ORAU TEAM
Dose Reconstruction Project for NIOSH

Oak Ridge Associated Universities I Dade Moeller & Associates I MJW Corporation

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Area IV of the Santa Susana Field Laboratory, the Canoga Avenue Facility (Vanowen Building), the Downey Facility, and the De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International) – Occupational Medical Dose	Revision: 02 Effective Date: 10/31/2008 Type of Document: TBD Supersedes: Revision 01

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/03/2006	00	New technical basis document for the Energy Technical Center - Occupational Medical Dose. First approved issue. Initiated by Melton H. Chew.
09/08/2006	01	Revision to change the site name to Atomics International throughout the document in keeping with DOE site naming conventions. Updated required language in Section 3.1. Purpose section (Section 3.2) and Scope section (Section 3.3) were added. Approved Revision 01. No further changes occurred as a result of formal internal review. Incorporates NIOSH formal review comments. Training required: As determined by the Task Manager. Initiated by Melton H. Chew.
10/31/2008	02	Revision to change the site name to Area IV of the Santa Susana Field Laboratory, the Canoga Avenue Facility, the Downey Facility, and the De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International) to match the new DOE site naming conventions. Added Attributions and Annotations section. Organ doses are revised as follows: • AP lumbar spine, before 1971, uterine dose is decreased by a factor of 10; correcting an error, • AP and LAT lumbar spine, after 1997, except for breast and remainder, all organ doses are marginally decreased due to a change in beam quality assumption, • AP and LAT lumbar spine, all years, remainder organ dose is increased by a factor ranging from 2 to 15 due to a change in the reference organ used to define the remainder. Doses to skin at additional locations to the primary beam entrance are added in accordance with Revision 01 of ORAUT-PROC-0031. All skin doses at newly tabulated locations are lower than the skin dose at the primary beam entrance location. Maximum organ dose tables for PA and LAT chest, and AP and LAT lumbar spine, are deleted in accordance with Revision 01 of ORAUT-PROC-0031. A discrepancy between the dose tables and the text is corrected. The corrected frequency is lower to ensure any misunderstanding due to the discrepancy that would result in a favorable to claimant dose assessment. Text in Section 3.5.1.2 about examination frequency is relocated to Section 3.4 where it logically belongs. Breast doses from AP lumbar spine projections for periods after 1971 are increased by a factor 2.2 to 2.6. For the LAT lumbar spine projections the breast dose increases range from no change, up to a factor of 1.1. The increase results from a change in the assumed dose conversion factors recommended by the Principal Medical Dosimetrist. The term "view" is globally replaced with the more modern term "projection" and the term Entrance Skin Exposure (ESE) is replaced by the more modern term "entrance air kerma." The term "routine" when describing examination frequency is replaced by the more descriptive word "periodic." The terms "entrance" and "exit" in Tables 3-2 through 3-5 are replaced with "pre-employment" and

		"termination." Additional information on eye/brain organ doses prior to 1971 is added to Tables 3-2 and 3-3. The column showing entrance skin exposure in Table 3-2 through 3-5 is eliminated as this is not needed for dose reconstruction. The possibility that photon energy could be less than 30 keV is eliminated as this is applicable only to mammography. Testes dose in Table 3-5 associated with LAT lumbar spine exposures after 1997 decreases by 60% as a data error in the DCF is corrected. The description of skin doses has been modified to match that in newly issued guidance, and skin dose tables have been separated into two each for clarity in describing doses under poorly collimated versus well collimated exposure conditions. Incorporates formal NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Task Manager. Initiated by Melton H. Chew.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	anterior-posterior
AI	Atomics International
cGy	centigray
cm	centimeter
DCF	dose conversion factor
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	entrance skin exposure
ETEC	Energy Technology Engineering Center
FDA	Food and Drug Administration
Gy	gray
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt (1,000 electron-volts)
kVp	kilovolts-peak
LAT	lateral
mA	milliampere
mAs	milliampere-second
mGy	milligray
mm	millimeter
mR	milliroentgen
NAA	North American Aviation
NIOSH	National Institute for Occupational Safety and Health
PA	posterior-anterior
POC	probability of causation
R	roentgen
s	second
SID	source-to-image distance
SSD	source-to-skin distance
SRDB Ref ID	Site Research Database reference identification (number)
SSFL	Area IV Santa Susana Field Laboratory (See Section 3.3 for a discussion of the naming conventions used in this document.)
U.S.C.	United States Code
yr	year

§ section or sections

3.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide 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

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

3.2 PURPOSE

The purpose of this document is to provide a technical basis for evaluation of the occupational medical dose for EEOICPA claimants who were employed at Area IV of the Santa Susana Field Laboratory, the Canoga Avenue Facility (Vanowen Building), the Downey Facility, and the De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International [AI]) described below.

3.3 SCOPE

The scope of this document is technical data in relation to medical X-rays provided to workers as a condition of employment.

The facility, which includes four locations, has been identified in various ways over time. The name Santa Susana Field Laboratory (SSFL) is used to represent all of them unless more specific location information is warranted. In that context, SSFL includes Area IV of the Santa Susana Field Laboratory, which has also been known as the Nuclear Development Field Laboratory, Liquid Metal Engineering Center, and Energy Technology Engineering Center; portions of the Downey facility; the Vanowen Building at the Canoga facility; and the De Soto facility.

