for fluorosis monitoring, organ doses for a complete set of projections should be assumed unless there is evidence to the contrary in the individual employee's record.

Table 7. Typical protocols for thoracic and cervical spine examinations.

Procedure	Projections
Thoracic spine	AP and LAT, right and left posterior obliques, total of 4.
Cervical spine	AP and LAT, right and left posterior obliques, total of 4.

The incident air kerma for the thoracic spine is derived from measured skin dose (1.3 and 2.9 rad for the AP and LAT/OBL, respectively) in Lincoln and Gupton (1958, Table VII), and Equation 6, resulting in an incident air kerma of 0.985 cGy and 2.20 for the AP and LAT/OBL, respectively, and an HVL of 2.0 mm Al. It is assumed that all four projections were taken on 14-in. × 17-in. film with a poorly collimated beam. Figure 8 illustrates the approximately scaled poorly and well-collimated beams for the AP thoracic spine.

DCFs were selected from ICRP Publication 34 (ICRP 1982) tables according to the location of the organs in relation to the poorly collimated beam. The thyroid is assumed to be in the poorly collimated beam, but not the eye/brain, the dose to which is usually determined using the DCF for the thyroid. For thoracic spine procedures, the dose equivalent to the eye/brain is assumed to be 10% of the dose equivalent to the thyroid. This estimate is based on the finding that scattered radiation produces a dose to the testes equal to 10% of the central beam dose when the testes are just outside a beam (Kereiakes and Rosenstein 1980, p. 205). The dose equivalents for the ovaries and testes are taken directly from measured doses reported in Lincoln and Gupton (1958, Table VII). The dose equivalents for the urinary bladder, prostate, colon, and rectum are based on the DCF for the ovary because these organs are all assumed to be outside the poorly collimated beam. The dose

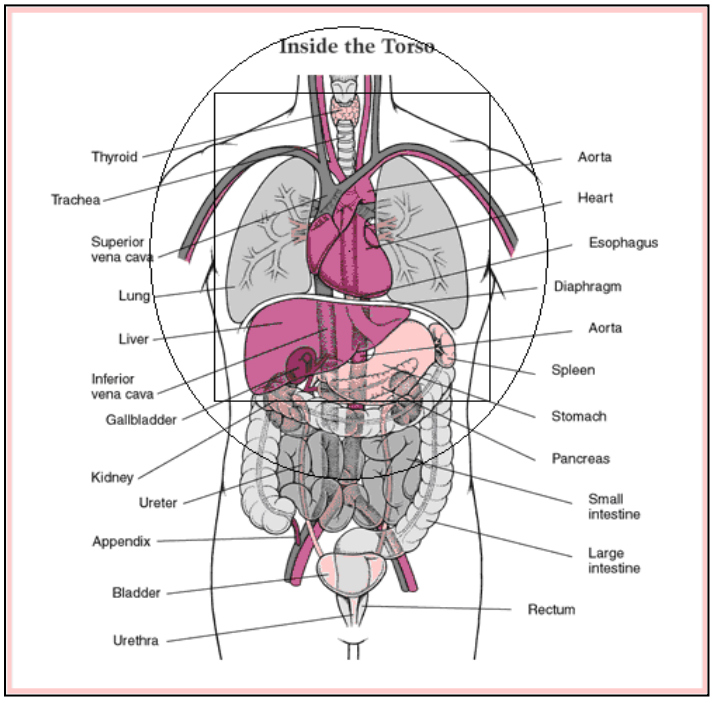

Figure 8. Beam areas in relation to body anatomy for the AP thoracic spine.

equivalents to the lungs, liver, gall bladder, spleen, thymus, esophagus, stomach, bone surfaces and remainder organs are all based on the DCF for the lungs.

The DCF for the thyroid for the LAT thoracic spine does not seem to reflect irradiation by the primary beam. Thus, for the LAT thoracic spine projection, the thyroid dose equivalent is based on the DCF for the LAT cervical spine, where the thyroid is definitely in the primary beam. The dose equivalent to the eye/brain seems to be approximately 10% of the dose equivalent to the thyroid simply by using the DCF for the thyroid for the LAT thoracic spine and, therefore, that DCF was used.

The right posterior oblique (RPO) and left posterior oblique (LPO) of the thoracic spine are positioned similarly to the LAT thoracic spine position (i.e., about 20° from the LAT). The organ dose equivalents, then, are assumed to be the same for the LAT thoracic spine and the RPO and LPO. The skin dose equivalents, however, are different depending on whether the right or left side is closest to the beam.

Organ dose equivalents for the thoracic spine are provided in Table A-12, and the skin dose equivalents are in Table A-13 in Attachment A.

There is much less data in the literature for the cervical spine. Data on technical factors for cervical spine X-rays were obtained from Braestrup and Wyckoff (1958, Tables VI and VII, pp. 140-141). The pertinent data from these tables is excerpted in Table 8.

Incident air kerma values for the AP, LAT, and OBL cervical spine projections were derived from the Braestrup and Wyckoff data in Table 3 and Equation 7.

$$K_{a,i}\,(\text{cGy})(\text{air}) = (\text{R}/100\text{mAs})(\text{actual mAs})(\text{SID}/\text{SSD})^2\,(2.58\text{E-}4\ \text{C/kg R}^{-1})\,(33.97\ \text{J/C})(100\text{cGy/Gy})(1\text{Gy}/1\text{J kg}^{-1}) \quad (7)$$

where

$K_{a,i}$ is the incident air kerma to be used in organ dose calculations in units of cGy in air;

R/100mAs from Table 7

Actual mAs from Table 7

$(91cm/SSD)^2$ is the inverse square correction for the exposure measured at 91 cm from Table 7 to the SSD of interest from Table 3

2.58E-4 C/kg R^{-1} is the conversion factor for converting exposure in R to C/kg

33.97J/C is the mean energy expended per ion pair formed in air

Table 8. Relevant technical factors for cervical spine projections.

Projection	Technique factors[a]			R/100 mAs[a,b]	SSD[c]	HVL (mm Al)[d]
	kVp	mAs	SID (cm)			
AP C-spine	58	100	91	0.4	82	2.0
LAT C-spine	70	150	152[e]	0.2	153[f]	2.0
Posterior OBL C-spine	--	--	91	--	82	2.0

a. Excerpted data from Braestrup and Wyckoff (1958, Tables VI and VII, pp. 140-141).
b. Interpolated for the kVp closest to the kVp listed in the technique factor column, and for the listed SSD.
c. SSD from Table 1.
d. Based on kVp and 2.5 mm Al equivalent total filtration reported in Braestrup and Wyckoff (1958).
e. Longer SID used for the LAT cervical spine to reduce magnification.
f. The SSD for the LAT cervical spine = 183 cm – 15 cm – 5 cm – 10 cm = 153 cm. The 10 cm accounts for the fact that during the LAT cervical spine, the shoulder is against the cassette holder, so the side of the neck is not actually in contact with the cassette holder, affecting the SSD calculation.

When positioned for a LAT cervical spine radiograph, the worker's shoulder is against the cassette holder, and the neck is assumed to be another 10 cm away from, and not in contact with, the cassette holder, affecting the SSD calculation. Incident air kerma for the posterior OBL cervical spine is estimated to be the same as the incident air kerma for the AP projection because the position is similar and the tissue thickness of the neck is the same. The HVL is based on the kVp listed in Table 7, and 2.5 mm Al equivalent total filtration from Braestrup and Wyckoff (1958, Table VI). It is assumed that all four projections were taken on 10-in. × 12-in. film with a poorly collimated beam. Figure 9 illustrates the approximately scaled poorly and well-collimated beams for the LAT cervical spine.

The DCF values in ICRP Publication 34 (ICRP 1982) for the cervical spine are based on the assumption that the image receptor is 102 cm from the X-ray source, and the beam is collimated to an image receptor size of 25.4 cm × 30.5 cm (where 30.5 cm represents the dimension parallel to the height of the worker). DCFs for the breast are not computed in ICRP Publication 34 for the cervical spine procedure. The DCF for the lungs was used instead. The DCFs used for dose reconstruction in this TIB are provided in Table 5.

Measured doses for the ovaries and testes are again used, this time from published values in Braestrup and Wyckoff (1958). The measured dose for the ovary is also assigned to the urinary bladder, prostate, colon, rectum, and uterus. Organ dose equivalents for the cervical spine are provided in Table A-12, and the skin dose equivalents are in Table A-13 in Attachment A.

8.0 UNCERTAINTY ANALYSIS FOR OCCUPATIONAL MEDICAL X-RAY DOSES

Error (deviation from the correct, true, or conventionally accepted value of a quantity) and uncertainty (potential range of a stated, measured, assumed, or otherwise determined value of a quantity) provide an indication of the confidence of the dose estimates. Error implies knowledge of what the correct or

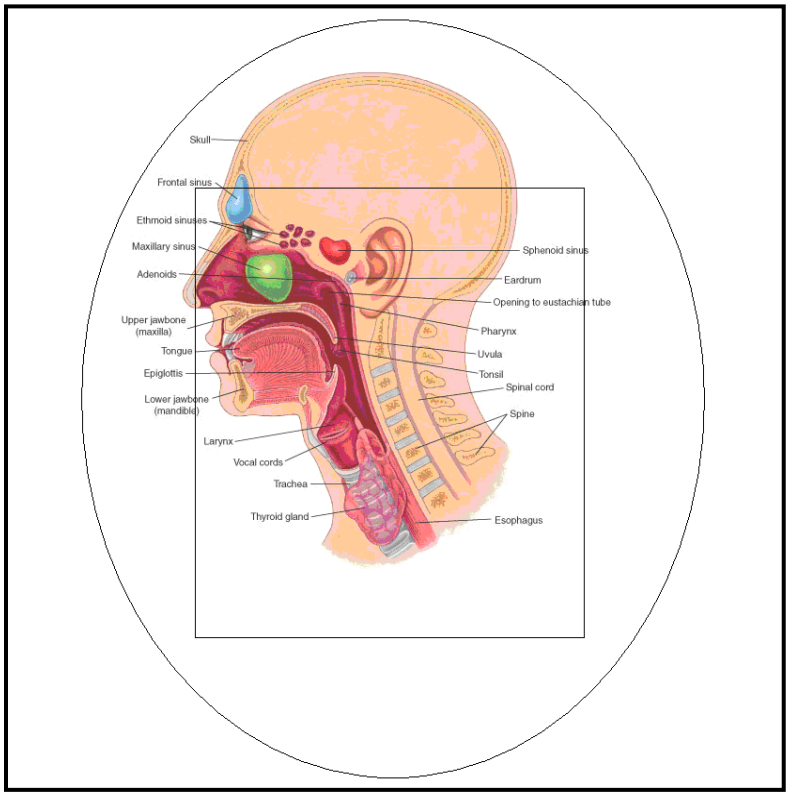

Figure 9. Beam areas in relation to body anatomy for the LAT cervical spine.

actual value is, which is, of course, not known. Therefore, the more appropriate factor is uncertainty, which is expressed in terms of a confidence level (e.g., a 99% confidence level indicates that the correct or true value, although not actually known, has a 99% probability of falling within the cited range). Uncertainty includes both precision (reproducibility of the measurement) and accuracy (how close the measurement or estimate of dose comes to the actual or correct value).

