ORAU TEAM
Dose Reconstruction
Project for NIOSH

Oak Ridge Associated Universities | Dade Moeller | MJW Technical Services

DOE Review Release 07/06/2017

Rocky Flats Plant – Occupational Medical Dose	ORAUT-TKBS-0011-3	Rev. 02
	Effective Date:	06/27/2017
	Supersedes:	Revision 01

Subject Expert(s): Brian P. Martin

Document Owner Approval:	Signature on File Mutty M. Sharfi, Document Owner	Approval Date:	06/23/2017
Concurrence:	Signature on File John M. Byrne, Objective 1 Manager	Concurrence Date:	06/22/2017
Concurrence:	Signature on File Scott R. Siebert, Objective 3 Manager	Concurrence Date:	06/23/2017
Concurrence:	Signature on File James P. Griffin, Deputy Project Director	Concurrence Date:	06/23/2017
Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	06/27/2017

FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/09/2004	00	New Technical Basis Document for the Rocky Flats Plant – Occupational Medical Dose. First approved issue. Initiated by Robert Meyer.
04/23/2007	01	Approved Revision 01 initiated to revise Table 3.4.2-2 (now Table 3-6), text, and dose estimate tables to be consistent with ORAUT-OTIB-0006 Rev 03 PC-1. Revised Table 3.2-1 (now Table 3-1) and text to specify the inclusion of termination X-rays for the period of 1952-1986. Revised Table 3.4.1-2 (now Table 3-5) per commitment tracking form dated 02/06/2006. Revised to include attribution information per ORAU direction. The Worker Outreach comment from CT-0203 was addressed. Worker outreach comment from the June 23, 2004, meeting of the United Steelworkers of America Local 8031 and Rocky Flats Security Officers Local Union 1 was addressed in Section 3.1. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of document. This revision results in an increase in assigned dose and a PER is required. Training required: As determined by the Task Manager. Initiated by Robert Meyer.
06/27/2017	02	Revision initiated to update occupational medical X-ray doses for PFG, AP and LAT lumbar spine, and AP chest examinations. The AP chest examination dose update is specific to those performed starting June 11, 2001. Skin dose guidance and doses are also included in Attachment 1 of this revision based on information presented in ORAUT-OTIB-0006 Rev 04. Additional information regarding the availability of X-ray inventory sheets starting around February 2009 is included. CLL uncertainty parameters have been included as well. Updated Table A-2 to separate skin dose values for PA chest examinations between 1971 and 2001 into two time periods (1971-1984 and 1985-2001). Corrected transcription errors in Table A-1 of 8 skin doses for LAT exams performed prior through 1970 to correctly reflect values listed in ORAUT-OTIB-0006 Rev 04. Incorporates formal internal review comments. No changes occurred as a result of formal NIOSH review. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Brian P. Martin.

TABLE OF CONTENTS

SECTION **TITLE** **PAGE**

LIST OF TABLES

TABLE **TITLE** **PAGE**

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AP	anterior-posterior
AWE	atomic weapons employer
cGy	centigray
cm	centimeter
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	entrance skin exposure
Gy	gray
HVL	half-value layer
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
kV	kilovolt
kVp	kilovolts-peak
LAT	lateral
m	meter
mA	milliampere
mAs	milliampere-second
mGy	milligray
mm	millimeter
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
PER	program evaluation report
PFG	photofluorography
R	roentgen
RFP	Rocky Flats Plant
s	second
SEC	Special Exposure Cohort
SID	source-to-image distance
SRDB Ref ID	Site Research Database Reference Identification (number)
SSD	source-to-skin distance
Sv	sievert
TBD	technical basis document

U.S.C. United States Code

§ section or sections

3.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word “facility” is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an “AWE facility” or a “DOE facility.” The terms AWE and DOE facility are defined in sections 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. An AWE facility means “a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling.” 42 U.S.C. § 7384l(5). On the other hand, a DOE facility is defined as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program);” and with regard to which DOE has or had a proprietary interest, or “entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services.” 42 U.S.C. § 7384l(12). The Department of Energy (DOE) determines whether a site meets the statutory definition of an AWE facility and the Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Accordingly, a Part B claim for benefits must be based on an energy employee’s eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility’s designated time period and location (i.e., covered employee). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. Unlike the abovementioned statutory provisions on DOE facility definitions that contain specific descriptions or exclusions on facility designation, the statutory provision governing types of exposure to be included in dose reconstructions for DOE covered employees only requires that such exposures be incurred in the performance of duty. As such, NIOSH broadly construes radiation exposures incurred in the performance of duty to include all radiation exposures received as a condition of employment at covered DOE facilities in its dose reconstructions for covered employees. For covered employees at DOE facilities, individual dose reconstructions may also include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

3.1.1 Purpose

This technical basis document (TBD) describes the methods for estimating absorbed dose from X-ray exposure for Rocky Flats Plant (RFP) workers. Where data are unavailable, assumptions have been made that are favorable to claimants [1].

3.1.2 Scope

Section 3.2 provides background. Section 3.3 describes X-ray examination frequency at RFP. Section 3.4 provides information on equipment and techniques used at RFP, including assumptions necessitated by lack of protocol, measurement, or records data. Section 3.5 provides organ dose estimates by calendar year and type of X-ray. Section 3.6 documents uncertainties. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 3.7.

3.2 BACKGROUND

As part of the requirements for employment at RFP, entrance, exit, and periodic physical examinations were performed on all employees. These physical examinations included radiographic examinations of the lungs and, for some employees, the lumbar spine [2]. Diagnostic medical X-rays administered in conjunction with routine or special physical examinations and required for employment are occupational exposures (NIOSH 2007). Only medical exposures that were required as a condition of employment are included; diagnostic and therapeutic procedures that were not required for employment are excluded (e.g., exposures that were received in the treatment of work-related injuries).

As described in International Commission on Radiological Protection (ICRP) Publication 34, *Protection of the Patient in Diagnostic Radiology*, the amount of energy absorbed in the body and its distribution in specific organs can be determined by measurement or calculation (ICRP 1982). Absorbed dose in tissue, measured in units of gray, is equal to the energy absorbed per unit mass at a point in the human body. The quantity of radiation in terms of exposure from ionization of a specific mass of air by X-rays was in previous years measured in roentgens. The current International System of Units expresses this quantity in “air kerma” (kerma derives from <u>k</u>inetic <u>e</u>nergy <u>r</u>eleased per unit <u>ma</u>ss). An exposure of 1 R corresponds to an air kerma of 8.7 mGy.

The radiation dose from a given examination varies widely throughout the body. Doses are highly dependent on the technical factors, characteristics of the equipment, collimation of the beam, and number of films taken. The general equation for total annual occupational medical dose from NIOSH guidelines is (NIOSH 2007):

$$D_{om} = \sum nD_i \tag{3-1}$$

where

- D_{om} = occupational medical dose
- n = number of examinations in a calendar year
- D_i = dose from the X-ray procedure

The NIOSH guidelines state that medical records should contain the dates, types, and number of X-ray examinations, and that if no information is known about the energy spectra, values should conservatively be assumed to be in the 30- to 250-kV photon range, which is favorable to claimants. The guidelines also state that the uncertainty distribution about each X-ray procedure is assumed to follow a normal distribution, with D_{om} being the mean dose.