U.S. Atomic Energy Commission (AEC)-funded work at SSFL facility began in 1948. North American Aviation (NAA) entered into a contract with AEC to conduct nuclear research operations at Area IV and the Downey, Canoga, and De Soto sites. At that time, AI, an internal division of NAA, was the company's designated nuclear research and development division. In addition to the employees of the AI division, other employees of NAA who worked at any of the above sites during the AEC contract period are potentially eligible for EEOICPA benefits. While no evidence of the screening protocols have been found, it is clear from a review of actual X-rays and records in claim files that screening likely included chest and lumbar spine examinations. These examinations caused exposure of the lungs, spine, and other tissues of the body. Exposure came from the primary X-ray beam and from scattered radiation.

A review of randomly selected X-ray films that date back to 1956 provides insight into the occupational medical program (Morris 2005a). Individual SSFL medical charts do not contain X-ray films. If an old film is to be reviewed, the separate X-ray record must be retrieved. Three boxes of archived radiographs for approximately 300 individuals were reviewed. The boxes contained an envelope for each individual; each envelope contained films that spanned many years for that person. The outside of each file storage envelope describes the contents, so it is possible to determine the number and kind of radiograph and if the radiograph represents a preemployment examination, periodic reexamination, or a workup after an industrial injury. Radiographs that were associated with an industrial injury are typically identified as "IND"; they are not pertinent to dose reconstruction. Due to corporate reorganizations, the medical records of employees of the AI division of NAA are intermingled with records of Rocketdyne, another internal division of NAA. Employees of Rocketdyne (or any other employee of NAA) are potentially within the scope of EEOICPA if they worked at Area IV or the Downey, Canoga, or De Soto locations during the period when the AEC contract work was performed. In a few cases, a file was annotated "AI" indicating that the person was an AI employee, but in the majority of cases the employment status is not clear. The review of records suggests that:

- About half of the preemployment examinations included both posterior-anterior (PA) and lateral (LAT) chest projections and one or two projections (PA and LAT) of the lumbar spine. The remainder included only one PA chest projection.

- It was rare for an employee to have annual chest radiographs. Most individuals were never subjected to periodic radiographic reexamination.

- Of those who were reexamined, the typical periodic examination frequency was every 3 to 5 years. About half of those reexamined had one PA chest projection. Others had a PA chest and some form of lumbar spine examination.
- There was no evidence of collimation on the radiographs.
- There was no evidence to suggest the use of photofluorography.
- There was no evidence to suggest the use of fluoroscopy.
- There was no evidence to suggest the use of stereo chest films (same projection on two films, slightly displaced).
- All projections – PA chest, LAT chest, AP lumbar spine, and LAT lumbar spine – that were commonly found in the records were of the same size: 14 by 17 in.
- In a few cases, AP spot and LAT spot lumbar spine projections were observed, and in these cases a smaller film size, 10 by 12 in., was common.
- There was no evidence of the use of gonadal shielding in the lumbar spine radiographs.

Interviews (Chew 2005; Morris 2005a) with medical clinic personnel provided information on the equipment and techniques that were used between 1971 and 1997. By 1998, all radiographic examinations were subcontracted to West Hills Hospital in West Hills, California.

Neutron exposures were not used in occupational medical evaluations and are not part of the occupational medical dose. Similarly, there is no electron dose in the occupational medical dose.

3.4 EXAMINATION FREQUENCY

Existing programmatic documents do not furnish a complete record of the screening protocol that was used since 1948 to determine which workers were required to have X-ray examinations or the frequencies of the examinations for occupational health screening. Instead the screening protocol was inferred from the information described above (Morris 2005a). In addition, the claimant records provided by DOE are likely to provide information on the radiographs that were administered to the Energy Employee (EE). This is discussed in Section 3.5. The assumptions that are provided in this section should be used when the claimant record proves to be inadequate or unavailable.

3.4.1 Preemployment Examination

3.4.1.1 Before 1971

Radiation safety standards dating back to 1966 (Garcia and Alexander 1970) required “pre-exposure examinations” for radiation workers. This examination was to include a chest X-ray. It is reasonable to assume that this practice has been in effect for radiation workers since the origination of SSFL [1]. For dose reconstruction this should be interpreted as a preemployment physical requirement.

SSFL employees who were not radiation workers would not have been covered by the radiation safety standard. Therefore, some employees might not have received routine preemployment radiographic examinations. A review of SSFL X-ray film historical records (Morris 2005b) indicated that some employees had preemployment chest and lumbar spine radiographic examinations. Criteria for the selection of these employees have not been found.

A reasonable assumption [2] that gives the benefit of the doubt to claimants is that before 1971 all employees had a preemployment examination consisting of:

- PA chest film,
- LAT chest film,
- AP lumbar spine film,
- AP lumbar spine spot film,
- LAT lumbar spine film, and
- LAT lumbar spine spot film.

3.4.1.2 1972 Through 1997

In an interview, the nurse who took many of the radiographs, beginning in 1971, stated that preemployment physicals were routinely required of all SSFL personnel (Chew 2005). Such physicals included a PA chest radiograph. Lumbar spine radiographs were sometimes required, depending on the job description. No photofluorography was performed. This or a similar examination policy was probably in place before 1966 and continued well into the 1990s. A reasonable assumption [3] that gives the benefit of the doubt to claimants is that all employees had a preemployment examination consisting of:

- PA chest film,
- LAT chest film,
- AP lumbar spine film,
- AP lumbar spine spot film,
- LAT lumbar spine film, and
- LAT lumbar spine spot film.

