Document Title: **Occupational Medical X-Ray Dose Reconstruction for DOE Sites**		Document Number: Revision: Effective Date: Type of Document: Supersedes:	ORAUT-PROC-0061 03 03/03/2010 Procedure Revision 02
Subject Expert(s):	Elyse M. Thomas		
Site Expert(s):	N/A		
Approval:	Signature on File James P. Griffin, Document Owner	Approval Date:	03/01/2010
Concurrence:	Signature on File Kate Kimpan, Project Director	Concurrence Date:	03/01/2010
Approval:	Signature on File Stuart L. Hinnefeld, Interim Director, DCAS	Approval Date:	03/03/2010

☐ 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
12/01/2004	00	New document to provide direction for assignment of organ dose from medical X-ray exams based on TBD information. Incorporates formal internal and NIOSH review comments. First approved issue. Initiated by Steven E. Merwin.
07/21/2006	01	Revised to include additional sites with approved TBDs, new guidance on X-rays for locations of the skin, and additional X-ray procedures. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Incorporates additional NIOSH review comment. Training is required. Initiated by Robert C. Winslow.
01/02/2008	02	Revised to update Attachment C to include approved Request for Direction or Operational Change for X-Ray dose assignment to the face and to include updates based on current TBD revisions. Constitutes a total rewrite of the document. Revised to incorporate internal comments and to include recently approved TBDs, change column headings, and alignment of x-ray procedures to align with new headings in Attachment A. Incorporates second formal internal review comments. Revised to address OCAS comments. Training is required. Initiated by Robert C. Winslow.
03/03/2010	03	Revised to remove the LAT chest doses for Ames Laboratory in Notes to Table A-1 which are now included in a revised Ames Site Profile; to add guidance for skin dose for PA and LAT chest for post 1970; to better define dose to various areas of skin from PFG, PA and LAT chest pre-1970 and lumbar spine procedures; to remove Table A-1, the quick reference table, and Table B-1, the records availability table, and move them to shared space on the O drive so that they can be kept up to date as Site Profiles are revised; to move the responsibilities of the "subject expert - external dosimetry" to the "dose reconstruction group managers". Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training is required. Initiated by Elyse M. Thomas.

TABLE OF CONTENTS

1.0 PURPOSE

The purpose of this procedure is to provide direction on reconstruction of doses from occupational medical X-rays for the Oak Ridge Associated Universities (ORAU) Team Dose Reconstruction Project for the National Institute for Occupational Safety and Health (NIOSH). The Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) requires the assignment of external dose from medical X-ray examinations that were performed for occupational health screening and required as a condition of employment. This procedure relies on information in site technical basis documents (TBDs), and it supersedes some of the instructions for X-ray dose reconstruction in ORAUT-PROC-0006 Rev. 01, External Dose Reconstruction.

2.0 SCOPE

This procedure applies to Project employees who perform or supervise dose reconstruction for covered Energy Employees of the U.S. Department of Energy (DOE), its predecessor agencies, and certain of its contractors and subcontractors, and Atomic Weapons Employer (AWE) Facilities.

3.0 REFERENCES

Kereiakes, J. G., and M. Rosenstein, 1980, *Handbook of Radiation Doses in Nuclear Medicine and Diagnostic X-Ray*, CRC Press, Boca Raton, Florida, June NCRP (National Council on Radiation Protection and Measurements), 1976, Structural Shielding Design and Evaluation for Medical Use of X-rays and Gamma Rays of Energies up to 10 MeV, Report 49, Bethesda, Maryland

NCRP (National Council on Radiation Protection and Measurements), 1989, Medical X-Ray Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use), Report 102, Bethesda, Maryland

OCAS-IG-001, External Dose Reconstruction Implementation Guideline

OCAS-IG-003, Radiation Exposures Covered for Dose Reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act

ORAUT-OTIB-0006, Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures

ORAUT-PROC-0006, External Dose Reconstruction

4.0 RESPONSIBILITIES

4.1 Principal Medical Dosimetrist – Initiates revisions to medical dose TBDs, OTIBs, or Procedures should Dose Reconstructors or the Dose Reconstruction Group Managers report technical issues or discrepancies between published information and data in claim files. Provides guidance on issues and answers to technical questions that arise in the course of dose reconstruction and calculates organ doses based on technical information. Provides interpretation of case files or TBD information when necessary. Provides direction for the revision of this procedure as necessary based on revised or new information in TBDs or on feedback from Dose Reconstructors. Keeps Table A-1,

Quick-Reference Table For X-Ray Dose Assignments and Table B-1, X-ray Records Availability for DOE sites up to date as TBDs are revised. **(Project O Drive\Claims\DR Folders\DR Information\PROC-0061)**

4.2 Dose Reconstruction Group Manager – Informs the Principal Medical Dosimetrist of issues identified by Dose Reconstructors, or problems identified with implementation of this procedure. Provides additional guidance to Dose Reconstructors as needed.

