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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
01/15/2004	00	New Technical Basis Document for the Idaho National Engineering and Environmental Laboratory - Occupational Medical Dose. First approved issue. Initiated by Norman D. Rohrig.
05/28/2004	00 PC-1	Adds spleen to organ table on page 10. Eliminates date overlap in table on page 11. Initiated by Norman Rohrig. Approval: Signature on File 05/27/2004 Norman D. Rohrig, Document Owner Signature on File 05/27/2004 Task 3 Manager, Judson Kenoyer, Task 3, Manager Signature on File 05/27/2004 Richard E. Toohey, Project Director Signature on File 05/28/2004 James W. Neton, OCAS Health Science Administrator
01/31/2007	01	Approved Revision 01 as a result of biennial review. Revised language in the Purpose section as required by NIOSH. Attributions and Annotations section added. Changed treatment of eye and brain dose. As a result of internal formal review, add Table 3-3. Incorporates NIOSH formal review comments. This revision results in an increase in assigned dose and a PER is required. Constitutes a total rewrite of document. Initiated by Norman D. Rohrig.
12/21/2009	02	Revised to combine Argonne National Laboratory West Occupational Medical Dose technical basis document (ORAUT-TKBS-0026-3 Rev 01) into the Idaho National Laboratory Occupational Medical Dose technical basis document. Separated X-ray doses into posterior-anterior and lateral in Tables 3-7 and 3-8. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Jo Ann M. Jenkins.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	anterior-posterior
ANL-W	Argonne National Laboratory–West
CFR	Code of Federal Regulations
cm	centimeter
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
HVL	half-value layer
Hz	hertz
ICRP	International Commission on Radiological Protection
in.	inch
INL	Idaho National Laboratory
IREP	Interactive RadioEpidemiological Program
kg	kilogram
kVp	peak kilovolts or applied kilovoltage
LAT	lateral
lb	pound
mA	milliampere
mAs	milliampere-seconds
mm	millimeter
mrad	millirad
ms	millisecond
NCRP	National Council for Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
POC	probability of causation
s	second
SRDB Ref ID	Site Research Database Reference Identification (number)
SRS	Savannah River Site
TBD	technical basis 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.

3.1.1 Purpose

This section discusses the occupational medical dose workers received during employment at the Idaho National Laboratory (INL, formerly known as the Idaho National Engineering and Environmental Laboratory, the Idaho National Engineering Laboratory, and the National Reactor Testing Station) and Argonne National Laboratory–West (ANL-W), which have operated from February 1951 to the present. INL and ANL-W required preemployment and periodic physical examinations as part of their occupational health and safety program. At first, the U.S. Atomic Energy Commission (AEC) provided these medical examinations for all contractors and AEC personnel. Later, the service became the responsibility of the site prime contractor.

3.1.2 Scope

The pre-employment, periodic and termination examinations typically included chest X-rays. The dose from these procedures depended not only on the characteristics of the X-ray machine and the procedures that were used but also on the frequency of examinations. This section discusses the various X-ray techniques and equipment that have been used over the years at INL and ANL-W. The primary source of information on medical X-rays is *Idaho National Engineering and Environmental Laboratory (INEEL) History of the Occupational Medical Program (OMP) X-Ray Process* (Collings and Creighton 2002), a report Bechtel BWXT Idaho prepared at INL at the request of NIOSH.

Section 3.2 discusses examination frequencies, and Section 3.3 describes equipment and techniques. Sections 3.4 and 3.5 discuss organ doses and uncertainty, respectively. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 3.6.

3.2 EXAMINATION FREQUENCIES

Collings and Creighton (2002) reported that from 1954 to 1970, chest X-rays were performed on new hires and on radiation workers at ages 25, 30, 34, 37, and 40, every 2 years from ages 40 to 62, and then every year. They also reported that all employees went on this schedule in 1970. Table 3-1 from the 1960 annual report (AEC 1961) lists a somewhat different schedule:

Table 3-1. Chest X-ray schedule from 1960 annual report (AEC 1961).