3.4.1.3 After 1997

A 2005 interview with the medical director found that the policy on chest X-rays that is described in Section 3.4.1.2 was in place when he assumed his position in 1995 (Morris 2005a). By 1997, he was actively discouraging chest X-rays. Preemployment lumbar spine and chest radiography has not occurred as a condition of employment since 1997.

3.4.2 Periodic Examination

3.4.2.1 Before 1971

Radiation safety standards that date back to 1966 (Garcia and Alexander 1970) required periodic examinations at a minimum frequency of 1 yr for radiation workers. The standards also required termination examinations. The periodic examination included a chest X-ray. The standard does not require lumber spine examination. This or a similar examination policy was probably in place before 1966 and continued well into the 1990s. Dose reconstructors may assume each radiation worker had a PA and LAT radiographic chest examination every year and one AP and LAT lumbar spine with an AP and LAT lumbar spine spot film examination every 3 years [4].

For personnel who were not radiation workers, no information is available about the periodic radiographic examination schedule. A review of SSFL X-ray film historical records (Morris 2005b) suggests that some workers did undergo periodic surveillance. No clear frequency pattern was discernable, but annual examinations were rare. Among those who received periodic surveillance, 3 to 5 years (and often more) elapsed between radiographic examinations. Dose reconstructors may assume each person who was not a radiation worker had one PA and LAT radiographic chest examination every 3 years and one AP and LAT lumbar spine with an AP and LAT lumbar spine spot film examination every 3 years [5].

3.4.2.2 1971 Through 1997

The examination frequency and assumptions that are described for years before 1971 applies for the period from 1971 through 1997 [6].

3.4.2.3 After 1997

A 2005 interview with the medical director found that the policy on chest X-rays was in place when he assumed his position in 1995 (Morris 2005a). By 1997, he was actively discouraging routine chest X-ray screening. Lumbar spine and chest radiography have not been performed for screening since 1997.

Tables 3-2 through 3-5 include information on the frequency of chest radiography for periods throughout the SSFL operating history.

3.5 EQUIPMENT AND TECHNIQUES

3.5.1 Before 1971

No specific information is available on medical X-ray equipment and techniques that were used at SSFL before 1971. An interview with the current SSFL physician (Morris 2005a), who is familiar with the content of the historical medical files, and an inspection of randomly selected radiographs from this period (Morris 2005b) revealed no evidence that photofluorography, fluoroscopy, or stereo radiography was used at SSFL.

3.5.1.1 Chest Projections

The pre-1971 parameters for PA and LAT chest radiography are assumed values based on data for the “Pre-1970 Period” in Table 3-4 of ORAUT (2005). Therefore, 0.20 cGy is the assumed entrance kerma in the PA projection, and 0.50 cGy in LAT projection.

3.5.1.2 Lumbar Spine Projections

The pre-1971 default values for AP and LAT lumbar spine radiography are based on data for the technique that is described in Tables 7-7 through 7-9 of ORAUT (2005). Table 7-7 lists the AP and AP spot projection techniques as 80 kVp, 2.0 mm of Al HVL, 40 mA, for 4 s at a source-to-image distance (SID) of 99 cm with a 20-cm cone. Two AP projections are assumed: the AP and the AP spot. Table 7-7 lists LAT and LAT spot projection techniques as 86 kVp, 2.0 mm of Al HVL, 40 mA, for 8 s at SID of 99 cm with a 20-cm cone. Two LAT projections are assumed: the LAT and the LAT spot. Table 7-8 from ORAUT (2005) defines the entrance skin exposure (ESE) for both AP lumbar spine projections combined as 4.0 rem (1 rem is typically assumed for dosimetry purposes to be numerically the same as 1 cGy, so the entrance air kerma is interpreted to be 4 cGy) (ORAUT 2005, Section 3.1). The entrance air kerma for the combined LAT lumbar spine projections is 10 rem (10 cGy). If it can be shown that only one AP or LAT lumbar spine projection was made, it is reasonable to assume these values can be divided by 2 [7].

3.5.2 1971 Through 1997

An interview with the nurse/technician who operated the X-ray machine revealed that before or during 1971 a Picker X-ray system, Model 754971, was installed in the SSFL clinic (Chew 2005). The reported maximum settings on the unit were 125 kVp and 600 mA. The equipment was used for PA chest and lumbar spine projections. The normal technique for chest X-rays was to use 80- to 90-kVp tube potential and 1/60 s exposure time, which according to the notes in this interview resulted in an exposure of 200 mAs at a standard SID of 72 in.

The reported value of 200 mAs (Chew 2005) is unreasonably high, and is judged to be wrong (Morris 2008). If the Picker X-ray machine delivered a 200 mAs exposure to an X-ray film and cassette assembly, the resultant film would be overexposed and have no value as a diagnostic tool. The reviewing physician would have required the technique be changed to a lower exposure. For chest examinations PA projections, a value closer to 10 mAs is more likely (CRCPD 1994) and 20 mAs is a high estimate. Therefore, the value of 20 mAs is assumed. ORAUT (2005) suggests a conservative estimate for the entrance air kerma for the LAT projection of 2.5 times the PA entrance air kerma. Using this estimate, the analysis assumed the exposure for the LAT projection is 50 mAs. This TBD assumes these values for calculation of entrance air kerma and organ dose for chest X-rays.

