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Dose Reconstruction Project for NIOSH

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PUBLICATION RECORD

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03/28/2013	01	Revision to update doses according to site-specific information and recently revised ORAUT-OTIB-0006. Incorporates resolutions to Sanford Cohen & Associates comments. Also incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Michalene Rodriguez.

TABLE OF CONTENTS

SECTION **TITLE** **PAGE**

Acronyms and Abbreviations ... 4

3.1 Introduction ... 5
  3.1.1 Purpose ... 6
  3.1.2 Scope ... 6

3.2 Examination Types and Frequencies ... 6

3.3 Equipment and Techniques ... 7
  3.3.1 Photofluorography, April 1945–1956 ... 7
  3.3.2 Chest Radiography, 1944–1961 ... 8
  3.3.3 Chest Radiography, 1962–1970 ... 8
  3.3.4 Chest Radiography, 1971–1986 ... 8
  3.3.5 Chest Radiography, 1987–2000 ... 8

3.4 Organ Dose Calculations ... 9

3.5 Uncertainty ... 9

3.6 Attributions and Annotations ... 16

References ... 17

Glossary ... 19

LIST OF TABLES

TABLE **TITLE** **PAGE**

3-1 Frequency of screening chest X-rays at K-25 ... 6
3-2 X-ray equipment used at K-25 and incident air kerma values ... 9
3-3 Organ dose per X-ray procedure for chest X-ray examinations from 1944 to 2000 ... 11
3-4 Skin dose guidance and skin dose equivalents for chest projections, 1944 through 1970 ... 12
3-5 Skin dose guidance and skin dose equivalents for chest projections, 1971 through 2000 ... 13

ACRONYMS AND ABBREVIATIONS

CFR	Code of Federal Regulations
cGy	centigray
cm	centimeter
DCF	dose conversion factor
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ENSD	entrance skin dose
EXSD	exit skin dose
GE	General Electric
Gy	gray
HVL	half-value layer
in.	inch
IREP	Interactive RadioEpidemiology Program
kVp	peak kilovoltage
LAT	lateral
mA	milliampere
mm	millimeter
NIOSH	National Institute for Occupational Safety and Health
PA	posterior-anterior
PER	Program Evaluation Report
PFG	photofluorography
POC	probability of causation
RSD	remote skin dose
s	second
TBD	technical basis document
U.S.C.	United States Code
yr	year
§	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 sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

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 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility 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 Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) restrict the "performance of duty" referred to in 42 U S. C. § 7384n(b) to nuclear weapons work (NIOSH 2010).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (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

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1 The U.S. Department of Labor (DOL) is ultimately responsible under the EEOICPA for determining the POC.

3.1.1 Purpose

This Technical Basis Document (TBD) documents historical practices at the Oak Ridge Gaseous Diffusion Plant (K-25) and provides the basis for organ dose from medical X-ray procedures performed for occupational health screening at K-25.

3.1.2 Scope

The K-25 occupational health and safety program required preemployment, periodic physical, and termination health monitoring examinations from the beginning of its operation in 1944 (Author unknown 1946, p. 94; Author unknown 1949, p. 2). These examinations typically included chest X-rays. The doses from these procedures depended on the characteristics of the X-ray machine and the techniques used. Site-specific information about the K-25 X-ray screening program is used to the extent it is known.

3.2 EXAMINATION TYPES AND FREQUENCIES

The Carbide and Carbon Chemicals Corporation organized a medical department with a dispensary that contained X-ray equipment from the beginning of operations at K-25 in 1944 (Author unknown 1946, pp. 95-96). Before the dispensary was operational, the workers had their preemployment examinations at the Medical Services Building of the Oak Ridge Hospital (Author unknown 1946, p. 95). Nothing is known about the X-ray machine at the Oak Ridge Hospital, but the dose from preemployment chest X-rays taken at this off-site location should be included in dose reconstruction because it is a covered facility (ORAUT 2011b). Workers from the Ford, Bacon, and Davis Company and the H. K. Ferguson Company, both contractors, were also examined at the K-25 dispensary (Author unknown 1946, p. 96).

