DOE Review Release 03/18/2013

Document Title:	Document Number:	ORAUT-TKBS-0016-3
Mound Site – Occupational Medical Dose	Revision:	02
	Effective Date:	03/14/2013
	Type of Document:	TBD
	Supersedes:	Revision 01 PC-3

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Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	03/14/2013

☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
05/28/2004	00	New technical basis document for the Mound Site – Occupational Medical Dose. First approved issue. Initiated by Jeffrey S. Vollmer.
09/09/2004	01	Approved Issue of Revision 01. Initiated by Jeffrey S. Vollmer.
07/08/2005	01 PC-1	Approved page change revision. Page change initiated to correct organ dose estimates in Table 3-4 on page 7, in Section 3. No retraining is required. Initiated by Elyse M. Thomas. Document Owner: Signature on File 07/05/2005 Jeffrey S. Vollmer, TBD Team Leader Signature on File 07/05/2005 Judson L. Kenoyer, Task 3, Manager Signature on File 06/29/2005 Richard E. Toohey, Project Director Signature on File 07/08/2005 James W. Neton, Associate Director for Science
03/31/2006	01 PC-2	Approved page change revision. Page change initiated to include boilerplate language in Section 3.1 on pages 5 and 6. Makes changes to Tables 3-6, 3-7 and 3-8 on pages 9 and 10 as requested by NIOSH. No sections were deleted. Training required: As determined by the Task Manager. Initiated by Paul J. Demopoulos. Signature on File 03/17/2006 Paul J. Demopoulos, TBD Team Leader John M. Byrne Signature on File for 03/17/2006 Judson L. Kenoyer, Task 3 Manager Signature on File 03/17/2006 Edward F. Maher, Task 5 Manager Signature on File 03/22/2006 Kate Kimpan, Project Director Signature on File 03/31/2006 James W. Neton, Associate Director for Science
03/02/2009	01 PC-3	Approved page change initiated to remove information pertaining to Monsanto Chemical Company, the subject of a class of employees added to the Special Exposure Cohort. In Table 3-2 on page 7 in Section 3.2, a change was made in the first row to remove “Pre” from 1949. NIOSH required language was revised on pages 5 and 6 in Section 3.1. References were updated on pages 6 - 8, 15 in Sections 3.1, 3.2, 3.3, and Reference Section. Incorporates formal internal review comments. No changes occurred as a result of formal NIOSH review. No sections were deleted. Training required: As determined by the Task Manager. Initiated by Donald N. Stewart. Signature on File 02/25/2009 Donald N. Stewart, Document Owner Signature on File for 02/26/2009 John M. Byrne, Task 3 Manager

		Signature on File 02/26/2009 Edward F. Maher, Task 5 Manager Signature on File 02/26/2009 Kate Kimpan, Project Director Signature on File 03/02/2009 James W. Neton, Associate Director for Science
03/14/2013	02	Revision initiated to update the TBD with historical documents captured since the last revision, and to add skin doses for all procedures and periods. Incorporates formal internal review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Elyse M. Thomas.

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ACRONYMS AND ABBREVIATIONS

CFR	Code of Federal Regulations
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
ENSD	entrance skin dose
ESE	entrance skin exposure
EXSD	exit skin dose
Gy	gray
HVL	half-value layer
ICRP	International Commission on Radiological Protection
kVp	peak kilovoltage
LAT	lateral
mA	milliampere
mAs	milliampere-second
mGy	milligray
mm	millimeter
mR	milliroentgen
mrem	millirem
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PFG	photofluorography
POC	probability of causation
PA	posterior-anterior
RSD	remote skin dose
s	second
SRDB Ref ID	Site Research Database Reference Identification (number)
SSD	source-to-skin distance
TBD	technical basis document
U.S.C.	United States Code
§	section or sections

3.0 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

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

3.1 PURPOSE

Medical X-ray procedures that were performed for occupational health screening are required to be considered under EEOICPA as a contributor to the occupational radiation exposure of Mound workers. In general, the dose from such exposures was not measured, considered, or included as part of the overall occupational exposure of the employee, but is required to be estimated under EEOICPA. This technical basis document (TBD) describes the technical aspects of dose reconstruction from medical X-rays administered before employment and periodically thereafter for occupational health screening and as a condition of employment.

