DOE Review Release 04/22/2013

Document Title:	Document Number:	ORAUT-TKBS-0015-3
Portsmouth Gaseous Diffusion Plant – Occupational Medical Dose	Revision:	03
	Effective Date:	04/08/2013
	Type of Document:	TBD
	Supersedes:	Revision 02

Subject Expert(s): Elizabeth K. Algutifan and Elyse M. Thomas

Approval:	Signature on File Elizabeth K. Algutifan, Document Owner	Approval Date:	04/05/2013
Concurrence:	Signature on File John M. Byrne, Objective 1 Manager	Concurrence Date:	04/04/2013
Concurrence:	Signature on File Edward F. Maher, Objective 3 Manager	Concurrence Date:	04/04/2013
Concurrence:	Vickie S. Short Signature on File for Kate Kimpan, Project Director	Concurrence Date:	04/04/2013
Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	04/08/2013

☐ 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
01/05/2004	00	New technical basis document for the Portsmouth Gaseous Diffusion Plant – Occupational Medical Dose. First approved issue. Initiated by Mark Notich.
07/19/2004	01	Incorporates comments from internal and NIOSH formal reviews. Approved Issue of Revision 01. Initiated by Mark Notich.
07/07/2006	02	Deletes the uterus as an analogue/surrogate organ in Table 3-10 on page 16 in Section 3.4.5 as per Task 5 comment. Updates required introductory language on pages 6 and 7 in Section 3.1. Revised to change from a page change (Rev 01 PC-1-B) to a revision (Rev 02-A) as a result of NIOSH comment. Added a Purpose and Scope subsection to the Introduction (Section 3.1). Approved issue of Revision 02. This revision results in a reduction in assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Paul J. Demopoulos.
04/08/2013	03	This site profile was predominantly revised to address Sanford Cohen & Associates concerns about the document as identified in SC&A-TR-TASK1-0020, *Review of the NIOSH Site Profile for the Portsmouth Gaseous Diffusion Plant* (see Section 3.3.1). Added skin doses for all applicable projections and exposure periods. Updated information to conform with revised ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures*. Updated references and added Attributions and Annotations section. Revised information on exposure periods based on recent issuance of ORAUT-OTIB-0079, *Guidance on Assigning Occupational X-Ray Dose Under EEOICPA for X-Rays Administered Off Site. U*pdated pre-1982 X-ray doses, added lumbar spine doses, and added new period for 2010 – present based on new information. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Elizabeth K. Algutifan.

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AP	anterior-posterior
CFR	Code of Federal Regulations
cm	centimeter
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 Company
HVL	half-value layer
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
kVp	peak kilovoltage
LAT	lateral
m	meter
mA	milliampere
mm	millimeter
mR	milliroentgen
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
PA	posterior-anterior
PER	Program Evaluation Report
PFG	photofluorography
POC	probability of causation
PORTS	Portsmouth Gaseous Diffusion Plant
RSD	remote skin dose
SSD	source-to-skin distance
TBD	technical basis document
U.S.C.	United States Code
§	section or sections

3.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular 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.

3.1.1 Purpose

The purpose of this technical basis document (TBD) is to describe the occupational medical X-ray screening program and practices at the Portsmouth Gaseous Diffusion Plant (PORTS). This document discusses historical and current practices for the evaluation of dose from medical X-ray screening procedures for PORTS workers. Dose reconstructors will use this information as needed to assign medical X-ray doses to workers' EEOICPA claims at PORTS.

3.1.2 Scope

PORTS required preemployment, periodic, and termination physical examinations as part of its occupational health and safety program (Ely et al. 1957). These medical examinations typically included chest X-rays and, for some workers, preemployment lumbar spine X-rays. The doses from these X-ray procedures depended not only on the characteristics of the X-ray machine and the techniques used, but also on the frequency of the examinations. Other types of examinations, such as knee or ankle X-rays, were given for on-the-job injuries or at the discretion of the medical director. X-ray examinations other than posterior-anterior (PA) chest and AP and LAT lumbar spine X-rays do not appear to have been performed for occupational health screening and are, therefore, not eligible to be included in dose reconstruction under EEOICPA.