During the early years at K-25, when little was known about health effects of working with uranium, X-ray examinations were performed frequently in an effort to monitor worker health, perhaps as often as every 6 months (Kammer 1948, p. 8). Bocher (1948) writes that workers handling process material might be being X-rayed excessively. Table 3-1 lists the nominal frequency of examinations over the years during which X-rays were required as part of occupational health screening. Some workers might have received these X-rays on a schedule different from that listed in Table 3-1. Dose reconstructors should assign dose according to the X-rays performed for screening listed in the claim file records, and in the absence of records, according to the frequency listed in Table 3-1

Table 3-1. Frequency of screening chest X-rays at K-25.

Period	Frequency	Comment
1944–1945[a]	Preemployment, annual[b], and termination	All employees
1946–1959[a]	Preemployment, annual[b,c], and termination	All employees
1960–1979	Preemployment, every 1–2 yr, and termination	Radiation workers > 40 y old[d].
	Preemployment, every 2+ yr, and termination	Radiation workers < 40 years old[d].
1980–1989	Preemployment, annual, and termination	All radiation workers[e]
1990–2002	Preemployment,	All radiation workers

	every 5th yr, and termination	

a. From Author unknown (1949, p. 24).
b. Some workers semiannually, with potential for exposure to uranium dust (Kammer 1948).
c. Nickel workers every few months (Stoddard 1952).
d. Author unknown (1964, p. 6).
e. Collins (1988).

Other radiographic examinations of K-25 employees that might have occurred were nonoccupational in the sense they were necessitated by illness or injury and were not part of the employee occupational health screening process.

3.3 EQUIPMENT AND TECHNIQUES

3.3.1 Photofluorography, April, 1945–1956

X-ray service was provided in the K-25 dispensary in October 1944, and a photofluorography (PFG) machine was added in April 1945 (Author unknown 1946, p. 96). PFG had widespread use throughout the United States for tuberculosis screening in the 1930s and was state-of-the-art medical technology when work began at the K-25 plant as part of the Manhattan Project. Eventually, PFG was phased out in favor of the conventional chest X-ray examination using 14-in. × 17-in. film**.**

The PFG machine at K-25 was a General Electric (GE) Photoroentgen X-ray machine (Author unknown 1949, p. 12) that was used with a grid to produce miniature 4-in. × 5-in. stereoscopic posterior-anterior (PA) chest X-rays (Cardarelli 2000). The stereoscopic technique produces two images of the chest (on 4-in. × 10-in. film) at slightly different angles, resulting in a three-dimensional image of the chest when viewed through a stereoscope (Laughlin et al. 1957). While two references refer to PFG at K-25 on either 4-in. × 5-in. or 4-in. × 10-in. film (Cardarelli 2000, and author unknown 1949, p. 12), the K-25 claim file records indicate PFG on 70 mm film, another common film type for PFG images (Laughlin et al. 1957).

At K-25, a stereo PFG was “taken on every person hired by the companies served by the Dispensary” (Author unknown 1949, p. 12). Lyon (1949, p. 7) writes that both the preemployment and the annual examination were made on the PFG unit at K-25, with “all other chest X-rays” made on a 14-in. × 17-in. film. Prior to 1957, the exam type is often unclear in records provided by the DOE. For instance the phrase “P.A. view of the chest” is recorded frequently, but this can imply either a conventional 14-in. x 17-in. or a PFG X-ray. Recently, films located in the film jackets for several workers with employment prior to 1957 were measured. The results reveal that approximately 77% of the X-ray exams were 4-in x 10-in PFG examinations.

Dose reconstructors should assign dose based on X-rays listed in the actual records of the energy employee. PFGs are sometimes described by the notation of “70 mm”; however, in many instances the film type is not mentioned in the medical records. Consequently, prior to 1957 dose reconstructors should assume that the statement “P.A. view of the chest” represents a PFG exam. Dose reconstructors can also request that the film size be measured for accuracy. In the absence of records, the frequency listed in Table 3-1 should be assumed for PFG exams beginning April, 1945 through 1956. Unless otherwise noted, X-rays performed at the Oak Ridge Hospital should be considered conventional 14-in. x 17-in. film and the dose values obtained from ORAUT-OTIB-0006.

A survey performed on the machines at K-25 listed the technique factors for PFG as 68 kVp, 200 mA, and 3/4 s (Gupton et al. 1957, p. 22). It is assumed that this technique is for one view (i.e., not stereo) and, therefore, is doubled to determine the incident air kerma for PFG. The survey does not include half-value layer (HVL) or total filtration information, so an HVL of 2.5 mm Al at 68 kVp is assumed for dose reconstruction. All the organ doses in this TBD are based on the assumption of stereo PFG. The incident air kerma of 2.191 cGy for stereo PFG is determined from the technique factors used at K-25 (mentioned above), and the average air kerma rate from Table B-3 of NCRP Report 102 (1997), and corrected to the SSD.

