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PUBLICATION RECORD

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12/29/2004	00	Technical basis document for the Los Alamos National Laboratory – Occupational Medical Dose. Incorporates comments from internal and NIOSH reviews. First approved issue. Initiated by Jack E. Buddenbaum.
09/14/2010	01	Revised to incorporate data captured since the last revision to better document what has come to be known about PFG at LANL, and to add skin doses for all projections and periods. Added references and included Attributions and Annotations Section. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Donald N. Stewart.

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ACRONYMS AND ABBREVIATIONS

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
ERDA	Energy Research and Development Administration
EXSD	Exit Skin Dose
Gy	Gray
HVL	half value layer
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
kerma	kinetic energy released in matter
kVp	peak kilovoltage
LANL	Los Alamos National Laboratory
LAT	lateral
mA	milliampere
mGy	milligray
mm	millimeter
mrem	millirem
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
PFG	photofluorography
POC	probability of causation
RSD	Remote Skin Dose
s	second
SSD	source-to-skin distance
SRDB	Site Research Database
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 historic 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) define “performance of duty” for DOE employees with a covered cancer or restrict the “duty” to nuclear weapons work (NIOSH 2007).

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 2007):

- 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

The purpose of this TBD is to describe the occupational medical X-ray screening program and practices at Los Alamos National Laboratory (LANL). Dose reconstructors will use this information as needed to assign medical X-ray doses to workers' EEOICPA claims at LANL.

3.1.2 Scope

LANL had an occupational health program starting in 1949. The purpose of the program was to medically screen new personnel, perform termination physicals, discover disease, and periodically examine workers exposed to hazards (Hempelman 1945; Shipman 1949; Shipman et al. 1951). These medical examinations typically included chest X-rays (LANL 1947). The doses from these radiographic procedures depended not only on the characteristics of the X-ray machine and the procedures used, but also on the frequency of the examinations. This TBD describes the technical aspects of X-ray dose from screening X-rays administered before employment and periodically thereafter as a condition of employment at LANL.

3.2 EXAMINATION FREQUENCIES

Table 3-1 lists frequencies of chest X-rays through the years for specific groups of workers. Workers received preemployment and termination chest X-rays. Hempelman recommended annual chest X-rays for workers exposed to radiation and every 6 months for workers handling uranium, plutonium, polonium, and beryllium oxide (Hempelman 1944, pg. 5). Workers in the glass-blowing shop, because of their exposure to silica flour and ground glass, were also to be X-rayed every 6 months (Grier and Hardy 1949).

Table 3-1. Default frequency of occupational chest X-rays at LANL.

Period	Frequency	Workers	Chest X-ray projections
1943–1956	Preemployment	All workers.	Single-projection PFG (Shipman 1955,1958)
	Semiannual	Workers handling uranium, plutonium, polonium, and beryllium oxide, and glass blowers (Hempleman 1944; Grier and Hardy 1949)	Single-projection PFG (Shipman 1955,1958)
	Annual	Workers exposed to radiation (Hempelman 1944)	Single-projection PFG (Shipman 1955, 1958)
	Termination	All workers.	Single-projection PFG (Shipman 1955, 1958)
1957–1976	Preemployment	All workers (Shipman 1958)	PA
	Every 3 years	All workers (Shipman 1958)	PA
	Termination	All workers.	PA
1977–present	Annual	Asbestos and beryllium workers, and workers >45 years old (ERDA 1975; Voelz et al. 1981)	PA and LAT (Gutierrez and Haynie 1977, Haynie and Gutierrez 1978)
	Biennial	All workers <45 years old (ERDA 1975)	PA and LAT (Gutierrez and Haynie 1977; Haynie and Gutierrez 1978)
2002–present	Every 5 years	All workers (Antonsen 1998)	PA and LAT

Shipman states that photofluorography (PFG) was used unless factors dictated that a 14- by 17-in. film would be better (Shipman 1955, p. 23). Several historical monthly progress reports document the number of PFG and 14- by 17-in. films performed by the occupational medical service and, in almost all cases, the number of PFGs exceed the number of 14- by 17-in. films in a given period, indicating the common use of this imaging technique at LANL (Shipman 1948, 1950, 1955; Grier 1949, p. 18). It appears that both the PFG and the 14- by 17-in. chest films consisted of a single posterior-anterior

(PA) projection in the earliest period (Shipman 1948) [1]. Dose reconstructors should be able to identify the PFG examinations in the claim file records when a “film number” is recorded on the X-ray record. The film number indicates the use of roll film (rather than sheet film) commonly used in the PFG camera apparatus. PFG at LANL ended in 1956 (Shipman 1958, p. 35).