3.2 SCOPE

Section 3.3 describes the types, frequencies, and equipment Mound used over the years for medical X-ray procedures. Section 3.4 describes the technical bases of organ doses from those procedures, and Section 3.5 discusses uncertainty. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 3.6.

3.3 EXAMINATION TYPES, FREQUENCY, AND EQUIPMENT

In the absence of individual X-ray examination data in the claim file records, dose reconstructors should assume the X-ray examination frequencies listed in Table 3-1. The following sections provide more details for the periods in Table 3-1.

Table 3-1. Frequency of chest X-rays for occupational health screening.

Period	Frequency	Comment
1947–1969[a,b]	Preemployment, annual (some semi-annual), and termination	All employees. It is uncertain which employees might have had semiannual X-rays.
1970–1979[b]	Annually	Certain employees according to job category.
	Every 2 yr	Certain employees according to job category.
1980–1987[c]	Every 6 yr	Employees under age 35.
	Every 4 yr	Employees between age 35 to 44.
	Every 2 yr	Employees age 45 and older.
	Annually	Asbestos workers.
	Annually	Any employee considered at risk in workplace (e.g., welders, etc).
1988–1997[d]	Every 6 yr	Employees under age 40.
	Every 4 yr	Employees between age 40 and 50.
	Every 2 yr	Employees age 50 and older.
	Annually	Smoker, any age.
1998–2003[e]	Every 5 yr	Employees under age 35.
	Every 4 yr	Employees between age 35 to 44.
	Every 2 yr	Employees age 45 and older.
	Annually	Smoker, any age.

a. Bradley (1948, 1949, 1950).
b. KMCN (ca. 2002, p. 1).
c. KMCN (ca. 2002, p. 4).
d. KMCN (ca. 2002, p. 7).
e. KMCN (ca. 2002, p. 87).

3.3.1 <u>Photofluorography</u>

No evidence has been found for photofluorography (PFG) at Mound, either in the collected historical documents or in the individual claim file records [1]. Therefore, dose reconstructors should not assume PFG X-rays for Mound workers.

3.3.2 Chest Radiography from 1947 to 1969

From 1947 through 1950, the X-rays of workers appear to have been taken on site at Mound, with a Picker X-ray machine in the Administration Building (Lueckerath 1948, p. 52). During this time, all workers appear to have received a preemployment posterior-anterior (PA) chest X-ray, an annual PA chest X-ray during the annual physical examination, and a termination PA chest X-ray (Bradley 1948, 1949, 1950). Some of the workers were X-rayed semiannually, although it is uncertain which workers these were. Dose reconstructors should include dose from the semiannual PA chest X-rays when they are found in the claim file records.

Not much more is known about the equipment or techniques starting in 1951. It appears that the workers continued to receive a preemployment PA chest X-ray, an annual PA chest X-ray during the annual physical examination, and a termination PA chest X-ray (KMCN ca. 2002, p. 1). The organ doses from this period come from ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (ORAUT-2011b).

3.3.3 Chest Radiography from 1970 to 1979

The frequency of the chest X-rays seems to have stayed the same during this period. Most employees probably received a preemployment, annual, and termination PA chest X-ray. It is possible that some workers were X-rayed every other year (KMCN ca. 2002, p. 1). Dose reconstructors should assume an annual frequency of PA chest X-rays unless the claim file records show that they were done every other year.