This TBD contains supporting evidence for the evaluation of occupational X-ray dose from medical screening of workers at PORTS.

3.2 EXAMINATION FREQUENCIES

The PORTS medical records include notations in individual worker files regarding the date and purpose of the X-ray examinations, and are assumed to be complete. Almost all of the X-rays in the claim file records are PA chests, but a subset of workers received preemployment lumbar spine X-rays.

Review of the available historical documentation pertaining to the occupational medical program at PORTS and in the claim file records from 1954 to the present revealed that the PA chest on 14-in. × 17-in. film was the most common screening procedure in connection with preemployment, periodic, or termination medical examinations, but that some workers received a PFG chest, or preemployment anterior-posterior (AP) and lateral (LAT) lumbar spine X-ray. Any other radiographic examinations of PORTS employees that might have occurred were necessitated by illness or injury and, therefore, were not part of the screening process.

Dose reconstructors should assign dose from chest (including PFG) and lumbar spine X-rays according to the recorded frequency in the provided medical records in each worker's claim file. Dose reconstructors can use the default frequency to assign X-ray dose if individual worker records were not submitted by the site for a particular worker. Table 3-1 lists the default frequency of chest X-rays for different age groups through the years and identifies specific groups of workers. Typically, one PA chest projection was taken.

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

Period	Exam	Frequency	Comment
1954–1987	PA Chest (14 in. by 17 in.)	Preemployment/termination, annual periodic[a]	All workers.
	PFG (1954-1957)	Annually	All workers.
1988–1997	PA Chest (14 in. by 17 in.)	Preemployment/termination[b]	All workers.
		Annually[b]	Be workers and asbestos workers > 35 years old.
		Every 5 years[b]	Asbestos workers.
1998–present	PA Chest (14 in. by 17 in.)	Preemployment/termination[c]	All workers, except pregnant women.
		Every 5 years, or annually if >35 years old	Asbestos workers.
		Every 10 years if <30 years old.	All workers except asbestos workers.
		Every 5 years if 30–45 years old.	All workers except asbestos workers.
		Every 3 years if >45 years old.	All workers except asbestos workers.

a. From a review of claim file records.
b. Conrad (1988).
c. Barch and Noel (1998, p. 6).

3.3 EQUIPMENT AND TECHNIQUES

3.3.1 Chest Photofluorography

Chest photofluorography (PFG) was used sporadically until as late as the early 1960s. PFG used a smaller film (for example 4-in. × 5-in.), a smaller source-to-skin distance (SSD) (42 in.), and a higher peak kilovoltage (kVp) and a greater exposure than conventional chest radiography on 14-in. × 17-in. film. Exposure was regulated by photometers, which used the exposure to the film to determine the time of exposure.

Evidence of PFG is found in several claim file records for PORTS workers, although no historical information about a PFG machine at PORTS has been found in captured records. They appear in the claim file records from 1954 to 1957. All records indicate stereoscopic PFG performed on 4-in. × 10-in. film. Because the PFG machine could have been in a mobile van that stopped at the PORTS facility, the PFG should be assumed to have been performed on the PORTS site.

Because no historical information has been located for the PFG machine used to radiograph PORTS workers, the organ doses for PFG come from ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-ray Procedures* (ORAUT 2011). These are reproduced in Attachment A, Tables A-1 and A-2.

3.3.2 Chest Radiography 1954 Through 1981

There was a dispensary building at PORTS from the beginning of operations, and it appears to have contained an X-ray room (Wingfoot 1954; ORAUT 2012). However, no more specific information about the type of X-ray equipment or technique factors has been found for this period. Therefore, the organ doses for this period are based on the information in ORAUT-OTIB-0006 (ORAU 2011). Since ORAUT-OTIB-0006 assumes poor collimation before 1970, the same assumption is made for PORTS, and the organ doses reported here reflect that assumption.