3.5.2.1 Chest Projections

For simplicity, this TBD assumes the performance of all chest radiographs at 90 kVp because this produces a higher average air kerma rate than 80 kVp and is, therefore, favorable to claimants [8]. The machine filtration is not known so, consistent with the recommendation of ORAUT (2005) for machines before 1980, this TBD analysis assumed it to be 2.5 mm Al. Based on Table B.3 in NCRP (1989), a single-phase machine with an SID of 183 cm (72 in.) and operating at 90 kVp produces an average air kerma rate of 0.18 cGy/100 mAs. For a 20-mAs exposure in the AP projection, this equates to average air kerma of 0.036 cGy. For 50 mAs in the LAT projection, this equates to an average air kerma of 0.09 cGy. Correcting for a source to skin distance (SSD) of 154 cm, the entrance air kerma (numerically the same as the ESE) is 0.050 cGy for the PA projection and 0.130 cGy for the LAT projection. These entrance air kerma values are used to calculate organ doses, as discussed in Section 3.1 of ORAUT (2005).

3.5.2.2 Lumbar Spine Projections

No specific information is available on the lumbar spine technique that was used at SSFL in this period; the default data in ORAUT (2005) for lumbar spine projections is derived from 1953 data and unlikely to reflect the practice 2 decades later. The lumbar spine technique was probably a modern one [9], similar to that which was described in 1995 by the Conference of Radiation Control Program Directors (CRCPD 2001). As a consequence, this analysis assumes the technique to be 78 kVp, 294 mAs, half-value layer of 3.1 mm Al, with an average entrance air kerma of 0.370 cGy.

3.5.3 After 1997

In 1997, the Picker system was retired and radiographic examinations were performed on a subcontract basis at West Hills Hospital. That arrangement continued at least through 2006. Considering the wide assortment of X-ray equipment at a modern medical center such as West Hills, it is not possible to identify the specific equipment and techniques that were used. However, it is reasonable to assume the use of modern well-maintained equipment for exposures [10].

3.5.3.1 Chest Projections

This TBD bases its assumption of the post-1997 default values for PA and LAT chest on data for the “Post-1985 Period” in Table 3-4 of ORAUT (2005). The entrance kerma for the PA projection is 0.05 cGy. For the LAT projection, the entrance kerma is 0.13 cGy.

3.5.3.2 Lumbar Spine Projections

No specific information is available on the lumbar spine technique that was used at SSFL during this period; the default data in ORAUT (2005) for lumbar spine projections is derived from 1953 data and unlikely to reflect the practice 2 decades later. The lumbar spine technique was probably a modern one, similar to that which was described in 1995 by the Conference of Radiation Control Program Directors (CRCPD 2001) [11]. The TBD analysis assumes that the technique is 78 kVp, 294 mAs, with an average entrance air kerma of 0.370 cGy.

3.6 ORGAN DOSE CALCULATIONS

With the exception of measured values taken from tables, and dose to the skin, estimates of the mean dose equivalents to individual organs from a given X-ray exposure are the product of the entrance air kerma and a dose conversion factor (DCF) from ICRP (1982) or some other source (ORAUT 2005). Skin doses calculations are described in Morris (2008).

For well-collimated chest and lumbar spine radiographs of differing beam quality, ICRP (1982) contains tables of DCFs for as many as seven organs and the total (whole) body based on an adult anthropomorphic phantom. For an organ that is not listed in these tables but is needed for the Interactive RadioEpidemiological Program (IREP), the DCF is usually that for the anatomically closest organ in the ICRP tables. Table 3-1 lists ICRP reference organs for IREP analogues (ORAUT 2005), assuming a properly collimated chest X-rays. ICRP (1982) lists different DCFs for males and females for the lung, bone marrow, and total (whole) body. The larger of the two values is assigned for the dose equivalent to the IREP organ analogues.

Table 3-1. Analogues for IREP organs not included in ICRP (1982) for use with properly collimated chest X-rays .

Anatomical location	ICRP (1982) reference organ	IREP organ analogue
Thorax	Lung	Thymus Esophagus Stomach Bone surface Liver/gall bladder/spleen Remainder organs
Abdomen	Ovaries	Urinary/bladder Colon/rectum
Head and neck	Thyroid	Eye/brain

Source: ORAUT (2005, Table 3-2).

The ICRP tables were developed under the assumption that the primary X-ray beam is collimated to the image receptor size, which is reasonable subsequent to 1971. Earlier techniques were probably not well collimated (ORAUT 2005 A2.4.2). Because no information about the collimation practices before 1971 was discovered, the application of these DCF tables to the early X-ray machines must occur in a way that compensates for the possible lack of collimation. ORAUT (2005) assessed allowance for this circumstance during different periods in the past based on ICRP (1982).

The ICRP DCFs give the average dose equivalent in a given organ in milligray for different beam qualities when the entrance kerma (air kerma in air without backscatter) is 1 Gy. ORAUT (2005) approximated that an ESE of 1 R produces a skin entrance kerma of 1 rad. In addition to simplifying the computations, this assumption is well within relatively large uncertainties from other sources and is favorable to claimants.