In 1973, the Mound newsletter published an article about the occupational health program with a picture of the X-ray equipment, perhaps after new equipment was purchased (Monsanto 1973, p. 9). The article mentions the preemployment chest X-rays. Survey measurements are available for 1974, on a Westinghouse machine (Moser 1974). The survey form states the total filtration in the machine is 3 mm Al equivalent, and that the exposure time is 1/20 of a second for chest X-rays (assuming PA chest X-rays). The peak kilovoltage for chests is not specified. In spite of incomplete information and some issues in interpreting the survey results, it is reasonable to assume that the incident air kerma for this period is approximately 0.013 cGy, given the measurement data of 11 mR at 183 cm, converting from exposure to air kerma at a skin entrance of 155 cm, and assuming 80 kVp for the PA chest and a half-value layer (HVL) of 2.6 mm Al (based on 3 mm Al total filtration at 80 kVp).

3.3.4 Chest Radiography from 1980 to 1987

A formal schedule of when chest X-rays would be taken as part of the physical examination process was developed during this period (Reagan 1983). As part of the new frequency schedule, new employees might not have had preemployment X-rays if an X-ray report was available for one of the last 3 years. The schedule is summarized in Table 3-1.

The Westinghouse machine might still have been in use during this period, although that is not definitively known. A Kodak technique chart that was developed specifically for Mound and dated in 1981 provides technique factors for PA and lateral (LAT) chests for this period (Kodak 1981). The PA chest technique (for a 23-cm chest) is given as 77 kVp, 10 mAs, and 106 kVp, and the LAT chest technique (for a 34-cm LAT chest) as 13.5 mAs. Using average air kerma rates from National Council on Radiological Protection and Measurements (NCRP) Report 102 (NCRP 1997), these technique factors result in an incident air kerma of 0.02 cGy for PA chest X-rays.

3.3.5 Chest Radiography from 1988 to 1997

An X-ray machine survey from 1988 shows that the X-ray equipment during this period was a Transworld machine (Weinel 1988). While some in house survey results are available for several years throughout the late 1980s and the early 1990s, no technique factors for chest X-rays are recorded. A U.S. Food and Drug Administration inspector surveyed the same Transworld machine in 1995 and 1997 (Barnett 1997). At that time, the ESEs the FDA inspector measured were 16.4 mR and 15.9 mR, respectively. The higher of the two measurements was used to determine the incident air kerma, which is 0.0144 cGy for this period.

The frequency of screening seems to have changed during this period (KMCN ca. 2002, p. 7). In comparison with the previous period, it was recommended that workers have a chest X-ray every 6 years up to age 40 (instead of age 35), every 4 years up to age 50 (instead of 45), and every 2 years age 50 and older (instead of age 45 and older). These are summarized in Table 3-1.

In 1988, a LAT chest projection was required for women with known breast augmentations; the frequency of these examinations is not known (KMCN ca. 2002, p. 2). Dose reconstructors should include dose from LAT chest projections when present in the claim file records for this period.

3.3.6 Chest Radiography from 1998 to 2003

The FDA surveyed the Transworld X-ray machine again in 2000, and measured the entrance skin exposure (ESE) as 14.9 mR (Bolen 2000). Because this is not a big change from the previous period (ESE = 15.9 mR), the organ doses for this period are the same as those for the last period.

However, the screening frequency appears to have changed again (KCMN ca. 2002, p. 87). This slightly different examination frequency is summarized in Table 3-1 along with the other frequencies over the years for different groups based on information from the Mound data files.

In the absence of claim file records, dose reconstructors should assign dose from X-rays according to the frequency in Table 3-1.

Table 3-2 summarizes the technical parameters and incident air kerma for PA and LAT chest projections.

Table 3-2. Technical factors for PA and LAT chest X-rays.