Shipman writes that the periodic examinations were done every 3 years unless conditions indicated otherwise (Shipman 1958, p. 34). Starting in about 1977, two chest projections [PA and lateral (LAT)] were being performed routinely for screening (Gutierrez and Haynie 1977; Haynie and Gutierrez 1978). No more information is available for the X-ray screening frequency after the late 1970s, although documents (e.g., LASL 1979) refer to being in compliance with Chapter 0528 of the Energy Research and Development Administration (ERDA) Contractor Occupational Medical Program manual, which required annual X-ray screening for workers more than 45 years old, and biennial X-ray screening for workers less than 45 years old (ERDA 1975). An analysis of X-ray records submitted by LANL shows that, on average, workers were X-rayed about every 2 years [2]. In 2002, when the Food and Drug Administration performed a survey of the X-ray equipment, the survey questionnaire indicated that LANL was no longer routinely performing chest X-ray screening on workers (Antonsen 1998).

A couple of historical documents mention the existence of mammography equipment (Valentine 1989, p. 95) and mammography screening (LANL 1991). Mammography screening was likely offered to employees as a convenience to them [4]. Dose from mammography is not included as part of occupational medical dose in this TBD since mammography screening is commonplace in the general population, and risk from exposure to mammography screening is assumed to be included in the risk models of IREP [5].

LANL medical records, including X-ray records, are available from LANL on special request. In the absence of X-ray records, dose reconstructors should assume the frequencies from Table 3-1. The records state if the X-ray was “routine” (i.e., screening, sometimes abbreviated “Rt”), or “special” (i.e., diagnostic – not screening). The records also provide the worker’s employer at LANL (Zia, ERDA, Atomic Energy Commission, University of California, etc.).

3.3 EQUIPMENT AND TECHNIQUES

Organ doses from occupational medical X-rays administered at LANL are presented for all the types of X-ray equipment employed over the operational period. The types of X-ray equipment used over time are listed in Table 3-2. Tables 3-3 and 3-4 list the specific technique factors reported by LANL, and measured or estimated beam qualities for the different machines.

Table 3-2. X-ray equipment used at LANL.

Technique	Period	Equipment
PFG[a]	1943–1956	Unknown, 70-mm fluororoentgenogram, single exposure. Default values from ORAUT (2005) for a single, non stereo exposure are used for this period.
Type I (a)	1943–1969	Unknown. Default values for 14- by 17–in. radiographic chest from ORAUT (2005) are used for this period.
Type I (b)	1970–1975	Unknown. Default values for 14- by 17–in. radiographic chest from ORAUT (2005) are used for this period.
Type II	1976–1984	General Electric KX810; 4-mm total filtration will be assumed for this period.
Type III	1985–1994	General Electric DXD 350II Control, Single-Phase Generator, Auto Collimator, 12:1 Grid, 3-mm Al equivalent total filtration. Kodak X-Omatic 90-s cold water processor, 400 speed film-screen system, Kodak Lanex cassettes-rare earth. Fuji Ortho G film. (Antonsen 1998; Shalkowski, Richardson, and Schlapper 1990)
Type IV[b]	1995–2002	General Electric DXD 350II Control, Single-Phase Generator, Auto Collimator, 12:1 Grid, 3-mm Al equivalent total filtration. Kodak X-Omatic 90-s cold water processor, 400 speed film-screen system, Kodak Lanex cassettes-rare earth. Fuji Ortho G film.

		(Antonsen 1998)
Type V	2003–present	Quantum Medical Imaging Cosmos 22 Control, High Frequency Generator, Varian X-ray tube, Heustis medical collimator. 2.5-mm Al equivalent total filtration. CXDI22 Canon sensor-digital camera. (Velarde 2009)

a. PFG = Photofluorography
b. Type IV equipment same as Type III, different technique factors used.