4.3 Claims Processing Support Group Manager – On request by Dose Reconstructors, submits a DOE discrepancy request for additional X-ray data.

4.4 Dose Reconstructor – Informs the Dose Reconstruction Group Manager of issues with implementation of this procedure that are identified during the course of performing dose reconstructions. Applies published dose values; requests assistance from the Dose Reconstruction Group Manager and Principal Medical Dosimetrist when published values do not exist and need to be developed.

5.0 GENERAL

As described in OCAS-IG-001, External Dose Reconstruction Implementation Guideline, and OCAS-IG-003, Radiation Exposures Covered for Dose Reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act, doses from occupational medical X-ray procedures that are performed on Energy Employees for occupational health screening and as a condition of employment must be included in dose reconstructions for this Project. This requirement is complicated by the fact that the doses from these procedures were not typically measured, nor were they considered or included by the site as a part of the overall occupational exposure of the Energy Employee. Because these exposures were not monitored, reconstruction of doses must rely on information in ORAU Team technical information bulletins (OTIBs), site-specific TBDs, and the medical and health physics literature. Dose from medical X-ray screening procedures is assigned during the Energy Employee's verified employment period, including the remedial period if applicable, but is not assigned during the residual contamination period.

Typical X-ray procedures eligible to be included in dose reconstruction under EEOICPA are (1) photofluorography (PFG), posterior-anterior (PA), and lateral (LAT) 14” x 17” chest X-rays to screen for tuberculosis and lung cancer; (2) anterior-posterior (AP) and LAT lumbar spine X-rays (and sometimes AP or LAT spot projections) to screen for back anomalies, particularly for Energy Employees who performed heavy lifting; and (3) AP pelvis, thoracic spine, or cervical spine X-rays to screen for fluorosis in Energy Employees who were exposed to fluoride. Most other procedures (such as extremities) were performed in cases of work-related injury, which excludes them from the "screening" category and, as a result, should not be included in dose reconstruction. Additional projections (such as oblique or lordotic chest projections) that are requested to better visualize suspicious areas on a radiograph are also not generally “screening” (i.e. performed on all workers regardless of history, symptoms, or complaint) and therefore generally excluded from dose reconstruction. However, there are some exceptions where additional projections were part of the screening protocol (for example, oblique chests may have been part of the screening protocol for asbestos workers). The TBDs should provide descriptions of the screening procedures for each respective site.

All occupational X-ray doses are assigned in the Interactive RadioEpidemiological Program (IREP) computer code as follows:

Exposure Rate: **Acute**
Radiation Type: **Photons E = 30–250 keV**

Other IREP parameters depend on the specific dose reconstruction approach used. Section 6.0 of this procedure provides direction for assignment of occupational X-ray doses for Energy Employees from specific DOE sites based on approved TBDs. If the relevant site-specific TBD has not been issued, the Dose Reconstructors should review ORAUT-OTIB-0006, Dose Reconstruction from Occupationally Related X-Ray Procedures, and report and request needed dose information to their Dose Reconstruction Group Manager and the Principal Medical Dosimetrist.

Section 6.0 describes a procedure for three general dose reconstruction approaches used for calculating the probability of causation (POC): Overestimate, Best Estimate, and Minimizing. The POC is used by the U.S. Department of Labor (DOL) as the decision basis for determining compensability. These three general approaches are distinguished as follows:

5.1 Overestimate

5.1.1 The general philosophy for an Overestimate approach is to assign dose from all eligible X-ray procedures under EEOICPA for each site where the Energy Employee worked.

5.1.2 An Overestimate approach is typically applied to cases with a clear POC of less than 50%.

5.1.3 There is no need to request case-specific X-ray data if not immediately available.

5.2 Best Estimate

5.2.1 The general philosophy for a Best-Estimate approach is to assign dose from all eligible X-ray procedures under EEOICPA for each site where the Energy Employee worked. However, some X-rays should be excluded from a Best-Estimate approach. For example, prehire and rehire procedures more than 1 year before DOL-verified employment should not be included. However, if records provide documented extenuating circumstances for a delay in the start of employment, X-ray procedures up to 2 years before DOL-verified employment may be considered. Based on the possibility of physical changes over time, it is expected that prehire and rehire X-ray procedures more than 1 or 2 years before DOL-verified employment would have had to have been redone to verify the physical condition of the potential Energy Employee. If records indicate such additional X-ray procedures, all of the prehire and rehire procedures should be included in the dose reconstruction.