Period	Chest projection	Total filtration (mm Al)	HVL (mm Al)	Current (mA)	Voltage (kVp)	Exposure time (s)	Incident air kerma (cGy)
1947–1959[a]	PA	Unknown	Unknown	Unknown	Unknown	Unknown	0.2
1970–1979[b]	PA	3.0	2.5 (assumed)	Unknown	80 (assumed)	1/20	0.013
1980–1987[c]	PA	Unknown	2.5 (assumed)	Unknown (10 mAs)	77	Unknown (10 mAs)	0.02
1988–2003[d,e]	PA	Unknown	3.0	200	84	1/20	0.0144
	LAT	Unknown	3.0	200	110	1/20	0.036[f]

a. From ORAUT (2011b).
b. Moser (1974, p. 33–39).
c. KMCN ca. (2002, pp. 15–16).
d. Barnett (1997, p. 84).
e. See Section 3.2.6.
f. Incident air kerma equals 2.5 times the PA incident air kerma for same period (2.5 × 0.0144 cGy = 0.036 mGy).

3.4 ORGAN DOSE CALCULATIONS

Organ doses are calculated by multiplying the incident air kerma in Tables 3-2 and 3-3 by the appropriate organ dose conversion factor either from Tables A.2 to A.8 in International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982) or their substitutes from ORAUT-OTIB-0006 (2011b). The specific organ doses are shown in Tables 3-3 and 3-4 for PA and LAT chest procedures for all periods. Skin dose guidance is provided in Table 3-5, and skin doses for all areas of skin are provided in Table 3-6.

Table 3-3. Organ dose estimates (rem) for PA chest radiographs.

Organ	Organ dose 1947–1969	Organ dose 1970–1979	Organ dose 1980–1987	Organ dose 1988–1997	Organ dose 1998–2003
Thyroid	3.48E-02	4.16E-04	6.66E-04	6.62E-04	6.62E-04
Eye/brain	6.40E-03	4.16E-04	6.66E-04	6.62E-04	6.62E-04
Ovaries	2.50E-02	1.30E-05	2.08E-05	2.59E-05	2.59E-05
Urinary bladder/prostate	2.50E-02	1.30E-05	2.08E-05	2.59E-05	2.59E-05
Colon/rectum	2.50E-02	1.30E-05	2.08E-05	2.59E-05	2.59E-05
Testes	5.00E-03	1.30E-07	2.08E-07	1.44E-07	1.44E-07
Male lungs	8.38E-02	5.45E-03	8.72E-03	7.14E-03	7.14E-03
Female lungs	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Thymus	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Esophagus	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Stomach	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Bone surface	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Liver/gall bladder/spleen/pancreas	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Remainder organs	9.02E-02	5.86E-03	9.38E-03	7.70E-03	7.70E-03
Breast	9.80E-03	6.37E-04	1.02E-03	9.94E-04	9.94E-04
Uterus	2.50E-02	1.69E-05	2.70E-05	3.31E-05	3.31E-05
Male bone marrow	1.84E-02	1.20E-03	1.91E-03	1.68E-03	1.68E-03
Female bone marrow	1.72E-02	1.12E-03	1.79E-03	1.61E-03	1.61E-03
Entrance skin[a]	2.70E-01	1.76E-02	2.81E-02	2.02E-02	2.02E-02

a. Entrance skin dose was determined by multiplying the incident air kerma by backscatter factors of 1.35 and 1.4, for HVLs of 2.5 and 3.0 mm Al, respectively, from NCRP (1997, Table B-8).

Table 3-4. Organ dose estimates (rem) for LAT chest radiographs from 1988 to 2003.

Organ	Organ dose
Thyroid	4.79E-03
Eye/brain	4.79E-03
Ovaries	3.24E-05
Urinary bladder/prostate	3.24E-05
Colon/rectum	3.24E-05
Testes	3.60E-06
Male lungs	8.50E-03
Female lungs	9.61E-03
Thymus	9.61E-03
Esophagus	9.61E-03
Stomach	9.61E-03
Bone surface	9.61E-03
Liver/gall bladder/spleen/pancreas	9.61E-03
Remainder organs	9.61E-03
Breast	1.03E-02
Uterus	3.24E-05
Male bone marrow	1.73E-03
Female bone marrow	1.37E-03
Entrance skin[a]	5.04E-02

a. Entrance skin dose was determined by multiplying the incident air kerma by backscatter factor of 1.4 for HVL of 3.0 mm Al, from NCRP (1997, Table B-8).

