



ORAU TEAM Dose Reconstruction Project for NIOSH

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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
06/24/2005	00	New technical basis document for the Weldon Spring Plant – Occupational Medical Dose. Incorporates formal NIOSH and internal review comments. Training is not required. First approved issue. Initiated by Robert Meyer.
01/30/2013	01	Revised to incorporate historical documents captured since the first revision, to include skin doses for all areas of skin, and to address SC&A comments. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by David P. Harrison.

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ACRONYMS AND ABBREVIATIONS

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
HVL	half-value layer
kerma	initial kinetic energy of charged particles liberated by uncharged ionizing radiation per unit mass
LAT	lateral
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
PFG	photofluorography
POC	probability of causation
RSD	Remote skin dose
SRDB	Site Research Database
TBD	technical basis document
U.S.C.	United States Code
WSP	Weldon Spring Plant
§	section or sections

3.1 OCCUPATIONAL MEDICAL DOSE

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 causation¹] 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 **Introduction**

As part of the requirements for employment at the Weldon Spring Plant (WSP) from 1955 through 1966 (the WSP operational period) and from 1985 to 2002 (the WSP remediation period), all workers received periodic physical examinations (MCW 1958–1967). These included annual radiographic examinations of the chest, as recorded in claim file records and in medical records for WSP workers, and periodic chest X-ray examinations for remediation workers exposed to asbestos or using respirators (Lopez 2004). NIOSH, in its role to reconstruct occupational dose under the EEOICPA (42 U.S.C. § 7384-7385), has classified medical X-rays administered for occupational health screening in conjunction with routine physical examinations as occupational exposures (NIOSH 2002). This TBD presents what is currently known about such medical X-ray exposures received by workers at WSP. In addition, this TBD provides dose estimates for workers who might have been present between 1966 and 1985, including security personnel who might have received X-ray examinations as a requirement of employment. It also provides estimates for post-1985 remediation personnel.

3.1.2 **Examination Frequency**

The frequency and type of X-ray examinations are recorded in claim file records and in medical records for WSP workers from 1955 through 1966 (MCW 1958–1967). Neither a protocol for the frequency of chest X-ray examinations as a function of job category nor a reference to any other type of X-ray screening examination having been performed has been located. However, the references clearly indicate that chest X-ray examinations were performed annually from 1955 through 1966, and medical records indicate that both the posterior-anterior (PA) and lateral (LAT) projections were taken. Therefore, the assumption in this TBD is that annual PA and LAT chest X-ray examinations were made on all employees. It is also assumed that the same frequency of chest X-ray examinations would have been used for security personnel from 1966 through 1985, since no evidence has been found to the contrary [1].

For the post-1985 remediation period, some workers might have received chest X-ray examinations; such examinations might not have been mandatory on an annual basis. Specifically, respirator users or asbestos workers were probably required to have chest X-rays for the first medical examination, after which X-ray examinations occurred every 2 or 5 years depending on the work performed; it is assumed that PA and LAT chest X-rays were performed at each examination (Lopez 2004).

3.1.3 **Equipment and Techniques**

Weldon Spring had a dispensary with X-ray equipment on site in Building 410 (Davies 1969, p. 79). However, no machine-specific information has been located. To date, there has been no indication in claim file records or captured medical records that photofluorography (PFG) was ever used at WSP [2].

3.1.4 **Organ Doses**

This TBD provides organ dose estimates from occupational X-ray examinations administered at WSP from 1955 through 1969, 1970 to 1985, and post-1985 using default dose estimates from ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-ray Procedures* (ORAUT 2011). For the years before 1970, the default values assume minimal beam collimation and a half-value layer (HVL) of 2.5 mm Al. For 1970 to 1985, the default values assume that the beams were collimated and the HVL was 2.5 mm Al. For post-1985, the default values assume collimation and an HVL of 4.0 mm Al. The organ dose estimates from ORAUT-OTIB-0006 are included in Table 3-1 for convenience. Skin dose guidance is provided in Table 3-2, and skin doses for all areas of skin are provided in Table 3-3.

Table 3-1. Organ dose estimates for chest X-rays (rem) as presented in ORAUT (2011).