5.2.2 A Best-Estimate approach is typically applied to cases for which the POC exceeds 50% if the X-ray dose is maximized or to cases for which a best estimate can be obtained with minimal effort.

5.2.3 All available X-ray data should be requested from the site (if not already provided) if the compensability decision could be affected.

5.3 **Minimizing**

5.3.1 The Minimizing approach for the assignment of dose from eligible X-ray procedures under EEOICPA may only be used when the POC for the case is greater than 50%. The general philosophy is to assign dose from eligible X-ray procedures in the most efficient manner possible to achieve a POC greater than 50%. In other words, if the POC is greater than 50% without including dose from X-ray procedures, the X-ray doses should not be included.

5.3.2 Only case-specific X-ray data can be used.

6.0 PROCEDURE

Dose Reconstructor

6.1 Reviews the information in the case file.

6.2 Determines the approach (Overestimate, Best Estimate, Minimizing, or Skin) to apply to reconstruct the dose. For Overestimate, proceeds to Section 6.2.1; for Best Estimate, proceeds to Section 6.2.2; for Minimizing, proceeds to Section 6.2.3; and for Skin, proceeds to Section 6.2.4.

6.2.1 Overestimate Approach

NOTE: The Overestimate approach in Table A-1, Quick-Reference Table For X-Ray Dose Assignments (now on the Project O Drive\Claims\DR Folders\DR Information\PROC-0061), while based on information in site-specific TBDs, might include higher frequencies than those in the TBDs to ensure that the approach is, in fact, an overestimate. In addition, Table A-1 directs Dose Reconstructors to the tables in the TBD for assignment of the proper organ dose. Unless otherwise noted in Table A-1, doses from the TBDs should be multiplied by 1.3 (1.35 for some TBDs) to account for uncertainty in an overestimate (and the doses treated as constants in IREP), or doses may be assigned as a normal distribution in IREP Parameter 1 and multiplied by 0.3 (0.35 for some TBDs) in Parameter 2.

NOTE: The Savannah River Site and K-25 TBDs indicate years when PFG and PA chest procedures may have been performed during the same timeframe. If it cannot be determined which procedure was performed, the Dose Reconstructor should apply the higher organ dose for the overestimate.

6.2.1.1 Reviews the case files from DOE to determine frequencies and types of X-rays in the Energy Employee's records.

6.2.1.2 If the records indicate more or different types of X-ray procedures eligible under EEOICPA that could result in higher organ doses in comparison to the doses based on the Overestimates in Table A-1, includes doses from the additional procedures and/or frequencies, and notifies the Dose Reconstruction Group Manager and Principal Medical Dosimetrist of these differences.

6.2.1.3 As a general rule for an Overestimate approach, does not need to request case-specific X-ray data if the data were not included in the DOE submittal; however, places the case on hold and requests the data if it is suspected the data are needed to ensure results favorable to the claimant.

6.2.2 Best-Estimate Approach

NOTE: Table A-1 provides information on the best-estimate frequency and type of procedures for Energy Employees at specific sites and directs Dose Reconstructors to the TBD to determine X-ray frequency and type and to the tables in the TBD for assignment of the proper organ dose.

6.2.2.1 The hierarchy of information used to assign dose from X-rays should be as follows:

6.2.2.1.1 Energy employee records showing X-ray procedures: Does not add dose for years where there is no X-ray recorded for that year.

6.2.2.1.2 Phone interview summary, especially if no records of X-ray procedures are provided by the site, even after requesting the information.

6.2.2.1.3 Information in the TBD about historical X-ray procedure frequency if it cannot be determined from records or phone interviews.

6.2.2.2 Unless otherwise noted, assigns the doses from the TBD as a normal distribution in IREP Parameter 1 and assigns the doses from the TBD multiplied by 0.3 in Parameter 2.

NOTE: A Best Estimate of the X-ray dose must be conducted with either:

- An approved site TBD, and X-ray records in the DOE submittal. An additional request should be initiated by the dose reconstructor to obtain the X-ray records if they are not automatically submitted with every case. The only exceptions are currently Y-12 and INL, who are not providing X-ray records.

6.2.2.3 An agreed upon method with NIOSH for sites for which a Site Profile will not be written. Reviews the files in the case and uses the provided information with the organ-specific dose information in the site TBD to develop a best estimate of the dose.

6.2.2.4 If the Energy Employee's X-ray records are not included in the DOE submittal, and if the information might affect the case compensability, places the case on hold and requests the necessary information from the Claims Processing Support Group Manager.

NOTE: For Y-12 and INL cases, it is acceptable to use the frequency information published in the site TBDs.

NOTE: The requested information could include information that is not typically provided by the sites in response to bulk requests. Table B-1 in Attachment B contains details on the types of information that are normally included in the DOE submittals for sites that are listed in Table A-1.