3.3 EXAMINATION FREQUENCY

Beginning in February of 2009, the RFP records group committed to providing an X-ray "inventory" with new EEOICPA responses going forward. The RFP records group reviews documented films and provides a list of all X-ray examinations. Film records are provided in a spreadsheet which contains claimant name, NIOSH ID number, examination type, date of examination, and number of X-rays taken. X-ray records collected prior to February 2009 may be incomplete, including those summarized on 3x5 inch index cards and individual X-ray records. Dose reconstructors may request an X-ray inventory spreadsheet for claims prior to February 2009. The information presented below may be used in the absence of claimant specific information.

The frequency of X-ray examinations varied significantly for RFP workers. Before approximately 1986, many production workers received single-view chest X-rays on a nearly annual basis. (In a sample of medical records of production workers, no one was found to have consistently received annual chest X-rays due to occasional missed examinations and periods when examinations were apparently not provided on an annual basis [3].) Inspection of medical records has not revealed more specific designations of X-ray protocol by worker classification or job description [4]. Based on the records that were reviewed during preparation of this document, no worker received such examinations more often than annually [5]. Inclusion of termination chest X-rays is recommended for the period from 1952 to 1985 because they were common at other DOE sites and despite the fact that termination X-rays are believed by former medical workers to have been uncommon at RFP [6]. Table 3-1 lists frequency assumptions from 1952 through 1985.

Table 3-1. Default X-ray examination frequencies.[a]

Period	Frequency	View	Comment
1952–1968	Annual	Chest (PFG)	All workers
1952–1974	Once	Lumbar (AP and LAT)	All workers
1969–1985	Annual and termination	Chest (PA)	All workers

a. Default frequencies provide overestimating assumptions for the assignment of RFP occupational medical dose in the absence of a RFP X-ray inventory.

Between 1952 and 1974, all workers received spinal X-rays during their initial employment (pre-hire) medical examination. This X-ray series consisted of a 14- by 17-in. AP view and a 10- by 12-in. lateral (LAT) view of the lumbosacral spine [7].

In the absence of a RFP provided X-ray film inventory or claim specific information, an approach to the estimation of the X-rays that is favorable to claimants is to assume lumbosacral spine X-rays were taken if the energy employee started work between 1952 and 1974. If an annual PFG examination (through 1968) or single-view chest X-ray is also assumed until 1974, this potential overestimation of X-ray use compensates for the few repeat radiographs that were taken because of the poor quality of the initial X-ray [8].

In the absence of a RFP provided X-ray inventory, it can be assumed that all personnel at RFP had an annual chest X-ray examination starting in 1969 (after removal of fluoroscope as discussed below). A protocol for frequency of a single posterior-anterior (PA) view chest X-ray as a function of job category was not fully established until approximately 1986 (Table 3-2). After that date, the frequency of routine chest X-rays varied widely depending on job description.

3.4 EQUIPMENT AND TECHNIQUES

Although RFP radiological practices are assumed to have followed standards of medical practice to minimize dose to the workers, the type of equipment, technique factors, and machine calibrations are not fully known for years before 2001. Members of the RFP TBD team interviewed medical and records group personnel and Colorado Department of Public Health and Environment personnel and determined that X-ray machine records for equipment in use before 2001 are not readily available [9]. However, some information has been found in relation to equipment type and ratings; these data have been used in conjunction with default data where necessary to provide estimates of potential exposure that are favorable to claimants. Individual medical records should contain notations about dates and purposes of X-ray examinations, but reviews of medical records showed that this was not always the case before the mid-1970s [10].

Default X-ray organ dose estimates are provided for the periods before June 11, 2001, for which the equipment and techniques are unknown (ORAUT 2011). Organ dose estimates for occupational X-rays from June 11, 2001 to the present are provided in Table 3-7. The use of proxy data for the earlier periods is based on the belief that RFP, like other DOE sites, used the standard radiological procedures of the time. All assumptions were conservative (favorable to claimants). The default dose estimates are from the ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-ray Procedures* (ORAUT 2011) for chest and lumbar spine X-rays.

Photofluorography (PFG) exams were performed at RFP based on X-ray inventory records received with new EEOICPA responses after February 2009. Also, a note indicating that a fluoroscope was removed from the plant in 1968 indicating that fluoroscopy was performed (ORAUT 2003). Default estimates of PFG exposure from ORAUT (2011) have been recommended in this TBD for the assignment of dose from PFGs.

Efforts will continue to find related information for RFP. However, until more accurate records are found, these assumptions provide estimates for medical X-ray exposure that are favorable to claimants.

Tables 3-2 and 3-3 summarize known information about equipment and techniques.

Table 3-2. Description of X-ray equipment at RFP and proxy information.

Period	Classification	Equipment	Source
July 1953–August 30,1976	Type IV	Keleket	ORAUT 2003
September 1, 1976–May 28, 1987	Type III	Generator unknown; Victoreen R Meter; BRH test stand; X-ray timer; aluminum filter set; light meter	ORAUT 2003
May 29, 1987–March 6, 2001	Type II	Eureka XMA tube; Generator unknown	ORAUT 2003 [14]
June 11, 2001–present	Type I	Hologic/BXT202W	ORAUT 2003 [15]

Table 3-3. Equipment settings and ratings (ORAUT 2003).

Period	Machine	View	Current (mA)	Voltage (kVp)	Exposure time (s)
1952–1974	Type IV	Lumbar AP[c]	200	140	Unknown
1952–1974	Type IV	Lumbar LAT[c]	200	140	Unknown
7/1953–8/30/1976	Type IV[b]	Chest PA	200	140	Unknown
9/01/1976–5/28/1987	Type III[b]	Chest PA	Unknown	80	Unknown
5/29/1987–3/6/2001	Type II[b]	Chest PA	360	130	Unknown
6/11/2001–present	Type I[a]	Chest PA	300	110	0.003

a. Typical setting varied from 0.8 mAs for an average-sized person to 2.3 mAs for a very large person; 2.3 mA was used to be conservative.

b. Maximum machine ratings (ORAUT 2003); data not used to calculate doses, but are presented for informational purposes.

c. Performed only from 1952 to 1974 [13]; settings are maximum machine ratings (ORAUT 2003).

3.5 ORGAN DOSE ESTIMATES

This section provides organ dose estimates. Section 3.5.1 describes the method used to estimate these doses, and Section 3.5.2 discusses the results.