Organ	Projection	1955–1970	1971–1985	1986–2002
Thyroid	PA	3.48E-02	3.20E-03	3.90E-03
	LAT	6.85E-02	2.88E-02	2.13E-02
Eye/brain	PA	6.40E-03	3.20E-03	3.90E-03
	LAT	6.85E-02	2.88E-02	2.13E-02
Ovaries	PA	2.50E-02	1.00E-04	2.60E-04
	LAT	1.30E-02	1.50E-04	3.25E-04
Urinary bladder/prostate	PA	2.50E-02	1.00E-04	2.60E-04
	LAT	1.30E-02	1.50E-04	3.25E-04
Colon/rectum	PA	2.50E-02	1.00E-04	2.60E-04
	LAT	1.30E-02	1.50E-04	3.25E-04
Testes	PA	5.00E-03	1.00E-06	5.00E-07
	LAT	2.50E-03	2.50E-05	1.30E-05
Lungs (male)	PA	8.38E-02	4.19E-02	3.14E-02
	LAT	9.65E-02	4.83E-02	4.07E-02
Lungs (female)	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Thymus	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Esophagus	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Stomach	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Bone surface	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Liver/gall bladder/spleen/pancreas	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Remainder organs	PA	9.02E-02	4.51E-02	3.37E-02
	LAT	1.01E-01	5.50E-02	4.56E-02
Breast	PA	9.80E-03	4.90E-03	5.80E-03
	LAT	1.28E-01	6.38E-02	4.46E-02
Uterus	PA	2.50E-02	1.30E-04	2.60E-04
	LAT	1.30E-02	1.50E-04	2.73E-04
Bone marrow (male)	PA	1.84E-02	9.20E-03	8.90E-03
	LAT	1.85E-02	9.25E-03	9.88E-03
Bone marrow (female)	PA	1.72E-02	8.60E-03	8.60E-03
	LAT	1.45E-02	7.25E-03	7.67E-03
Entrance skin ^a	PA	2.70E-01	1.35E-01	7.00E-02
	LAT	6.75E-01	3.38E-01	1.82E-01

a. Entrance skin dose is determined by multiplying the incident air kerma by the backscatter factors of 1.35 and 1.40 for HVL of 2.5 mm Al and 3.0 or 4.0 mm Al, respectively, from National Council on Radiation Protection and Measurements Report 102 (NCRP 1997, Table B-8). Skin doses for all areas of skin are provided in Table 3-3.

Table 3-2. Skin dose guidance for various chest projections and periods.

Area of skin	PA through 1970	LAT through 1970	PA 1971-present	LAT 1971-present
Right front shoulder	EXSD	ENSD	EXSD	ENSD
Right back shoulder	ENSD	ENSD	ENSD	ENSD
Left front shoulder	EXSD	EXSD	EXSD	EXSD
Left back shoulder	ENSD	EXSD	ENSD	EXSD
Right upper arm to elbow	ENSD	ENSD	10% ENSD	ENSD
Left upper arm to elbow	ENSD	EXSD	10% ENSD	EXSD

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

Table 3-3. Skin dose (rem) from various chest projections, 1955–2002.^a

Area of skin	PA 1955–1970	LAT 1955–1970	PA 1971–1985	LAT 1971–1985	PA 1986–2002	LAT 1986–2002
Right front shoulder	5.9E-03	6.75E-01	2.9E-03	3.38E-01	2.4E-03	1.82E-01
Right back shoulder	2.70E-01	6.75E-01	1.35E-01	3.38E-01	7.00E-02	1.82E-01
Left front shoulder	5.9E-03	3.0E-03	2.9E-03	1.5E-03	2.4E-03	1.4E-03
Left back shoulder	2.70E-01	3.0E-03	1.35E-01	1.5E-03	7.00E-02	1.4E-03
Right upper arm to elbow	2.70E-01	6.75E-01	1.35E-02	3.38E-01	7.0E-03	1.82E-01
Left upper arm to elbow	2.70E-01	3.0E-03	1.35E-02	1.5E-03	7.0E-03	1.4E-03
Left hand	2.70E-01	6.75E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Right hand	2.70E-01	6.75E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Left elbow, forearm, wrist	2.70E-01	6.75E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Right elbow, forearm, wrist	2.70E-01	6.75E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Right side of head including ear and temple	2.70E-02	6.85E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Left side of head including ear and temple	2.70E-02	6.85E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Front left thigh	8.E-05	1.E-04	4.E-05	5.E-05	3.E-05	4.E-05