Table 3-3. Technique factors used for each type of X-ray equipment[a].

Machine	Projection	Current (mA)	Voltage (kVp)	Exposure time(s)
Type I(a) 1943–1969	Unknown	Unknown	Unknown	Unknown
Type I(b) 1970–1975	Unknown	Unknown	Unknown	Unknown
Type II 1976–1984[b]	PA chest	300	90	1/30
Type III 1985–1994[c]	PA chest	200	102	1/30
Type IV 1995–2002[d]	PA chest	200	114	1/60
Type V 2003	PA chest	200	104	1/30

a. PA indicates a posterior/anterior projection; the average PA chest measures 24 cm, the average lateral chest measures 36 cm.
b. Gutierrez and Haynie (1976).
c. Shalkowski, Richardson, and Schlapper (1990).
d. Antonsen (1998).

Table 3-4. Beam quality (HVL) values used to determine dose conversion factors (DCFs) for dose calculations.

Machine type	Dates of use	Total filtration [Al equiv., mm] (reported or estimated)	HVL, based on filtration and kVp (NCRP 1989)	HVL used for DCF selection (ICRP 1982)
PFG	1943–1956	Unknown (2.5 mm[a])	2.5 mm	2.5 mm
Type I(a)	1943–1969	Unknown (2.5 mm[a])	2.5 mm	2.5 mm
Type I (b)	1970–1975	Unknown (2.5 mm[a])	2.5 mm	2.5 mm
Type II	1976–1984[b]	3.75 mm	3.3 mm at 90 kVp	3.5 mm
Type III	1985–1994[c]	3.5 mm	3.4 mm at 100 kVp	3.5 mm
Type IV	1995–2002[d]	3.5 mm	3.7 mm at 110 kVp	4.0 mm
Type V	2003–present	2.5 mm	3.4 mm	3.5 mm

a. Based on ORAUT (2005).
b. Gutierrez and Haynie (1976).
c. Shalkowski, Richardson, and Schlapper (1990).
d. Antonsen (1998).

As mentioned above, PFG was performed from 1943 to 1956 (Shipman 1955, 1958). During this time, chest X-rays were also performed on 14- by 17-in. film (Shipman 1954), but nothing is known about this equipment, other than it was probably in the hospital (Shipman 1952). The first mention of a specific brand and model of X-ray equipment is in Gutierrez and Haynie (1976). The General Electric X-ray machine is mentioned, along with the technical information collected during a survey of that machine in the new occupational medical building. Even though Gutierrez and Haynie shows a possible total filtration of 6.75-mm Al equivalent resulting from the summation of the individual component filtration equivalents, it seems doubtful that this much filtration was actually used for the following reasons [3]:

1. To obtain the possible total of 6.75-mm Al eq., the equivalent filtration of the collimator and the removable filters were added together. Removable filters (placed in a slot) were usually used with a cone-type beam limiting device because such a device did not have any inherent filtration. However, an adjustable collimator does have some inherent filtration. Apparently, an adjustable light-localizing collimator was added to this machine (Guitierrez and Haynie 1976), making removable filters unnecessary. When the thickness of the removable filters is

left out of the summation, the total is about 3.75-mm Al eq., which is a much more believable amount.

2. It is extremely doubtful that a radiologist would have accepted radiographs produced with 6.75-mm Al filtration. With that much filtration, there would have been little differential absorption in tissue and little contrast in the image.

For these reasons, the total filtration for this period is assumed to be 3.75-mm Al eq., resulting in a half value layer (HVL) of 3.3-mm Al at 90 kVp.

Another General Electric machine, the GE DXD 350ll, was installed in 1985 and used until approximately 2003 (Antonsen 1998). In 2003, a Quantum Medical Imaging Odyssey X-ray machine was installed (Velarde 2009).

3.4 ORGAN DOSES

This section presents X-ray organ doses for occupational X-rays administered at LANL for all types of equipment and all periods.