In theory, a large number of factors can introduce uncertainties or affect the X-ray machine output and dose to the worker. However, in practice only five factors can be reasonably considered to have a meaningful or significant impact on dose uncertainty. These are:

1. Measurement error
2. Variation in kilovoltage (kVp)
3. Variation in beam current (mA)
4. Variation in exposure time (s)
5. Distance from the worker to the source of the X-rays (SSD)

The influence of such other factors as use of screens, grids, film speed, and development, while potentially variable, do not affect the beam output *per se* except indirectly as these can influence the machine settings (i.e., kVp, mA, and time).

The organ dose equivalents in this TIB are based on incident air kerma values from published literature. These actual X-ray beam measurements were made with R-meters or similar ionization chamber instruments suitably designed for measurement of photons in the medical X-ray energy range. If properly calibrated and used, R-meters and similar instruments typically and historically have had an uncertainty of ±2% for photon energies below 400 keV (Kathren and Larson 1969). Although more recent versions of these instruments might provide a somewhat smaller uncertainty,

perhaps on the order of ±1% (NBS 1985; Lamperti, Loftus, and Loevenger 1988), for conservatism, the uncertainty range of ±2% will be applied to measurements of air kerma.

For a given set of machine settings and parameters, X-ray output is theoretically constant. In general, for a given kVp setting, variation in kVp falls within ±5% of the machine setting (Seibert, Barnes, and Gould 1991). As noted above, beam intensity is approximately proportional to the 1.7 power of the kilovoltage; this translates to an uncertainty of approximately ±8.6% in output beam intensity in the 80- to 100-kVp range used in medical radiography. For conservatism, this is rounded up to ±9%.

Similarly, slight variations in tube current are normal; as a tube ages, or heats up from use, current can change and typically drops. With all other factors constant, beam output will be reduced in direct proportion to the change in tube current. The reduction in beam output from current variation is not more than a few percent under normal operating conditions; large decreases are readily detectable and result in maintenance on the machine to restore the output or, as a temporary measure, an increase in the current or kilovoltage to provide the necessary exposure for proper film density. The estimated uncertainty in beam intensity or output attributable to current variation is ±5%.

Another parameter that has potential to affect the dose from a radiographic procedure, perhaps significantly, is the time of exposure. A single-phase, full-wave-rectified machine produces 120 pulses of X-rays per second. In an exposure time of 1/20 of a second, only six pulses would result. A small error in the timer that resulted in a change of only ±1 pulse would correspondingly affect the output by ±17%; for an exposure time of 1/30 of a second, the change in output corresponding to a deviation of ±1 pulse is ±25%. Early mechanical timers were inaccurate; accuracy improved significantly with the introduction of electronic timers. The assumed uncertainty in beam output attributable to timers is ±25%.

The final factor likely to affect worker dose relates to distance from the source of the X-rays, which is an important determinant of the incident air kerma. For a given procedure using a standard SID, the SSD will be determined largely by the body thickness of the worker and the accuracy of the positioning. Information on worker thickness is rarely available, even in the medical literature. The estimated variation in SSD is no more than a few centimeters, with an upper limit of perhaps 7.5 cm for typical workers. Using the inverse square law, this indicates an uncertainty of ±10% from this source.

There are two approaches to determine the combined uncertainty from these five potential sources of uncertainty. The first, and most conservative in that it gives the greatest range, would be to assume that the uncertainties are additive, which would give an uncertainty range of 2 + 9 +5 + 25 + 10 = ±51%. However, a more reasonable approach would be to assume that the uncertainties are in fact random, and therefore to compute the combined statistical uncertainty as the square root of the sum of the squares of all the uncertainties, which is ±28.9%. Rounding this up to ±30% would seem to provide an adequate and suitably conservative indication of uncertainty. Therefore, for a derived dose equivalent to an individual organ, a total combined standard uncertainty of ±30% can be assumed. Dose reconstructors should, therefore, input the organ dose equivalent as the mean of a normal distribution, with a standard uncertainty of ±30%.

Entrance skin dose measurements were made on nine workers of varying chest thicknesses (builds) at the Savannah River Plant, (Cooley 1967). While Cooley does not report the measured chest thicknesses for these nine workers, the entrance skin doses are reported and reflect the increase in exposure needed to radiograph thicker body parts, in this case, chests. The measured entrance skin doses in this small study would already include the uncertainty in the technical factors (kVp, mA, and time) used to make the exposures, and can therefore be used a reasonable check of the uncertainty calculated above. The standard uncertainty of the range of measurements reported in Cooley is 5.6, or 21%. This would seem to indicate that the 30% standard uncertainty calculated above is a

reasonable estimate of uncertainty to use in dose reconstruction of organ dose from medical X-ray procedures.

9.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references in the reference section of this document.

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Table A-1. Skin dose guidance for chest projections for the poor collimation period through 1970.

Area of skin	Basis for PFG	Basis for PA chest through 1970[a]	Basis for LAT chest through 1970	Basis for AP lordotic chest through 1970	Basis for RAO chest through 1970	Basis for LAO chest through 1970	Basis for chest fluoroscopy through 1970[a]
R front shoulder	EXSD	EXSD	ENSD	ENSD	EXSD	EXSD	EXSD
R back shoulder	ENSD	ENSD	ENSD	EXSD	ENSD	ENSD	ENSD
L front shoulder	EXSD	EXSD	EXSD	ENSD	EXSD	EXSD	EXSD
L back shoulder	ENSD	ENSD	EXSD	EXSD	ENSD	ENSD	ENSD
R upper arm to elbow	10% ENSD	ENSD	ENSD	ENSD	ENSD	ENSD	ENSD
L upper arm to elbow	10% ENSD	ENSD	EXSD	ENSD	ENSD	ENSD	ENSD
L hand	ENSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD	ENSD
R hand	ENSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD	ENSD
L elbow, forearm, wrist	10% ENSD	ENSD	10% ENSD	ENSD	10% ENSD	10% ENSD	ENSD
R elbow, forearm, wrist	10% ENSD	ENSD	10% ENSD	ENSD	10% ENSD	10% ENSD	ENSD
R side of head (including temple and ear)	10% ENSD	10% ENSD	Eye/brain	10% ENSD	10% EXSD	10% ENSD	10% ENSD
L side of head (including temple and ear)	10% ENSD	10% ENSD	Eye/brain	10% ENSD	10% ENSD	10% EXSD	10% ENSD
Front L thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Back L thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Front R thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Back R thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
L knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)
R knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)
L side of face	Eye/brain	Eye/brain	Eye/brain	ENSD	ENSD	EXSD	Eye/brain
R side of face	Eye/brain	Eye/brain	Eye/brain	ENSD	EXSD	ENSD	Eye/brain
L side of neck	10% ENSD	ENSD	Eye/brain	ENSD	ENSD	EXSD	ENSD
R side of neck	10% ENSD	ENSD	Eye/brain	ENSD	EXSD	ENSD	ENSD
Back of head	10% ENSD	10% ENSD	Eye/brain	EXSD	10% ENSD	10% ENSD	10% ENSD
Front of neck	Eye/brain	Eye/brain	Eye/brain	ENSD	Eye/brain	Eye/brain	Eye/brain
Back of neck	10% ENSD	ENSD	Eye/brain	EXSD	ENSD	ENSD	ENSD
Front torso: base of neck to end of sternum	EXSD	EXSD	Lung[b]	ENSD	EXSD	EXSD	EXSD
Front torso: end of sternum to lowest rib	EXSD	EXSD	Lung[b]	ENSD	EXSD	EXSD	EXSD
Front torso: lowest rib to iliac crest	EXSD	EXSD	Lung[b]	ENSD	EXSD	EXSD	EXSD
Front torso: iliac crest to pubis	10% EXSD	10% EXSD	10% Lung[b]	10% ENSD	10% EXSD	10% EXSD	10% EXSD
Back torso: base of neck to mid-back	ENSD	ENSD	Lung[b]	EXSD	ENSD	ENSD	ENSD
Back torso: mid-back to lowest rib	ENSD	ENSD	Lung[b]	EXSD	ENSD	ENSD	ENSD

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Area of skin	Basis for PFG	Basis for PA chest through 1970[a]	Basis for LAT chest through 1970	Basis for AP lordotic chest through 1970	Basis for RAO chest through 1970	Basis for LAO chest through 1970	Basis for chest fluoroscopy through 1970[a]
Back torso: lowest rib to iliac crest	ENSD	ENSD	Lung[b]	EXSD	ENSD	ENSD	ENSD
Back torso: buttocks (Iliac crest and below)	10% ENSD	10% ENSD	10% Lung[b]	10% EXSD	10% ENSD	10% ENSD	10% ENSD
Right torso: base of neck to end of sternum	ENSD	ENSD	ENSD	ENSD	EXSD	ENSD	ENSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	ENSD	EXSD	ENSD	ENSD
Right torso: lowest rib to iliac crest	ENSD	ENSD	ENSD	ENSD	EXSD	ENSD	ENSD
Right torso: iliac crest to pubis (R hip)	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% ENSD	10% ENSD
Left torso: base of neck to end of sternum	ENSD	ENSD	EXSD	ENSD	ENSD	EXSD	ENSD
Left torso: end of sternum to lowest rib	ENSD	ENSD	EXSD	ENSD	ENSD	EXSD	ENSD
Left torso: lowest rib to iliac crest	ENSD	ENSD	EXSD	ENSD	ENSD	EXSD	ENSD
Left torso: iliac crest to pubis (L hip)	10% ENSD	10% ENSD	10% EXSD	10% ENSD	10% ENSD	10% EXSD	10% ENSD

a. Skin dose guidance for chest fluoroscopy is the same as the guidance for the PA chest through 1970.
b. The higher of the male or female lung dose value should be used for both genders.

Table A-2. Skin dose guidance for lumbar spine and pelvis projections for the poor collimation period through 1970.