3.3.3 Chest Radiography 1982 Through 1991

There is evidence that a General Electric (GE) KXE 225 machine was installed at PORTS in 1982 (Author unknown 1985, p. 29). In 1984, measurements were made on this machine, which indicate a half-value layer (HVL) of 2.4 mm Al at 60 kVp, and a measured entrance skin exposure (ESE) of 10 mR for a PA chest (Bassett 1984).

While actual techniques are not known for this period, organ doses were derived assuming an HVL of 3.5 mm Al, because chest X-rays would have been performed at a higher kVp than that at which the HVL was measured. The 10-mR ESE was converted to incident air kerma according to equation (1) in ORAUT-OTIB-0006 (ORAU 2011) for the organ dose calculations. Organ doses are listed in Attachment A, Tables A-1 and A-2.

A procedure manual for the medical X-ray quality assurance tests by Bassett (1985) describes the tests that were presumably performed during this period.

3.3.4 Chest Radiography 1992 Through 2009

A survey was made on GE equipment by Food and Drug Administration personnel in 1992 (Bolen 1992). It is not clear if this is the same GE equipment that was installed in 1982. At that time, the technique for PA chest X-rays was reported as 110 kVp, 320 mA, and 0.083 second. The ESE was measured by Bolen with a 23-cm chest phantom, with a resultant ESE of 17 mR at 110 to 120 kVp (Bolen 1992). The 17-mR ESE was converted to incident air kerma according to equation (1) in ORAUT-OTIB-0006 (ORAU 2011) for the organ dose calculations.

In 1994, measurements were made on the X-ray machine, which indicate an HVL of 3.3 mm Al at 80 kVp (Author unknown 1994). The HVL for dose reconstruction is assumed to be 4.0 mm Al (NCRP 1997) at the 110 to 120 kVp reportedly used for chest radiography (Bolen 1992). Organ doses based on these measurements are listed in Tables A-1 and A-2.

3.3.5 Chest Radiography 2010 Through the Present

In approximately 2010, a Toshiba high frequency X-ray machine was installed at PORTS (ORAUT 2012). This machine uses anatomical selectors on the control panel and, therefore, traditional technique factors might not be available until measurements are made and documented on this machine. Therefore, the doses from this period are based on those in ORAUT-OTIB-0006 (ORAU 2011).

A summary description of the X-ray equipment used at PORTS is included in Table 3-2.

Table 3-2. Description of the X-ray equipment used at PORTS.

Technique	Period	Equipment
PFG	1954–1957	No specific information available
Conventional 14-in. × 17-in. chest X-rays	1954–1981	No specific information available
Conventional 14-in. × 17-in. chest X-rays	1982–1991	GE KXE 225
Conventional 14-in. × 17-in. chest X-rays	1992–2009	GE equipment
Conventional 14-in. × 17-in. chest X-rays	2010–present	Toshiba equipment

3.3.6 Lumbar Spine Radiography 1970-1975 (approximate)

As mentioned above, most of the X-rays of workers during this period were PA chests, but a subset of workers received an AP and LAT lumbar spine X-ray as preemployment screening, especially around the 1970 to 1975 timeframe, although these dates are approximate. If lumbar spine X-rays were

taken as preemployment screening and appear in the claim file records, dose reconstructors should include the dose from them in the dose reconstruction. The organ doses from the lumbar spine procedures come from ORAUT-OTIB-0006 (ORAU 2011).

3.4 ORGAN DOSE CALCULATIONS

Specific organ doses to be assigned for PA chest X-rays calculated using the dose conversion factors found in International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982) are given in Attachment A, Table A-1. Doses were calculated according to the method described in ORAUT-OTIB-0006 (ORAUT 2011). Doses for organs not listed in ICRP Publication 34 but specified in the Interactive RadioEpidemiological Program (IREP) code were determined according to the scheme described in ORAUT-OTIB-0006.

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 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 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%.

3.6 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the References section of this document.