There is no evidence of PFGs performed at K-25 after 1956 from a review of claim file records, which corroborates other information on K-25 (Cardarelli 2000; Cardarelli et al. 2002).

3.3.2 <u>Chest Radiography, 1944–1961</u>

A Westinghouse machine was used to produce 14-in. × 17-in. chest radiographs (Author unknown 1949, p. 12). The radiographs were used to investigate suspicious areas on PFG images, so it is possible that some employees had both PFG and conventional chest X-rays from 1944 to 1956. After 1956, only conventional PA chest radiographs were taken, which substantially reduced radiation dose per examination.

The 1957 survey (Gupton et al. 1957, p. 22) provides technique factors for conventional PA chest radiographs on 14-in. × 17-in. for the Westinghouse machine at K-25. According to the survey, PA chests were performed at 65 kVp, 200 mA, and 1/10 s. These data were used to determine the incident air kerma for conventional chest radiographs for this period, using an average air kerma rate from Table B-3 of NCRP Report 102 (1997), and corrected to the SSD, resulting in an incident air kerma of 2.79E-02 cGy. The survey does not include HVL or total filtration information, so an HVL of 2.0 mm Al at 65 kVp is assumed for dose reconstruction.

3.3.3 <u>Chest Radiography, 1962–1970</u>

A Westinghouse 300-mA machine replaced the 200-mA machine in 1962 (Cardarelli 2000; Cardarelli et al. 2002).

Information on either technique factors or beam measurements was not found for the Westinghouse machine presumably installed in 1962. Therefore, the incident air kerma comes from Cardarelli (2000) for this time period. As recommended in ORAUT-OTIB-0006, poor collimation is assumed for this period.

3.3.4 <u>Chest Radiography, 1971–1986</u>

Additional X-ray exposure was introduced in the early 1970s when the health monitoring program added a lateral (LAT) chest projection to the chest X-ray examination procedure (Cardarelli 2000). The claim file records do not always indicate the LAT chest projection, but there is a change in the notation for the mid- to late 1970s from “PA chest” to “Chest,” which presumably included two projections (PA and LAT). Dose reconstructors should assign dose from both a PA and LAT chest for this period.

The X-ray machine used in this period is presumed to be the same as that for 1962 to 1970, the Westinghouse machine. However, because no information from this machine has been found, the incident air kerma comes from Cardarelli (2000) for this time period. As recommended in ORAUT-OTIB-0006, good collimation is assumed for this period.

3.3.5 <u>Chest Radiography, 1987–2000</u>

In 1988, the Food and Drug Administration performed a survey of the Bennett general-purpose X-ray machine that had been installed “recently” at K-25 (Collins 1988). While the exact date of installation is not known, Cardarelli (2000) and Cardarelli et al. (2002) state that a new machine was installed in

1987. They mention the Bennett machine, but also mention a Westinghouse machine in several places. It is assumed that a Bennett machine was installed, not a Westinghouse machine. The significance for dose reconstruction is that the Bennett machines used high-frequency generators in their designs. However, no other specific information is available about the Bennett machine or the technique factors used, so the incident air kerma comes from Cardarelli (2000) for this time period.

Table 3-2 lists the X-ray equipment used at K-25 and the incident air kerma assumed for dose reconstruction.

Table 3-2. X-ray equipment used at K-25 and incident air kerma values.

Period	X-ray machine	kVp (kV)	Assumed HVL (mm Al)	Image size	Incident air kerma (cGy) PA chest	Incident air kerma (cGy) LAT chest
1945–1956	GE (PFG)	68	2.5	4 **in.** × 5 **in.** or 70 mm	2.191[a]	--
1944–1961	Westinghouse 200-mA	65	2.0	14 **in.** × 17 **in.**	0.0279[b]	--
1962–1970	Westinghouse 300-mA	-	2.5[c]	14 **in.** × 17 **in.**	0.0260[c]	
1971–1986	Westinghouse 300-mA	-	4.0[c]	14 **in.** × 17 **in.**	0.010[c]	0.030[c]
1987–2000	Bennett	-	4.0[c]	14 **in.** × 17 **in.**	0.022[c]	0.035[c]

a. Based on technique factors in Gupton, Tuck, Davis, and Lincoln (1957) and average kerma rates in NCRP (1997). The reported incident air kerma is for stereo PFG views.
b. Based on technique factors in Gupton, Tuck, Davis, and Lincoln (1957) and average kerma rates in NCRP (1997).
c. From Cardarelli (2000).