Area of skin	Basis for AP and AP spot lumbar spine through 1970	Basis for LAT and LAT spot lumbar spine through 1970	Basis for LPO lumbar spine through 1970	Basis for RPO lumbar spine through 1970	Basis for AP pelvis through 1970
R front shoulder	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD
R back shoulder	10% EXSD	10% ENSD	10% ENSD	10% EXSD	10% EXSD
L front shoulder	10% ENSD	10% EXSD	10% EXSD	10% ENSD	10% ENSD
L back shoulder	10% EXSD	10% EXSD	10% EXSD	10% EXSD	10% EXSD
R upper arm to elbow	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% ENSD
L upper arm to elbow	10% ENSD	10% EXSD	10% EXSD	10% ENSD	10% ENSD
L hand	ENSD	10% EXSD	10% EXSD	10% ENSD	ENSD
R hand	ENSD	10% ENSD	10% ENSD	10% EXSD	ENSD
L elbow, forearm, wrist	ENSD	10% EXSD	10% EXSD	10% ENSD	ENSD
R elbow, forearm, wrist	ENSD	10% ENSD	10% ENSD	10% EXSD	ENSD
R side of head (including temple and ear)	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of head (including temple and ear)	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front L thigh	10% ENSD	10% EXSD	10% ENSD	10% ENSD	10% ENSD
Back L thigh	10% EXSD	10% EXSD	10% EXSD	10% EXSD	10% EXSD
Front R thigh	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD
Back R thigh	10% EXSD	10% ENSD	10% EXSD	10% EXSD	10% EXSD
L knee and below	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)

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Area of skin	Basis for AP and AP spot lumbar spine through 1970	Basis for LAT and LAT spot lumbar spine through 1970	Basis for LPO lumbar spine through 1970	Basis for RPO lumbar spine through 1970	Basis for AP pelvis through 1970
R knee and below	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
L side of face	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of face	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of head	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front torso: base of neck to end of sternum	10% ENSD	Lung[a]	10% ENSD	10% ENSD	10% ENSD
Front torso: end of sternum to lowest rib	ENSD	Lung[a]	ENSD	ENSD	ENSD
Front torso: lowest rib to iliac crest	ENSD	Lung[a]	ENSD	ENSD	ENSD
Front torso: iliac crest to pubis	ENSD	Lung[a]	ENSD	ENSD	ENSD
Back torso: base of neck to mid-back	10% EXSD	Lung[a]	10% EXSD	10% EXSD	10% EXSD
Back torso: mid-back to lowest rib	EXSD	Lung[a]	EXSD	EXSD	EXSD
Back torso: lowest rib to iliac crest	EXSD	Lung[a]	EXSD	EXSD	EXSD
Back torso: buttocks (Iliac crest and below)	EXSD	Lung[a]	EXSD	EXSD	EXSD
Right torso: base of neck to end of sternum	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% ENSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	EXSD	ENSD
Right torso: lowest rib to iliac crest	ENSD	ENSD	ENSD	EXSD	ENSD
Right torso: iliac crest to pubis (R hip)	ENSD	ENSD	ENSD	EXSD	ENSD
Left torso: base of neck to end of sternum	10% ENSD	10% EXSD	10% EXSD	10% ENSD	10% ENSD
Left torso: end of sternum to lowest rib	ENSD	EXSD	EXSD	ENSD	ENSD
Left torso: lowest rib to iliac crest	ENSD	EXSD	EXSD	ENSD	ENSD
Left torso: iliac crest to pubis (L hip)	ENSD	EXSD	EXSD	ENSD	ENSD

a. The higher of the male or female lung dose value should be used for both genders.

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Table A-3. Skin dose guidance for thoracic spine projections for the poor collimation period through 1970.

Area of skin	Basis for AP thoracic spine through 1970	Basis for LAT thoracic spine through 1970	Basis for RPO thoracic spine through 1970	Basis for LPO thoracic spine through 1970
R front shoulder	ENSD	ENSD	ENSD	ENSD
R back shoulder	EXSD	ENSD	EXSD	EXSD
L front shoulder	ENSD	EXSD	ENSD	ENSD
L back shoulder	EXSD	EXSD	EXSD	EXSD
R upper arm to elbow	ENSD	ENSD	ENSD	ENSD
L upper arm to elbow	ENSD	EXSD	ENSD	ENSD
L hand	10% ENSD	10% ENSD	10% ENSD	10% ENSD
R hand	10% ENSD	10% ENSD	10% ENSD	10% ENSD
L elbow, forearm, wrist	ENSD	10% ENSD	10% ENSD	10% ENSD
R elbow, forearm, wrist	ENSD	10% ENSD	10% ENSD	10% ENSD
R Side of head (including temple and ear)	10% ENSD	10% ENSD	10% EXSD	10% ENSD
L Side of head (including temple and ear)	10% ENSD	10% ENSD	10% ENSD	10% EXSD
Front left thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Back left thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Front right thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Back right thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
L knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)
R knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)
L side of face	10% ENSD	Eye/brain	10% ENSD	10% EXSD
R side of face	10% ENSD	Eye/brain	10% EXSD	10% ENSD
L side of neck	ENSD	Eye/brain	ENSD	EXSD
R side of neck	ENSD	Eye/brain	EXSD	ENSD
Back of head	10% EXSD	Eye/brain	10% ENSD	10% ENSD
Front of neck	ENSD	Eye/brain	Thyroid	Thyroid
Back of neck	EXSD	Eye/brain	EXSD	EXSD
Front torso: base of neck to end of sternum	ENSD	Lung[a]	ENSD	ENSD
Front torso: end of sternum to lowest rib	ENSD	Lung[a]	ENSD	ENSD
Front torso: lowest rib to iliac crest	ENSD	Lung[a]	ENSD	ENSD
Front torso: iliac crest to pubis	10% ENSD	10% lung[a]	10% ENSD	10% ENSD
Back torso: base of neck to mid-back	EXSD	Lung[a]	EXSD	EXSD
Back torso: mid-back to lowest rib	EXSD	Lung[a]	EXSD	EXSD
Back torso: lowest rib to iliac crest	EXSD	Lung[a]	EXSD	EXSD
Back torso: buttocks (Iliac crest and below)	10% EXSD	10% lung[a]	10% EXSD	10% EXSD
Right torso: base of neck to end of sternum	ENSD	ENSD	EXSD	ENSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	EXSD	ENSD
Right torso: lowest rib to iliac crest	ENSD	ENSD	EXSD	ENSD
Right torso: iliac crest to pubis (R hip)	10% ENSD	10% ENSD	10% EXSD	10% ENSD
Left torso: base of neck to end of sternum	ENSD	EXSD	ENSD	EXSD
Left torso: end of sternum to lowest rib	ENSD	EXSD	ENSD	EXSD
Left torso: lowest rib to iliac crest	ENSD	EXSD	ENSD	EXSD
Left torso: iliac crest to pubis (L hip)	10% ENSD	10% EXSD	10% ENSD	10% EXSD

a. The higher of the male or female lung dose value should be used for both genders.

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Table A-4. Skin dose guidance for cervical spine projections for the poor collimation period through 1970.

Area of skin	Basis for AP cervical spine through 1970	Basis for LAT cervical spine through 1970	Basis for RPO cervical spine through 1970	Basis for LPO cervical spine through 1970
R front shoulder	10% ENSD	ENSD	10% ENSD	10% ENSD
R back shoulder	10% EXSD	ENSD	10% EXSD	10% EXSD
L front shoulder	10% ENSD	EXSD	10% ENSD	10% ENSD
L back shoulder	10% EXSD	EXSD	10% EXSD	10% EXSD
R upper arm to elbow	10% ENSD	10% ENSD	10% EXSD	10% ENSD
L upper arm to elbow	10% ENSD	10% EXSD	10% ENSD	10% ENSD
L hand	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)
R hand	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)
L elbow, forearm, wrist	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)
R elbow, forearm, wrist	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)	RSD (0.40m)
R side of head (including temple and ear)	ENSD	ENSD	EXSD2[a]	ENSD
L side of head (including temple and ear)	ENSD	EXSD2[a]	ENSD	EXSD2[a]
Front left thigh	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)
Back left thigh	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)
Front right thigh	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)
Back right thigh	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)	RSD (0.70m)
L knee and below	RSD (1.00m)	RSD (1.00m)	RSD (1.00m)	RSD (1.00m)
R knee and below	RSD (1.00m)	RSD (1.00m)	RSD (1.00m)	RSD (1.00m)
L side of face	ENSD	EXSD2[a]	ENSD	EXSD2[a]
R side of face	ENSD	ENSD	EXSD2[a]	ENSD
L side of neck	ENSD	EXSD2[a]	ENSD	EXSD2[a]
R side of neck	ENSD	ENSD	EXSD2[a]	ENSD
Back of head	EXSD	ENSD	ENSD	ENSD
Front of neck	ENSD	ENSD	ENSD	ENSD
Back of neck	EXSD2[a]	EXSD2[a]	EXSD2[a]	EXSD2[a]
Front torso: base of neck to end of sternum	ENSD	10% ENSD	ENSD	ENSD
Front torso: end of sternum to lowest rib	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Front torso: lowest rib to iliac crest	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Front torso: iliac crest to pubis	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)
Back torso: base of neck to mid-back	EXSD	10% ENSD	EXSD	EXSD
Back torso: mid-back to lowest rib	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Back torso: lowest rib to iliac crest	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Back torso: buttocks (Iliac crest and below)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)
Right torso: base of neck to end of sternum	10% ENSD	ENSD	10% ENSD	10% ENSD
Right torso: end of sternum to lowest rib	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Right torso: lowest Rib to iliac crest	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Right torso: iliac crest to pubis (R hip)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)

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Area of skin	Basis for AP cervical spine through 1970	Basis for LAT cervical spine through 1970	Basis for RPO cervical spine through 1970	Basis for LPO cervical spine through 1970
Left torso: base of neck to end of sternum	10% ENSD	EXSD	10% ENSD	10% ENSD
Left torso: end of sternum to lowest rib	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Left torso: lowest rib to iliac crest	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)	RSD (0.30m)
Left torso: iliac crest to pubis (L hip)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)	RSD (0.50m)

a. EXSD2 is the EXSD calculated at 15 cm (thickness of the neck) as opposed to 24 or 34 cm (the thickness of the chest).

Table A-5. Skin dose guidance for chest projections for the good collimation period after 1970.

Area of skin	Basis for PA chest after 1970	Basis for LAT chest after 1970	Basis for AP lordotic chest after 1970	Basis for RAO chest after 1970	Basis for LAO chest after 1970
R front shoulder	EXSD	ENSD	ENSD	EXSD	EXSD
R back shoulder	ENSD	ENSD	EXSD	ENSD	ENSD
L front shoulder	EXSD	EXSD	ENSD	EXSD	EXSD
L back shoulder	ENSD	EXSD	EXSD	ENSD	ENSD
R upper arm to elbow	10% ENSD	ENSD	ENSD	10% ENSD	10% ENSD
L upper arm to elbow	10% ENSD	EXSD	ENSD	10% ENSD	10% ENSD
L hand	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD
R hand	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD
L elbow, forearm, wrist	10% ENSD	10% ENSD	ENSD	10% ENSD	10% ENSD
R elbow, forearm, wrist	10% ENSD	10% ENSD	ENSD	10% ENSD	10% ENSD
R side of head (including temple and ear)	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% ENSD
L side of head (including temple and ear)	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
Front left thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Back left thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Front right thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
Back right thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)
L knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)
R knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)
L side of face	Eye/brain	10% ENSD	ENSD	10% ENSD	10% EXSD
R side of face	Eye/brain	10% ENSD	ENSD	10% EXSD	10% ENSD
L side of neck	10% ENSD	10% ENSD	ENSD	10% ENSD	10% EXSD
R side of neck	10% ENSD	10% ENSD	ENSD	10% EXSD	10% ENSD
Back of head	10% ENSD	10% ENSD	EXSD	10% ENSD	10% ENSD
Front of neck	Thyroid	10% ENSD	ENSD	Thyroid	Thyroid
Back of neck	10% ENSD	10% ENSD	EXSD	10% ENSD	10% ENSD
Front torso: base of neck to end of sternum	EXSD	Lung[a]	ENSD	EXSD	EXSD
Front torso: end of sternum to lowest rib	EXSD	Lung[a]	ENSD	EXSD	EXSD
Front torso: lowest rib to iliac crest	10% EXSD	10% lung[a]	ENSD	10% EXSD	10% EXSD