This TBD analysis used the following guidelines to develop Tables 3-2 through 3-9.

When an organ dose equivalent difference between male and female organs exists, the higher value is listed in Tables 3-2 through 3-5.

ICRP (1982) does not tabulate dose conversion factors for lumbar spine projections for the female breast, but the table includes the comment "Not computed but small compared to the projections listed above." The basis for the DCFs used in the calculations is in Morris (2008).

Default assumptions in ORAUT (2005) are used unless specific data or documented assumptions to the contrary are cited. If specific claimant files indicate the use of photofluorography, dose reconstructors should apply the default parameters and organ dose factor values in ORAUT (2005).

Table 3-2 is a summary of parameters and organ doses for 14- by 17-in. PA chest radiography for periods during which each X-ray system was in use. Table 3-3 is a summary of parameters and organ doses for LAT chest radiography. The calculations are detailed in Morris (2008). Lung dose is used as a surrogate for remainder organ dose [12].

Tables 3-4 and 3-5 summarize parameters and organ doses for AP and LAT lumbar spine radiography, respectively. The calculations are detailed in Morris (2008). Lumbar spine films are sometimes done in pairs: a large 14- by 17-in. radiograph and a smaller spot film of the same projection. If the claimant medical records indicate the use of both a large format and spot film of the same projection, dose reconstructors should double the doses in Tables 3-4 and 3-5 to represent the dose for that pair of exposures [13]. Ovary dose is used as a surrogate for remainder organ dose [14].

Tables 3-6 through 3-13 lists doses for regions of the skin on the entrance and exit side of the primary beam. Tables 3-6 and 3-7 provide data associated with the PA chest projection, and Tables 3-8 and 3-9 provide data associated with the LAT chest projection. Tables 3-10 and 3-11 provide data associated with the AP lumbar spine projection, and Tables 3-12 and 3-13 provide data associated with the LAT lumbar spine projection.

3.7 DOSE RECONSTRUCTION

The records DOE provided are likely to include adequate information to define the date, type, and count of X-ray examinations that were administered to the Energy Employee for screening and as a condition of employment. The default periodic examination frequency will provide a maximizing dose estimate.

To perform a best estimate dose the dose reconstructors should consider requesting that the notes on the exterior of the envelope(s) that contain the Energy Employee's X-ray films be transcribed and provided. These notes should give insight to the reason that the exposures were made, for example pre-employment examination, periodic screening, or diagnosis of injury. Dose reconstructors should assume that any radiograph that was <u>not</u> a PA chest, LAT chest, AP lumbar spine, or LAT lumbar spine projection was diagnostic, not to be included in dose reconstruction under EEOICPA. If the X-ray envelope notes associate the annotation "IND" or "industrial" with a particular exposure, that means the radiograph was a diagnostic exposure (i.e., associated with a workplace injury). "IND" radiographs are not included in dose reconstruction.

The photon energy associated with occupational medical X-ray dose is in the 30-to-250-keV energy group. Assignment of all SSFL occupational medical doses to the 30-to-250-keV energy group is favorable to claimants and recommended (ORAUT 2005).

For purposes of skin dose calculations note that standard radiographic imagining procedures require the subject to be positioned in a particular orientation. Consequently the entrance skin dose side for lateral projections is well known. This orientation information is reflected in Tables 3-6 through 3-16.

3.8 UNCERTAINTY

ORAUT (2005) analyzed uncertainties in the required occupational medical X-ray organ doses. The document considered several major sources of uncertainty: measurement errors; variations in applied voltage (peak voltage), beam current and exposure time; and uncertainties due to worker size and placement. ORAUT (2005) assesses the relative error in an individual entrance air kerma or organ dose to be ±30% at 1 standard deviation. The actual doses could have been as much as 30% larger than those listed in Tables 3-2 through 3-13.

3.9 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.

[1] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Data that are cited in Morris (2005b) support the assumption that radiographic examinations performed for screening were at no time more frequent than annual. These data also shows that spot films of any kind were rare. The default assumptions for radiographic frequency are based on professional judgment and are likely to be biased to be favorable to the claimant.

[2] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Data that are cited in Morris (2005b) are applicable to all workers at SSFL because the records of radiation workers are intermingled with those of nonradiation workers.

[3] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Professional judgment that is informed by the data that is cited in Morris (2005b).

[4] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Professional judgment that is informed by the data that is cited in Morris (2005b).

[5] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Professional judgment that is informed by the data that is cited in Morris (2005b).

[6] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Professional judgment that is informed by the data that is cited in Morris (2005b).

[7] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. The default values in Tables 7-8 and 7-10 of ORAUT (2005) are based on a single exposure that has been doubled to account for the possibility that a spot film was taken at the same time. The data are separated here to accommodate the more likely situation that a spot film was not taken. No exposure or dose data exists separately for spot films, so following the precedent in ORAUT (2005) the assumption is made that the entrance air kerma is the same for both the normal exposure and the spot film.

[8] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. An X-ray tube that is operated at a fixed current produces an entrance air kerma directly proportional to the operating potential. See the discussion in Section 2.1 of ORAUT (2005).

[9] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. The equipment was similar to the kind that is found at any contemporary private clinic in the United States and therefore is well represented by the survey results that are presented in the CRCPD report.

[10] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Hospital accreditation practices in the United States ensure that reasonably modern equipment is available as a standard of care.