REFERENCES

Author unknown, 1985, PMS Data Record – Tables A. [SRDB Ref ID: 75962, pp. 24-27]

Author unknown, 1994, Above Table X-Ray Survey Report, March 3. [SRDB Ref ID: 23928, pp. 2-4]

Barch, D., and A. A. Noel, 1998, *Chest X-Ray Frequency*, ESH-M-086, Piketon, Ohio, November 20. [SRDB Ref ID: 75987, pp. 3-7]

Bassett, A. C., 1984, "Medical X-ray Quality Assurance," memorandum to [Name redacted] (Medical Department), Goodyear Atomic Corporation, Industrial Hygiene and Health Physics, Piketon, Ohio, August 28. [SRDB Ref ID: 75967]

Bassett, A. C., 1985, *Medical X-ray Quality Assurance Tests*, GAT-S-39, Goodyear Atomic Corporation, Industrial Hygiene and Health Physics, Piketon, Ohio, January 15. [SRDB Ref ID: 8158]

Bolen, T. R., 1992, "X-Ray Facility Survey," letter to W. Lyon (Martin Marietta Energy Systems), Department of Health and Human Services, Public Health Service, Food and Drug Administration, Cincinnati, Ohio, August 24. [SRDB Ref ID: 23924]

Conrad, D. E., 1988, "Chest X-Radiography," April 5. [SRDB Ref ID: 75985]

Ely, T., Harris, W.B., Sterner, J.H., Schoen, A.A., and Hayes, D.F., 1957. "Health Protection at Paducah and Portsmouth," memorandum to [Name redacted], April 16. [SRDB Ref ID: 98610]

ICRP (International Commission on Radiological Protection), 1982, *Protection of the Patient in Diagnostic Radiology*, Publication 34, Pergamon Press, Oxford, England.

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

NCRP (National Council on Radiation Protection and Measurements), 1997, *Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use)*, Report 102, Third Reprinting, Bethesda, Maryland.

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

ORAUT (Oak Ridge Associated Universities Team) 2012. *Documented Communication on the Occupational Medical Program at Portsmouth,* Oak Ridge, Tennessee, December 3. [SRDB Ref ID: 121127]

Wingfoot (Wingfoot Clan Newsletter), 1954. *GAT Medical Program Emphasizes Prevention*, December, 15, 1954. [SRDB Ref ID: 120061]

GLOSSARY

anterior-posterior (AP)
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.

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.

gaseous diffusion plant
Facility where uranium hexafluoride (UF_6) gas is filtered to enrich the ^{235}U and separate it from ^{238}U.

half-value layer (HVL)
Thickness of a specified substance, usually specified in millimeters of aluminum, that attenuates an X-ray beam to one half the original kerma rate. It is a measure of the X-ray beam quality.

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*.

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 screening 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 35 mm, 70 mm, 4-inch × 5-inch, or 4-inch × 10-inch film. PFG was the primary method of screening large populations for tuberculosis before the advent of nonradiographic screening methods.

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.

radiography

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

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.

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 (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.

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*.

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.

ATTACHMENT A
ORGAN DOSE TABLES
Page 1 of 6

Table A-1. Organ dose equivalents (rem) for chest projections for all periods.[a]