Dose values for PFG at LANL are based on the default values for PFG in *Dose Reconstruction from Occupationally Related X-Ray Procedures* (ORAUT 2005), except the doses are calculated for a single-exposure PFG (not stereo exposures) and reproduced in Table 3-5. Dose reconstructors should be able to identify the PFG examinations in the claim file records when the examination occurred between 1943 and 1956, and when a “film number” is recorded, indicating the use of roll rather than sheet film. Dose reconstructors should assume a two-exposure stereo PFG only when the words “serial 1 and 2” appear on the record or radiologist’s interpretation.

Dose values for conventional 14- by 17-in. chest radiography for LANL from 1943 to 1975 are also based on the default values for chest radiography in *Dose Reconstruction from Occupationally Related X-Ray Procedures* (ORAUT 2005).

Dose values for the remaining periods are calculated using average air kerma rates from Table B.3 of National Council on Radiation Protection and Measurements (NCRP) Report 102 (NCRP 1989). The data in Table B.3 were corrected to a source-to-skin distance (SSD) of 154 cm, and for the actual voltage, current, and phase of the machines used at LANL for the various periods. For both PA and LAT chest projections, a standard source-to-image distance of 72 in. (183 cm) was assumed for all periods. Entrance air kerma in air from the LAT chest projection is estimated at 2.5 times more than the PA entrance kerma (ORAUT 2005). It is assumed that all the X-ray machines were single-phase except the high-frequency Type V unit. International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982) contains tables of average absorbed dose (mGy) in selected organs for selected X-ray projections at 1-Gy entrance kerma (i.e., air kerma without backscatter) and selected beam qualities (i.e., various HVLs). The organ doses are found by multiplying the ICRP organ DCFs by the entrance air kerma in air. The resulting organ doses for all machines and periods are listed in Table 3-5.

Skin doses were calculated using the method described in ORAUT-OTIB-0006 (ORAUT-2005). Table 3-6 lists the skin dose guidance for various areas of skin for various projections. Table 3-7 lists skin doses from all machines and periods calculated according to the guidance.

Doses were generally determined by analogy with anatomical location for organs not listed in ICRP Publication 34 (ICRP 1982) but specified in the Interactive RadioEpidemiological Program (IREP) computer program, according to the guidance in ORAUT-OTIB-0006 (ORAUT 2005).

3.5 UNCERTAINTY

ORAUT-OTIB-0006 (ORAUT 2005) 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 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

Table 3-5. Organ dose equivalents (rem) for chest projections for all periods.

Organ	Projection	PFG 1943–1956[a]	1943–1969[b]	1970–1975[b]	1976–1984	1985–1994	1995–2002	2003–present
Thyroid	PA	2.61E-01	3.48E-02	3.20E-03	1.55E-03	1.30E-03	9.05E-04	2.17E-03
	LAT	---	---	---	9.44E-03	7.93E-03	4.76E-03	1.32E-02
Eye/brain	PA	4.80E-02	6.40E-03	3.20E-03	1.55E-03	1.30E-03	9.05E-04	2.17E-03
	LAT	---	---	---	9.44E-03	7.93E-03	4.76E-03	1.32E-02
Ovaries	PA	1.25E-02	2.50E-02	1.00E-04	8.00E-05	6.72E-05	6.03E-05	1.12E-04
	LAT	---	---	---	1.00E-04	8.40E-05	7.25E-05	1.40E-04
Urinary/bladder	PA	1.25E-02	2.50E-02	1.00E-04	8.00E-05	6.72E-05	6.03E-05	1.12E-04
	LAT	---	---	---	1.00E-04	8.40E-05	7.25E-05	1.40E-04
Colon/rectum	PA	1.25E-02	2.50E-02	1.00E-04	8.00E-05	6.72E-05	6.03E-05	1.12E-04
	LAT	---	---	---	1.00E-04	8.40E-05	7.25E-05	1.40E-04
Testes	PA	2.50E-03	5.00E-03	1.00E-06	2.50E-07	2.10E-07	1.16E-07	3.50E-07
	LAT	---	---	---	6.25E-06	5.25E-06	2.90E-06	8.75E-06
Lungs (male)	PA	6.29E-01	8.38E-02	4.19E-02	1.41E-02	1.19E-02	7.28E-03	1.98E-02
	LAT	---	---	---	1.73E-02	1.45E-02	9.08E-03	2.42E-02
Lungs (female)	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Thymus	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Esophagus	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Stomach	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Bone surface	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Liver/gall bladder/ spleen	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Remainder organs	PA	6.77E-01	9.02E-02	4.51E-02	1.53E-02	1.28E-02	7.82E-03	2.14E-02
	LAT	---	---	---	1.94E-02	1.63E-02	1.02E-02	2.71E-02
Breast	PA	7.35E-02	9.80E-03	4.90E-03	2.28E-03	1.91E-03	1.35E-03	3.19E-03
	LAT	---	---	---	1.98E-02	1.66E-02	9.95E-03	2.77E-02
Uterus	PA	1.25E-02	2.50E-02	1.30E-04	7.50E-05	6.30E-05	6.03E-05	1.05E-04
	LAT	---	---	---	8.75E-05	7.35E-05	6.09E-05	1.23E-04