[11] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Hospital accreditation practices in the United States ensure that reasonably modern equipment is available as a standard of care.

[12] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Either the lung or the breast is the organ with the highest dose in chest exposures. Use of the lung dose overestimates the value for any other organ except the breast, which is tabulated separately.

[13] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. The default values in Tables 7-8 and 7-10 of ORAUT (2005) are based on a single exposure that has been doubled to account for the possibility that a spot film was taken at the same time. The data are separated here to accommodate the more likely situation that a spot film was not taken. No exposure or dose data exists separately for spot films, so following the precedent in ORAUT (2005) the assumption is made that the entrance air kerma is the same for both the normal exposure and the spot film.

[14] Robert L. Morris. Principal Health Physicist. M. H. Chew & Associates. November 2007. Either the ovary or uterus is the organ with the highest dose in lumbar spine exposures. Use of the ovary dose overestimates the value for any other organ except the uterus, which is tabulated separately.

Table 3-2. Parameters and organ doses (rem) per exposure for 14- by 17-in. PA chest radiography.

Period	Frequency	Applicability	Eye/brain	Thyroid[a]	Ovaries[a]	Testes[a]	Lungs[a, c]	Breast[a]	Uterus (embryo)[a]	Bone marrow[a, c]	Remainder[b]
Pre-1971	Pre-employment: likely Periodic annual: likely Termination: likely	All radiation workers	6.40E-03	3.48E-02	2.5E-02	5.0E-03	9.02E-02	9.80E-03	2.5E-02	1.84E-02	9.02E-02 (b)
Pre-1971	Pre-employment: likely Periodic assumed to be at 3-yr intervals Termination: not likely	Nonradiation workers	6.40E-03	3.48E-02	2.5E-02	5.0E-03	9.02E-02	9.80E-03	2.5E-02	1.84E-02	9.02E-02 (b)
1971 to 1997	Pre-employment: likely Periodic annual: likely Termination: likely	All radiation workers	1.60E-03	1.60E-03	5.00E-05	5.00E-07	2.26E-02	2.45E-03	6.50E-05	4.60E-03	2.26E-02
1971 to 1997	Pre-employment: likely Periodic: assumed to be at 3-yr intervals Termination: not likely	Nonradiation workers	1.60E-03	1.60E-03	5.00E-05	5.00E-07	2.26E-02	2.45E-03	6.50E-05	4.60E-03	2.26E-02
1998 to present	Highly unlikely	All workers	3.90E-03	3.90E-03	2.60E-04	5.00E-07	3.37E-02	5.80E-03	2.60E-04	8.90E-03	3.37E-02

a. Organs identified in ICRP (1982).
b. Female lung is the reference organ for "Remainder."
c. Male bone marrow data and female lung data are reported as these produce the highest values.

Table 3-3. Parameters and organ doses (rem) per exposure for 14- by 17-in. LAT chest radiography.

Period	Frequency	Applicability	Eye/brain	Thyroid[a]	Ovaries[a]	Testes[a]	Lungs[a, c]	Breast[a]	Uterus (embryo)[a]	Bone marrow[a, c]	Remainder[b]
Pre-1971	Pre-employment: likely Periodic annual: likely Termination: likely	All radiation workers	6.85E-2	6.85E-02	1.3E-02	2.5E-03	1.10E-01	1.28E-01	1.3E-02	1.85E-02	1.10E-01
Pre-1971	Pre-employment: likely Periodic assumed to be at 3-yr intervals Termination: not likely	Nonradiation workers	6.85E-02	6.85E-02	1.3E-02	2.5E-03	1.10E-01	1.28E-01	1.3E-02	1.85E-02	1.10E-01
1971 to 1997	Pre-employment: likely Periodic annual: likely Termination: likely	All radiation workers	1.50E-02	1.50E-02	7.80E-05	1.30E-05	: 2.86E-02	3.32E-02	7.80E-05	4.81E-03	2.86E-02
1971 to 1997	Pre-employment: likely Periodic: assumed to be at 3-yr intervals Termination: not likely	Nonradiation workers	1.50E-02	1.50E-02	7.80E-05	1.30E-05	2.86E-02	3.32E-02	7.80E-05	4.81E-03	2.86E-02
1998 to present	Highly unlikely	All workers	2.13E-02	2.13E-02	3.25E-04	1.30E-05	4.56E-02	4.46E-02	2.73E-04	9.88E-03	4.56E-02

a. Organs identified in ICRP (1982).
b. Female lung is the reference organ for "Remainder."
c. Male bone marrow and female lung data are reported as these produce the highest values.

Table 3-4. Parameters and organ doses (rem) for a single-exposure AP lumbar spine radiograph[b].

Period	Frequency	Applicability	Thyroid[a]	Ovaries[a]	Testes[a]	Lungs[a]	Breast[a]	Uterus (embryo)[a]	Bone marrow[a]	Remainder[c]
Pre-1971	Pre-employment: likely Periodic annual: assumed to be at 3-yr intervals Termination: not likely	All workers	4.00E-04	5.60E-01	2.70E-02	1.24E-01	3.60E-02	4.34E-01	4.80E-02	5.6E-01
1971 to 1997	Pre-employment: likely Periodic: assumed to be at 3-yr intervals Termination: not likely	All workers	1.11E-04	7.99E-02	1.55E-03	2.92E-02	4.85E-03	1.06E-01	1.37E-02	7.99E-02
1998 to present	Highly unlikely	All workers	2.22E-04	1.01E-01	2.37E-03	3.52E-02	5.92E-03	1.31E-01	1.96E-02	1.01E-01

a. Organs identified in ICRP (1982).
b. ESE and organ doses are presented for a single AP or spot AP lumbar spine projection. If both AP and spot AP lumbar spine projections were imaged, double the entrance air kerma and organ doses in this row.
c. Ovary is the reference organ for "Remainder".