Organ	PFG 1954–1957[a]	PA chest 14- × 17-in. 1954–1970[b]	PA chest 14- × 17-in. 1971–1981[b]	PA chest 14- × 17-in. 1982–1991[c]	PA chest 14- × 17-in. 1992–2009[d]	PA chest 14- × 17-in. 2010–present[b]
Thyroid	3.94E–01	3.48E-02	3.20E-03	5.43E–04	1.16E-03	3.90E-03
Eye/brain	7.25E–02	6.40E-03	3.20E-03	5.43E–04	1.16E-03	3.90E-03
Ovaries	2.50E–02	2.50E-02	1.00E-04	2.80E–05	7.75E-05	2.60E-04
Urinary bladder/prostate	2.50E–02	2.50E-02	1.00E-04	2.80E–05	7.75E-05	2.60E-04
Colon/rectum	2.50E–02	2.50E-02	1.00E-04	2.80E–05	7.75E-05	2.60E-04
Testes	5.00E–03	5.00E-03	1.00E-06	8.76E–08	1.49E-07	5.00E-07
Lungs (male)	9.50E–01	8.38E-02	4.19E-02	4.95E–03	9.36E-03	3.14E-02
Lungs (female)	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Thymus	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Esophagus	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Stomach	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Bone surface	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Liver/gall bladder/ spleen/pancreas	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Remainder organs	1.02E+00	9.02E-02	4.51E-02	5.35E–03	1.00E-02	3.37E-02
Breast	1.11E–01	9.80E-03	4.90E-03	7.98E–04	1.73E-03	5.80E-03
Uterus	2.50E–02	2.50E-02	1.30E-04	2.63E–05	7.75E-05	2.60E-04
Bone marrow (male)	2.09E–01	1.84E-02	9.20E-03	1.28E–03	2.65E-03	8.90E-03
Bone marrow (female)	1.95E–01	1.72E-02	8.60E-03	1.24E–03	2.56E-03	8.60E-03
Entrance skin[e]	3.06E+00	2.70E-01	1.35E-01	1.24E–02	2.12E-02	7.00E-02

a. Doses for PFG are from ORAUT-OTIB-0006 (ORAUT 2011) and assumed to be stereoscopic views.
b. Based on ORAUT-OTIB-0006 (ORAUT 2011).
c. Based on Bassett (1984).
d. Based on Bolen (1992) and Author unknown (1994).
e. Entrance skin dose (ENSD) is determined by multiplying the incident air kerma by the backscatter factors of 1.35, 1.41, and 1.42 for HVLs of 2.5, 3.5, and 4.0 mm Al, respectively, from National Council on Radiation Protection and Measurements (NCRP) Report 102 (NCRP 1997, Table B-8). Skin doses for all areas of skin are provided in Tables A-3 and A-4.

Table A-2. Organ dose equivalents (rem) for AP and LAT lumbar spine projections, 1970 to 1975 (approximately).[a]

Organ	AP lumbar spine	LAT lumbar spine
Thyroid	2.73E-04	3.48E-05
Eye/brain	2.73E-04	3.48E-05
Ovaries	1.97E-01	1.64E-01
Urinary bladder/prostate	1.97E-01	1.64E-01
Colon/rectum	1.97E-01	1.64E-01
Testes	3.82E-03	2.78E-03
Lungs (male)	7.19E-02	4.87E-02
Lungs (female)	7.19E-02	4.87E-02
Thymus	7.19E-02	4.87E-02
Esophagus	7.19E-02	4.87E-02
Stomach	1.97E-01	1.64E-01
Bone surface	1.97E-01	1.64E-01
Liver/gall bladder/spleen/pancreas	1.97E-01	1.64E-01
Remainder organs	1.97E-01	1.64E-01
Breast	9.56E-04	2.07E-03
Uterus	2.61E-01	1.08E-01

ATTACHMENT A
ORGAN DOSE TABLES
Page 2 of 6

Organ	AP lumbar spine	LAT lumbar spine
Bone marrow (male)	3.37E-02	7.66E-02
Bone marrow (female)	3.37E-02	7.66E-02
Entrance skin[b]	1.230E+00	4.70E+00

a. Based on ORAUT-OTIB-0006, (ORAUT 2011), one AP and one LAT projection.
b. ENSD is determined by multiplying the incident air kerma by the backscatter factor of 1.35, for HVL of 2.5 mm Al, from NCRP Report 102 (NCRP 1997, Table B-8). Skin doses for all areas of skin are provided in Table A-5.