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Area of skin	Basis for PA chest after 1970	Basis for LAT chest after 1970	Basis for AP lordotic chest after 1970	Basis for RAO chest after 1970	Basis for LAO chest after 1970
Front torso: iliac crest to pubis	10% EXSD	10% lung[a]	10% ENSD	10% EXSD	10% EXSD
Back torso: base of neck to mid-back	ENSD	Lung[a]	EXSD	ENSD	ENSD
Back torso: mid-back to lowest rib	ENSD	Lung[a]	EXSD	ENSD	ENSD
Back torso: lowest rib to iliac crest	10% ENSD	10% Lung[a]	EXSD	10% ENSD	10% ENSD
Back torso: buttocks (Iliac crest and below)	10% ENSD	10% Lung[a]	10% EXSD	10% ENSD	10% ENSD
Right torso: base of neck to end of sternum	ENSD	ENSD	ENSD	EXSD	ENSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	EXSD	ENSD
Right torso: lowest rib to iliac crest	10% ENSD	10% ENSD	ENSD	10% EXSD	10% ENSD
Right torso: iliac crest to pubis (R hip)	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% ENSD
Left torso: base of neck to end of sternum	ENSD	EXSD	ENSD	ENSD	EXSD
Left torso: end of sternum to lowest rib	ENSD	EXSD	ENSD	ENSD	EXSD
Left torso: lowest rib to iliac crest	10% ENSD	10% EXSD	ENSD	10% ENSD	10% EXSD
Left torso: iliac crest to pubis (L hip)	10% ENSD	10% EXSD	10% ENSD	10% ENSD	10% EXSD

a. The higher of the male or female lung dose value should be used for both genders.

Table A-6. Skin dose guidance for lumbar spine projections for the good collimation period after 1970.[a]

Area of skin	Basis for AP and AP spot lumbar spine after 1970	Basis for LAT and LAT spot lumbar spine after 1970	Basis for LPO lumbar spine after 1970	Basis for RPO lumbar spine after 1970
R front shoulder	10% ENSD	10% ENSD	10% ENSD	10% ENSD
R back shoulder	10% EXSD	10% ENSD	10% ENSD	10% EXSD
L front shoulder	10% ENSD	10% EXSD	10% EXSD	10% ENSD
L back shoulder	10% EXSD	10% EXSD	10% EXSD	10% EXSD
R upper arm to elbow	10% ENSD	10% ENSD	10% ENSD	10% EXSD
L upper arm to elbow	10% ENSD	10% EXSD	10% EXSD	10% ENSD
L hand	10% ENSD	10% EXSD	10% EXSD	10% ENSD
R hand	10% ENSD	10% ENSD	10% ENSD	10% EXSD
L elbow, forearm, wrist	10% ENSD	10% EXSD	10% EXSD	10% ENSD
R elbow, forearm, wrist	10% ENSD	10% ENSD	10% ENSD	10% EXSD
R side of head (including temple and ear)	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of head (including temple and ear)	Eye/brain	Eye/brain	Eye/brain	Eye/brain

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Area of skin	Basis for AP and AP spot lumbar spine after 1970	Basis for LAT and LAT spot lumbar spine after 1970	Basis for LPO lumbar spine after 1970	Basis for RPO lumbar spine after 1970
Front L thigh	10% ENSD	10% EXSD	10% ENSD	10% ENSD
Back L thigh	10% EXSD	10% EXSD	10% EXSD	10% EXSD
Front R thigh	10% ENSD	10% ENSD	10% ENSD	10% ENSD
Back R thigh	10% EXSD	10% ENSD	10% EXSD	10% EXSD
L knee and below	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
R knee and below	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
L side of face	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of face	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of head	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front torso: base of neck to end of sternum	10% ENSD	Lung[b]	10% ENSD	10% ENSD
Front torso: end of sternum to lowest rib	ENSD	Lung[b]	ENSD	ENSD
Front torso: lowest rib to iliac crest	ENSD	Lung[b]	ENSD	ENSD
Front torso: iliac crest to pubis	ENSD	Lung[b]	ENSD	ENSD
Back torso: base of neck to mid-back	10% EXSD	Lung[b]	10% EXSD	10% EXSD
Back torso: mid-back to lowest rib	EXSD	Lung[b]	EXSD	EXSD
Back torso: lowest rib to iliac crest	EXSD	Lung[b]	EXSD	EXSD
Back torso: buttocks (Iliac crest and below)	EXSD	Lung[b]	EXSD	EXSD
Right torso: base of neck to end of sternum	10% ENSD	10% ENSD	10% ENSD	10% EXSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	EXSD
Right torso: lowest rib to iliac crest	ENSD	ENSD	ENSD	EXSD
Right torso: iliac crest to pubis (R hip)	ENSD	ENSD	ENSD	EXSD
Left torso: base of neck to end of sternum	10% ENSD	10% EXSD	10% EXSD	10% ENSD
Left torso: end of sternum to lowest rib	ENSD	EXSD	EXSD	ENSD
Left torso: lowest rib to iliac crest	ENSD	EXSD	EXSD	ENSD
Left torso: iliac crest to pubis (L hip)	ENSD	EXSD	EXSD	ENSD

a. The pelvis, thoracic spine, and cervical spine would not have been performed for screening after 1970.
b. The higher of the male or female lung dose value should be used for both genders.

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Table A-7 Organ dose equivalents (rem) for chest projections for all periods.[a,b]

Organ	Projection	Through 1970	1971–1985	Post-1985
Thyroid	PFG[c]	3.94E-01	---[d]	---[d]
	PA	3.48E-02	3.20E-03	3.90E-03
	LAT/OBL	6.85E-02	2.88E-02	2.13E-02
	AP lordotic	1.74E-01	3.17E-02	---[d]
	Fluoro[e]	3.75E-01	---[d]	---[d]
Eye/brain	PFG[c]	7.25E-02	---[d]	---[d]
	PA	6.40E-03	3.20E-03	3.90E-03
	LAT/OBL	6.85E-02	2.88E-02	2.13E-02
	AP lordotic	1.74E-01	3.17E-02	---[d]
	Fluoro[e]	5.25E-02	---[d]	---[d]
Ovaries[a]	PFG[c]	2.50E-02[a]	---[d]	---[d]
	PA	2.50E-02[a]	1.00E-04	2.60E-04
	LAT/OBL	1.30E-02[a]	1.50E-04	3.25E-04
	AP lordotic	4.66E-02	2.00E-04	---[d]
	Fluoro[e]	1.50E-03	---[d]	---[d]
Urinary/bladder/prostate[a]	PFG[c]	2.50E-02[a]	---[d]	---[d]
	PA	2.50E-02[a]	1.00E-04	2.60E-04
	LAT/OBL	1.30E-02[a]	1.50E-04	3.25E-04
	AP lordotic	4.66E-02	2.00E-04	---[d]
	Fluoro[e]	1.50E-03	---[d]	---[d]
Colon/rectum[a]	PFG[c]	2.50E-02[a]	---[d]	---[d]
	PA	2.50E-02[a]	1.00E-04	2.60E-04
	LAT/OBL	1.30E-02[a]	1.50E-04	3.25E-04
	AP lordotic	4.66E-02	2.00E-04	---[d]
	Fluoro[e]	1.50E-03	---[d]	---[d]
Testes[a]	PFG[c]	5.00E-03[a]	---[d]	---[d]
	PA	5.00E-03[a]	1.00E-06	5.00E-07
	LAT/OBL	2.50E-03	2.50E-05	1.30E-05
	AP lordotic	3.60E-03	1.00E-06	---[d]
	Fluoro[e]	2.50E-05	---[d]	---[d]
Lungs (male)	PFG[c]	9.50E-01	---[d]	---[d]
	PA	8.38E-02	4.19E-02	3.14E-02
	LAT/OBL	9.65E-02	4.83E-02	4.07E-02
	AP lordotic	9.46E-02	4.73E-02	---[d]
	Fluoro[e]	8.38E-01	---[d]	---[d]
Lungs (female)	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	7.06E-02	3.53E-02	---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]
Thymus	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	9.46E-02	4.73E-02	---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]

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Organ	Projection	Through 1970	1971–1985	Post-1985
Esophagus	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	9.46E-02	4.73E-02	---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]
Stomach	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	9.46E-02	4.73E-02	---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]
Bone surface	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	9.46E-02		---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]
Liver/gall bladder/spleen	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	9.46E-02	4.73E-02	---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]
Remainder organs	PFG[c]	1.02E-00	---[d]	---[d]
	PA	9.02E-02	4.51E-02	3.37E-02
	LAT/OBL	1.10E-01	5.50E-02	4.56E-02
	AP lordotic	9.46E-02	4.73E-02	---[d]
	Fluoro[e]	8.88E-01	---[d]	---[d]
Breast	PFG[c]	1.11E-01	---[d]	---[d]
	PA	9.80E-03	4.90E-03	5.80E-03
	LAT/OBL	1.28E-01	6.38E-02	4.46E-02
	AP lordotic	1.67E-01	8.36E-02	---[d]
	Fluoro[e]	8.00E-02	---[d]	---[d]
Uterus[a]	PFG[c]	2.50E-02[a]	---[d]	---[d]
	PA	2.50E-02[a]	1.30E-04	2.60E-04
	LAT/OBL	1.30E-02[a]	1.50E-04	2.73E-04
	AP lordotic	6.10E-02	1.50E-04	---[d]
	Fluoro[e]	1.75E-03	---[d]	---[d]
Bone marrow (male)	PFG[c]	2.09E-01	---[d]	---[d]
	PA	1.84E-02	9.20E-03	8.90E-03
	LAT/OBL	1.85E-02	9.25E-03	9.88E-03
	AP lordotic	9.60E-03	4.80E-03	---[d]
	Fluoro[e]	1.73E-01	---[d]	---[d]
Bone marrow (female)	PFG[c]	1.95E-01	---[d]	---[d]
	PA	1.72E-02	8.60E-03	8.60E-03
	LAT/OBL	1.45E-02	7.25E-03	7.67E-03
	AP lordotic	9.60E-03	4.80E-03	---[d]
	Fluoro[e]	1.58E-01	---[d]	---[d]

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Organ	Projection	Through 1970	1971–1985	Post-1985
Entrance skin[f]	PFG[c]	3.06E+00	---[d]	---[d]
	PA	2.70E-01	1.35E-01	7.00E-02
	LAT/OBL	6.75E-01	3.38E-01	1.82E-01
	AP lordotic	2.70E-01	1.35E-01	---[d]
	Fluoro[e]	3.30E+00	---[d]	---[d]

a. Dose equivalents through 1970 are based on measured values (Rising and Soldat 1959; Webster and Merrill 1957) for testes, ovaries, uterus, and analogues.
b. Rounded to nearest tenth of a millirem.
c. PFG dose equivalents are for stereo projections (two exposures). If only one projection was taken, these dose equivalents should be halved.
d. Procedure not performed for screening in this period.
e. Fluoro dose equivalents based on 5 R/min for 30 seconds, with an HVL of 2.0 mm Al eq.
f. Entrance skin dose equivalents determined by multiplying the incident air kerma by the backscatter factors of 1.35 and 1.42 for HVL of 2.5 mm Al and 4.0 mm Al, respectively, from NCRP Report 102 (NRCP 1997, Table B-8). Skin dose equivalents for all areas of skin are provided in Tables A-8 and A-9.