3.5.1 Parameters and Estimation Method

The ICRP (1982) guidance uses the following parameters to estimate air kerma and absorbed dose:

1. Source-to-image distance (SID) in centimeters,
2. Total filtration (millimeters of aluminum),
3. Estimate of person thickness for AP and LAT projections, and
4. Machine settings (mAs, kVp, film size, and single- or three-phase).

If measured air kerma data are available, these should be used. If not, air kerma rates can be estimated from Figure 3-1 (ICRP 1982) if average technique factors and total filtration are known.

Figure 3-1 is for single-phase machines; results should be multiplied by 1.8 for three-phase machines. The machine at RFP from June 11, 2001, is assumed to have been three-phase. Once the kerma rate is estimated, the air kerma at 100 cm is calculated by multiplying the estimated air kerma rate by the number of mAs for each radiograph (ICRP 1982).

Next, the source-to-skin distance (SSD) is calculated by subtracting the AP or LAT thickness of the standard (reference) worker or person and distance between the worker and the film (default distance of 5 cm) from the SID. Air kerma at the SSD is then estimated using the following equation:

$$\textit{air kerma at SSD}\ (\text{mGy}) = (100/\textit{SSD})^2 \times \textit{air kerma at 1 m}\ (\text{mGy}) \quad (3\text{-}2)$$

Tables A.2 through A.9 of ICRP (1982) are then used to estimate organ dose directly. Dose to the skin was estimated by multiplying the air kerma at SSD by the appropriate factor from Table B-8 of National Council of Radiation Protection and Measurements Report 102 (NCRP 1989). The tables list organ doses in milligray normalized to an air kerma of 1 Gy in air at the skin, as a function of half-value layers (HVLs) in millimeters of aluminum. In addition, ICRP (1982, Appendix A) provides tables for estimating the HVL if it is not known. Table 3-4 lists all such values that were used in this TBD.

The ICRP tables that were used to estimate absorbed dose do not include all organs that have been identified in the Interactive RadioEpidemiological Program (IREP). For those organs that are included in the IREP, but are not specifically identified in the ICRP tables, the dose conversion coefficient that is anatomically closest to the IREP-specified organs can be used to estimate dose. For example, the factor for the lung can be applied to all other organs in the thoracic cavity, such as the esophagus and bone surface (ORAUT 2011). For abdominal organs (e.g., bladder and colon), the dose coefficient for ovaries should be used (ORAUT 2011). This approach should be either favorable to claimants or neutral. Table 3-5 provides analogs for IREP organs.

Dose estimates for PA chest X-rays and pre-hire AP and LAT lumbar spine X-rays are presented in Tables 3-6 and 3-7 for each organ in ICRP (1982). All dose estimates are default values as presented in ORAUT (2011) with the exception of those for June 11, 2001, to present, which are based on known machine settings (ORAUT 2003) and information such as HVL supplied by former medical workers (ORAUT 2006).

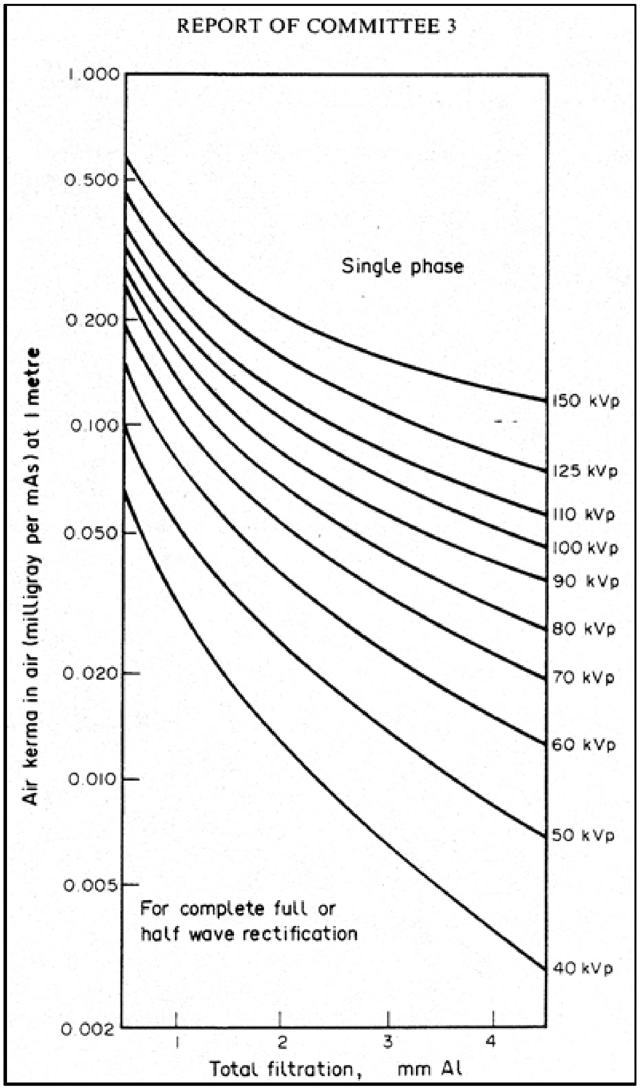

Figure 3-1. Kerma in air at 1 m from X-ray source as a function of total filtration for various values of tube potential (from ICRP 1982).

PFG was used at RFP, but no information about protocol has been found. Lacking information about PFG at RFP, default dose estimates have been used (ORAUT 2011).

3.5.2 Organ Dose Estimates

Table 3-6 lists default organ dose estimates from PA chest X-rays for each period. Table 3-7 lists the default organ dose estimates for AP and LAT lumbar spine X-rays (note that the values have been halved to account for two views; ORAUT 2011). Table 3-8 lists default PFG exposure from chest examinations (ORAUT 2011) to be used when evidence of PFG examinations are found for a specific claim. Skin dose views for RFP X-ray examinations prior to June 11, 2001 should be assigned based on those presented in ORAUT (2011). Skin dose views for RFP X-ray examinations from June 11, 2001 and later were determined based on the guidance presented in ORAUT (2010) and are presented in Attachment 1.

At this time, there is insufficient information to calculate site-specific organ doses for RFP. This is true specifically for chest X-rays before 2001, all lumbar spine X-rays, and all PFG examinations. The

Table 3-4. ICRP dose conversion factors; absorbed dose (1 mGy) for organs at various Al HVL (1-Gy entrance air kerma in air without backscatter). Image size 35.6 by 43.2 cm (ORAUT 2011).