Table 3-5. Parameters and organ doses (rem) for a single-exposure LAT lumbar spine radiograph[b].

Period	Frequency	Applicability	Thyroid[a]	Ovaries[a]	Testes[a]	Lungs[a]	Breast[a]	Uterus (Embryo)[a]	Bone marrow[a]	Remainder[c]
Pre-1971	Pre-employment: likely Periodic: assumed to be at 3-yr intervals Termination: not likely	All workers	5.00E-05	7.60E-01	5.6E-02	5.00E-02	4.75E-02	1.00E-01	7.50E-02	7.60E-01
1971 to 1997	Pre-employment: likely Periodic: assumed to be at 3-yr intervals Termination: not likely	All workers	3.70E-06	1.74E-02	2.96E-04	5.18E-03	1.85E-03	1.15E-02	8.14E-03	1.74E-02
1998 to present	Highly unlikely	All workers	3.70E-06	2.48E-02	4.44E-04	6.29E-03	2.59E-03	1.67E-02	1.15E-02	2.48E-02

a. Organs identified in ICRP (1982).
b. ESE and organ doses are listed for a single LAT or spot LAT lumbar spine projection. If both LAT and spot LAT lumbar spine projections were imaged, double the entrance air kerma and organ doses in this row.
c. Ovary is the reference organ for "Remainder".

Table 3-6. Skin doses per exposure for poorly collimated PA chest radiography.

Poorly Collimated PA Chest Skin Dose	**Pre-1971**
Region of the Skin	
Entrance (Posterior) Side of the Body	
Inside primary beam: back and sides of chest to iliac crest, back of shoulders, back of neck, upper arms, elbows, forearms, and palms of hands.	2.78E-01
Outside but near primary beam: back of head, ears, and buttocks	2.78E-02
Exit (Anterior) side of the body	
Inside primary beam: front of chest, front of shoulders, front of upper abdomen (to iliac crest), front of neck.	6.30E-03
Backs of hands	2.41E-01
Outside but near primary beam: face, front lower abdomen from iliac crest to pubis	6.30E-04
All skin covering the following	
Thighs to top of knees	9.05E-05
Knees and below	3.31E-05

Table 3-7. Skin doses per exposure for well collimated PA chest radiography.

Well Collimated PA Chest Skin Dose	**1972 to 1997**	**1998 to present**
Region of the Skin		
Entrance (Posterior) Side of the Body		
Inside primary beam: back and sides of chest from base of neck to lowest rib, and back of shoulders	6.95E-02	7.10E-02
Outside but near primary beam: back of head, neck, ears, buttocks, arms, and hands	6.95E-03	7.10E-03
Exit (Anterior) side of the body		
Inside primary beam: front of chest from base of neck to lowest rib, and front of shoulders.	1.58E-03	2.16E-03
Outside but near primary beam: face	1.60E-03	3.90E-03
Outside but near primary beam: front lower abdomen from iliac crest to pubis	1.58E-04	2.16E-04
All skin covering the following		
Thighs to top of knees	2.26E-05	2.79E-05
Knees and below	8.27E-06	1.02E-05

Table 3-8. Skin doses per exposure for poorly collimated LAT chest radiography.

Poorly Collimated LAT Chest Skin Dose	Pre-1971
Region of the Skin	
Entrance (Right) Side of the Body	
Inside primary beam: right side of torso from base of neck to iliac crest, including right shoulder, and upper right arm to elbow.	6.95E-01
Outside but near primary beam: head, face, ears, right side of hip, elbows, forearms, and hands	6.95E-02
Exit (Anterior) side of the body	
Inside primary beam: left side of torso from base of neck to iliac crest, including left shoulder, and upper left arm to elbow.	3.22E-03
Outside but near primary beam: left side of hip	3.22E-04
Front and Back (Anterior and Posterior)	
Inside primary beam: front and back of torso from base of neck to iliac crest (lung)	1.10E-01
Outside but near primary beam: buttocks and front of lower abdomen (10% lung)	1.10E-02
All skin covering the following	
Thighs to top of knees	2.26E-04
Knees and below	8.27E-05

Table 3-9. Skin doses per exposure for well collimated LAT chest radiography.

Well Collimated LAT Chest Skin Dose	1972 to 1997	1998 to present
Region of the Skin		
Entrance (Right) Side of the Body		
Inside primary beam: right side of torso from base of neck to lowest rib, including right shoulder, and upper right arm to elbow	1.81E-01	1.85E-01
Outside but near primary beam: head, face, ears, right side of hip, right elbow, right forearm, and right hand	1.81E-02	1.85E-02
Exit (Left) side of the body		
Inside primary beam: left side of torso from base of neck to lowest rib, including left shoulder, and upper left arm to elbow.	8.37E-04	1.24E-03
Outside but near primary beam: left side of hip, left elbow, left forearm, and left hand	8.37E-05	1.24E-04
Front and Back (Anterior and Posterior)		
Inside primary beam: front and back of torso from base of neck to lowest rib (Lund dose)	2.86E-02	4.56E-02
Outside but near primary beam: buttocks and front of abdomen (10% lung)	2.86E-03	4.56E-03
All skin covering the following		
Thighs to top of knees	5.88E-05	7.25E-05
Knees and below	2.15E-05	2.65E-05

Table 3-10. Skin doses per exposure for single-exposure poorly collimated AP lumbar spine radiography[a].