Table A-3. Skin dose guidance and skin dose equivalents (rem) for chest projections, 1954 to 1981.[a]

Area of skin	PFG 1954–1957		PA chest 1954–1970		PA chest 1971–1981	
	Guidance	Dose	Guidance	Dose	Guidance	Dose
Right front shoulder	EXSD	6.67E–02	EXSD	5.9E-03	EXSD	2.9E-03
Right back shoulder	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Left front shoulder	EXSD	6.67E–02	EXSD	5.9E-03	EXSD	2.9E-03
Left back shoulder	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Right upper arm to elbow	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Left upper arm to elbow	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Left hand	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.35E-02
Right hand	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.35E-02
Left elbow, forearm, wrist	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Right elbow, forearm, wrist	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Right side of head (including ear and temple)	10% ENSD	3.06E–01	10% ENSD	2.70E-02	10% ENSD	1.35E-02
Left side of head (including ear and temple)	10% ENSD	3.06E–01	10% ENSD	2.70E-02	10% ENSD	1.35E-02
Front left thigh	RSD (0.52 m)	9.E–04	RSD (0.52 m)	8.E-05	RSD (0.52 m)	4.E-05
Back left thigh	RSD (0.52 m)	9.E–04	RSD (0.52 m)	8.E-05	RSD (0.52 m)	4.E-05
Front right thigh	RSD (0.52 m)	9.E–04	RSD (0.52 m)	8.E-05	RSD (0.52 m)	4.E-05
Back right thigh	RSD (0.52 m)	9.E–04	RSD (0.52 m)	8.E-05	RSD (0.52 m)	4.E-05
Left knee and below	RSD (0.86 m)	3.E–04	RSD (0.86 m)	3.E-05	RSD (0.86 m)	1.E-05
Right knee and below	RSD (0.86 m)	3.E–04	RSD (0.86 m)	3.E-05	RSD (0.86 m)	1.E-05
Left side of face	Eye/brain	7.25E–02	Eye/Brain	6.4E-03	Eye/Brain	3.2E-03
Right side of face	Eye/brain	7.25E–02	Eye/Brain	6.4E-03	Eye/Brain	3.2E-03
Left side of neck	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Right side of neck	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Back of head	10% ENSD	3.06E–01	10% ENSD	2.70E-02	10% ENSD	1.35E-02
Front of neck	Eye/brain	7.25E–02	Eye/Brain	6.4E-03	Thyroid	3.2E-03
Back of neck	10% ENSD	3.06E–01	ENSD	2.70E-01	10% ENSD	1.35E-02
Front torso: base of neck to end of sternum	EXSD	6.67E–02	EXSD	5.9E-03	EXSD	2.9E-03
Front torso: end of sternum to lowest rib	EXSD	6.67E–02	EXSD	5.9E-03	EXSD	2.9E-03
Front torso: lowest rib to iliac crest	EXSD	6.67E–02	EXSD	5.9E-03	10% EXSD	3.E-04
Front torso: iliac crest to pubis	10% EXSD	6.7E–03	10% EXSD	6.E-04	10% EXSD	3.E-04
Back torso: base of neck to mid–back	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01

ATTACHMENT A
ORGAN DOSE TABLES
Page 3 of 6

Area of skin	PFG 1954–1957		PA chest 1954–1970		PA chest 1971–1981	
	Guidance	Dose	Guidance	Dose	Guidance	Dose
Back torso: mid–back to lowest rib	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Back torso: lowest rib to iliac crest	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.35E-02
Back torso: buttocks (Iliac crest and below)	10% ENSD	3.06E–01	10% ENSD	2.70E-02	10% ENSD	1.35E-02
Right torso: base of neck to end of sternum	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Right torso: end of sternum to lowest rib	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Right torso: lowest rib to iliac crest	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.35E-02
Right torso: iliac crest to pubis (right hip)	10% ENSD	3.06E–01	10% ENSD	2.70E-02	10% ENSD	1.35E-02
Left torso: base of neck to end of sternum	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Left torso: end of sternum to lowest rib	ENSD	3.06E+00	ENSD	2.70E-01	ENSD	1.35E-01
Left torso: lowest rib to iliac crest	ENSD	3.06E+00	ENSD	2.70E-01	10% ENSD	1.35E-02
Left torso: iliac crest to pubis (left hip)	10% ENSD	3.06E–01	10% ENSD	2.70E-02	10% ENSD	1.35E-02