Organ	Chest PA (through 1970)[a,b] 2.5 mm Al HVL, SID = 183 cm,	Chest PA[a] (1971 to 1985), 2.5 mm Al HVL SID=183 cm,	Chest PA[a] (1985 to present), 4 mm Al HVL, SID = 183 cm,	Lumbar spine AP[c] (through 1970), 2 mm Al HVL	Lumbar spine LAT[c] (through 1970), 2 mm AL HVL	Lumbar spine AP,[c] 1971-1974 2 mm Al HVL	Lumbar spine LAT,[c] 1971-1974 2 mm AL HVL
Thyroid	174[d]	32	78	0.2	0.01	0.3	0.01
Eye/brain	32	32	78	0.2	0.01	0.3	0.01
Ovaries	N/A	1	5.2	N/A	N/A	216	47
Liver/gall bladder/spleen	451	451	674	160	31	216	47
Urinary bladder	N/A	1	5.2	160	31	216	47
Colon/rectum	N/A	1	5.2	160	31	216	47
Testes	N/A	0.01	0.01	N/A[e]	N/A	4.2	0.8
Lungs (male)	419	419	628	62	10	79	14
Lungs (female)	451	451	674	62	10	79	14
Thymus	451	451	674	62	10	79	14
Esophagus	451	451	674	62	10	79	14
Stomach	451	451	674	160	31	216	47
Bone surfaces	451	451	674	160	31	216	47
Remainder	451	451	674	160	31	216	47
Breast	49	49	116	18[f]	9.5[f]	N/A	N/A
Uterus (embryo)	N/A	1.3	5.2	217	20	287	31
Bone marrow (male)	92	92	178	24	15	37	22
Bone marrow (female)	86	86	172	24	15	37	22
Skin	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

a. Dose conversion factors from ICRP (1982, Tables A.2 through A.9), ORAUT (2011).
b. Assumes minimal collimation.
c. From ORAUT (2011).
d. Dose conversion factor for AP cervical spine corrected for depth by 0.2.
e. N/A = not applicable as reported in ORAUT (2011).
f. Organ dose values for the testes, ovaries, and lumbar spine reflect actual measurement per Lincoln and Gupton (1958).
g. Dose conversion factors for lumbar spine examination not given in ICRP (1982). Values for the respective upper gastrointestinal examinations (i.e., AP and LAT) were used instead.

Table 3-5. 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 or ovary
Urinary bladder, Colon/rectum, prostate	Ovary
Eye/brain	Thyroid

a. As presented in ORAUT (2011).

organ doses that are presented here will be revised if additional site-specific information is found that allows more refined calculation of organ doses.

3.6 UNCERTAINTIES

As stated in ORAUT (2011), “error” is defined as deviation from the correct, true, or conventionally accepted value of a quantity, and “uncertainty” is defined in terms of the potential range of a stated, measured, assumed, or otherwise determined value of a quantity. Error and uncertainty provide an indication of confidence in the dose estimates. Uncertainty, expressed in terms of a confidence level, is a more appropriate term than error, which implies that the actual value is known. Uncertainty, stated as a probability of falling within a stated range, includes precision and reproducibility of the measurement as well as accuracy (that is, how close the estimate comes to the actual value).

Although many factors can introduce uncertainty and error into X-ray dose estimates, five factors contribute the most: measurement error, variation in peak kilovoltage, variation in beam current, variation in exposure time, and SSD. Film speed, use of screens, or use of grids would not affect the beam output intensity. The lack of records for these measurements for most years at RFP introduces a large uncertainty into the dose estimates that cannot be readily quantified, although there is no apparent reason to believe that practices at RFP were different from those at other facilities or from recommended standards of the medical community at the time [14]. Therefore, use of default estimates and reliance on information from other DOE sites when site-specific information was unavailable is likely to closely approximate X-ray performance at RFP. The following estimates of uncertainty associated with X-ray exposure are from ORAUT (2011), which was relied upon for default information. Further, these same factors affect dose estimates of PFG X-rays; proxy default information for PFG is from ORAUT (2011) in the absence of useful records at RFP.

ORAUT (2011) reports that recorded X-ray doses largely derive from actual measurements of X-ray machine output with R-meters or similar ionization chamber devices. These typically had a reported uncertainty of ±2% for photon energies below 400 keV, if properly calibrated and used. Although newer machinery might have a smaller uncertainty, ±2% should be used to be conservative.

Variation in peak kilovoltage generally falls within ±5% of the machine setting. Beam intensity is approximately proportional to the 1.7 power of the kilovoltage, which results in an uncertainty of approximately 9% in relation to beam intensity for voltages between 110 and 120 kVp (ORAUT 2011).

Variations in tube current are normal and generally small. As tube current drops, beam intensity also falls in direct proportion to the tube current. Large decreases in beam output would be readily detected and would indicate the need for machine maintenance or, as a temporary measure, an increase in the current or voltage to provide the necessary intensity for proper radiography. However, there is no evidence that such a procedure was ever needed or applied at RFP. Consistent with ORAUT (2011), the variation in tube current is assumed to be approximately ±5%.

Exposure time can also significantly affect the dose from radiography (exposure times are a fraction of a second). Even a small variation in exposure time due to timer error can significantly change beam output. Because early X-ray machine timers are known to have been inaccurate, uncertainty in beam output due to timers is assumed to be ±25% (ORAUT 2011). Therefore, it is recommended that ±25% be applied for RFP estimates, particularly because site-specific exposure time was available only for the present machine.

SSD can contribute to variability because the entrance skin exposure is determined by this distance. Variations result from accuracy of positioning as well as worker size (thickness). As expressed in ORAUT (2011), this is generally thought to vary by no more than a few centimeters, with an upper limit of 7.5 cm (±10%).

Table 3-6. Organ dose estimates for PA chest.

Through 1970,
HVL = 2.5 mm Al. entrance kerma = 0.20 cGy[b]

Organ	mGy	rem
Thyroid	3.48E-01	3.48E-02
Eye/brain	6.40E-02	6.40E-03
Ovaries	2.50E-01[c]	2.50E-02[c]
Liver/gall bladder/spleen	9.02E-01	9.02E-02
Urinary bladder	2.50E-01[c]	2.50E-02[c]
Colon/rectum	2.50E-01[c]	2.50E-02[c]
Testes	5.00E-02[c]	5.00E-03[c]
Lungs (male)	8.38E-01	8.38E-02
Lungs (female)	9.02E-01	9.02E-02
Thymus	9.02E-01	9.02E-02
Esophagus	9.02E-01	9.02E-02
Stomach	9.02E-01	9.02E-02
Bone surfaces	9.02E-01	9.02E-02
Remainder	9.02E-01	9.02E-02
Female breast	9.80E-02	9.80E-03
Uterus	2.50E-01[c]	2.50E-02[c]
Bone marrow (male)	1.84E-01	1.84E-02
Bone marrow (female)	1.72E-01	1.72E-02
Skin	2.70E+00	2.70E-01

1971 to 1985,
HVL = 2.5 mm Al, entrance kerma = 0.10 cGy[b]