Age	Radiation area employees badged	Nonradiation employees unbadged
18–24	4 yr	At age 30
25–39	3 yr	5 yr
40–49	2 yr	3 yr
50–59	1 yr	2 yr
Over 60	1 yr	1 yr

This schedule is corroborated by a memorandum (Sommers 1961). The dose reconstructor should assume that the 1960 schedule applies to dose reconstruction for all workers in the 1954 to 1970 period because it uses historical documentation. It also involved more examinations and is therefore favorable to claimants.

A review of the NIOSH-Office of Compensation Analysis and Support (OCAS) Claims Tracking System (NOCTS) showed that the database contains ANL-W worker X-ray records. From this it can be concluded that chest X-rays were given annually from 1959 to about 1975. It can be assumed that they were given annually before that time. This contradicts the practice at INL even though these X-rays were given through the INL medical organization.

The Appendix to Chapter 0528 of the *AEC Manual* (AEC 1969) specified the following:

- A chest X-ray would be part of a medical examination.
- Workers under age 40 would receive an examination at a frequency that was influenced by several factors.
- Workers over age 40 would receive an examination at least every 2 years and approximately annually when indicated.

The schedule in the table is consistent with that requirement except for ages 40 to 49. The 1971 annual report (AEC 1972) states the schedule for examinations was, “at time of hire, at ages 25, 30, 34, 37, and 40, every two years until age 62 and then annually.” This is identical to that reported by Collings and Creighton (2002), and it is assumed to apply from 1970 to 1976.

Beginning in 1976, physicals occurred every 2 years for workers under age 45 and every year for those over age 45 (Collings and Creighton 2002). On February 1, 1978, chest X-rays were eliminated on periodic physicals except for high-risk individuals (as determined by the physician), in which case they were performed every 4 years (Collings and Creighton 2002). Records from the exposures are reported in each worker’s medical file. When available, the energy employee’s actual X-ray examination records should be used to assign occupational medical dose. Tables 3-2 and 3-3 list the X-ray schedule to use when the employee’s records are not available.

Table 3-2 INL default X-ray schedule

Period	Worker category/age	Frequency	Exposure type
Before 1954	No information; assume annual		PA
1954–1969	New hires		PA
	Radiation workers		
	18–24	Every 4 yr	
	25–39	Triennial	
	40–49	Biennial	
	50 and over	Annual	
	Nonradiation workers		
	30–39	Every 5 yr	
	40–49	Triennial	
	50–59	Biennial	
	60 and over	Annual	
1970-1976	New hires		PA, LAT
	25, 30, 34, 37, 40		
	40–62	Biennial	
	>62	Annual	
1977-1978	New hires		PA, LAT
	≤45	Biennial	
	>45	Annual	
1979-Jan 1990	New hires		PA
	High risk	Every 4 yr	
Feb 1990–present	New hires		PA, LAT
	High risk	Every 4 yr	

Table 3-3 ANL-W default X-ray schedule

Period	Worker Category/Age	Frequency	Exposure Type
Before 1954	No information; assume annual		PA
1954–1974	New hires		PA
		Annual	
1975-1976	New hires		PA, LAT
	25, 30, 34, 37, 40		
	40–62	Biennial	
	>62	Annual	
1977-1978	New hires		PA, LAT
	≤45	Biennial	
	>45	Annual	
1979-Jan 1990	New hires		PA
	High risk	4 years	
Feb 1990- present	New hires		PA, LAT
	High risk	4 years	

3.3 EQUIPMENT AND TECHNIQUES

The standard distance from source to image was 72 in. (183 cm) for the posterior-anterior (PA; back to front) and lateral (LAT) chest exams.

The records indicate that none of the INL examinations used photofluorography (Rohrig 2003). The 1971 annual report stated that a medical van took 22% of the 4,426 X-ray examinations and mentioned the Idaho Falls Navy dispensary as providing X-ray examinations (AEC 1972). Both of these facilities performed standard chest X-rays (Rohrig 2003) and did not do photofluorography. A key-word search of the INL records system using the words *collimation*, *fluoroscopic*, *Health and Safety*, *Health and Safety Services*, *Medical X-ray*, *photofluorography*, and *X-ray* resulted in nothing that indicated the use of photofluorographic techniques (Vivian and Rockhold 2003).