Area of skin	PA 1955– 1970	LAT 1955– 1970	PA 1971– 1985	LAT 1971– 1985	PA 1986– 2002	LAT 1986– 2002
Back left thigh	8.E-05	1.E-04	4.E-05	5.E-05	3.E-05	4.E-05
Front right thigh	8.E-05	1.E-04	4.E-05	5.E-05	3.E-05	4.E-05
Back right thigh	8.E-05	1.E-04	4.E-05	5.E-05	3.E-05	4.E-05
Left knee and below	3.E-05	4.E-05	1.E-05	2.E-05	1.E-05	1.E-05
Right knee and below	3.E-05	4.E-05	1.E-05	2.E-05	1.E-05	1.E-05
Left side of face	6.4E-03	6.85E-02	3.2E-03	3.38E-02	3.9E-03	1.82E-02
Right side of face	6.4E-03	6.85E-02	3.2E-03	3.38E-02	3.9E-03	1.82E-02
Left side of neck	2.70E-01	6.85E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Right side of neck	2.70E-01	6.85E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Back of head	2.70E-02	6.85E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Front of neck	6.4E-03	6.85E-02	3.2E-03	3.38E-02	3.9E-03	1.82E-02
Back of neck	2.70E-01	6.85E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Front torso: base of neck to end of sternum	5.9E-03	1.10E-01	2.9E-03	5.50E-02	2.4E-03	4.56E-02
Front torso: end of sternum to lowest rib	5.9E-03	1.10E-01	2.9E-03	5.50E-02	2.4E-03	4.56E-02
Front torso: lowest rib to iliac crest	5.9E-03	1.10E-01	3.E-04	5.5E-03	2.E-04	4.6E-03
Front torso: iliac crest to pubis	6.E-04	1.10E-02	3.E-04	5.5E-03	2.E-04	4.6E-03
Back torso: base of neck to mid-back	2.70E-01	1.10E-01	1.35E-01	5.50E-02	7.00E-02	4.56E-02
Back torso: mid-back to lowest rib	2.70E-01	1.10E-01	1.35E-01	5.50E-02	7.00E-02	4.56E-02
Back torso: lowest rib to iliac crest	2.70E-01	1.10E-01	1.35E-02	5.5E-03	7.0E-03	4.6E-03
Back torso: buttocks (Iliac crest and below)	2.70E-02	1.10E-02	1.35E-02	5.5E-03	7.0E-03	4.6E-03
Right torso: base of neck to end of sternum	2.70E-01	6.75E-01	1.35E-01	3.38E-01	7.00E-02	1.82E-01
Right torso: end of sternum to lowest rib	2.70E-01	6.75E-01	1.35E-01	3.38E-01	7.00E-02	1.82E-01
Right torso: lowest rib to iliac crest	2.70E-01	6.75E-01	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Right torso: iliac crest to pubis (right hip)	2.70E-02	6.75E-02	1.35E-02	3.38E-02	7.0E-03	1.82E-02
Left torso: base of neck to end of sternum	2.70E-01	3.0E-03	1.35E-01	1.5E-03	7.00E-02	1.4E-03
Left torso: end of sternum to lowest rib	2.70E-01	3.0E-03	1.35E-01	1.5E-03	7.00E-02	1.4E-03
Left torso: lowest rib to iliac crest	2.70E-01	3.0E-03	1.35E-02	1.E-04	7.0E-03	1.E-04
Left torso: iliac crest to pubis (left hip)	2.70E-02	3.E-04	1.35E-02	1.E-04	7.0E-03	1.E-04

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

3.1.5 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 ($\pm 2\%$),
2. Variation in peak kilovoltage ($\pm 9\%$),
3. Variation in X-ray beam current ($\pm 5\%$),
4. Variation in exposure time ($\pm 25\%$), and
5. Variation in source-to-skin distance (SSD) as a result of worker size ($\pm 10\%$).

The 10% uncertainty in output intensity as a result of worker size was based on an inverse square correction of output intensity changes from differences from the standard chest thickness of ± 7.5 cm.

These uncertainties are assumed to be random; therefore, the combined statistical uncertainty was calculated as the square root of the sum of the squares of all the uncertainties, which is $\pm 28.9\%$. Rounding this up to $\pm 30\%$ 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 $\pm 30\%$ can be assumed. Dose reconstructors should, therefore, input the organ dose equivalent as the mean of a normal distribution with a standard uncertainty of $\pm 30\%$.

3.2 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional references, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database (SRDB).

- [1] Thomas, Elyse M. ORAU Team. Principal Medical Dosimetrist. August 2010. Reviews of claims with submitted X-ray data and historical records show annual frequency of X-rays.
- [2] Thomas, Elyse M. ORAU Team. Principal Medical Dosimetrist. August 2010. Reviews of claims with submitted X-ray data and historical records do not indicate any references at all to PFG having been performed for screening.

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