Organ	mGy	rem
Thyroid	3.20E-02	3.20E-03
Eye/brain	3.20E-02	3.20E-03
Ovaries	1.00E-03	1.0E-04
Liver/gall bladder/spleen	4.51E-01	4.51E-02
Urinary bladder	1.00E-03	1.00E-04
Colon/rectum	1.00E-03	1.00E-04
Testes	1.00E-05	1.00E-06
Lungs (male)	4.19E-01	4.19E-02
Lungs (female)	4.51E-01	4.51E-02
Thymus	4.51E-01	4.51E-02
Esophagus	4.51E-01	4.51E-02
Stomach	4.51E-01	4.51E-02
Bone surfaces	4.51E-01	4.51E-02
Remainder	4.51E-01	4.51E-02
Female breast	4.90E-02	4.90E-03
Uterus	1.30E-03	1.30E-04
Bone marrow (male)	9.20E-02	9.20E-03
Bone marrow (female)	8.60E-02	8.60E-03
Skin	1.35E+00	1.35E-01

1985 to June 4, 2001,
HVL = 4.0 mm Al, entrance kerma = 0.05 cGy[b]

Organ	mGy	rem
Thyroid	3.90E-02	3.90E-03
Eye/brain	3.90E-02	3.90E-03
Ovaries	2.60E-03	2.60E-04
Liver/gall bladder/spleen	3.37E-01	3.37E-02
Urinary bladder	2.60E-03	2.60E-04
Colon/rectum	2.60E-03	2.60E-04
Testes	5.00E-06	5.00E-07
Lungs (male)	3.14E-01	3.14E-02
Lungs (female)	3.37E-01	3.37E-02
Thymus	3.37E-01	3.37E-02
Esophagus	3.37E-01	3.37E-02
Stomach	3.37E-01	3.37E-02
Bone surfaces	3.37E-01	3.37E-02
Remainder	3.37E-01	3.37E-02
Female breast	5.80E-02	5.80E-03
Uterus	2.60E-03	2.60E-04
Bone marrow (male)	8.90E-02	8.90E-03
Bone marrow (female)	8.60E-02	8.60E-03
Skin	7.00E-01	7.00E-02

June 11, 2001, to present [15],
HVL = 4.0 mm Al; air kerma at skin = 0.129 mGy[a]

Organ	mGy	rem
Thyroid	1.01E-02	1.01E-03
Eye/brain	1.01E-02	1.01E-03
Ovaries	6.72E-04	6.72E-05
Liver/gall bladder/spleen	8.71E-02	8.71E-03
Urinary bladder	6.72E-04	6.72E-05
Colon/rectum	6.72E-04	6.72E-05
Testes	1.29E-06	1.29E-07
Lungs (male)	8.12E-02	8.12E-03
Lungs (female)	8.71E-02	8.71E-03
Thymus	8.71E-02	8.71E-03
Esophagus	8.71E-02	8.71E-03
Stomach	8.71E-02	8.71E-03
Bone surfaces	8.71E-02	8.71E-03
Remainder	8.71E-02	8.71E-03
Female breast	1.50E-02	1.50E-03
Uterus	6.72E-04	6.72E-05
Bone marrow (male)	2.30E-02	2.30E-03
Bone marrow (female)	2.22E-02	2.22E-03
Skin	1.84E-01	1.84E-02

a. HVL determined from former medical workers (ORAUT 2006); machine settings from a memorandum to file (ORAUT 2003).
b. As presented in ORAUT (2011).
c. Modified from Webster and Merrill (1957) as presented in ORAUT (2011).

Table 3-7. Organ dose estimates for AP and LAT lumbar spine, 1952 to 1974.

Organ	AP lumbar spine 1952–1974 Entrance kerma 1.44 cGy[a]	LAT lumbar spine 1952–1974 Entrance kerma 3.79 cGy[a]	AP lumbar spine 1971–1974 Entrance kerma 0.91 cGy	LAT lumbar spine 1971–1974 Entrance kerma 3.48 cGy
Thyroid	2.88E-04	3.79E-05	2.73E-04	3.48E-05
Eye/brain	2.88E-04	3.79E-05	2.73E-04	3.48E-05
Ovaries	5.60E-01[b]	7.10E-01[b]	1.97E-01	1.64E-01
Urinary bladder	2.30E-01	1.17E-01	1.97E-01	1.64E-01
Colon/rectum	2.30E-01	1.17E-01	1.97E-01	1.64E-01
Testes	2.70E-02[b]	5.60E-02[b]	3.82E-03	2.78E-03
Lung	8.93E-02	3.79E-02	7.19E-02	4.87E-02
Liver/gall bladder/spleen	2.30E-01	1.17E-01	1.97E-01	1.64E-01
Thymus	8.93E-02	3.79E-02	7.19E-02	4.87E-02
Esophagus	8.93E-02	3.79E-02	7.19E-02	4.87E-02
Stomach	2.30E-01	1.17E-01	1.97E-01	1.64E-01
Bone surfaces	2.30E-01	1.17E-01	1.97E-01	1.64E-01
Remainder	2.30E-01	1.17E-01	1.97E-01	1.64E-01
Female breast[a]	4.78E-03	7.58E-03	9.56E-04	2.07E-03
Uterus	3.12E-01	7.58E-02	2.61E-02	1.08E-01
Bone marrow	3.46E-02	5.69E-02	3.37E-02	7.66E-02
Skin[c]	1.90E+00	5.00E+00	1.23E+00	4.70E+00

a. As presented in ORAUT (2011)
b. Organ dose values for the testes and ovaries for lumbar spine reflect actual measurement reported in Lincoln and Gupton (1958).
c. Skin dose values include backscatter factor of 1.32 from NCRP (1989, Table B.8).

Table 3-8. Organ dose estimates for photofluorography, 1952 to 1968 (as presented in ORAUT 2011). Entrance kerma = 2.27 cGy; HVL = 2.5 mm Al; all estimates are for uncollimated beams.

Organ	View	Dose conversion factor,[a] HVL 2.5 mm Al, uncollimated (mGy per Gy air kerma)	Organ dose, uncollimated (rem)
Thyroid	PA	174	3.94E-01
Eye/brain	PA	32	7.25E-02
Ovaries	PA	N/A	2.50E-02[b]
Liver/gall bladder	PA	451	1.02E+00
Urinary bladder	PA	N/A	2.50E-02[b]
Colon/rectum	PA	N/A	2.50E-02[b]
Testes	PA	N/A	5.00E-03[b]
Lungs (male)	PA	419	9.50E-01
Lungs (female)	PA	451	1.02E+00
Thymus	PA	451	1.02E+00
Esophagus	PA	451	1.02E+00
Stomach	PA	451	1.02E+00
Bone surfaces	PA	451	1.02E+00
Remainder	PA	451	1.02E+00
Breast	PA	49	1.11E-01
Uterus	PA	N/A	2.50E-02[c]
Bone marrow (male)	PA	92	2.09E-01
Bone marrow (female)	PA	86	1.95E-01
Skin[c]	PA	N/A	3.06E+00

a. Dose conversion factors from, ICRP (1982, Tables A.2 through A.9).
b. Modified from Webster and Merrill (1957), as reported in ORAUT (2011).
c. Assuming back scatter factor of 1.32.