Organ	Projection	PFG 1943–1956[a]	1943–1969[b]	1970–1975[b]	1976–1984	1985–1994	1995–2002	2003–present
Bone marrow (male)	PA	1.38E-01	1.84E-02	9.20E-03	3.65E-03	3.07E-03	2.06E-03	5.11E-03
	LAT	---	---	---	3.81E-03	3.20E-03	2.20E-03	5.34E-03
Bone marrow (female)	PA	1.29E-01	1.72E-02	8.60E-03	3.53E-03	2.96E-03	2.00E-03	4.94E-03
	LAT	---	---	---	3.00E-03	2.52E-03	1.71E-03	4.20E-03
Entrance skin[c]	PA	2.03E+00	2.70E-01	1.35E-01	3.50E-02	2.94E-02	1.62E-02	4.90E-02
	LAT	---	---	---	8.75E-02	7.35E-02	4.06E-02	1.23E-01

a. Doses for PFG are from ORAUT-OTIB-0006 (ORAUT 2005), but are halved because LANL did not typically perform stereo PFG.
b. Doses before 1976 are based on values in ORAUT-OTIB-0006 (ORAUT 2005).
c. Entrance skin dose is determined by multiplying the entrance air kerma in air by the backscatter factors of 1.35 and 1.40 for HVL of 2.5-mm Al and 3.0 or 4.0-mm Al, respectively, from NCRP Report 102 (NRCP 1989, Table B-8). Skin doses for all areas of skin are provided in Table 3-7.

Table 3-6. Skin dose guidance for various chest projections and periods.

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

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

Table 3-7. Skin dose (rem) from various chest projections, 1943–present.[a]

Area of skin	PFG 1943–1956	PA 1943–1969	PA 1970–1975	PA 1976–1984	LAT 1976–1984	PA 1985–1994	LAT 1985–1994	PA 1995–2002	LAT 1995–2002	PA 2003–present	LAT 2003–present
Right front shoulder	4.42E-02	5.9E-03	2.9E-03	1.0E-03	8.75E-02	9.E-04	7.35E-02	5.E-04	4.06E-02	1.4E-03	1.23E-01
Right back shoulder	2.03E+00	2.70E-01	1.35E-01	3.50E-02	8.75E-02	2.94E-02	7.35E-02	1.62E-02	4.06E-02	4.90E-02	1.23E-01
Left front shoulder	4.42E-02	5.9E-03	2.9E-03	1.0E-03	5.E-04	9.E-04	5.E-04	5.E-04	3.E-04	1.4E-03	8.E-04
Left back shoulder	2.03E+00	2.70E-01	1.35E-01	3.50E-02	5.E-04	2.94E-02	5.E-04	1.62E-02	3.E-04	4.90E-02	8.E-04
Right upper arm to elbow	2.03E-01	2.70E-01	1.35E-02	3.50E-03	8.75E-02	2.9E-03	7.35E-02	1.6E-03	4.06E-02	4.9E-03	1.23E-01
Left upper arm to elbow	2.03E-01	2.70E-01	1.35E-02	3.50E-03	5.E-04	2.9E-03	5.E-04	1.6E-03	3.E-04	4.9E-03	8.E-04
Left hand	2.03E+00	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Right hand	2.03E+00	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Left elbow, forearm, wrist	2.03E-01	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Right elbow, forearm, wrist	2.03E-01	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Right side of head including ear and temple	2.03E-01	2.70E-02	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Left side of head including ear and temple	2.03E-01	2.70E-02	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Front left thigh	6.E-04	8.E-05	4.E-05	1.E-05	2.E-05	1.E-05	1.E-05	6.E-06	9.E-06	2.E-05	2.E-05
Back left thigh	6.E-04	8.E-05	4.E-05	1.E-05	2.E-05	1.E-05	1.E-05	6.E-06	9.E-06	2.E-05	2.E-05
Front right thigh	6.E-04	8.E-05	4.E-05	1.E-05	2.E-05	1.E-05	1.E-05	6.E-06	9.E-06	2.E-05	2.E-05
Back right thigh	6.E-04	8.E-05	4.E-05	1.E-05	2.E-05	1.E-05	1.E-05	6.E-06	9.E-06	2.E-05	2.E-05