3.4 ORGAN DOSE CALCULATIONS

Organ doses for PFG, PA, and LAT chest X-rays were based on the method described in ORAUT-OTIB-0006 (ORAUT 2011a) and dose conversion factors in ICRP Publication 34 (1982). ICRP (1982) provides tables of average absorbed dose (in milligrays) in selected organs for selected X-ray projections at 1-Gy entrance kerma (i.e., air kerma without backscatter) for selected projections and selected beam qualities (i.e., various HVLs). These tables list the basic dose conversion factors (DCFs) for converting air kerma to organ dose. Substitute DCFs for organs that are listed in the Interactive RadioEpidemiology Program (IREP) but without unique DCFs in ICRP Publication 34 (1982) were selected as described in ORAUT-OTIB-0006 or are footnoted in the organ dose tables. Air kerma was obtained from Table 3-2.

Table 3-3 lists the organ doses for all periods. Skin doses for all skin areas were determined according to the method described in ORAUT-OTIB-0006 (ORAUT 2011a) and listed in Tables 3-4 and 3-5.

3.5 UNCERTAINTY

ORAUT-OTIB-0006 (ORAUT 2011) lists the major sources of uncertainty in X-ray output intensity and subsequent effect on dose to the worker. The five sources of uncertainty are

1. X-ray beam measurement error (±2%),
2. Variation in peak kilovoltage (±9%),
3. Variation in X-ray beam current (±5%),
4. Variation in exposure time (±25%), and
5. Variation in source-to-skin distance as a result of worker size (±10%).

The 10% uncertainty in output intensity as a result of worker size was based on an inverse square correction of output intensity changes from differences of standard chest thickness of ±7.5 cm.

These uncertainties are assumed to be random; therefore, the combined statistical uncertainty was calculated as the square root of the sum of the squares of all the uncertainties, which is ±28.9%. Rounding this up to ±30% provides 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%.

Table 3-3. Organ dose[a] per X-ray procedure for chest X-ray examinations from 1944 to 2000.

Organ	Projection	April, 1945–1956 GE; PFG (rem)	1944–1961 Westinghouse 14-in. × 17-in. (rem)	1962–1970 Westinghouse 14-in. × 17-in. (rem)[b]	1971–1986 Westinghouse 14-in. × 17-in. (rem)[b]	1987–2000 Bennett 14-in. × 17-in. (rem)[b]
Thyroid	PA	3.81E-01[c]	4.18E-03[c]	4.52E-03[c]	7.80E-04	1.72E-03
	LAT				4.92E-03	5.74E-03
Eye/brain	PA	7.01E-02[d]	5.85E-04[d]	8.32E-04[d]	7.80E-04	1.72E-03
	LAT				4.92E-03	5.74E-03
Ovaries	PA	2.19E-03[e]	3.21E-03[f]	4.37E-03	5.20E-05	1.14E-04
	LAT				7.50E-05	8.75E-05
Bladder/prostate	PA	2.19E-03[e]	3.21E-03[f]	4.37E-03	5.20E-05	1.14E-04
	LAT				7.50E-05	8.75E-05
Colon/rectum	PA	2.19E-03[e]	3.21E-03[f]	4.37E-03	5.20E-05	1.14E-04
	LAT				7.50E-05	8.75E-05
Testes	PA	2.19E-05[e]	1.59E-04[f]	2.37E-04	1.00E-07	2.20E-07
	LAT				3.00E-06	3.50E-06
Lungs (male)	PA	9.18E-01	9.34E-03	1.09E-02	6.28E-03	1.38E-02
	LAT				9.39E-03	1.10E-02
Lungs (female)	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Liver/gall bladder/spleen	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Thymus	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Esophagus	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Stomach	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Bone Surfaces	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Remainder	PA	9.88E-01	9.90E-03	1.17E-02	6.74E-03	1.48E-02
	LAT				1.05E-02	1.23E-02
Breast	PA	1.07E-01	8.92E-04	1.27E-03	1.16E-03	2.55E-03
	LAT				1.03E-02	1.20E-02
Uterus	PA	2.85E-03[e]	2.87E-03[f]	3.87E-03	5.20E-05	1.14E-04
	LAT				6.30E-05	7.35E-05
Bone marrow (male)	PA	2.02E-01	1.92E-03	2.39E-03	1.78E-03	3.92E-03
	LAT				2.28E-03	2.66E-03
Bone marrow (female)	PA	1.88E-01	1.76E-03	2.24E-03	1.72E-03	3.78E-03
	LAT				1.77E-03	2.07E-03