Consistent with ORAUT (2011), the statistical root mean square was calculated to estimate total uncertainty (ORAUT 2011). The root mean square is the square root of the sum of the squares of the individual uncertainty values, and equals 28.9%. An estimate of 30% uncertainty is larger than the default NIOSH guidance standard deviation recommendation of 20% (NIOSH 2007).

The tissue at risk for chronic lymphocytic leukemia is the B-lymphocytes. The dose to the B-lymphocytes was determined using the method in ORAUT-RPRT-0064, *Medical Dose to the B-Lymphocytes* (ORAUT 2014), site-specific information, and ICRP Publication 34 DCFs (ICRP 1982). Table 3-9 provides dose distributions and statistical parameters for input into the Interactive RadioEpidemiological Program (IREP) for determining dose to the B-lymphocytes.

Table 3-9. IREP dose distributions and statistical parameters for the dose to the B-lymphocytes.

Projection	Year	Distribution	Parameters 1, 2, and 3
PFG	1952–1968	Use OTIB-0006 PFG	Use OTIB-0006 PFG
PA chest	1952–1970	Use OTIB-0006 through1970	Use OTIB-0006 through1970
AP LS	1952–1970	Use OTIB-0006 through1970	Use OTIB-0006 through1970
LAT LS	1952–1970	Use OTIB-0006 through 1970	Use OTIB-0006through 1970
AP LS	1971-1974	Use OTIB-0006 after 1970	Use OTIB-0006 after 1970
LAT LS	1971-1974	Use OTIB-0006 after 1970	Use OTIB-0006 after 1970
PA chest	1971–1985	Use OTIB-0006 1971-1985	Use OTIB-0006 1971-1985
PA chest	1986–2001	Use OTIB-0006 1986–present	Use OTIB-0006 1986–present
PA chest	2002–present	Weibull3	2.124902, 0.003815, and –7.1779E-07

3.7 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional References, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database (SRDB).

[1] Lopez, Theresa. Oak Ridge Associated Universities (ORAU) Team. Senior Toxicologist. July 2006.
In the absence of data or protocols, assumptions that needed to be made were favorable to claimants.

[2] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on work history at the site and available protocols. Documented July 18, 2003.

[3] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files at RFP. Documented July 18, 2003.

[4] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files at RFP. Documented July 18, 2003.

[5] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files at RFP. Documented July 18, 2003.

[6] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files at RFP and interviews with medical personnel. Documented July 18, 2003.

[7] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on personal history of working at the site and medical file review. Documented July 18, 2003.

[8] Lopez, Theresa. ORAU Team. Senior Toxicologist. July 2006.
An annual single-view chest X-ray is likely an overestimate of actual practice because a review of medical files found that chest X-rays rarely occurred on an annual basis, probably due to scheduling and machine availability. However, this assumption is favorable to claimants because it encompasses more X-rays than were probably taken.

[9] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Documented July 18, 2003. Also documented by Robert Meyer, August 13, 2003.

[10] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files and discussions. Documented July 18, 2003.

[11] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files and discussions. Documented July 18, 2003.

[12] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on review of medical files and discussions. Documented July 18, 2003.

[13] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on medical personnel interviews and review of medical files. Documented July 18, 2003.

[14] Lopez, Theresa. ORAU Team. Senior Toxicologist. July 2006.
Calculated from information given to J. Furman by the Occupational Medicine Group at RFP. Documented July 18, 2003.

[15] Furman, J. ORAU Team. Former Medical Director, Rocky Flats Plant. July 2003.
Based on personal work history at the site.

REFERENCES

EG&G (Edgerton, Germeshausen, and Grier), 1991, *Occupational Health Medical Examination Criteria*, Appendix I, Rocky Flats Plant, Golden, Colorado, November. [SRDB Ref ID: 71527]

ICRP (International Commission on Radiological Protection), 1982, *Protection of the Patient in Diagnostic Radiology*, Publication 34, Pergamon Press, Oxford, England. [SRDB Ref ID: 32466]

Lincoln, T. A., and E. D. Gupton, 1958, "Radiation Doses in Diagnostic X-Ray Procedures," *Radiology*, volume 71, pp. 208–215. [SRDB Ref ID: 11099]

NCRP (National Council of Radiation Protection and Measurements), 1989, *Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use)*, Report 102, Bethesda, Maryland, June 30. [SRDB Ref ID: 32467]

NIOSH (National Institute for Occupational Safety and Health), 2007, *External Dose Reconstruction Implementation Guideline,* OCAS-IG-001, Rev. 3, Office of Compensation Analysis and Support, Cincinnati, Ohio, November 21.

NIOSH (National Institute for Occupational Safety and Health), 2010, *Radiation Exposures Covered for Dose Reconstructions Under Part B of the Energy Employees Occupational Illness Compensation Program Act*, DCAS-IG-003, Rev. 1, Division of Compensation Analysis and Support, Cincinnati, Ohio, October 5.

ORAUT (Oak Ridge Associated Universities Team), 2003, "Regarding Location of Rocky Flats X-Ray Documents," memorandum to file, Oak Ridge, Tennessee, October 21. [SRDB Ref ID: 12408]

ORAUT (Oak Ridge Associated Universities Team), 2006, "2001 X-Ray Machine Settings for RFP," documented communication, Oak Ridge, Tennessee, August 2. [SRDB Ref ID: 25014]

ORAUT (Oak Ridge Associated Universities Team), 2010, *Occupational Medical X-Ray Dose Reconstruction for DOE Sites,* ORAUT-PROC-0061, Rev 03, Oak Ridge, Tennessee, March 3. [SRDB Ref ID: 79758]

ORAUT (Oak Ridge Associated Universities Team), 2011, *Dose Reconstruction from Occupational Medical X-Ray Procedures*, ORAUT-OTIB-0006, Rev. 04, Oak Ridge, Tennessee, June 20.

ORAUT (Oak Ridge Associated Universities Team), 2014, *Medical Dose to the B-Lymphocytes*, ORAUT-RPRT-0064, Rev. 00, Oak Ridge, Tennessee, June 03.

Webster, E. W., and O. E. Merrill, 1957, "Measurements of Gonadal Dose in Radiographic Examinations," *New England Journal of Medicine*, volume 257, pp. 811–819. [SRDB Ref ID: 11100]

GLOSSARY

air kerma in air

The sum of kinetic energy of all charged particles liberated per unit mass of air. The unit is the joule per kilogram and is given the special name gray.

exposure

In this document, measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

gray (Gy)

International System unit of absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium; 1 gray equals 1 joule per kilogram or 100 rads.

kerma

Measure in units of absorbed dose (usually grays but sometimes rads) of the energy released by radiation from a given amount of a substance. Kerma is the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged ionizing particles (neutrons and photons) per unit mass of a specified material. Free-in-air kerma refers to the amount of radiation at a location before adjustment for any external shielding from structures or terrain. The word derives from kinetic energy released per unit mass.

lumbosacral spine

Region of the spine including the five lumbar vertebrae (lower back) and the five fused sacral vertebrae (posterior wall of the pelvis).

radiation

Subatomic particles and electromagnetic rays (photons) with kinetic energy that interact with matter through various mechanisms that involve energy transfer.

rem

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

roentgen (R)

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive or negative charge equal to 2.58×10^{-4} coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0 degrees Celsius and standard atmospheric pressure. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

skin dose

See *shallow dose equivalent*.

sievert (Sv)

International System unit for dose equivalent, which indicates the biological damage caused by radiation. The unit is the radiation value in gray (equal to 1 joule per kilogram) multiplied by a weighting factor for the type of radiation and a weighting factor for the tissue; 1 sievert equals 100 rem.

shallow dose equivalent

Dose equivalent in units of rem or sievert at a depth of 0.07 millimeters (7 milligrams per square centimeter) in tissue equal to the sum of the penetrating and nonpenetrating doses.