Area of skin	PFG 1943–1956	PA 1943–1969	PA 1970–1975	PA 1976–1984	LAT 1976–1984	PA 1985–1994	LAT 1985–1994	PA 1995–2002	LAT 1995–2002	PA 2003–present	LAT 2003–present
Left knee and below	2.E-04	3.E-05	1.E-05	5.E-06	6.E-06	4.E-06	5.E-06	2.E-06	3.E-06	6.E-06	9.E-06
Right knee and below	2.E-04	3.E-05	1.E-05	5.E-06	6.E-06	4.E-06	5.E-06	2.E-06	3.E-06	6.E-06	9.E-06
Left side of face	4.80E-02	6.4E-03	3.2E-03	1.6E-03	8.75E-03	1.3E-03	7.4E-03	9.E-04	4.1E-03	2.2E-03	1.23E-02
Right side of face	4.80E-02	6.4E-03	3.2E-03	1.6E-03	8.75E-03	1.3E-03	7.4E-03	9.E-04	4.1E-03	2.2E-03	1.23E-02
Left side of neck	2.03E-01	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Right side of neck	2.03E-01	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Back of head	2.03E-01	2.70E-02	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Front of neck	4.80E-02	6.4E-03	3.2E-03	1.6E-03	8.75E-03	1.3E-03	7.4E-03	9.E-04	4.1E-03	2.2E-03	1.23E-02
Back of neck	2.03E-01	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Front torso: base of neck to end of sternum	4.42E-02	5.9E-03	2.9E-03	1.0E-03	1.94E-02	9.E-04	1.63E-02	5.E-04	1.02E-02	1.4E-03	2.71E-02
Front torso: end of sternum to lowest rib	4.42E-02	5.9E-03	2.9E-03	1.0E-03	1.94E-02	9.E-04	1.63E-02	5.E-04	1.02E-02	1.4E-03	2.71E-02
Front torso: lowest rib to iliac crest	4.42E-02	5.9E-03	3.E-04	1.0E-04	1.94E-03	9.E-05	1.6E-03	5.E-05	1.0E-03	1.4E-04	2.7E-03
Front torso: iliac crest to pubis	4.4E-03	6.E-04	3.E-04	1.0E-04	1.94E-03	9.E-05	1.6E-03	5.E-05	1.0E-03	1.4E-04	2.7E-03
Back torso: base of neck to mid-back	2.03E+00	2.70E-01	1.35E-01	3.50E-02	1.94E-02	2.94E-02	1.63E-02	1.62E-02	1.02E-02	4.90E-02	2.71E-02
Back torso: mid-back to lowest rib	2.03E+00	2.70E-01	1.35E-01	3.50E-02	1.94E-02	2.94E-02	1.63E-02	1.62E-02	1.02E-02	4.90E-02	2.71E-02
Back torso: lowest rib to iliac crest	2.03E+00	2.70E-01	1.35E-02	3.50E-03	1.94E-03	2.9E-03	1.6E-03	1.6E-03	1.0E-03	4.9E-03	2.7E-03
Back torso: buttocks (Iliac crest and below)	2.03E-01	2.70E-02	1.35E-02	3.50E-03	1.94E-03	2.9E-03	1.6E-03	1.6E-03	1.0E-03	4.9E-03	2.7E-03
Right torso: base of neck to end of sternum	2.03E+00	2.70E-01	1.35E-01	3.50E-02	8.75E-02	2.94E-02	7.35E-02	1.62E-02	4.06E-02	4.90E-02	1.23E-01
Right torso: end of sternum to lowest rib	2.03E+00	2.70E-01	1.35E-01	3.50E-02	8.75E-02	2.94E-02	7.35E-02	1.62E-02	4.06E-02	4.90E-02	1.23E-01
Right torso: lowest rib to iliac crest	2.03E+00	2.70E-01	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Right torso: iliac crest to pubis (right hip)	2.03E-01	2.70E-02	1.35E-02	3.50E-03	8.75E-03	2.9E-03	7.4E-03	1.6E-03	4.1E-03	4.9E-03	1.23E-02
Left torso: base of neck to end of sternum	2.03E+00	2.70E-01	1.35E-01	3.50E-02	5.E-04	2.94E-02	5.E-04	1.62E-02	3.E-04	4.90E-02	8.E-04