Table A-8. Skin dose equivalents (rem) from chest projections through 1970.[a]

Area of skin	PFG 1943–1962	Chest fluoro	PA chest through 1970	LAT chest through 1970	AP lordotic chest through 1970	RAO chest through 1970	LAO chest through 1970
Right front shoulder	6.67E-02	6.32E-02	5.9E-03	6.75E-01	2.70E-01	3.0E-03	3.0E-03
Right back shoulder	3.06E+00	3.30E+00	2.70E-01	6.75E-01	5.9E-03	6.75E-01	6.75E-01
Left front shoulder	6.67E-02	6.32E-02	5.9E-03	3.0E-03	2.70E-01	3.0E-03	3.0E-03
Left back shoulder	3.06E+00	3.30E+00	2.70E-01	3.0E-03	5.9E-03	6.75E-01	6.75E-01
Right upper arm to elbow	3.06E-01	3.30E+00	2.70E-01	6.75E-01	2.70E-01	6.75E-01	6.75E-01
Left upper arm to elbow	3.06E-01	3.30E+00	2.70E-01	3.0E-03	2.70E-01	6.75E-01	6.75E-01
Left hand	3.06E+00	3.30E+00	2.70E-01	6.75E-02	2.70E-02	6.75E-02	6.75E-02
Right hand	3.06E+00	3.30E+00	2.70E-01	6.75E-02	2.70E-02	6.75E-02	6.75E-02
Left elbow, forearm, wrist	3.06E-01	3.30E+00	2.70E-01	6.75E-02	2.70E-01	6.75E-02	6.75E-02
Right elbow, forearm, wrist	3.06E-01	3.30E+00	2.70E-01	6.75E-02	2.70E-01	6.75E-02	6.75E-02
Right side of head including temple and ear	3.06E-01	3.30E-01	2.70E-02	6.85E-02	2.70E-02	3.E-04	6.75E-02
Left side of head including temple and ear	3.06E-01	3.30E-01	2.70E-02	6.85E-02	2.70E-02	6.75E-02	3.E-04
Front left thigh	9.E-04	8.E-04	8.E-05	1.E-04	8.E-05	1.E-04	1.E-04
Back left thigh	9.E-04	8.E-04	8.E-05	1.E-04	8.E-05	1.E-04	1.E-04
Front right thigh	9.E-04	8.E-04	8.E-05	1.E-04	8.E-05	1.E-04	1.E-04
Back right thigh	9.E-04	8.E-04	8.E-05	1.E-04	8.E-05	1.E-04	1.E-04
Left knee and below	3.E-04	3.E-04	3.E-05	4.E-05	3.E-05	4.E-05	4.E-05
Right knee and below	3.E-04	3.E-04	3.E-05	4.E-05	3.E-05	4.E-05	4.E-05
Left side of face	7.25E-02	5.25E-02	6.4E-03	6.85E-02	2.70E-01	6.75E-01	3.0E-03
Right side of face	7.25E-02	5.25E-02	6.4E-03	6.85E-02	2.70E-01	3.0E-03	6.75E-01
Left side of neck	3.06E-01	3.30E+00	2.70E-01	6.85E-02	2.70E-01	6.75E-01	3.0E-03
Right side of neck	3.06E-01	3.30E+00	2.70E-01	6.85E-02	2.70E-01	3.0E-03	6.75E-01
Back of head	3.06E-01	3.30E-01	2.70E-02	6.85E-02	5.9E-03	6.75E-02	6.75E-02
Front of neck	7.25E-02	5.25E-02	6.4E-03	6.85E-02	2.70E-01	6.85E-02	6.85E-02
Back of neck	3.06E-01	3.30E+00	2.70E-01	6.85E-02	5.9E-03	6.75E-01	6.75E-01
Front torso: base of neck to end of sternum	6.67E-02	6.32E-02	5.9E-03	1.10E-01	2.70E-01	3.0E-03	3.0E-03

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Area of skin	PFG 1943–1962	Chest fluoro	PA chest through 1970	LAT chest through 1970	AP lordotic chest through 1970	RAO chest through 1970	LAO chest through 1970
Front torso: end of sternum to lowest rib	6.67E-02	6.32E-02	5.9E-03	1.10E-01	2.70E-01	3.0E-03	3.0E-03
Front torso: lowest rib to iliac crest	6.67E-02	6.32E-02	5.9E-03	1.10E-01	2.70E-01	3.0E-03	3.0E-03
Front torso: iliac crest to pubis	6.7E-03	6.3E-03	6.E-04	1.10E-02	2.70E-02	3.E-04	3.E-04
Back torso: base of neck to mid-back	3.06E+00	3.30E+00	2.70E-01	1.10E-01	5.9E-03	6.75E-01	6.75E-01
Back torso: mid-back to lowest rib	3.06E+00	3.30E+00	2.70E-01	1.10E-01	5.9E-03	6.75E-01	6.75E-01
Back torso: lowest rib to iliac crest	3.06E+00	3.30E+00	2.70E-01	1.10E-01	5.9E-03	6.75E-01	6.75E-01
Back torso: buttocks (Iliac crest and below)	3.06E-01	3.30E-01	2.70E-02	1.10E-02	6.E-04	6.75E-02	6.75E-02
Right torso: base of neck to end of sternum	3.06E+00	3.30E+00	2.70E-01	6.75E-01	2.70E-01	3.0E-03	6.75E-01
Right torso: end of sternum to lowest rib	3.06E+00	3.30E+00	2.70E-01	6.75E-01	2.70E-01	3.0E-03	6.75E-01
Right torso: lowest rib to iliac crest	3.06E+00	3.30E+00	2.70E-01	6.75E-01	2.70E-01	3.0E-03	6.75E-01
Right torso: iliac crest to pubis (right hip)	3.06E-01	3.30E-01	2.70E-02	6.75E-02	2.70E-02	3.E-04	6.75E-02
Left torso: base of neck to end of sternum	3.06E+00	3.30E+00	2.70E-01	3.0E-03	2.70E-01	6.75E-01	3.0E-03
Left torso: end of sternum to lowest rib	3.06E+00	3.30E+00	2.70E-01	3.0E-03	2.70E-01	6.75E-01	3.0E-03
Left torso: lowest rib to iliac crest	3.06E+00	3.30E+00	2.70E-01	3.0E-03	2.70E-01	6.75E-01	3.0E-03
Left torso: iliac crest to pubis (Left hip)	3.06E-01	3.30E-01	2.70E-02	3.E-04	2.70E-02	6.75E-02	3.E-04

a. Values less than 0.1 mrem shown to one significant digit.

Table A-9. Skin dose equivalents (rem) from various chest projections post-1970.[a]

Area of skin	PA chest 1971–1985	LAT chest 1971–1985	AP lordotic chest 1971–1985	RAO chest 1971–1985	LAO chest 1971–1985	PA chest post-1985	LAT chest post-1985	RAO chest post-1985	LAO chest post-1985
Right front shoulder	2.9E-03	3.38E-01	1.35E-01	1.5E-03	1.5E-03	2.4E-03	1.82E-01	1.4E-03	1.4E-03
Right back shoulder	1.35E-01	3.38E-01	2.9E-03	3.38E-01	3.38E-01	7.00E-02	1.82E-01	1.82E-01	1.82E-01
Left front shoulder	2.9E-03	1.5E-03	1.35E-01	1.5E-03	1.5E-03	2.4E-03	1.4E-03	1.4E-03	1.4E-03
Left back shoulder	1.35E-01	1.5E-03	2.9E-03	3.38E-01	3.38E-01	7.00E-02	1.4E-03	1.82E-01	1.82E-01
Right upper arm to elbow	1.35E-02	3.38E-01	1.35E-01	3.38E-02	3.38E-02	7.0E-03	1.82E-01	1.82E-02	1.82E-02
Left upper arm to elbow	1.35E-02	1.5E-03	1.35E-01	3.38E-02	3.38E-02	7.0E-03	1.4E-03	1.82E-02	1.82E-02
Left hand	1.35E-02	3.38E-02	1.35E-02	3.38E-02	3.38E-02	7.0E-03	1.82E-02	1.82E-02	1.82E-02