Claims Processing Support Group Manager

6.2.2.5 If requested by the Dose Reconstructor, submits a DOE discrepancy request for additional X-ray data.

6.2.2.6 Notifies the Dose Reconstructor if the requested additional information is not available.

Dose Reconstructor

6.2.2.7 If notified that the requested additional information is not available:

6.2.2.7.1 Proceeds with the case and makes appropriate judgments based on the available information, including information provided during the interview process to assign dose.

6.2.2.7.2 Uses assumptions favorable to the claimant when necessitated by a lack of reliable information.

6.2.3 Minimizing Approach

NOTE: Table A-1 provides site-specific information for assignment of minimized doses for X-ray procedures.

6.2.3.1 Assigns dose only for those X-rays that are listed in the energy employee records and were certain to have been performed for screening.

6.2.3.2 Unless otherwise noted in Table A-1, assigns the values as constants.

6.2.3.3 If records that indicate the type and frequency of X-ray procedures are not available and the inclusion of X-ray dose could raise the calculated POC to 50% or greater, uses a Best-Estimate approach using the site TBD and other available information (see Section 6.2.2).

6.2.3.4 NOTE: A combination of a Minimizing approach and a Best-Estimate approach is acceptable because the overall goal is to arrive at the correct compensability decision in the most efficient manner possible, provided an adequate basis exists for the dose assignments.

6.2.4 Skin Cancer Approach

6.2.4.1 Follows Sections 6.2.1 through 6.2.3 for skin cancer cases depending on the approach.

NOTE: The X-ray dose assignment for skin cancer cases needs careful consideration because knowledge about where the X-ray beam enters the body in relation to the location of the skin cancer is necessary. While entrance skin dose values can be considered overestimates for parts of the body NOT in the primary entrance beam, they <u>cannot</u> be applied for a Best-Estimate or Minimizing approach except for skin cancers within the X-ray field at the point of entrance, such as the back for a PA chest projection. Other locations on the skin might also have been within the X-ray field before 1970, when adequate collimation to limit the beam to the area of interest for the procedure might not have been used. Tables C-1 through C-6 in Attachment C provide guidance on the assignment of X-ray doses to various areas of skin for several common screening procedures, and for various time periods. Some site occupational medical TBDs include doses for the skin that are (1) in the beam, (2) on the exit side of the body, (3) near but outside the primary beam or exit beam, and (4) remote from the beam that should be assigned, as appropriate, when they are available. When this information is not already provided in the site-specific TBD, Attachment C provides guidance in using published values; however, the Principal Medical Dosimetrist should be notified when specific organ or skin doses are needed and are not previously published.

6.2.4.2 To assign skin doses for Best-Estimate or Minimizing approaches, determines the location of the cancer based on information in the case file and then determines the appropriate X-ray dose value from published tables.

NOTE: Previously, dose reconstructors assigned dose to skin based on an analogous organ in proximity to the location of the cancer. However, appropriately developed skin doses are preferable to application of doses from analogous organs because of the relatively low effective energy of X-rays and the depth of analogous organs in relation to the skin surface.

6.2.4.3 Consults with the Principal Medical Dosimetrist for further guidance in this area, or to request development of skin doses.

Principal Medical Dosimetrist

6.2.4.4 Calculates skin doses needed by dose reconstructors that are not previously published.

6.2.4.5 Notifies the Dose Reconstruction Group Managers of any changes of interpretation or new information that could affect multiple cases, or if additional screening X-rays are identified in the case records that are not discussed in the site-specific occupational medical TBDs.

Dose Reconstruction Group Manager

6.2.4.6 Provides guidance to Dose Reconstructors on dose reconstruction processes, procedures, and policies.

6.2.4.7 Notifies the Principal Medical Dosimetrist of issues raised and/or problems identified by dose reconstructors regarding occupational medical dose and site specific occupational medical TBDs so that solutions can be developed.

7.0 RECORDS

None

8.0 APPLICABLE DOCUMENTS

8.1 Drivers

Contract No. 200-2009-29263, Dose Reconstruction and Related Activities to Support NIOSH's Responsibilities under the EEOICPA

ORAUT-PLAN-0001, Quality Assurance Program Plan

ORAUT-PLAN-0009, Project Management Plan

8.2 Forms

None

9.0 DEFINITIONS AND ACRONYMS

AP – anterior-posterior (X-ray projection).

BSF – backscatter factor.

cm – centimeter.

DOE – U.S. Department of Energy.

DOL – U.S. Department of Labor.

EEOICPA – Energy Employees Occupational Illness Compensation Program Act of 2000.

EAK – Entrance Air Kerma in air is the sum of kinetic energy of all charged particles liberated per unit mass of air where the X-ray beam enters the body. The unit is the joule per kilogram ($J\ kg^{-1}$) and is given the special name gray (Gy).