Area of skin	PFG 1943–1956	PA 1943–1969	PA 1970–1975	PA 1976–1984	LAT 1976–1984	PA 1985–1994	LAT 1985–1994	PA 1995–2002	LAT 1995–2002	PA 2003–present	LAT 2003–present
Left torso: end of sternum to lowest rib	2.03E+00	2.70E-01	1.35E-01	3.50E-02	5.E-04	2.94E-02	5.E-04	1.62E-02	3.E-04	4.90E-02	8.E-04
Left torso: lowest rib to iliac crest	2.03E+00	2.70E-01	1.35E-02	3.50E-03	5.E-05	2.9E-03	5.E-05	1.6E-03	3.E-05	4.9E-03	8.E-05
Left torso: iliac crest to pubis (left hip)	2.03E-01	2.70E-02	1.35E-02	3.50E-03	5.E-05	2.9E-03	5.E-05	1.6E-03	3.E-05	4.9E-03	8.E-05

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

square correction of output intensity changes resulting from differences of standard chest thickness of ±7.5 cm.

Information on worker thickness is rarely available, even in the medical literature. However, at the Savannah River Site, entrance skin dose measurements were made on nine workers of varying chest thicknesses (builds) (Cooley 1967). While Cooley did not report the measured chest thicknesses for these nine workers, the entrance skin doses were reported and reflect the increases in exposure needed to radiograph thicker body parts, in this case chests. Cooley reported the mean of the measured entrance skin doses as 27 mrem. The standard uncertainty of the range of measurements is 5.6, resulting in an uncertainty of 21% from this source.

Substituting this value into the calculation for combined uncertainty described in ORAUT-OTIB-0006 (ORAUT 2005) rather than the 10% value used in that document, the resultant standard uncertainty is 34% from these five sources. Rounding this up to 35% would seem to provide an adequate and suitably conservative indication of uncertainty.

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 M. ORAU Team. Principal Medical Dosimetrist. June 2010.
Review of claims with submitted X-ray data show only one film number listed for PFG in most cases, and a single PA projection for the 14- by 17-in. chest films.

[2] Thomas, Elyse M. ORAU Team. Principal Medical Dosimetrist. June 2010.
Reviews of claims with submitted X-ray data show frequency of X-rays to be about every 2 years.

[3] Thomas, Elyse M. ORAU Team. Principal Medical Dosimetrist. June 2010.
The removable filtration placed in a slot was usually used with a cone-type beam limiting device, not with adjustable collimators. Apparently, this machine was modified with the addition of a light-localizing collimator. The removable filters were most likely removed when the adjustable collimator was added, leaving a total filtration of about 3.75-mm Al eq., a much more reasonable amount. It is extremely doubtful that a radiologist would have accepted reading very-low-contrast images that would have resulted from the use of such a heavily filtered beam as 6.75-mm Al eq.

[4] Thomas, Elyse M. ORAU Team. Principal Medical Dosimetrist. June 2010.
Mammography would not have been used to screen for occupational disease. It is not uncommon for mammography screening to be offered to women employees at the workplace, as a convenience to them, and to encourage them to be screened.

[5] Thomas, Elyse M. ORAU Team. Principal Medical Dosimetrist. June 2010.
The IREP risk models include risk from x-ray exams in the general population, and therefore it is assumed that the risk from mammography, as a screening technique used in the general population, is included in IREP.

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