Table 3-5. Skin dose guidance for various chest projections and periods.[a]

Area of skin	PA through 1970	LAT through 1970	PA 1971-present	LAT 1971-present
Right front shoulder	EXSD	ENSD	EXSD	ENSD
Right back shoulder	ENSD	ENSD	ENSD	ENSD
Left front shoulder	EXSD	EXSD	EXSD	EXSD
Left back shoulder	ENSD	EXSD	ENSD	EXSD
Right upper arm to elbow	ENSD	ENSD	10% ENSD	ENSD
Left upper arm to elbow	ENSD	EXSD	10% ENSD	EXSD
Left hand	ENSD	10% ENSD	10% ENSD	10% ENSD
Right hand	ENSD	10% ENSD	10% ENSD	10% ENSD
Left elbow, forearm, wrist	ENSD	10% ENSD	10% ENSD	10% ENSD
Right elbow, forearm, wrist	ENSD	10% ENSD	10% ENSD	10% ENSD
Right side of head (including ear and temple)	10% ENSD	Eye/Brain	10% ENSD	10% ENSD
Left side of head (including ear and temple)	10% ENSD	Eye/Brain	10% ENSD	10% ENSD
Front left thigh	RSD (0.52 m)	RSD (0.52m)	RSD (0.52 m)	RSD (0.52 m)
Back left thigh	RSD (0.52 m)	RSD (0.52m)	RSD (0.52 m)	RSD (0.52 m)
Front right thigh	RSD (0.52 m)	RSD (0.52m)	RSD (0.52 m)	RSD (0.52 m)
Back right thigh	RSD (0.52 m)	RSD (0.52m)	RSD (0.52 m)	RSD (0.52 m)
Left knee and below	RSD (0.86 m)	RSD (0.86m)	RSD (0.86 m)	RSD (0.86 m)
Right knee and below	RSD (0.86 m)	RSD (0.86m)	RSD (0.86 m)	RSD (0.86 m)
Left side of face	Eye/Brain	Eye/Brain	Eye/Brain	10% ENSD
Right side of face	Eye/Brain	Eye/Brain	Eye/Brain	10% ENSD
Left side of neck	ENSD	Eye/Brain	10% ENSD	10% ENSD
Right side of neck	ENSD	Eye/Brain	10% ENSD	10% ENSD
Back of head	10% ENSD	Eye/Brain	10% ENSD	10% ENSD
Front of neck	Eye/Brain	Eye/Brain	Thyroid	10% ENSD
Back of neck	ENSD	Eye/Brain	10% ENSD	10% ENSD
Front torso: base of neck to end of sternum	EXSD	Lung	EXSD	Lung

Area of skin	PA through 1970	LAT through 1970	PA 1971-present	LAT 1971-present
Front torso: end of sternum to lowest rib	EXSD	Lung	EXSD	Lung
Front torso: lowest rib to iliac crest	EXSD	Lung	10% EXSD	10% Lung
Front torso: iliac crest to pubis	10% EXSD	10% Lung	10% EXSD	10% Lung
Back torso: base of neck to mid-back	ENSD	Lung	ENSD	Lung
Back torso: mid-back to lowest rib	ENSD	Lung	ENSD	Lung
Back torso: lowest rib to iliac crest	ENSD	Lung	10% ENSD	10% Lung
Back torso: buttocks (Iliac crest and below)	10% ENSD	10% Lung	10% ENSD	10% Lung
Right torso: base of neck to end of sternum	ENSD	ENSD	ENSD	ENSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	ENSD
Right torso: lowest rib to iliac crest	ENSD	ENSD	10% ENSD	10% ENSD
Right torso: iliac crest to pubis (right hip)	10% ENSD	10% ENSD	10% ENSD	10% ENSD
Left torso: base of neck to end of sternum	ENSD	EXSD	ENSD	EXSD
Left torso: end of sternum to lowest rib	ENSD	EXSD	ENSD	EXSD
Left torso: lowest rib to iliac crest	ENSD	EXSD	10% ENSD	10% EXSD
Left torso: iliac crest to pubis (left hip)	10% ENSD	10% EXSD	10% ENSD	10% EXSD

a. ENSD = entrance skin dose; EXSD = exit skin dose; RSD = remote skin dose.