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Area of skin	PA chest 1971–1985	LAT chest 1971–1985	AP lordotic chest 1971–1985	RAO chest 1971–1985	LAO chest 1971–1985	PA chest post-1985	LAT chest post-1985	RAO chest post-1985	LAO chest post-1985
Right hand	1.35E-02	3.38E-02	1.35E-02	3.38E-02	3.38E-02	7.0E-03	1.82E-02	1.82E-02	1.82E-02
Left elbow, forearm, wrist	1.35E-02	3.38E-02	1.35E-01	3.38E-02	3.38E-02	7.0E-03	1.82E-02	1.82E-02	1.82E-02
Right elbow, forearm, wrist	1.35E-02	3.38E-02	1.35E-01	3.38E-02	3.38E-02	7.0E-03	1.82E-02	1.82E-02	1.82E-02
Right side of head including temple and ear	1.35E-02	3.38E-02	1.35E-02	1.E-04	3.38E-02	7.0E-03	1.82E-02	1.E-04	1.82E-02
Left side of head including temple and ear	1.35E-02	3.38E-02	1.35E-02	3.38E-02	1.E-04	7.0E-03	1.82E-02	1.82E-02	1.E-04
Front left thigh	4.E-05	5.E-05	4.E-05	5.E-05	5.E-05	3.E-05	4.E-05	4.E-05	4.E-05
Back left thigh	4.E-05	5.E-05	4.E-05	5.E-05	5.E-05	3.E-05	4.E-05	4.E-05	4.E-05
Front right thigh	4.E-05	5.E-05	4.E-05	5.E-05	5.E-05	3.E-05	4.E-05	4.E-05	4.E-05
Back right thigh	4.E-05	5.E-05	4.E-05	5.E-05	5.E-05	3.E-05	4.E-05	4.E-05	4.E-05
Left knee and below	1.E-05	2.E-05	1.E-05	2.E-05	2.E-05	1.E-05	1.E-05	1.E-05	1.E-05
Right knee and below	1.E-05	2.E-05	1.E-05	2.E-05	2.E-05	1.E-05	1.E-05	1.E-05	1.E-05
Left side of face	3.2E-03	3.38E-02	1.35E-01	3.38E-02	1.E-04	3.9E-03	1.82E-02	1.82E-02	1.E-04
Right side of face	3.2E-03	3.38E-02	1.35E-01	1.E-04	3.38E-02	3.9E-03	1.82E-02	1.E-04	1.82E-02
Left side of neck	1.35E-02	3.38E-02	1.35E-01	3.38E-02	1.E-04	7.0E-03	1.82E-02	1.82E-02	1.E-04
Right side of neck	1.35E-02	3.38E-02	1.35E-01	1.E-04	3.38E-02	7.0E-03	1.82E-02	1.E-04	1.82E-02
Back of head	1.35E-02	3.38E-02	2.9E-03	3.38E-02	3.38E-02	7.0E-03	1.82E-02	1.82E-02	1.82E-02
Front of neck	3.2E-03	3.38E-02	1.35E-01	2.88E-02	2.88E-02	3.9E-03	1.82E-02	2.13E-02	2.13E-02
Back of neck	1.35E-02	3.38E-02	2.9E-03	3.38E-02	3.38E-02	7.0E-03	1.82E-02	1.82E-02	1.82E-02
Front torso: base of neck to end of sternum	2.9E-03	5.50E-02	1.35E-01	1.5E-03	1.5E-03	2.4E-03	4.56E-02	1.4E-03	1.4E-03
Front torso: end of sternum to lowest rib	2.9E-03	5.50E-02	1.35E-01	1.5E-03	1.5E-03	2.4E-03	4.56E-02	1.4E-03	1.4E-03
Front torso: lowest rib to iliac crest	3.E-04	5.5E-03	1.35E-01	1.E-04	1.E-04	2.E-04	4.6E-03	1.E-04	1.E-04
Front torso: iliac crest to pubis	3.E-04	5.5E-03	1.35E-02	1.E-04	1.E-04	2.E-04	4.6E-03	1.E-04	1.E-04
Back torso: base of neck to mid-back	1.35E-01	5.50E-02	2.9E-03	3.38E-01	3.38E-01	7.00E-02	4.56E-02	1.82E-01	1.82E-01
Back torso: mid-back to lowest rib	1.35E-01	5.50E-02	2.9E-03	3.38E-01	3.38E-01	7.00E-02	4.56E-02	1.82E-01	1.82E-01
Back torso: lowest rib to iliac crest	1.35E-02	5.5E-03	2.9E-03	3.38E-02	3.38E-02	7.0E-03	4.6E-03	1.82E-02	1.82E-02
Back torso: buttocks (Iliac crest and below)	1.35E-02	5.5E-03	3.E-04	3.38E-02	3.38E-02	7.0E-03	4.6E-03	1.82E-02	1.82E-02
Right torso: base of neck to end of sternum	1.35E-01	3.38E-01	1.35E-01	1.5E-03	3.38E-01	7.00E-02	1.82E-01	1.4E-03	1.82E-01
Right torso: end of sternum to lowest rib	1.35E-01	3.38E-01	1.35E-01	1.5E-03	3.38E-01	7.00E-02	1.82E-01	1.4E-03	1.82E-01
Right torso: lowest rib to iliac crest	1.35E-02	3.38E-02	1.35E-01	1.E-04	3.38E-02	7.0E-03	1.82E-02	1.E-04	1.82E-02

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Area of skin	PA chest 1971–1985	LAT chest 1971–1985	AP lordotic chest 1971–1985	RAO chest 1971–1985	LAO chest 1971–1985	PA chest post-1985	LAT chest post-1985	RAO chest post-1985	LAO chest post-1985
Right torso: iliac crest to pubis (right hip)	1.35E-02	3.38E-02	1.35E-02	1.E-04	3.38E-02	7.0E-03	1.82E-02	1.E-04	1.82E-02
Left torso: base of neck to end of sternum	1.35E-01	1.5E-03	1.35E-01	3.38E-01	1.5E-03	7.00E-02	1.4E-03	1.82E-01	1.4E-03
Left torso: end of sternum to lowest rib	1.35E-01	1.5E-03	1.35E-01	3.38E-01	1.5E-03	7.00E-02	1.4E-03	1.82E-01	1.4E-03
Left torso: lowest rib to iliac crest	1.35E-02	1.E-04	1.35E-01	3.38E-02	1.E-04	7.0E-03	1.E-04	1.82E-02	1.E-04
Left torso: iliac crest to pubis (Left hip)	1.35E-02	1.E-04	1.35E-02	3.38E-02	1.E-04	7.0E-03	1.E-04	1.82E-02	1.E-04

a. Values less than 0.1 mrem shown to one significant digit.

Table A-10. Organ dose equivalents (rem) for lumbar spine and pelvis projections for all periods.[a]

Organ	Projection	Through 1970	Post-1970
Thyroid	AP or AP spot lumbar spine[b]	2.88E-04	2.73E-04
	LAT or LAT spot lumbar spine[c]	3.79E-05	3.48E-05
	AP pelvis	1.52E-05	---[g]
Eye/brain	AP or AP spot lumbar spine[b]	2.88E-04	2.73E-04
	LAT or LAT spot lumbar spine[c]	3.79E-05	3.48E-05
	AP pelvis	1.52E-05	---[g]
Ovaries[a]	AP or AP spot lumbar spine[b]	5.60E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	7.10E-01	1.64E-01
	AP pelvis	6.50E-01	---[g]
Urinary/bladder/prostate[d]	AP or AP spot lumbar spine[b]	2.30E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	1.17E-01	1.64E-01
	AP pelvis	2.64E-01	---[g]
Colon/rectum[d]	AP or AP spot lumbar spine[b]	2.30E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	1.17E-01	1.64E-01
	AP pelvis	2.64E-01	---[g]
Testes[a]	AP or AP spot lumbar spine[b]	2.70E-02	3.82E-03
	LAT or LAT spot lumbar spine[c]	5.60E-02	2.78E-03
	AP pelvis	6.40E-01	---[g]
Lungs (male)	AP or AP spot lumbar spine[b]	8.93E-02	7.19E-02
	LAT or LAT spot lumbar spine[c]	3.79E-02	4.87E-02
	AP pelvis	1.52E-03	---[g]
Lungs (female)	AP or AP spot lumbar spine[b]	8.93E-02	7.19E-02
	LAT or LAT spot lumbar spine[c]	3.79E-02	4.87E-02
	AP pelvis	1.52E-03	---[g]
Thymus	AP or AP spot lumbar spine[b]	8.93E-02	7.19E-02
	LAT or LAT spot lumbar spine[c]	3.79E-02	4.87E-02
	AP pelvis	1.52E-03	---[g]

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Organ	Projection	Through 1970	Post-1970
Esophagus	AP or AP spot lumbar spine[b]	8.93E-02	7.19E-02
	LAT or LAT spot lumbar spine[c]	3.79E-02	4.87E-02
	AP pelvis	1.52E-03	---[g]
Stomach[d]	AP or AP spot lumbar spine[b]	2.30E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	1.17E-01	1.64E-01
	AP pelvis	2.64E-01	---[g]
Bone surface[d]	AP or AP spot lumbar spine[b]	2.30E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	1.17E-01	1.64E-01
	AP pelvis	2.64E-01	---[g]
Liver/gall bladder/spleen[d]	AP or AP spot lumbar spine[b]	2.30E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	1.17E-01	1.64E-01
	AP pelvis	2.64E-01	---[g]
Remainder organs[d]	AP or AP spot lumbar spine[b]	2.30E-01	1.97E-01
	LAT or LAT spot lumbar spine[c]	1.17E-01	1.64E-01
	AP pelvis	2.64E-01	---[g]
Breast[e]	AP or AP spot lumbar spine[b]	4.78E-03	9.56E-04
	LAT or LAT spot lumbar spine[c]	7.58E-03	2.07E-03
	AP pelvis	7.79E-03	---[g]
Uterus	AP or AP spot lumbar spine[b]	3.12E-01	2.61E-01
	LAT or LAT spot lumbar spine[c]	7.58E-02	1.08E-01
	AP pelvis	3.71E-01	---[g]
Bone marrow (male)	AP or AP spot lumbar spine[b]	3.46E-02	3.37E-02
	LAT or LAT spot lumbar spine[c]	5.69E-02	7.66E-02
	AP pelvis	3.50E-02	---[g]
Bone marrow (female)	AP or AP spot lumbar spine[b]	3.46E-02	3.37E-02
	LAT or LAT spot lumbar spine[c]	5.69E-02	7.66E-02
	AP pelvis	3.50E-02	---[g]
Entrance skin[f]	AP or AP spot lumbar spine[b]	1.900E+00[a]	1.200E+00
	LAT or LAT spot lumbar spine[c]	5.00E+00[a]	4.59E+00
	AP pelvis	2.000E+00[a]	---[g]

a. Doses through 1970 are based on measured values (Lincoln and Gupton 1958) for skin, testes, and ovaries.
b. Dose equivalents are for one projection. If both AP and AP spot are being included as the default frequency, the listed dose equivalents should be doubled.
c. Dose equivalents are for one projection. If both LAT and LAT spot are being included as the default frequency, the listed dose equivalents should be doubled.
d. The DCF for the ovary is used to determine organ dose equivalents for the Remainder organs and other organs in the primary beam for projections of the lumbar spine and pelvis.
e. Breast dose equivalents determined by using the method described by Huda and Bissessur, 1990.
f. Skin dose equivalents for all areas of skin are provided in Tables A-11.
g. Not performed for screening in this period.

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Table A-11. Skin dose equivalent (rem) from lumbar spine and pelvis projections for all periods.[a]