ENSD – Entrance skin dose – ENSD is calculated by multiplying the entrance air kerma in air by a backscatter factor based on the half-value layer of the X-ray beam.

EXSD – Exit skin dose is calculated by multiplying the entrance air kerma in air by an absorption factor based on the half-value layer.

HVL – Half-value layer.

in. – inch.

INL – Idaho National Laboratory.

IREP – Interactive RadioEpidemiological Program.

keV – kiloelectron-volt.

kVp – kilovolts-peak, applied kilovoltage.

LAT – lateral (X-ray projection).

m – meter.

mm – millimeter.

mrem – millirem.

NCRP – National Council on Radiation Protection and Measurements.

NIOSH – National Institute for Occupational Safety and Health.

OCAS – Office of Compensation and Analysis Support.

ORAU – Oak Ridge Associated Universities.

OTIB – ORAU Team technical information bulletin.

PA – posterior-anterior (X-ray projection).

PFG – photofluorography.

POC – probability of causation.

RSD – Remote Skin Dose is the dose to areas of skin that are at a distance from the area of the X-ray beam. The source of the dose to these areas of skin is scatter produced within the body from the primary X-ray beam.

SEC – Special Exposure Cohort.

Screening – Screening x-rays are systematic examinations performed on asymptomatic people, without history, complaint, physical findings, or physician evaluation.

Site Profile - (1) The combination of five technical basis documents (TBDs), each written to describe a specific technical area related to a covered site or sites, along with an introduction.

Technical basis document (TBD) – For this procedure, TBD means an Occupational Medical Dose TBD or Occupational Medical Dose section of a site profile.

ATTACHMENT A
TABLE A-1 QUICK-REFERENCE TABLE FOR X-RAY DOSE ASSIGNMENTS

Table A-1 has been moved to shared drive space so that it can be kept up to date as TBDs are revised. It is available on the **Project O Drive\Claims\DR Folders\DR Information\PROC-0061.**

ATTACHMENT B
X-RAY RECORDS AVAILABILITY FOR DOE SITES

Table B-1 has been moved to shared drive space so that it can be kept up to date as TBDs are revised. It is available on the **Project O Drive\Claims\DR Folders\DR Information\PROC-0061.**

ATTACHMENT C
GUIDANCE FOR ASSIGNMENT OF X-RAY DOSE TO THE SKIN

The normalized areas of skin are listed in the tables below, along with the associated basis for assignment of skin dose for common screening procedures, common projections, and for various time periods. The skin doses assigned are the entrance skin dose (ENSD), the exit skin dose (EXSD), the outside but near entrance skin dose (10% ENSD), the outside but near exit skin dose (10% EXSD), and the remote skin dose (RSD) given with the distance from beam center.

Table C-1 provides generic guidance for the assignment of dose to various areas of skin from PFG chest, PA and LAT chest, and lumbar spine projections for X-rays taken prior to 1970 when poor collimation is assumed. Table C-2 provides generic guidance for the assignment of dose to various areas of the skin from chest and lumbar spine projections performed after 1970, when collimation practices are assumed to have been better.

Table C-1. Generic guidance for the assignment of dose to various areas of the skin for the pre-1970 poor collimation period for various procedures and projections.

Area of skin	Basis for PFG	Basis for PA chest before 1970	Basis for LAT chest before 1970	Basis for AP and AP spot lumbar spine before 1970	Basis for LAT and LAT spot lumbar spine before 1970	LPO basis for LPO lumbar spine before 1970	RPO basis for RPO lumbar spine before 1970
R front shoulder	EXSD	EXSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
R back shoulder	ENSD	ENSD	ENSD	10% EXSD	10% ENSD	10% ENSD	10% EXSD
L front shoulder	EXSD	EXSD	EXSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
L back shoulder	ENSD	ENSD	EXSD	10% EXSD	10% EXSD	10% EXSD	10% ENSD
R upper arm to elbow	10% ENSD	ENSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
L upper arm to elbow	10% ENSD	ENSD	EXSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
L hand	ENSD	ENSD	10% ENSD	ENSD	10% EXSD	10% EXSD	10% ENSD
R hand	ENSD	ENSD	10% ENSD	ENSD	10% ENSD	10% ENSD	10% EXSD
L elbow, forearm, wrist	10% ENSD	ENSD	10% ENSD	ENSD	10% EXSD	10% EXSD	10% ENSD
R elbow, forearm, wrist	10% ENSD	ENSD	10% ENSD	ENSD	10% ENSD	10% ENSD	10% EXSD
R side of head (including ear)	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of head (including ear)	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front left thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	10% ENSD	10% EXSD	10% ENSD	10% ENSD
Back left thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	10% EXSD	10% EXSD	10% EXSD	10% EXSD
Front right thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	10% ENSD	10% ENSD	10% ENSD	10% ENSD
Back right thigh	RSD (0.52m)	RSD (0.52m)	RSD (0.52m)	10% EXSD	10% ENSD	10% EXSD	10% EXSD
L knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
R knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.86m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
L side of face	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R Side of Face	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain

Area of skin	Basis for PFG	Basis for PA chest before 1970	Basis for LAT chest before 1970	Basis for AP and AP spot lumbar spine before 1970	Basis for LAT and LAT spot lumbar spine before 1970	LPO basis for LPO lumbar spine before 1970	RPO basis for RPO lumbar spine before 1970
L side of neck	10% ENSD	ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of neck	10% ENSD	ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of head	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front of neck	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of neck	10% ENSD	ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front torso: base of neck to end of sternum	EXSD	EXSD	Lung	10% ENSD	Lung[a]	10% ENSD	10% ENSD
Front torso: end of sternum to lowest rib	EXSD	EXSD	Lung	ENSD	Lung[a]	ENSD	ENSD
Front torso: lowest rib to iliac crest	EXSD	EXSD	Lung	ENSD	Lung[a]	ENSD	ENSD
Front torso: iliac crest to pubis	10% EXSD	10% EXSD	10% Lung	ENSD	Lung[a]	ENSD	ENSD
Back torso: base of neck to mid-back	ENSD	ENSD	Lung	10% EXSD	Lung[a]	10% EXSD	10% EXSD
Back torso: mid-back to lowest rib	ENSD	ENSD	Lung	EXSD	Lung[a]	EXSD	EXSD
Back torso: lowest rib to iliac crest	ENSD	ENSD	Lung	EXSD	Lung[a]	EXSD	EXSD
Back torso: buttocks (Iliac crest and below)	10% ENSD	10% ENSD	10% Lung	EXSD	Lung[a]	EXSD	EXSD
Right torso: base of neck to end of sternum	ENSD	ENSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	ENSD	ENSD	ENSD	EXSD
Right torso: lowest rib to iliac crest	ENSD	ENSD	ENSD	ENSD	ENSD	ENSD	EXSD
Right torso: Iliac crest to pubis (R hip)	10% ENSD	10% ENSD	10% ENSD	ENSD	ENSD	ENSD	EXSD
Left torso: base of neck to end of sternum	ENSD	ENSD	EXSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD

ATTACHMENT C
GUIDANCE FOR ASSIGNMENT OF X-RAY DOSE TO THE SKIN

Area of skin	Basis for PFG	Basis for PA chest before 1970	Basis for LAT chest before 1970	Basis for AP and AP spot lumbar spine before 1970	Basis for LAT and LAT spot lumbar spine before 1970	LPO basis for LPO lumbar spine before 1970	RPO basis for RPO lumbar spine before 1970
Left torso: end of sternum to lowest rib	ENSD	ENSD	EXSD	ENSD	EXSD	EXSD	ENSD
Left torso: Lowest rib to iliac crest	ENSD	ENSD	EXSD	ENSD	EXSD	EXSD	ENSD
Left torso: Iliac crest to pubis (L hip)	10% ENSD	10% ENSD	10% EXSD	ENSD	EXSD	EXSD	ENSD

Table C-2. Generic guidance for the assignment of dose to various areas of the skin after 1970 for the period of better collimation for various procedures and projections.