Table 3-6. Skin dose (rem) from various chest projections, 1947 to 2003.[a]

Area of skin	PA 1947–1969	PA 1970–1979	PA 1980–1987	PA 1988–2003	LAT 1988–2003
Right front shoulder	5.9E-03	4.E-04	6.E-04	5.E-04	5.04E-02
Right back shoulder	2.70E-01	1.76E-02	2.81E-02	2.02E-02	5.04E-02
Left front shoulder	5.9E-03	4.E-04	6.E-04	5.E-04	2.E-04
Left back shoulder	2.70E-01	1.76E-02	2.81E-02	2.02E-02	2.E-04
Right upper arm to elbow	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.04E-02
Left upper arm to elbow	2.70E-01	1.8E-03	2.8E-03	2.0E-03	2.E-04
Left hand	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Right hand	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Left elbow, forearm, wrist	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Right elbow, forearm, wrist	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Right side of head including ear and temple	2.70E-02	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Left side of head including ear and temple	2.70E-02	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Front left thigh	8.E-05	5.E-06	9.E-06	7.E-06	8.E-06
Back left thigh	8.E-05	5.E-06	9.E-06	7.E-06	8.E-06
Front right thigh	8.E-05	5.E-06	9.E-06	7.E-06	8.E-06
Back right thigh	8.E-05	5.E-06	9.E-06	7.E-06	8.E-06
Left knee and below	3.E-05	2.E-06	3.E-06	2.E-06	3.E-06
Right knee and below	3.E-05	2.E-06	3.E-06	2.E-06	3.E-06
Left side of face	6.4E-03	3.7E-03	7.E-04	7.E-04	5.0E-03
Right side of face	6.4E-03	3.7E-03	7.E-04	7.E-04	5.0E-03
Left side of neck	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Right side of neck	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Back of head	2.70E-02	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Front of neck	6.4E-03	3.7E-03	7.E-04	7.E-04	5.0E-03
Back of neck	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Front torso: base of neck to end of sternum	5.9E-03	4.E-04	6.E-04	5.E-04	9.6E-03
Front torso: end of sternum to lowest rib	5.9E-03	4.E-04	6.E-04	5.E-04	9.6E-03
Front torso: lowest rib to iliac crest	5.9E-03	4.E-05	6.E-05	5.E-05	1.E-03
Front torso: iliac crest to pubis	6.E-04	4.E-05	6.E-05	5.E-05	1.E-03
Back torso: base of neck to mid-back	2.70E-01	1.76E-02	2.81E-02	2.02E-02	9.6E-03
Back torso: mid-back to lowest rib	2.70E-01	1.76E-02	2.81E-02	2.02E-02	9.6E-03
Back torso: lowest rib to iliac crest	2.70E-01	1.8E-03	2.8E-03	2.0E-03	1.E-03
Back torso: buttocks (Iliac crest and below)	2.70E-02	1.8E-03	2.8E-03	2.0E-03	1.E-03
Right torso: base of neck to end of sternum	2.70E-01	1.76E-02	2.81E-02	2.02E-02	5.04E-02

Area of skin	PA 1947–1969	PA 1970–1979	PA 1980–1987	PA 1988–2003	LAT 1988–2003
Right torso: end of sternum to lowest rib	2.70E-01	1.76E-02	2.81E-02	2.02E-02	5.04E-02
Right torso: lowest rib to iliac crest	2.70E-01	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Right torso: iliac crest to pubis (right hip)	2.70E-02	1.8E-03	2.8E-03	2.0E-03	5.0E-03
Left torso: base of neck to end of sternum	2.70E-01	1.76E-02	2.81E-02	2.02E-02	2.E-04
Left torso: end of sternum to lowest rib	2.70E-01	1.76E-02	2.81E-02	2.02E-02	2.E-04
Left torso: lowest rib to iliac crest	2.70E-01	1.8E-03	2.8E-03	2.0E-03	2.E-05
Left torso: iliac crest to pubis (left hip)	2.70E-02	1.8E-03	2.8E-03	2.0E-03	2.E-05

a. Values less than 1 mrem shown to one significant digit.