Area of skin	AP or AP spot lumbar spine through 1970	LAT or LAT spot lumbar spine through 1970	Pelvis through 1970	AP or AP spot lumbar spine post 1970	LAT or LAT spot lumbar spine post 1970
Right front shoulder	1.90E-01	5.00E-01	2.00E-01	1.20E-01	4.59E-01
Right back shoulder	3.6E-03	5.00E-01	3.8E-03	2.6E-03	4.59E-01
Left front shoulder	1.90E-01	1.90E-03	2.00E-01	1.20E-01	2.0E-03
Left back shoulder	3.6E-03	1.90E-03	3.8E-03	2.6E-03	2.0E-03
Right upper arm to elbow	1.90E-01	5.00E-01	2.00E-01	1.20E-01	4.59E-01
Left upper arm to elbow	1.90E-01	1.90E-03	2.00E-01	1.20E-01	2.0E-03
Left hand	1.90E+00	1.90E-03	2.00E+00	1.20E-01	2.0E-03
Right hand	1.90E+00	5.00E-01	2.00E+00	1.20E-01	4.59E-01
Left elbow, forearm, wrist	1.90E+00	1.90E-03	2.00E+00	1.20E-01	2.0E-03
Right elbow, forearm, wrist	1.90E+00	5.00E-01	2.00E+00	1.20E-01	4.59E-01
Right side of head including temple and ear	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Left side of head including temple and ear	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Front left thigh	1.90E-01	1.90E-03	2.00E-01	1.20E-01	2.0E-03
Back left thigh	3.6E-03	1.90E-03	3.8E-03	2.6E-03	2.0E-03
Front right thigh	1.90E-01	5.00E-01	2.00E-01	1.20E-01	4.59E-01
Back right thigh	3.6E-03	5.00E-01	3.8E-03	2.6E-03	4.59E-01
Left knee and below	4.E-04	5.E-04	4.E-04	3.E-04	5.E-04
Right knee and below	4.E-04	5.E-04	4.E-04	3.E-04	5.E-04
Left side of face	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Right side of face	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Left side of neck	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Right side of neck	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Back of head	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Front of neck	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Back of neck	3.E-04	3.E-05	1.E-05	3.E-04	3.E-05
Front torso: base of neck to end of sternum	1.90E-01	3.32E-02	2.00E-01	1.20E-01	4.87E-02
Front torso: end of sternum to lowest rib	1.90E+00	3.32E-02	2.00E+00	1.20E+00	4.87E-02
Front torso: lowest rib to iliac crest	1.90E+00	3.32E-02	2.00E+00	1.20E+00	4.87E-02
Front torso: iliac crest to pubis	1.90E+00	3.32E-02	2.00E+00	1.20E+00	4.87E-02
Back torso: base of neck to mid-back	3.6E-03	3.32E-02	3.8E-03	2.6E-03	4.87E-02
Back torso: mid-back to lowest rib	3.64E-02	3.32E-02	3.83E-02	2.61E-02	4.87E-02
Back torso: lowest rib to iliac crest	3.64E-02	3.32E-02	3.83E-02	2.61E-02	4.87E-02
Back torso: buttocks (Iliac crest and below)	3.64E-02	3.32E	3.83E-02	2.61E-02	4.87E-02
Right torso: base of neck to end of sternum	1.90E-01	5.00E-01	2.00E-01	1.20E-01	4.59E-01
Right torso: end of sternum to lowest rib	1.90E+00	5.00E+00	2.00E+00	1.20E+00	4.59E+00
Right torso: lowest rib to iliac crest	1.90E+00	5.00E+00	2.00E+00	1.20E+00	4.59E+00
Right torso: iliac crest to pubis (right hip)	1.90E+00	5.00E+00	2.00E+00	1.20E+00	4.59E+00
Left torso: base of neck to end of sternum	1.90E-01	1.90E-03	2.00E-01	1.20E-01	2.0E-03
Left torso: end of sternum to lowest rib	1.90E+00	1.90E-02	2.00E+00	1.20E+00	2.02E-02
Left torso: lowest rib to iliac crest	1.90E+00	1.90E-02	2.00E+00	1.20E+00	2.02E-02
Left torso: iliac crest to pubis (left hip)	1.90E+00	1.90E-02	2.00E+00	1.20E+00	2.02E-02

a. Values less than 0.1 mrem shown to one significant digit.

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Table A-12. Organ dose equivalents (rem) for thoracic and cervical spine projections through 1960.

Organ	Thoracic spine projection	Through 1960	Cervical spine projection	Through 1960
Thyroid	AP	9.26E-02	AP	3.25E-01
	LAT	1.23E-01	LAT	1.46E-02
	RPO	1.23E-01	RPO	3.25E-01
	LPO	1.23E-01	LPO	3.25E-01
Eye/brain	AP	9.26E-03	AP	3.25E-01
	LAT	8.80E-03	LAT	1.46E-02
	RPO	8.80E-03	RPO	3.25E-01
	LPO	8.80E-03	LPO	3.25E-01
Ovaries	AP	2.80E-02[a]	AP	6.00E-05[a]
	LAT	4.60E-02[a]	LAT	2.00E-04[a]
	RPO	4.60E-02	RPO	6.00E-05
	LPO	4.60E-02	LPO	6.00E-05
Urinary/bladder/prostate	AP	6.90E-04[c]	AP	6.00E-05
	LAT	2.20E-04[c]	LAT	2.00E-04
	RPO	2.20E-04	RPO	6.00E-05
	LPO	2.20E-04	LPO	6.00E-05
Colon/rectum	AP	6.90E-04[c]	AP	6.00E-05
	LAT	2.20E-04[c]	LAT	2.00E-04
	RPO	2.20E-04	RPO	6.00E-05
	LPO	2.20E-04	LPO	6.00E-05
Testes	AP	1.00E-03[a]	AP	2.70E-04[a]
	LAT	2.00E-03[a]	LAT	9.20E-04[a]
	RPO	2.00E-03	RPO	2.70E-04
	LPO	2.00E-03	LPO	2.70E-04
Lungs (male)	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.35E-01[b]	LAT	5.98E-03
	RPO	2.35E-01	RPO	6.48E-03
	LPO	2.35E-01	LPO	6.48E-03
Lungs (female)	AP	2.33E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03
	LPO	2.82E-01	LPO	6.48E-03
Thymus	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03
	LPO	2.82E-01	LPO	6.48E-03
Esophagus	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03
	LPO	2.82E-01	LPO	6.48E-03
Stomach	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03
	LPO	2.82E-01	LPO	6.48E-03
Bone surface	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03

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	LPO	2.82E-01	LPO	6.48E-03
Liver/gall bladder/spleen	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03
	LPO	2.82E-01	LPO	6.48E-03
Remainder organs	AP	3.27E-01[b]	AP	6.48E-03
	LAT	2.82E-01[b]	LAT	5.98E-03
	RPO	2.82E-01	RPO	6.48E-03
	LPO	2.82E-01	LPO	6.48E-03
Breast	AP	3.61E-01	AP	6.48E-03
	LAT	1.23E-02	LAT	5.98E-03
	RPO	1.23E-02	RPO	6.48E-03
	LPO	1.23E-02	LPO	6.48E-03
Uterus	AP	4.93E-04	AP	6.00E-05[a]
	LAT	2.20E-04	LAT	2.00E-04[a]
	RPO	2.20E-04	RPO	6.00E-05
	LPO	2.20E-04	LPO	6.00E-05
Bone marrow (male)	AP	2.86E-02	AP	4.75E-03
	LAT	3.96E-02	LAT	4.42E-03
	RPO	3.96E-02	RPO	4.75E-03
	LPO	3.96E-02	LPO	4.75E-03
Bone marrow (female)	AP	2.27E-02	AP	4.75E-03
	LAT	3.08E-02	LAT	4.42E-03
	RPO	3.08E-02	RPO	4.75E-03
	LPO	3.08E-02	LPO	4.75E-03
Entrance skin[d]	AP	1.30E+00[a]	AP	5.70E-01
	LAT	2.90E+00[a]	LAT	3.43E-01
	RPO	2.90E+00	RPO	5.70E-01
	LPO	2.90E+00	LPO	5.70E-01

a. Dose equivalents through 1970 are based on measured values (Lincoln and Gupton 1958) for skin, testes, and ovaries for the thoracic spine, and measured values (Braestrup and Wycoff 1958) for testes, ovaries, and uterus for the cervical spine.
b. The higher of the two lung DCFs is used to determine organ dose equivalents for the Remainder organs and other organs in the primary beam for projections of the thoracic spine.
c. The DCF for the ovary is used to determine organ dose equivalents for the urinary bladder, prostate, colon, and rectum for projections of the thoracic spine.
d. Skin dose equivalents for all areas of skin are provided in Tables A-13.

Table A-13. Skin dose equivalent (rem) from thoracic and cervical spine projections through 1960.[a]

Area of skin	AP thoracic spine	LAT thoracic spine	RPO thoracic spine	RPO thoracic spine	AP cervical spine	LAT cervical spine	RPO cervical spine	LPO cervical spine
Right front shoulder	1.30E+00	2.90E+00	2.90E+00	2.90E+00	5.70E-02	3.43E-01	5.70E-02	5.70E-02
Right back shoulder	2.49E-02	2.90E+00	1.10E-02	1.10E-02	1.1E-03	3.43E-01	1.1E-03	1.1E-03
Left front shoulder	1.30E+00	1.10E-02	2.90E+00	2.90E+00	5.70E-02	1.3E-03	5.70E-02	5.70E-02
Left back shoulder	2.49E-02	1.10E-02	1.10E-02	1.10E-02	1.1E-03	1.3E-03	1.1E-03	1.1E-03
Right upper arm to elbow	1.30E+00	2.90E+00	2.90E+00	2.90E+00	5.70E-02	3.43E-02	1.1E-03	5.70E-02
Left upper arm to elbow	1.30E+00	1.10E-02	2.90E+00	2.90E+00	5.70E-02	1.E-04	5.70E-02	5.70E-02
Left hand	1.30E-01	2.90E-01	2.90E-01	2.90E-01	4.E-04	3.E-04	4.E-04	4.E-04
Right hand	1.30E-01	2.90E-01	2.90E-01	2.90E-01	4.E-04	3.E-04	4.E-04	4.E-04
Left elbow, forearm, wrist	1.30E+00	2.90E-01	2.90E-01	2.90E-01	4.E-04	3.E-04	4.E-04	4.E-04
Right elbow, forearm, wrist	1.30E+00	2.90E-01	2.90E-01	2.90E-01	4.E-04	3.E-04	4.E-04	4.E-04