From 1954 to February 1990, X-ray examinations were performed with a single-phase General Electric Model DXD350 machine. The voltage was 90 kVp, the current was 300 mA, and the duration of the exposure was 1/15 s (67 ms). Added filtration of 2 mm Al was used, and a 10:1 grid was used to reduce scatter radiation (Collings and Creighton 2002). Tube window thickness is assumed to be about 0.5 mm Al equivalent. Based on Table A16 of International Commission on Radiological Protection (ICRP) Publication 34, *Protection of the Patient in Diagnostic Radiology*, the half-value layer (HVL) at 90 kVp and 2.5 mm Al total filtration is 2.58 mm Al (ICRP 1982).

From February 1990 to the present, X-rays were performed with a high frequency Gendex Model 110-0030G2. The voltage is 100 kVp, the current is 300 mA, and the duration is 32 ms. Added filtration of 2 mm Al was used, and a 10:1 grid was used to reduce scatter radiation (Collings and Creighton 2002). Tube window thickness is assumed to be about 0.5 mm. Based on Table A17 of ICRP Publication 34, the HVL at 100 kVp and 2.5 mm Al total filtration is 3.3 mm Al (ICRP 1982).

Practices before 1954 are unclear. Offsite facilities might have been contracted to perform the examinations. The default value for entrance kerma of 200 mrad (ORAUT 2005a) is assumed for that period.

From 1954 to 1970, the chest X-ray consisted of a single PA projection (Collings and Creighton 2002). From 1970 to 1978, the procedure consisted of both PA and LAT projections (Collings and Creighton 2002). From 1978 to 1990, the LAT projection was dropped and only a PA projection was made (Collings and Creighton 2002). For the latest period from 1990 to the present, there have been both PA and LAT projections (Collings and Creighton 2002). For LAT projections, the exposure time was about 1.25-1.4 times that of the PA view [1]. An exposure time of 1.4 times that of the PA view was used to calculate doses from LAT projections. In Collings and Creighton (2002), the terms PA and AP (anterior-posterior, front to back) appear somewhat interchangeably. Creighton attributed this presumed interchangeable usage to a typographical error. The August 21, 1975, U.S. Energy Research and Development Administration requirement for occupational medical programs (replaced in 1982) specified the minimum requirements for chest X-rays and specified a PA projection at least once every 5 years as well as when transferring to a job with cardiorespiratory system stress (ERDA 1975).

Collimation and control of scatter for the INL facilities generally followed the state of the medical art as it improved. However, in the absence of particular information about collimation, this analysis assumed the dose conversion factors from Table 6-5 of ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures* ORAUT (2005a), for the pre-1970 period.

3.4 ORGAN DOSES

The entrance air kerma for 100 mAs can be determined from Table B3 of National Council on Radiation Protection and Measurements (NCRP) Report 102 (NCRP 1989) and the beam voltage, distance, and total filtration. The entrance air kerma for 100 mAs is then adjusted by the actual mAs used to determine the actual entrance air kerma at INL. Table 3-4 lists the skin entrance air kerma values in millirad.

Table 3-4. Skin entrance air kerma values (mrad).

Air kerma	PA	LAT
Pre-1954	200	500
1954–January 1990[a]	52	74
February 1990–present[a]	53	76

a. Table B-3 of NCRP Report 102 and site specific technique factors

Tables A2 to A9 of ICRP Publication 34 list Monte Carlo calculation results of the ratio of organ doses to air kerma for a 70-kg (154-lb) man or woman for the thyroid, ovaries, testes, lungs, female breast, uterus (embryo), active bone marrow, and total body under different exposure conditions (ICRP 1982). These dose conversion factor results are shown in Table 3-5.

Table 3-5. Dose conversion factors for ICRP Publication 34 organs.

Publication 34 organs										
Period	Geometry	Thyroid	Testes	Lungs (female)	Lungs (male)	Breast	Ovary	Uterus	Bone marrow (male)	Bone marrow (female)
Before 1970[a]	PA	174	NA	451	419	49	NA	NA	92	86
	LAT	137	NA	220	193	255	NA	NA	37	29
1970–1990[b]	PA	32	<0.01	451	419	49	1	1.3	92	86
	LAT	115	<0.1	220	193	255	0.6	0.6	37	29
1990–present[b]	PA	62	<0.01	610	565	91	3.2	3.0	146	141
	LAT	151	<0.1	310	276	316	1.6	1.4	61	48

a. Based on ORAUT-OTIB-0006 (ORAUT 2005a) and/or measurements by Webster therein.
b. HVLs for 2.5 and 3.5 mm Al were used in place of the values for 2.58 and 3.3 mm of Al .