Organ	Projection	April, 1945–1956 GE; PFG (rem)	1944–1961 Westinghouse 14-in. × 17-in. (rem)	1962–1970 Westinghouse 14-in. × 17-in. (rem)[b]	1971–1986 Westinghouse 14-in. × 17-in. (rem)[b]	1987–2000 Bennett 14-in. × 17-in. (rem)[b]
Entrance Skin	PA	2.96E+00[g]	3.68E-02[g]	3.51E-02[g]	1.42E-02[g]	3.12E-02[g]
	LAT				4.26E-02[g]	4.97E-02[g]

a. Dose conversion factors from Tables A.2 through A.9, ICRP (1982).
b. Based on Cardarelli (2000).
c. Dose conversion factor for anterior-posterior C-spine multiplied by depth dose correction factor of 0.20 as described in ORAUT-OTIB-0006 (2011a).
d. Dose conversion factor for PA chest.
e. Dose conversion factor for PA chest. Because of short SID used in PFG, these organs are not considered to be in the primary beam.
f. Dose conversion factor for PA abdomen, since these organs are considered to be in the primary beam of a poorly collimated field.
g. Incident air kerma multiplied by a backscatter factor (NCRP 1997) of 1.32, 1.35, or 1.4 for HVLs of 2.0, 2.5, and 4.0 mm Al, respectively.

Table 3-4. Skin dose guidance and skin dose equivalents (rem) for chest projections, 1944 through 1970[a].

Area of skin	PFG April, 1945–1956		PA chest 1944–1961		PA chest 1962–1970	
	Guidance	Dose	Guidance	Dose	Guidance	Dose
Right front shoulder	EXSD	6.45E-02	EXSD	7.E-04	EXSD	8.E-04
Right back shoulder	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Left front shoulder	EXSD	6.45E-02	EXSD	7.E-04	EXSD	8.E-04
Left back shoulder	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Right upper arm to elbow	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02
Left upper arm to elbow	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02
Left hand	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Right hand	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Left elbow, forearm, wrist	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02
Right elbow, forearm, wrist	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02
Right side of head (including ear and temple)	10% ENSD	2.96E-01	10% ENSD	3.7E-03	10% ENSD	3.5E-03
Left side of head (including ear and temple)	10% ENSD	2.96E-01	10% ENSD	3.7E-03	10% ENSD	3.5E-03
Front left thigh	RSD (0.52 m)	8.E-04	RSD (0.52 m)	9.E-06	RSD (0.52m)	1.E-05
Back left thigh	RSD (0.52 m)	8.E-04	RSD (0.52 m)	9.E-06	RSD (0.52m)	1.E-05
Front right thigh	RSD (0.52 m)	8.E-04	RSD (0.52 m)	9.E-06	RSD (0.52m)	1.E-05
Back right thigh	RSD (0.52 m)	8.E-04	RSD (0.52 m)	9.E-06	RSD (0.52m)	1.E-05
Left knee and below	RSD (0.86 m)	3.E-04	RSD (0.86 m)	3.E-06	RSD (0.86m)	4.E-06
Right knee and below	RSD (0.86 m)	3.E-04	RSD (0.86 m)	3.E-06	RSD (0.86m)	4.E-06
Left side of face	Eye/brain	7.01E-02	Eye/brain	6.E-04	Eye/Brain	8.E-04
Right side of face	Eye/brain	7.01E-02	Eye/brain	6.E-04	Eye/Brain	8.E-04
Left side of neck	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02
Right side of neck	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02
Back of head	10% ENSD	2.96E-01	10% ENSD	3.7E-03	10% ENSD	3.5E-03
Front of neck	Eye/brain	7.01E-02	Eye/brain	6.E-04	Eye/Brain	8.E-04
Back of neck	10% ENSD	2.96E-01	ENSD	3.68E-02	ENSD	3.51E-02