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Area of skin	AP thoracic spine	LAT thoracic spine	RPO thoracic spine	RPO thoracic spine	AP cervical spine	LAT cervical spine	RPO cervical spine	LPO cervical spine
Right side of head including temple and ear	1.30E-01	2.90E-01	1.1E-03	2.90E-01	5.70E-01	3.43E-01	4.76E-02	5.70E-01
Left side of head including temple and ear	1.30E-01	2.90E-01	2.90E-01	1.1E-03	5.70E-01	2.87E-02	5.70E-01	4.76E-02
Front left thigh	3.E-04	4.E-04	4.E-04	4.E-04	1.E-04	9.E-05	1.E-04	1.E-04
Back left thigh	3.E-04	4.E-04	4.E-04	4.E-04	1.E-04	9.E-05	1.E-04	1.E-04
Front right thigh	3.E-04	4.E-04	4.E-04	4.E-04	1.E-04	9.E-05	1.E-04	1.E-04
Back right thigh	3.E-04	4.E-04	4.E-04	4.E-04	1.E-04	9.E-05	1.E-04	1.E-04
Left knee and below	1.E-04	1.E-04	1.E-04	1.E-04	7.E-05	4.E-05	7.E-05	7.E-05
Right knee and below	1.E-04	1.E-04	1.E-04	1.E-04	7.E-05	4.E-05	7.E-05	7.E-05
Left side of face	1.30E-01	7.7E-03	2.90E-01	1.1E-03	5.70E-01	2.87E-02	5.70E-01	4.76E-02
Right side of face	1.30E-01	7.7E-03	1.1E-03	2.90E-01	5.70E-01	3.43E-01	4.76E-02	5.70E-01
Left side of neck	1.30E+00	7.7E-03	2.90E+00	1.10E-02	5.70E-01	2.87E-02	5.70E-01	4.76E-02
Right side of neck	1.30E+00	7.7E-03	1.10E-02	2.90E+00	5.70E-01	3.43E-01	4.76E-02	5.70E-01
Back of head	2.5E-03	7.7E-03	2.90E-01	2.90E-01	1.09E-02	3.43E-01	5.70E-01	5.70E-01
Front of neck	1.30E+00	7.7E-03	1.08E-01	1.08E-01	5.70E-01	3.43E-01	5.70E-01	5.70E-01
Back of neck	2.49E-02	7.7E-03	1.10E-02	1.10E-02	4.76E-02	2.87E-02	4.76E-02	4.76E-02
Front torso: base of neck to end of sternum	1.30E+00	2.46E-01	2.90E+00	2.90E+00	5.70E-01	3.43E-02	5.70E-01	5.70E-01
Front torso: end of sternum to lowest rib	1.30E+00	2.46E-01	2.90E+00	2.90E+00	8.E-04	5.E-04	8.E-04	8.E-04
Front torso: lowest rib to iliac crest	1.30E+00	2.46E-01	2.90E+00	2.90E+00	8.E-04	5.E-04	8.E-04	8.E-04
Front torso: iliac crest to pubis	1.30E-01	2.46E-02	2.90E-01	2.90E-01	3.E-04	2.E-04	3.E-04	3.E-04
Back torso: base of neck to mid-back	2.49E-02	2.46E-01	1.10E-02	1.10E-02	1.09E-02	3.43E-02	1.09E-02	1.09E-02
Back torso: mid-back to lowest rib	2.49E-02	2.46E-01	1.10E-02	1.10E-02	8.E-04	5.E-04	8.E-04	8.E-04
Back torso: lowest rib to iliac crest	2.49E-02	2.46E-01	1.10E-02	1.10E-02	8.E-04	5.E-04	8.E-04	8.E-04
Back torso: buttocks (Iliac crest and below)	2.5E-03	2.46E-02	1.1E-03	1.1E-03	3.E-04	2.E-04	3.E-04	3.E-04
Right torso: base of neck to end of sternum	1.30E+00	2.90E+00	1.10E-02	2.90E+00	5.70E-02	3.43E-01	5.70E-02	5.70E-02
Right torso: end of sternum to lowest rib	1.30E+00	2.90E+00	1.10E-02	2.90E+00	8.E-04	5.E-04	8.E-04	8.E-04
Right torso: lowest rib to iliac crest	1.30E+00	2.90E+00	1.10E-02	2.90E+00	8.E-04	5.E-04	8.E-04	8.E-04
Right torso: iliac crest to pubis (right hip)	1.30E-01	2.90E-01	1.1E-03	2.90E-01	3.E-04	2.E-04	3.E-04	3.E-04
Left torso: base of neck to end of sternum	1.30E+00	1.10E-02	2.90E+00	1.10E-02	5.70E-02	1.3E-03	5.70E-02	5.70E-02
Left torso: end of sternum to lowest rib	1.30E+00	1.10E-02	2.90E+00	1.10E-02	8.E-04	5.E-04	8.E-04	8.E-04
Left torso: lowest rib to iliac crest	1.30E+00	1.10E-02	2.90E+00	1.10E-02	8.E-04	5.E-04	8.E-04	8.E-04
Left torso: iliac crest to pubis (Left hip)	1.30E-01	1.1E-03	2.90E-01	1.1E-03	3.E-04	2.E-04	3.E-04	3.E-04

a. Values less than 0.1 mrem shown to one significant digit.

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Table A-14. DCFs used in determining dose equivalents (mGy/Gy × 1E-3rem-Gy/cGy-mGy).

	Through 1970					1971-1985		
Organ	HVL = 2.5 mm Al PFG	HVL = 2.0 mm Al Chest fluoro	HVL = 2.5 mm Al PA chest	HVL = 2.5 mm Al LAT/OBL chest	HVL = 2.5 mm Al AP lordotic chest	HVL = 2.5 mm Al PA chest	HVL = 2.5 mm Al LAT/OBL chest	HVL = 2.5 mm Al AP lordotic chest
Thyroid	1.74E-01	1.50E-01	1.74E-01	1.37E-01	8.68E-01	3.20E-02	1.15E-01	
Eye brain	3.20E-02	2.10E-02	3.20E-02	1.37E-01	8.68E-01	3.20E-02	1.15E-01	3.17E-01
Ovaries	N/A	6.00E-04	N/A	N/A	2.33E-01	1.00E-03	6.00E-04	3.17E-01
Liver/gall bladder/spleen	4.51E-01	3.55E-01	4.51E-01	2.20E-01	4.73E-01	4.51E-01	2.20E-01	2.00E-03
Urinary bladder/prostate	N/A	6.00E-04	N/A	N/A	2.33E-01	1.00E-03	6.00E-04	4.73E-01
Colon rectum	N/A	6.00E-04	N/A	N/A	2.33E-01	1.00E-03	6.00E-04	2.00E-03
Testes	N/A	1.00E-05	N/A	N/A	1.80E-02	1.00E-05	1.00E-04	2.00E-03
Lungs male	4.19E-01	3.35E-01	4.19E-01	1.93E-01	4.73E-01	4.19E-01	1.93E-01	1.00E-05
Lungs female	4.51E-01	3.55E-01	4.51E-01	2.20E-01	3.53E-01	4.51E-01	2.20E-01	4.73E-01
Thymus	4.51E-01	3.55E-01	4.51E-01	2.20E-01	4.73E-01	4.51E-01	2.20E-01	3.53E-01
Esophagus	4.51E-01	3.55E-01	4.51E-01	2.20E-01	4.73E-01	4.51E-01	2.20E-01	4.73E-01
Stomach	4.51E-01	3.55E-01	4.51E-01	2.20E-01	4.73E-01	4.51E-01	2.20E-01	4.73E-01
Bone surfaces	4.51E-01	3.55E-01	4.51E-01	2.20E-01	4.73E-01	4.51E-01	2.20E-01	4.73E-01
Remainder	4.51E-01	3.55E-01	4.51E-01	2.20E-01	4.73E-01	4.51E-01	2.20E-01	4.73E-01
Breast	4.90E-02	3.20E-02	4.90E-02	2.55E-01	8.36E-01	4.90E-02	2.55E-01	4.73E-01
Uterus	N/A	7.00E-04	N/A	N/A	3.05E-01	1.30E-03	6.00E-04	8.36E-01
Bone marrow male	9.20E-02	6.90E-02	9.20E-02	3.70E-02	4.80E-02	9.20E-02	3.70E-02	1.50E-03
Bone marrow female	8.60E-02	6.30E-02	8.60E-02	2.90E-02	4.80E-02	8.60E-02	2.90E-02	4.80E-02

Table A-14. DCFs used in determining dose equivalents (mGy/Gy × 1E-3rem-Gy/cGy-mGy) (cont'd.).

	1986 and later		Through 1970		1971 and later		Through 1970
Organ	HVL = 4.0 mm Al PA chest	HVL = 4.0 mm Al LAT/OBL chest	HVL = 2.0 mm Al AP lumbar spine	HVL = 2.0 mm Al LAT lumbar spine	HVL = 2.5 mm Al AP lumbar spine	HVL = 2.5 mm Al LAT lumbar spine	HVL = 2.0 mm Al AP pelvis
Thyroid	7.80E-02	1.64E-01	2.00E-04	1.00E-05	3.00E-04	1.00E-05	1.00E-05
Eye brain	7.80E-02	1.64E-01	2.00E-04	1.00E-05	3.00E-04	1.00E-05	1.00E-05
Ovaries	5.20E-03	2.50E-03	N/A	N/A	2.16E-01	4.70E-02	N/A
Liver/gall bladder/spleen	6.74E-01	3.51E-01	1.60E-01	3.10E-02	2.16E-01	4.70E-02	1.74E-01
Urinary bladder/prostate	5.20E-03	2.50E-03	1.60E-01	3.10E-02	2.16E-01	4.70E-02	1.74E-01
Colon rectum	5.20E-03	2.50E-03	1.60E-01	3.10E-02	2.16E-01	4.70E-02	1.74E-01
Testes	1.00E-05	1.00E-04	N/A	N/A	4.20E-03	8.00E-04	N/A
Lungs male	6.28E-01	3.13E-01	6.20E-02	1.00E-02	7.90E-02	1.40E-02	1.00E-03
Lungs female	6.74E-01	3.51E-01	6.20E-02	1.00E-02	7.90E-02	1.40E-02	1.00E-03
Thymus	6.74E-01	3.51E-01	6.20E-02	1.00E-02	7.90E-02	1.40E-02	1.00E-03
Esophagus	6.74E-01	3.51E-01	6.20E-02	1.00E-02	7.90E-02	1.40E-02	1.00E-03
Stomach	6.74E-01	3.51E-01	1.60E-01	3.10E-02	2.16E-01	4.70E-02	1.74E-01
Bone surfaces	6.74E-01	3.51E-01	1.60E-01	3.10E-02	2.16E-01	4.70E-02	1.74E-01
Remainder	6.74E-01	3.51E-01	1.60E-01	3.10E-02	2.16E-01	4.70E-02	1.74E-01
Breast	1.16E-01	3.43E-01	N/A	N/A	N/A	N/A	N/A
Uterus	5.20E-03	2.10E-03	2.17E-01	2.00E-02	2.87E-01	3.10E-02	2.44E-01
Bone marrow male	1.78E-01	7.60E-02	2.40E-02	1.50E-02	3.70E-02	2.20E-02	2.30E-02
Bone marrow female	1.72E-01	5.90E-02	2.40E-02	1.50E-02	3.70E-02	2.20E-02	2.30E-02

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Table A-14. DCFs used in determining dose equivalents (mGy/Gy × 1E-3rem-Gy/cGy-mGy) (cont'd).

Organ	Through 1960		Through 1960	
	HVL = 2.0 mm Al AP thoracic spine	HVL = 2.0 mm Al LAT/OBL thoracic spine	HVL = 2.0 mm Al AP/OBL cervical spine	HVL = 2.0 mm Al LAT cervical spine
Thyroid	9.40E-02	5.60E-02	7.53E-01	5.60E-02
Eye brain	9.40E-03	4.00E-03	7.53E-01	5.60E-02
Ovaries	N/A	N/A	N/A	N/A
Liver/gall bladder/spleen	3.32E-01	1.28E-01	1.50E-02	2.30E-02
Urinary bladder/prostate	7.00E-04	1.00E-04	N/A	N/A
Colon rectum	7.00E-04	1.00E-04	N/A	N/A
Testes	N/A	N/A	N/A	N/A
Lungs male	3.32E-01	1.07E-01	1.50E-02	2.30E-02
Lungs female	2.37E-01	1.28E-01	1.50E-02	2.30E-02
Thymus	3.32E-01	1.28E-01	1.50E-02	2.30E-02
Esophagus	3.32E-01	1.28E-01	1.50E-02	2.30E-02
Stomach	3.32E-01	1.28E-01	1.50E-02	2.30E-02
Bone surfaces	3.32E-01	1.28E-01	1.50E-02	2.30E-02
Remainder	3.32E-01	1.28E-01	1.50E-02	2.30E-02
Breast	3.67E-01	5.60E-03	1.50E-02	2.30E-02
Uterus	5.00E-04	1.00E-04	N/A	N/A
Bone marrow male	2.90E-02	1.80E-02	1.10E-02	1.70E-02
Bone marrow female	2.30E-02	1.40E-02	1.10E-02	1.70E-02