Area of skin	Basis for PA chest after 1970	Basis for LAT chest after 1970	Basis for AP and AP spot lumbar spine after 1970	Basis for LAT and LAT spot lumbar spine after 1970	LPO basis for LPO lumbar spine after 1970	RPO basis for RPO lumbar spine after 1970
R front shoulder	EXSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
R back shoulder	ENSD	ENSD	10% EXSD	10% ENSD	10% ENSD	10% EXSD
L front shoulder	EXSD	EXSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
L back shoulder	ENSD	EXSD	10% EXSD	10% EXSD	10% EXSD	10% ENSD
R upper arm to elbow	10% ENSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
L upper arm to elbow	10% ENSD	EXSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
L hand	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
R hand	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
L elbow, forearm, wrist	10% ENSD	10% ENSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
R elbow, forearm, wrist	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
R side of head (including ear)	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of head (including ear)	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front left thigh	RSD (0.52m)	RSD (0.52m)	10% ENSD	10% EXSD	10% ENSD	10% ENSD
Back left thigh	RSD (0.52m)	RSD (0.52m)	10% EXSD	10% EXSD	10% EXSD	10% EXSD
Front right thigh	RSD (0.52m)	RSD (0.52m)	10% ENSD	10% ENSD	10% ENSD	10% ENSD
Back right thigh	RSD (0.52m)	RSD (0.52m)	10% EXSD	10% ENSD	10% EXSD	10% EXSD
L knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
R knee and below	RSD (0.86m)	RSD (0.86m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)	RSD (0.60m)
L side of face	Eye/brain	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of face	Eye/brain	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
L side of neck	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
R side of neck	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of head	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front of neck	Thyroid	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Back of neck	10% ENSD	10% ENSD	Eye/brain	Eye/brain	Eye/brain	Eye/brain
Front torso: base of neck to end of sternum	EXSD	Lung	10% ENSD	Lung[a]	10% ENSD	10% ENSD
Front torso: end of sternum to lowest rib	EXSD	Lung	ENSD	Lung[a]	ENSD	ENSD
Front torso: lowest rib to iliac crest	10% EXSD	10% Lung	ENSD	Lung[a]	ENSD	ENSD
Front torso: iliac crest to pubis	10% EXSD	10% Lung	ENSD	Lung[a]	ENSD	ENSD
Back torso: base of neck to mid-back	ENSD	Lung	10% EXSD	Lung[a]	10% EXSD	10% EXSD
Back torso: mid-back to lowest rib	ENSD	Lung	EXSD	Lung[a]	EXSD	EXSD

ATTACHMENT C
GUIDANCE FOR ASSIGNMENT OF X-RAY DOSE TO THE SKIN

Back torso: lowest rib to iliac crest	10% ENSD	10% Lung	EXSD	Lung[a]	EXSD	EXSD
Back torso: buttocks (iliac crest and below)	10% ENSD	10% Lung	EXSD	Lung[a]	EXSD	EXSD
Right torso: base of neck to end of sternum	ENSD	ENSD	10% ENSD	10% ENSD	10% ENSD	10% EXSD
Right torso: end of sternum to lowest rib	ENSD	ENSD	ENSD	ENSD	ENSD	EXSD
Right torso: lowest rib to iliac crest	10% ENSD	10% ENSD	ENSD	ENSD	ENSD	EXSD
Right torso: iliac crest to pubis (r hip)	10% ENSD	10% ENSD	ENSD	ENSD	ENSD	EXSD
Left torso: base of neck to end of sternum	ENSD	EXSD	10% ENSD	10% EXSD	10% EXSD	10% ENSD
Left torso: end of sternum to lowest rib	ENSD	EXSD	ENSD	EXSD	EXSD	ENSD
Left torso: lowest rib to iliac crest	10% ENSD	10% EXSD	ENSD	EXSD	EXSD	ENSD
Left torso: iliac crest to pubis (l hip)	10% ENSD	10% EXSD	ENSD	EXSD	EXSD	ENSD

a. The gender specific lung dose should be used.

ATTACHMENT C
GUIDANCE FOR ASSIGNMENT OF X-RAY DOSE TO THE SKIN

Calculation of Skin Doses

The entrance skin dose (*ENSD*) is the skin dose where the X-ray beam enters the body. It is defined as the entrance air kerma in air (*EAK*) multiplied by a backscatter factor (*BSF*) dependent on the half-value layer (HVL) from Table B-8 of National Council on Radiation Protection and Measurements (NCRP) Report 102 (NCRP 1989):

$$ENSD = EAK \times BSF \quad \text{(C-1)}$$

The exit skin dose (*EXSD*) is the dose to the skin where the X-ray beam exits the body. It is defined as the entrance skin dose (*ENSD*) divided by an adjusted absorption factor (*AFF)*, which is the absorption factor (*AF*) for a given thickness of tissue tabulated in Table B.7 of NCRP Report 102 (NCRP 1989) and reproduced below in Table C-3, decreased by 10% as shown in Equations C-2 and C-3. For dose reconstruction under EEOICPA, a standard chest and abdomen thickness of 23 cm in the PA or AP dimension, and 34 cm in the LAT dimension is assumed.

$$EXSD = ENSD \big/ AFF \quad \text{(C-2)}$$

$$AFF = AF \times 0.9 \quad \text{(C-3)}$$

The entrance skin dose near but outside the primary beam (*ENSDNPB*) is 10% of the *ENSD* as shown in Equation C-4. This estimate is based on the finding that scattered radiation produces a dose to the testes equal to 10% of the central beam dose when the testes are just outside a beam (Kereiakes and Rosenstein 1980, p. 205).

$$ENSDNPB = ENSD \times 0.1 \quad \text{(C-4)}$$

The exit skin dose near but outside the primary beam (*EXSDNPB*) is similarly 10% of the *EXSD* as shown in Equation C-5.

$$EXSDNPB = EXSD \times 0.1 \quad \text{(C-5)}$$

The remote skin dose (*RSD*), shown in Equation C-6, is a function of:

- ENSD;
- Inverse square of the distance R from the center of the primary beam to nearest point on the skin surface of interest; and
- A ratio of scattered to incident exposure equal to 0.0005 based on the exposure at 1 m due to 90° scattering of 70-kVp radiation in accordance with Table B-2 of NCRP Report 49 (NCRP 1976)
- Average percent depth dose (*ADD*) of*:*
  - The midpoint value of a 23-cm torso (rounded to 12 cm to match the nearest tabulated value and to ensure bias favorable to claimants) and dependent on the HVL of the beam in

ATTACHMENT C
GUIDANCE FOR ASSIGNMENT OF X-RAY DOSE TO THE SKIN

NCRP Report 102 (NCRP 1989, Table B.8) for PA chest and AP lumbar spine procedures;

– The midpoint of a 34-cm torso (rounded to 16 cm to match the nearest tabulated value and to ensure bias favorable to claimants) and dependent on the HVL of the beam in NCRP Report 102 (NCRP 1989, Table B.8) for LAT lumbar spine procedures.

- A bias factor favorable to claimants of 1.1 to allow for 10% uncertainty in tabulated values of *ADD:*

$$RSD = ENSD \times 0.0005 \times ADD \times 1.1 \times \left(\frac{1}{R}\right)^2 \quad \text{(C-6)}$$

The distances for calculation of *RSD* for the PA chest X-ray procedures are:

- Skin of thighs to knees – 0.52 m
- Skin of knees and below– 0.86 m

The distances for calculation of *RSD* for the AP and LAT lumbar-spine procedures are:

- Skin of knees and below – 0.60 m

Table C-3. Absorption factor (NCRP 1989, Table B.7)

Thickness of overlying tissue to exit surface (centimeters)	Absorption factor (AF) Half-value layer (mm Al)					
	1.0	**1.5**	**2.0**	**3.0**	**4.0**	**5.0**
0	1.00	1.00	1.00	1.00	1.00	1.00
1	1.39	1.25	1.18	1.07	1.02	1.01
2	2.04	1.64	1.47	1.28	1.15	1.06
3	3.29	2.10	1.81	1.54	1.35	1.17
4	3.79	2.75	2.20	1.78	1.55	1.35
5	5.13	3.45	2.62	2.11	1.82	1.56
6	6.67	4.35	3.13	2.50	2.12	1.80
7	8.33	5.26	3.73	2.94	2.48	2.09
8	10.5	6.41	4.42	3.42	2.90	2.40
9	13.3	7.69	5.13	3.98	3.34	2.76
10	17.2	9.35	5.99	4.61	3.82	3.20
11	21.8	11.5	7.10	5.43	4.50	3.75
12	26.3	13.7	8.20	6.25	5.18	4.30
13	33.2	16.9	9.70	7.40	6.11	4.90
14	40.0	20.0	11.2	8.55	7.04	5.70
15	53.3	24.3	13.3	10.2	8.28	6.60
16	66.7	28.6	15.4	11.8	9.52	7.00
20	168	63.0	29.5	22.0	17.3	13.7
25	550	165	65.5	49.0	36.5	27.8
30	1,800	440	146	108	78.0	57.0
35		1,150	330	240	166	118

ATTACHMENT C
GUIDANCE FOR ASSIGNMENT OF X-RAY DOSE TO THE SKIN
Page 8 of 8

Table C-4. Excerpt from Table B.8 (NCRP 1989) average percentage depth doses for diagnostic X-ray beams

Depth (centimeters)	Average percentage depth dose (ADD)[a] Half-value layer (mm Al)				
	1.0	**1.5**	**2.0**	**3.0**	**4.0**
0	100	100	100	100	100
1	71.9	80.3	85.0	93.7	97.7
2	49.1	60.9	68.1	78.0	87.2
3	30.4	47.7	55.4	65.0	74.1
4	26.4	36.3	45.5	56.2	64.6
5	19.5	29.0	38.2	47.3	55.0
6	15.0	23.0	31.9	40.0	47.2
7	12.0	19.0	26.8	34.0	40.3
8	9.5	15.6	22.6	29.2	34.5
9	7.5	13.0	19.5	25.1	29.9
10	5.8	10.7	16.7	21.7	26.2
12	3.8	7.3	12.2	16.0	19.3
14	2.5	5.0	8.9	11.7	14.2
16	1.5	3.5	6.5	8.5	10.5
20	0.6	1.6	3.4	4.5	5.8
25	0.2	0.6	1.5	2.0	2.7
30	0.1	0.2	0.7	0.9	1.3
35	-	0.1	0.3	0.4	0.6

a. For 35 cm x 35 cm field size.