3.5 UNCERTAINTY

ORAUT-OTIB-0006 (ORAUT 2011b) 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 (SSD) 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 from the 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%.

3.6 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] Thomas, Elyse. Oak Ridge Associated Universities (ORAU) Team. Principal Medical Dosimetrist. January 2013.
Reviews of claims with submitted X-ray data and historical records do not indicate any references at all to PFG having been performed for screening.

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GLOSSARY

absorbed dose
Amount of energy (ergs or joules) deposited in a substance by ionizing radiation per unit mass (grams or kilograms) of the substance and measured in units of rads or grays.

alternating electric current
Electric current that flows alternately in one direction then the other.

ampere (A)
International System unit of electrical current equal to 1 coulomb per second.

beam quality
Empirical measure of the ability of a polyenergetic X-ray beam to penetrate matter affected by the kilovoltage, anode material, voltage waveform, and filtration of an X-ray tube. The half-value layer in millimeters of aluminum is a typical measure of X-ray beam quality for the energy range used in radiography. Also called beam hardness. See *filtration*.

dose conversion factor
Multiplier for conversion of potential dose to the personal dose equivalent to the organ of interest (e.g., liver or colon). In relation to radiography, ratio of dose equivalent in tissue or organ to entrance kerma in air at the surface of the person being radiographed.

dose equivalent
In units of rem or sievert, product of absorbed dose in tissue multiplied by a weighting factor and sometimes by other modifying factors to account for the potential for a biological effect from the absorbed dose.

electric current
Amount of charge per time passing a point in a conductor in units of amperes.

exposure
(1) In general, the act of being exposed to ionizing radiation. See *acute exposure* and *chronic exposure*. (2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

film
(1) In the context of external dosimetry, radiation-sensitive photographic film in a light-tight wrapping. See *film dosimeter*. (2) X-ray film.

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 *beam quality* and *half-value layer*.

frequency
In relation to electromagnetic radiation, number of cycles per second in units of hertz.

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.

half-value layer (HVL)
Thickness of a specified substance, usually specified in equivalent millimeters of aluminum, which, when introduced in the path of a given beam of radiation, reduces the kerma rate by one-half. See *filtration*.

image
Pattern of differential absorption of X-rays in tissue formed on radiographic (X-ray) film from interaction of light from intensifying screens and the film emulsion and after photographic development.

image quality
Detail, sharpness, optical density, and contrast of the images of structural details in a radiograph.

incident air kerma
Sum of the kinetic energy of all charged particles that are liberated per unit mass of air at the point where an X-ray beam enters the skin surface (without backscatter). The unit is the gray; 1 gray equals 1 joule per kilogram.

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.

phantom
Any structure that contains one or more tissue substitutes (any material that simulates a body of tissue in its interaction with ionizing radiation) and is used to simulate radiation interactions in the human body. Phantoms are primarily used in the calibration of *in vivo* counters and dosimeters.

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- 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. Not to be confused with fluoroscopy.

rad
Traditional unit for expressing absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium. A dose of 1 rad is equivalent to the absorption of 100 ergs per gram (0.01 joules per kilogram) of absorbing tissue. The rad has been replaced by the gray in the International System of Units (100 rads = 1 gray). The word derives from radiation absorbed dose.

radiography
The process of producing images on film (or other media) with radiation.

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, sometimes 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).

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.

source-to-skin distance (SSD)

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.

volt

International System unit of potential difference and electromotive force; 1 V equals 1 joule per coulomb.