For the pre-1970 period during which collimation is uncertain, organ dose values for PA chest from Table 6-5 of ORAUT-OTIB-0006 (ORAUT 2005a) were used. Under EEOICPA, cancers in several other organs are compensable, as listed in the Interactive RadioEpidemiological Program (IREP). The ratio of doses for two organs is affected by the relative atomic numbers of the tissue (bone dose is higher than dose in nearby muscle), the relative positions of the organ and the X-ray beam, and the depth in the body. Table 3-6 lists these other organs and the organs from Publication 34, which were used to estimate the dose. For the eye and brain, modified dose conversion factors from ORAUT-OTIB-0006 were used.

Table 3-6. General scheme for Dose Conversion Factors (DCFs) for IREP organs not included in ICRP 34 (ORAUT 2005).

Anatomical location	ICRP 34 DCF	IREP organ without specific DCF
Thorax	Lung	Thymus Esophagus Bone surface Stomach/spleen Liver/gall bladder
Abdomen	Ovaries	Urinary bladder Colon Uterus

HVLs of 2.5, 3.0, and 3.5 mm Al were used in place of the values of 2.58 and 3.3 mm Al. The skin entrance surface was assumed to be 30 cm from the film for the PA view and 40 cm from the film for the LAT view [2]. These distances account for body thickness and any other space between the person and the film. The entrance dose to the skin is the product of the entrance air kerma and a backscatter factor from Table B-8 of NCRP Report 102 (NCRP 1989). Dose to other areas of skin were determined in accordance with the general method described in OTIB-0006 (ORAUT 2005a). These values are shown in Attachment A. The organ dose from a PA projection is the product of the two table values, an inverse square correction, and the product of exposure current and time. Table 3-7 lists these values. The second row in Table 3-7 lists the organs identified in ICRP Publication 34 (ICRP 1982), and the fourth row lists the organs in IREP that are not in Publication 34.

Collings and Creighton (2002) states that a LAT projection was taken in addition to the PA from 1975 to 1978 and from 1990 to 2003. Table 3-8 provides the doses for the LAT exposure, which should be added to the associated value from Table 3-7 if both projections were used.

Table 3-7. Organ doses (mrad) from PA chests at INL and ANL-W.

Period			ICRP Publication 34 organs[a]								
	Thyroid	Testes	Lungs - female	Lungs - male	Breast	Ovary	Uterus embryo	Bone marrow - male	Bone marrow - female		
			Other organs								
			Thymus Esophagus Stomach Bone Surface Liver/spleen Gall bladder			Bladder colon				Entrance Skin	Eye brain
Before 1954	35	5	90	84	10	25	25	18	17	270	6
1954–1969	9	5	24	22	3	25	25	5	4	70	2
1970–Jan 1990	2	0.001	23	22	3	0.1	0.1	5	4	70	2
Feb 1990–present	3	0.001	32	30	5	0.2	0.2	8	7	74	3

a. ICRP (1982).

Table 3-8. Organ doses (mrad) from LAT chests at the INL and ANL-W.

		ICRP Publication 34 organs[a]									
Period	**Thyroid**	**Testes**	**Lungs - Female**	**Lungs - Male**	**Breast**	**Ovary**	**Uterus embryo**	**Bone marrow - Male**	**Bone marrow - Female**		
		Other organs									
			Thymus Esophagus Stomach Bone Surface Liver/spleen Gall bladder			**Bladder colon**				**Entrance Skin**	**Eye brain**
Before 1954	69	3	110	97	128	13	13	19	15	675	69
1954-1969	10	3	16	14	19	13	13	3	2	100	10
1970–Jan 1990	9	0.01	16	14	19	0.04	0.04	3	2	100	9
Feb 1990–present	11	0.01	24	21	24	0.1	0.1	5	4	106	11

a. ICRP (1982).