Area of skin	PFG April, 1945–1956		PA chest 1944–1961		PA chest 1962–1970	
	Guidance	Dose	Guidance	Dose	Guidance	Dose
Front torso: base of neck to end of sternum	EXSD	6.45E-02	EXSD	7.E-04	EXSD	8.E-04
Front torso: end of sternum to lowest rib	EXSD	6.45E-02	EXSD	7.E-04	EXSD	8.E-04
Front torso: lowest rib to iliac crest	EXSD	6.45E-02	EXSD	7.E-04	EXSD	8.E-04
Front torso: iliac crest to pubis	10% EXSD	6.4E-03	10% EXSD	7.E-05	10% EXSD	8.E-05
Back torso: base of neck to mid–back	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Back torso: mid–back to lowest rib	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Back torso: lowest rib to iliac crest	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Back torso: buttocks (Iliac crest and below)	10% ENSD	2.96E-01	10% ENSD	3.7E-03	10% ENSD	3.5E-03
Right torso: base of neck to end of sternum	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Right torso: end of sternum to lowest rib	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Right torso: lowest rib to iliac crest	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Right torso: iliac crest to pubis (right hip)	10% ENSD	2.96E-01	10% ENSD	3.7E-03	10% ENSD	3.5E-03
Left torso: base of neck to end of sternum	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Left torso: end of sternum to lowest rib	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Left torso: lowest rib to iliac crest	ENSD	2.96E+00	ENSD	3.68E-02	ENSD	3.51E-02
Left torso: iliac crest to pubis (left hip)	10% ENSD	2.96E-01	10% ENSD	3.7E-03	10% ENSD	3.5E-03

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

Table 3-5. Skin dose guidance and skin dose equivalents (rem) for chest projections, 1971 through 2000[a].

Area of skin	PA chest 1971–1986		LAT chest 1971–1986		PA chest 1987–2000		LAT chest 1987–2000	
	Guidance	Dose	Guidance	Dose	Guidance	Dose	Guidance	Dose
Right front shoulder	EXSD	5.E-04	ENSD	4.26E-02	EXSD	1.1E-03	ENSD	4.97E-02
Right back shoulder	ENSD	1.42E-02	ENSD	4.26E-02	ENSD	3.12E-02	ENSD	4.97E-02
Left front shoulder	EXSD	5.E-04	EXSD	3.E-04	EXSD	1.1E-03	EXSD	4.E-04
Left back shoulder	ENSD	1.42E-02	EXSD	3.E-04	ENSD	3.12E-02	EXSD	4.E-04
Right upper arm to elbow	10% ENSD	1.4E-03	ENSD	4.26E-02	10% ENSD	3.1E-03	ENSD	4.97E-02
Left upper arm to elbow	10% ENSD	1.4E-03	EXSD	3.E-04	10% ENSD	3.1E-03	EXSD	4.E-04
Left hand	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Right hand	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Left elbow, forearm, wrist	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Right elbow, forearm, wrist	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Right side of head (including ear and temple)	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Left side of head (including ear and temple)	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Front left thigh	RSD (0.52m)	6.E-06	RSD (0.52m)	8.E-06	RSD (0.52m)	1.E-05	RSD (0.52m)	9.E-06
Back left thigh	RSD (0.52m)	6.E-06	RSD (0.52m)	8.E-06	RSD (0.52m)	1.E-05	RSD (0.52m)	9.E-06