X-ray radiation

Electromagnetic radiation (photons) produced by bombardment of atoms by accelerated particles. X-rays are produced by various mechanisms including bremsstrahlung and electron shell transitions within atoms (characteristic X-rays). Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.

ATTACHMENT A
SKIN VIEW GUIDANCE AND DOSE TABLES

LIST OF TABLES

TABLE **TITLE** **PAGE**

ATTACHMENT A
SKIN VIEW GUIDANCE AND DOSE TABLES (continued)

Table A-1. Skin dose guidance and doses for examinations during poor collimation period, 1952 to 1970.

Area of Skin	Basis for PFG 1952–1968	PFG dose 1952–1968	Basis for PA chest through 1970	PA chest dose through 1970	Basis for AP lumbar through 1970	AP lumbar dose through 1970	Basis for LAT lumbar through 1970	LAT dose through 1970
R front shoulder	EXSD	6.67E-02	EXSD	5.9E-03	10% ENSD	1.90E-01	10% ENSD	5.00E-01
R back shoulder	ENSD	3.06E+00	ENSD	2.70E-01	10% EXSD	3.60E-03	10% ENSD	5.00E-01
L front shoulder	EXSD	6.67E-02	EXSD	5.9E-03	10% ENSD	1.90E-01	10% EXSD	1.90E-03
L back shoulder	ENSD	3.06E+00	ENSD	2.70E-01	10% EXSD	3.60E-03	10% EXSD	1.90E-03
R upper arm to elbow	10% ENSD	3.06E-01	ENSD	2.70E-01	10% ENSD	1.90E-01	10% ENSD	5.00E-01
L upper arm to elbow	10% ENSD	3.06E-01	ENSD	2.70E-01	10% ENSD	1.90E-01	10% EXSD	1.90E-03
L hand	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.90E+00	10% EXSD	1.90E-03
R hand	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.90E+00	10% ENSD	5.00E-01
L elbow, forearm, wrist	10% ENSD	3.06E-01	ENSD	2.70E-01	ENSD	1.90E+00	10% EXSD	1.90E-03
R elbow, forearm, wrist	10% ENSD	3.06E-01	ENSD	2.70E-01	ENSD	1.90E+00	10% ENSD	5.00E-01
R side of head (including temple and ear)	10% ENSD	3.06E-01	10% ENSD	2.70E-02	Eye/brain	2.88E-04	Eye/brain	3.79E-05
L side of head (including temple and ear)	10% ENSD	3.06E-01	10% ENSD	2.70E-02	Eye/brain	2.88E-04	Eye/brain	3.79E-05
Front left thigh	RSD (0.52m)	9.01E-04	RSD (0.52m)	8.E-05	10% ENSD	1.90E-01	10% EXSD	1.90E-03
Back left thigh	RSD (0.52m)	9.01E-04	RSD (0.52m)	8.E-05	10% EXSD	3.60E-03	10% EXSD	1.90E-03
Front right thigh	RSD (0.52m)	9.01E-04	RSD (0.52m)	8.E-05	10% ENSD	1.90E-01	10% ENSD	5.00E-01
Back right thigh	RSD (0.52m)	9.01E-04	RSD (0.52m)	8.E-05	10% EXSD	3.60E-03	10% ENSD	5.00E-01
L knee and below	RSD (0.86m)	9.01E-04	RSD (0.86m)	3.E-05	RSD (0.60m)	4.00E-04	RSD (0.60m)	5.00E-04
R knee and below	RSD (0.86m)	9.01E-04	RSD (0.86m)	3.E-05	RSD (0.60m)	4.00E-04	RSD (0.60m)	5.00E-04
L side of face	Eye/brain	7.25E-02	Eye/brain	6.4E-03	Eye/brain	3.00E-04	Eye/brain	3.00E-05
R side of face	Eye/brain	7.25E-02	Eye/brain	6.4E-03	Eye/brain	3.00E-04	Eye/brain	3.00E-05
L side of neck	10% ENSD	3.06E-01	ENSD	2.70E-01	Eye/brain	3.00E-04	Eye/brain	3.00E-05
R side of neck	10% ENSD	3.06E-01	ENSD	2.70E-01	Eye/brain	3.00E-04	Eye/brain	3.00E-05
Back of head	10% ENSD	3.06E-01	10% ENSD	2.70E-02	Eye/brain	3.00E-04	Eye/brain	3.00E-05
Front of neck	Eye/brain	7.25E-02	Eye/brain	6.4E-03	Eye/brain	3.00E-04	Eye/brain	3.00E-05
Back of neck	10% ENSD	3.06E-01	ENSD	2.70E-01	Eye/brain	3.00E-04	Eye/brain	3.00E-05
Front torso: base of neck to end of sternum	EXSD	6.67E-02	EXSD	5.9E-03	10% ENSD	1.90E-01	Lung	3.79E-02
Front torso: end of sternum to lowest rib	EXSD	6.67E-02	EXSD	5.9E-03	ENSD	1.90E+00	Lung	3.79E-02

ATTACHMENT A
SKIN VIEW GUIDANCE AND DOSE TABLES (continued)