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

Table A-4. Skin dose guidance and skin dose equivalents (rem) for chest projections, 1982 to present.[a]

Area of skin	PA chest ≥ 1971	PA chest 1982–1991	PA chest 1992–2009	PA chest 2010–present
	Guidance	Dose	Dose	Dose
Right front shoulder	EXSD	4.E-04	7.E-04	2.4E-03
Right back shoulder	ENSD	1.24E-02	2.12E-02	7.00E-02
Left front shoulder	EXSD	4.E-04	7.E-04	2.4E-03
Left back shoulder	ENSD	1.24E-02	2.12E-02	7.00E-02
Right upper arm to elbow	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Left upper arm to elbow	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Left hand	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Right hand	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Left elbow, forearm, wrist	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Right elbow, forearm, wrist	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Right side of head (including ear and temple)	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Left side of head (including ear and temple)	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Front left thigh	RSD (0.52m)	4.E-06	8.E-06	3.E-05
Back left thigh	RSD (0.52m)	4.E-06	8.E-06	3.E-05
Front right thigh	RSD (0.52m)	4.E-06	8.E-06	3.E-05

ATTACHMENT A
ORGAN DOSE TABLES
Page 4 of 6

Area of skin	PA chest ≥ 1971 Guidance	PA chest 1982–1991 Dose	PA chest 1992–2009 Dose	PA chest 2010–present Dose
Back right thigh	RSD (0.52m)	4.E-06	8.E-06	3.E-05
Left knee and below	RSD (0.86m)	2.E-06	3.E-06	1.E-05
Right knee and below	RSD (0.86m)	2.E-06	3.E-06	1.E-05
Left side of face	Eye/brain	5.E-04	1.2E-03	3.9E-03
Right side of face	Eye/brain	5.E-04	1.2E-03	3.9E-03
Left side of neck	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Right side of neck	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Back of head	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Front of neck	Thyroid	5.E-04	1.2E-03	3.9E-03
Back of neck	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Front torso: base of neck to end of sternum	EXSD	4.E-04	7.E-04	2.4E-03
Front torso: end of sternum to lowest rib	EXSD	4.E-04	7.E-04	2.4E-03
Front torso: lowest rib to iliac crest	10% EXSD	4.E-05	7.E-05	2.E-04
Front torso: iliac crest to pubis	10% EXSD	4.E-05	7.E-05	2.E-04
Back torso: base of neck to mid–back	ENSD	1.24E-02	2.12E-02	7.00E-02
Back torso: mid–back to lowest rib	ENSD	1.24E-02	2.12E-02	7.00E-02
Back torso: lowest rib to iliac crest	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Back torso: buttocks (Iliac crest and below)	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Right torso: base of neck to end of sternum	ENSD	1.24E-02	2.12E-02	7.00E-02
Right torso: end of sternum to lowest rib	ENSD	1.24E-02	2.12E-02	7.00E-02
Right torso: lowest rib to iliac crest	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Right torso: iliac crest to pubis (right hip)	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Left torso: base of neck to end of sternum	ENSD	1.24E-02	2.12E-02	7.00E-02
Left torso: end of sternum to lowest rib	ENSD	1.24E-02	2.12E-02	7.00E-02
Left torso: lowest rib to iliac crest	10% ENSD	1.2E-03	2.1E-03	7.0E-03
Left torso: iliac crest to pubis (left hip)	10% ENSD	1.2E-03	2.1E-03	7.0E-03

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

ATTACHMENT A
ORGAN DOSE TABLES
Page 5 of 6

Table A-5. Skin dose guidance and skin dose equivalents (rem) for lumbar spine projections, 1970 to 1975 (approximately).[a]