Area of skin	PA chest 1971–1986		LAT chest 1971–1986		PA chest 1987–2000		LAT chest 1987–2000	
	Guidance	Dose	Guidance	Dose	Guidance	Dose	Guidance	Dose
Front right thigh	RSD (0.52m)	6.E-06	RSD (0.52m)	8.E-06	RSD (0.52m)	1.E-05	RSD (0.52m)	9.E-06
Back right thigh	RSD (0.52m)	6.E-06	RSD (0.52m)	8.E-06	RSD (0.52m)	1.E-05	RSD (0.52m)	9.E-06
Left knee and below	RSD (0.86m)	2.E-06	RSD (0.86m)	3.E-06	RSD (0.86m)	4.E-06	RSD (0.86m)	3.E-06
Right knee and below	RSD (0.86m)	2.E-06	RSD (0.86m)	3.E-06	RSD (0.86m)	4.E-06	RSD (0.86m)	3.E-06
Left side of face	Eye/Brain	8.E-04	10% ENSD	4.3E-03	Eye/brain	1.7E-03	10% ENSD	5.0E-03
Right side of face	Eye/Brain	8.E-04	10% ENSD	4.3E-03	Eye/brain	1.7E-03	10% ENSD	5.0E-03
Left side of neck	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Right side of neck	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Back of head	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Front of neck	Thyroid	8.E-04	10% ENSD	4.3E-03	Thyroid	1.7E-03	10% ENSD	5.0E-03
Back of neck	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Front torso: base of neck to end of sternum	EXSD	5.E-04	Lung	1.05E-02	EXSD	1.1E-03	Lung	1.23E-02
Front torso: end of sternum to lowest rib	EXSD	5.E-04	Lung	1.05E-02	EXSD	1.1E-03	Lung	1.23E-02
Front torso: lowest rib to iliac crest	10% EXSD	5.E-05	10% Lung	1.1E-03	10% EXSD	1.E-04	10% Lung	1.2E-03
Front torso: iliac crest to pubis	10% EXSD	5.E-05	10% Lung	1.1E-03	10% EXSD	1.E-04	10% Lung	1.2E-03
Back torso: base of neck to mid–back	ENSD	1.42E-02	Lung	1.05E-02	ENSD	3.12E-02	Lung	1.23E-02
Back torso: mid–back to lowest rib	ENSD	1.42E-02	Lung	1.05E-02	ENSD	3.12E-02	Lung	1.23E-02
Back torso: lowest rib to iliac crest	10% ENSD	1.4E-03	10% Lung	1.1E-03	10% ENSD	3.1E-03	10% Lung	1.2E-03
Back torso: buttocks (Iliac crest and below)	10% ENSD	1.4E-03	10% Lung	1.1E-03	10% ENSD	3.1E-03	10% Lung	1.2E-03
Right torso: base of neck to end of sternum	ENSD	1.42E-02	ENSD	4.26E-02	ENSD	3.12E-02	ENSD	4.97E-02
Right torso: end of sternum to lowest rib	ENSD	1.42E-02	ENSD	4.26E-02	ENSD	3.12E-02	ENSD	4.97E-02
Right torso: lowest rib to iliac crest	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Right torso: iliac crest to pubis (right hip)	10% ENSD	1.4E-03	10% ENSD	4.3E-03	10% ENSD	3.1E-03	10% ENSD	5.0E-03
Left torso: base of neck to end of sternum	ENSD	1.42E-02	EXSD	3.E-04	ENSD	3.12E-02	EXSD	4.E-04
Left torso: end of sternum to lowest rib	ENSD	1.42E-02	EXSD	3.E-04	ENSD	3.12E-02	EXSD	4.E-04

Area of skin	PA chest 1971–1986		LAT chest 1971–1986		PA chest 1987–2000		LAT chest 1987–2000	
	Guidance	Dose	Guidance	Dose	Guidance	Dose	Guidance	Dose
Left torso: lowest rib to iliac crest	10% ENSD	1.4E-03	10% EXSD	3.E-05	10% ENSD	3.1E-03	10% EXSD	4.E-05
Left torso: iliac crest to pubis (left hip)	10% ENSD	1.4E-03	10% EXSD	3.E-05	10% ENSD	3.1E-03	10% EXSD	4.E-05

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

3.6 ATTRIBUTIONS AND ANNOTATIONS

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

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GLOSSARY

anterior-posterior
Physical orientation of the body relative to a penetrating directional radiation such that the radiation passes through the body from the front to the back. See *exposure geometry*.

backscatter
Reflection or refraction of radiation at angles over 90 degrees from its original direction.

bremsstrahlung
Electromagnetic radiation released as a result of inelastic scattering of a moving charged particle within the nucleus of an atom. X-rays produced in a typical medical X-ray tube frequently originate from inelastic scattering of accelerated electrons in the anode material.

collimation
Restriction of the size of an X-ray beam by various types of beam limiting devices. Collimation of the X-ray beam to the size of the image receptor (typically film) is considered good practice.