Area of Skin	Basis for PFG 1952–1968	PFG dose 1952–1968	Basis for PA chest through 1970	PA chest dose through 1970	Basis for AP lumbar through 1970	AP lumbar dose through 1970	Basis for LAT lumbar through 1970	LAT dose through 1970
Front torso: lowest rib to iliac crest	EXSD	6.67E-02	EXSD	5.9E-03	ENSD	1.90E+00	Lung	3.79E-02
Front torso: iliac crest to pubis	10% EXSD	6.67E-03	10% EXSD	6.E-04	ENSD	1.90E+00	Lung	3.79E-02
Back torso: base of neck to mid-back	ENSD	3.06E+00	ENSD	2.70E-01	10% EXSD	3.60E-03	Lung	3.79E-02
Back torso: mid-back to lowest rib	ENSD	3.06E+00	ENSD	2.70E-01	EXSD	3.64E-02	Lung	3.79E-02
Back torso: lowest rib to iliac crest	ENSD	3.06E+00	ENSD	2.70E-01	EXSD	3.64E-02	Lung	3.79E-02
Back torso: buttocks (Iliac crest and below)	10% ENSD	3.06E-01	10% ENSD	2.70E-02	EXSD	3.64E-02	Lung	3.79E-02
Right torso: base of neck to end of sternum	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.90E-01	10% ENSD	5.00E-01
Right torso: end of sternum to lowest rib	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.90E+00	ENSD	5.00E+00
Right torso: lowest rib to iliac crest	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.90E+00	ENSD	5.00E+00
Right torso: iliac crest to pubis (R hip)	10% ENSD	3.06E-01	10% ENSD	2.70E-02	ENSD	1.90E+00	ENSD	5.00E+00
Left torso: base of neck to end of sternum	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.90E-01	10% EXSD	1.90E-03
Left torso: end of sternum to lowest rib	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.90E+00	EXSD	1.90E-02
Left torso: lowest rib to iliac crest	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.90E+00	EXSD	1.90E-02
Left torso: iliac crest to pubis (L hip)	10% ENSD	3.06E-01	10% ENSD	2.70E-02	ENSD	1.90E+00	EXSD	1.90E-02

ATTACHMENT A
SKIN VIEW GUIDANCE AND DOSE TABLES (continued)

Table A-2. Skin dose guidance and doses, 1971 to present.

Area of Skin	Basis for AP lumbar 1971–1974	AP lumbar dose 1971–1974	Basis for LAT lumbar 1971–1974	LAT lumbar dose 1971–1974	Basis for PA chest 1971–present	PA chest dose 1971– 1984	PA chest dose 1985-2001	PA chest dose 2002–present
R front shoulder	10% ENSD	6.53E-02	10% ENSD	5.9E-03	EXSD	2.9E-03	2.87E-03	7.53E-04
R back shoulder	10% EXSD	3.00E+00	10% ENSD	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
L front shoulder	10% ENSD	6.53E-02	10% EXSD	5.9E-03	EXSD	2.9E-03	2.87E-03	7.53E-04
L back shoulder	10% EXSD	3.00E+00	10% EXSD	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
R upper arm to elbow	10% ENSD	3.00E-01	10% ENSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
L upper arm to elbow	10% ENSD	3.00E-01	10% EXSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
L hand	10% ENSD	3.00E+00	10% EXSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
R hand	10% ENSD	3.00E+00	10% ENSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
L elbow, forearm, wrist	10% ENSD	3.00E-01	10% EXSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
R elbow, forearm, wrist	10% ENSD	3.00E-01	10% ENSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
R side of head (including temple and ear)	Eye/brain	3.00E-01	Eye/brain	2.70E-02	10% ENSD	1.35E-02	7.00E-03	1.84E-03
L side of head (including temple and ear)	Eye/brain	3.00E-01	Eye/brain	2.70E-02	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Front left thigh	10% ENSD	8.82E-04	10% EXSD	8.E-05	RSD (0.52m)	4.E-05	2.28E-05	6.00E-06
Back left thigh	10% EXSD	8.82E-04	10% EXSD	8.E-05	RSD (0.52m)	4.E-05	2.28E-05	6.00E-06
Front right thigh	10% ENSD	8.82E-04	10% ENSD	8.E-05	RSD (0.52m)	4.E-05	2.28E-05	6.00E-06
Back right thigh	10% EXSD	8.82E-04	10% ENSD	8.E-05	RSD (0.52m)	4.E-05	2.28E-05	6.00E-06
L knee and below	RSD (0.60m)	8.82E-04	RSD (0.60m)	3.E-05	RSD (0.86m)	1.E-05	8.34E-06	3.71E-05
R knee and below	RSD (0.60m)	8.82E-04	RSD (0.60m)	3.E-05	RSD (0.86m)	1.E-05	8.34E-06	3.71E-05
L side of face	Eye/brain	7.25E-02	Eye/brain	6.4E-03	Eye/brain	3.2E-03	1.01E-03	1.01E-03
R side of face	Eye/brain	7.25E-02	Eye/brain	6.4E-03	Eye/brain	3.2E-03	1.01E-03	1.01E-03
L side of neck	Eye/brain	3.00E-01	Eye/brain	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
R side of neck	Eye/brain	3.00E-01	Eye/brain	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Back of head	Eye/brain	3.00E-01	Eye/brain	2.70E-02	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Front of neck	Eye/brain	7.25E-02	Eye/brain	6.4E-03	Thyroid	3.2E-03	1.01E-03	1.01E-03
Back of neck	Eye/brain	3.00E-01	Eye/brain	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Front torso: base of neck to end of sternum	10% ENSD	6.53E-02	Lung	5.9E-03	EXSD	2.9E-03	2.87E-03	7.53E-04
Front torso: end of sternum to lowest rib	ENSD	6.53E-02	Lung	5.9E-03	EXSD	2.9E-03	2.87E-03	7.53E-04
Front torso: lowest rib to iliac crest	ENSD	6.53E-02	Lung	5.9E-03	10% EXSD	3.E-04	2.87E-04	7.53E-05
Front torso: iliac crest to pubis	ENSD	6.53E-03	Lung	6.E-04	10% EXSD	3.E-04	2.87E-04	7.53E-05
Back torso: base of neck to mid-back	10% EXSD	3.00E+00	Lung	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02

ATTACHMENT A
SKIN VIEW GUIDANCE AND DOSE TABLES (continued)

Area of Skin	Basis for AP lumbar 1971–1974	AP lumbar dose 1971–1974	Basis for LAT lumbar 1971–1974	LAT lumbar dose 1971–1974	Basis for PA chest 1971–present	PA chest dose 1971– 1984	PA chest dose 1985-2001	PA chest dose 2002–present
Back torso: mid-back to lowest rib	EXSD	3.00E+00	Lung	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
Back torso: lowest rib to iliac crest	EXSD	3.00E+00	Lung	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Back torso: buttocks (Iliac crest and below)	EXSD	3.00E-01	Lung	2.70E-02	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Right torso: base of neck to end of sternum	10% ENSD	3.00E+00	10% ENSD	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
Right torso: end of sternum to lowest rib	ENSD	3.00E+00	ENSD	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
Right torso: lowest rib to iliac crest	ENSD	3.00E+00	ENSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Right torso: iliac crest to pubis (R hip)	ENSD	3.00E-01	ENSD	2.70E-02	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Left torso: base of neck to end of sternum	10% ENSD	3.00E+00	10% EXSD	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
Left torso: end of sternum to lowest rib	ENSD	3.00E+00	EXSD	2.70E-01	ENSD	1.35E-01	7.00E-02	1.84E-02
Left torso: lowest rib to iliac crest	ENSD	3.00E+00	EXSD	2.70E-01	10% ENSD	1.35E-02	7.00E-03	1.84E-03
Left torso: iliac crest to pubis (L hip)	ENSD	3.00E-01	EXSD	2.70E-02	10% ENSD	1.35E-02	7.00E-03	1.84E-03