Poorly Collimated AP Lumbar Spine Skin Dose	Pre-1971
Region of the Skin	
Entrance (Anterior) Side of the Body	
Inside primary beam: front of abdomen and chest from the armpits to below pubis, hand, forearms, and elbows.	2.64E+00
Outside but near primary beam: upper arms, front of shoulders, and front of thighs	2.64E-01
Exit (Posterior) side of the body	
Inside primary beam: back of abdomen and chest from the armpits to the buttocks..	9.94E-02
Outside but near primary beam: upper back, back of shoulders, back of thighs.	9.94E-03
All skin covering the following	
Neck face and ears	1.52E-03
Knees and below	6.74E-04

a. Double these values if an AP lumbar spine spot film was taken.

Table 3-11. Skin doses per exposure for single-exposure well collimated AP lumbar spine radiography[a].

Well Collimated AP Lumbar Spine Skin Dose	1972 to 1997	1998 to present
Region of the Skin		
Entrance (Anterior) Side of the Body		
Inside primary beam: front of abdomen from the end of the sternum to the pubis.	5.14E-01	5.14E-01
Outside but near primary beam: front of chest, upper arms, front of shoulders, elbows, forearms, hands, and front of thighs.	5.14E-02	5.14E-02
Exit (Posterior) side of the body		
Inside primary beam: back from the mid rib cage to the buttocks..	2.60E-02	2.60E-02
Outside but near primary beam: upper back, back of shoulders, back of thighs.	2.60E-03	2.60E-03
All skin covering the following		
Neck face and ears	3.84E-04	3.84E-04
Knees and below	1.71E-04	1.71E-04

a. Double these values if an AP lumbar spine spot film was taken.

Table 3-12. Skin doses per exposure for single-exposure poorly collimated LAT lumbar spine radiography[a].

Poorly Collimated LAT Lumbar Spine Skin Dose	Pre-1971
Region of the Skin	
Entrance (Right) Side of the Body	
Inside primary beam: right side of torso from the armpits to side of right thigh	6.60E+00
Outside but near primary beam: right shoulder, right arm, right hand, right thigh	6.60E-01
Exit (Left) side of the body	
Inside primary beam: left side of torso from armpits to left side of thigh.	1.12E-01
Outside but near primary beam: left shoulder, left arm, left hand, left thigh	1.12E-02
Front and Back (Anterior and Posterior)	
front and back of chest and abdomen from base of neck to pubis/buttocks	5.00E-02
All skin covering the following	
Neck face and ears	3.79E-03
Knees and below	1.68E-03

a. Double these values if a LAT lumbar spine spot film was taken.

Table 3-13. Skin doses per exposure for single-exposure well collimated LAT lumbar spine radiography[a].

Well Collimated LAT Lumbar Spine Skin Dose	1972 to 1997	1998 to present
Region of the Skin		
Entrance (Right) Side of the Body		
Inside primary beam: right side of torso from level of the base of the sternum to right hip	5.14E-01	5.14E-01
Outside but near primary beam: right shoulder, right arm, right hand, right thigh	5.14E-02	5.14E-02
Exit (Left) side of the body		
Inside primary beam: left side of torso from level of the base of the sternum to left hip	1.17E-02	1.17E-02
Outside but near primary beam: left shoulder, left arm, left hand, left thigh	1.17E-03	1.17E-03
Front and Back (Anterior and Posterior)		
Front and back of chest and abdomen from base of neck to pubis/buttocks: (lung dose)	5.18E-03	6.29E-03
All skin covering the following		
Neck face and ears	3.84E-04	3.84E-04
Knees and below	1.71E-04	1.71E-04

a. Double these values if a LAT lumbar spine spot film was taken.

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GLOSSARY

absorbed dose
Energy absorbed per unit mass; units are rad and gray.

backscatter
Radiation scattered backwards, enhancing skin dose in areas where an X-ray beam enters the body.

dose equivalent
Product of absorbed dose and a quality factor or radiation weighting factor. With absorbed dose in rad, unit is rem.

exposure
Amount of electric charge produced per unit mass of air by electromagnetic radiation.

gray (Gy)
Unit of absorbed dose, defined as 1 joule per kilogram. It is equal to 100 rad.

kerma
Sum of initial kinetic energies of all charged particles (including Auger electrons) liberated by uncharged radiation per unit mass. Units are rad and gray. The word derives from the phrase Kinetic Energy Released in Matter.

lumbar spine
The vertebrae of the lower back.

rad
Unit of absorbed dose, defined as 100 ergs per gram. It is equal to 0.01 Gy.

rem
Unit of dose equivalent.

roentgen (R)
Unit of exposure.

X-ray
(1) Electromagnetic radiation emitted by fast electrons slowing down in matter or in certain electronic transitions in atoms. (2) A radiograph produced by X-rays.