dose
In general, the specific amount of energy from ionizing radiation that is absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of rads, reps, or grays.

dose conversion factor
Ratio of dose equivalent in tissue or organ to entrance kerma in air at the surface of the person being radiographed.

error
Difference between the correct, true, or conventionally accepted value and the measured or estimated value. Sometimes used to mean estimated uncertainty. See *uncertainty*.

exposure geometry
Orientation (physical positioning) of a person or object in relation to a radiation source. This geometry is a factor in the radiation dose to various parts of the body. See *anterior-posterior*, *posterior-anterior*, and *lateral* in relation to radiography.

filtration
The process of filtering an X-ray beam, usually with millimeter thicknesses of aluminum material between the X-ray source and the film that preferentially absorbs photons from the beam. Usually measured in equivalent millimeters of aluminum. See *half-value layer*.

gaseous diffusion plant
Facility where uranium hexafluoride (UF_6) gas is filtered to enrich the ^{235}U and separate it from ^{238}U. The process requires enormous amounts of electric power and results in an increase in ^{235}U enrichment from 1% to about 3%.

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 Gy equals 1 joule per kilogram or 100 rads.

grid

Device that consists of a series of thin, closely spaced lead strips that is placed between the person being X-rayed and the X-ray film to reduce interaction of scattered radiation with the film.

half-value layer (HVL)

Thickness of a specified substance, usually specified in equivalent millimeters of aluminum, that reduces the kerma rate by one-half. A measure of the X-ray beam quality. See *filtration*.

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.

kilovoltage (kVp)

The electrical potential difference in units of kilovolts between the cathode and the anode in the X-ray generating tube. See *technique*.

lateral (LAT)

Orientation of the body during an X-ray procedure in which the X-rays pass from one side of the body to the other. See *exposure geometry*.

Manhattan Engineer District (MED)

Subdivision of the U.S. Army Corps of Engineers that administered the World War II Manhattan Project to develop the first nuclear bomb. The word *Manhattan* was chosen to divert attention from the Project's real purpose. The U.S. Atomic Energy Commission assumed control of MED facilities and activities in 1946.

Manhattan Project

See *Manhattan Engineer District*.

occupational medical dose

Dose from X-ray procedures performed for medical screening of workers as part of an occupational health program. Doses from X-rays used to diagnose diseases or injuries, even if incurred on the job, are not considered occupational and are, therefore, not eligible to be included in dose reconstruction under EEOICPA.

photofluorography (PFG)

Historical radiographic technique to produce chest images for screening a large number of people in a short period of time. The X-ray image produced on a fluorescent screen was photographed on 4-inch by 5-inch film. PFG was the primary method of screening large populations for tuberculosis before the advent of nonradiographic screening methods. Also called fluorography or mass miniature radiography.

posterior-anterior (PA)

Physical orientation of the body relative to a penetrating directional radiation field such that the radiation passes through the body from the back to the front. See *exposure geometry*.

preemployment X-ray

An X-ray, usually of the chest, taken before hire or assignment to a specific job. The purpose of preemployment X-rays was to screen for active disease, such as tuberculosis.

projection

Description of the path of an X-ray beam from the X-ray tube to the image receptor. For example, posterior-anterior and lateral are two common projections in chest radiography.

radiograph

Static images produced on radiographic film by gamma rays or X-rays after passing through matter. In the context of EEOICPA, radiographs are X-ray images of the various parts of the body used to screen for disease. See *radiology*.

stereoscopic

Noting or pertaining to simulated three-dimensional viewing of photographic or radiographic images with two views of the same image taken at slightly different angles.

source-to-skin distance

Distance from the X-ray machine target (anode) to the skin of the person being radiographed. This distance varies with the size of the person being radiographed.

technique

Combination of X-ray machine settings (technique factors) used to produce radiographs, which consists of the kilovoltage, tube current (milliamperes), and exposure time (seconds). The last two parameters are often multiplied to yield the electric charge that has crossed the X-ray tube during the exposure in units of milliampere-seconds. Any combination of time and tube current that produces a given product in milliampere-seconds produces the same exposure for a fixed peak kilovoltage. Also called technic.

uncertainty

Standard deviation of the mean of a set of measurements. The standard error reduces to the standard deviation of the measurement when there is only one determination. See *error*. Also called standard error.

X-ray

(1) See *X-ray radiation*. (2) See *radiograph*.

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.