Area of skin	AP lumbar spine ≥ 1971 Guidance	AP lumbar spine Dose	LAT lumbar spine ≥ 1971 Guidance	LAT lumbar spine Dose
Right front shoulder	10% ENSD	1.23E-01	10% ENSD	4.70E-01
Right back shoulder	10% EXSD	2.7E-03	10% ENSD	4.70E-01
Left front shoulder	10% ENSD	1.23E-01	10% EXSD	2.1E-03
Left back shoulder	10% EXSD	2.7E-03	10% EXSD	2.1E-03
Right upper arm to elbow	10% ENSD	1.23E-01	10% ENSD	4.70E-01
Left upper arm to elbow	10% ENSD	1.23E-01	10% EXSD	2.1E-03
Left hand	10% ENSD	1.23E-01	10% EXSD	2.1E-03
Right hand	10% ENSD	1.23E-01	10% ENSD	4.70E-01
Left elbow, forearm, wrist	10% ENSD	1.23E-01	10% EXSD	2.1E-03
Right elbow, forearm, wrist	10% ENSD	1.23E-01	10% ENSD	4.70E-01
Right side of head (including ear and temple)	Eye/brain	3.E-04	Eye/brain	3.E-05
Left side of head (including ear and temple)	Eye/brain	3.E-04	Eye/brain	3.E-05
Front left thigh	10% ENSD	1.23E-01	10% EXSD	2.1E-03
Back left thigh	10% EXSD	2.7E-03	10% EXSD	2.1E-03
Front right thigh	10% ENSD	1.23E-01	10% ENSD	4.70E-01
Back right thigh	10% EXSD	2.7E-03	10% ENSD	4.70E-01
Left knee and below	RSD (0.60m)	3.E-04	RSD (0.60m)	5.E-04
Right knee and below	RSD (0.60m)	3.E-04	RSD (0.60m)	5.E-04
Left side of face	Eye/brain	3.E-04	Eye/brain	3.E-05
Right side of face	Eye/brain	3.E-04	Eye/brain	3.E-05
Left side of neck	Eye/brain	3.E-04	Eye/brain	3.E-05
Right side of neck	Eye/brain	3.E-04	Eye/brain	3.E-05
Back of head	Eye/brain	3.E-04	Eye/brain	3.E-05
Front of neck	Eye/brain	3.E-04	Eye/brain	3.E-05
Back of neck	Eye/brain	3.E-04	Eye/brain	3.E-05
Front torso: base of neck to end of sternum	10% ENSD	1.23E-01	Lung	4.87E-02
Front torso: end of sternum to lowest rib	ENSD	1.23E+00	Lung	4.87E-02
Front torso: lowest rib to iliac crest	ENSD	1.23E+00	Lung	4.87E-02
Front torso: iliac crest to pubis	ENSD	1.23E+00	Lung	4.87E-02
Back torso: base of neck to mid–back	10% EXSD	2.7E-03	Lung	4.87E-02
Back torso: mid–back to lowest rib	EXSD	2.68E-02	Lung	4.87E-02
Back torso: lowest rib to iliac crest	EXSD	2.68E-02	Lung	4.87E-02
Back torso: buttocks (Iliac crest and below)	EXSD	2.68E-02	Lung	4.87E-02

ATTACHMENT A
ORGAN DOSE TABLES
Page 6 of 6

Area of skin	AP lumbar spine ≥ 1971 Guidance	AP lumbar spine Dose	LAT lumbar spine ≥ 1971 Guidance	LAT lumbar spine Dose
Right torso: base of neck to end of sternum	10% ENSD	1.23E-01	10% ENSD	4.70E-01
Right torso: end of sternum to lowest rib	ENSD	1.23E+00	ENSD	4.70E+00
Right torso: lowest rib to iliac crest	ENSD	1.23E+00	ENSD	4.70E+00
Right torso: iliac crest to pubis (right hip)	ENSD	1.23E+00	ENSD	4.70E+00
Left torso: base of neck to end of sternum	10% ENSD	1.23E-01	10% EXSD	2.1E-03
Left torso: end of sternum to lowest rib	ENSD	1.23E+00	EXSD	2.06E-02
Left torso: lowest rib to iliac crest	ENSD	1.23E+00	EXSD	2.06E-02
Left torso: iliac crest to pubis (left hip)	ENSD	1.23E+00	EXSD	2.06E-02

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