3.5 UNCERTAINTY

Uncertainties in the occupational medical dose result from uncertainties in the current, voltage, and time for the exposures. The organ doses are also influenced by the size of the worker [3]. For IREP organs where an analogue organ is used from the ICRP Publication 34 organs (ICRP 1982), the IREP organs are deeper in the body so the dose to the IREP organ is lower than the dose to the analogue organ. No estimate is made of this one-sided uncertainty because it cannot lead to a larger dose [4].

The assigned uncertainties in OTIB-0006 (ORAUT 2005a) are generically valid for X-ray programs. The standard uncertainty due to voltage was 9%, that due to current was 5%, and that due to time was 25%. The uncertainty for voltage assumed a 5% voltage uncertainty; because the output has a $V^{1.7}$ dependence, the resultant uncertainty is 9%. Output is directly proportional to current, which was assumed to have a 5% uncertainty [5]. The usually unfiltered voltage output from the voltage rectifier causes a pulsed character to the X-ray output at 120 Hz (twice the supply frequency). For short exposure times, this results in only a few pulses and thus a fairly large uncertainty due to time [6].

All Monte Carlo calculations have an uncertainty determined by the length of the run and the number of events scored for each calculation. For the organ dose calculations from ICRP Publication 34 (ICRP 1982), this uncertainty was not stated. Based on judgment, it is assumed to be 5% at 1 sigma, which would require at least 400 counts in each scoring unit [7].

The error due to an individual's body thickness has two causes: (1) an increase in superficial organ dose resulting from the fact that a larger person is physically closer to the radiation source, and (2) a potential decrease in dose to very deep organs resulting from additional shielding of these deep organs by overlying tissue. Information on worker thickness is rarely available, even in the medical literature. However, at SRS entrance skin dose measurements were made on nine workers of varying chest thicknesses (builds) (Cooley, 1967). While Cooley (1967) does not report the measured chest thicknesses for these nine workers, the entrance skin doses are reported and reflect the increases in exposure needed to radiograph thicker body parts, in this case, chests. The standard uncertainty of the range of measurements is 5.6, resulting in an uncertainty of 21% from this source.

Substituting this value into the root mean square calculation for combined uncertainty described in ORAUT-OTIB-0006 (ORAUT 2005) instead of the 10% value used in that document, the resultant standard uncertainty is 35% from these five sources. For further conservatism, it may be appropriate to assume that errors are all positive and that only +35% should be used as suggested in ORAUT-OTIB-0006 (ORAUT 2005).

3.6 ATTRIBUTIONS AND ANNOTATIONS

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

Norman Rohrig served as the initial Document Owner for this document. Mr. Rohrig was previously employed at INL which shared boundaries with ANL-W and used the same Dosimetry systems and his work involved management, direction or implementation of radiation protection and/or health physics program policies, procedures or practices related to atomic weapons activities at the site. This revision has been overseen by a new Document Owner, who is fully responsible for the content of this document, including all findings and conclusions. In all cases where information or prior studies or writings from Mr. Rohrig are relied upon in this document by the Document Owner, those materials are fully attributed to the source.

[1] Rohrig, Norman. ORAU Team. Site Expert. July 2003.
Stated in phone conversation by Dr. Paul Creighton, INL Medical Director.

[2] Rohrig, Norman. ORAU Team. Site Expert.
Chest thickness for reference man is 23 cm. These values allow for some leeway, which result in values favorable to claimants.

[3] Rohrig, Norman. ORAU Team. Site Expert.
Because radiation is attenuated by the body, the dose conversion factor is reduced for a larger person. Operators can increase the voltage slightly to compensate, which could increase the dose to an organ.

[4] Rohrig, Norman. ORAU Team. Site Expert.
If an organ is deeper in the body than a reference organ, there will be more attenuation to reach that organ.

[5] Rohrig, Norman. ORAU Team. Site Expert.
This is the same value as used for SRS and assumed in ORAUT-OTIB-0006 (ORAUT 2005a).

[6] Rohrig, Norman. ORAU Team. Site Expert.
For the early machine, the exposure time was 1/15 s or 8 pulses at 120 Hz from a full-wave rectifier power supply. A likely uncertainty is 1 pulse or 12.5%, which is less than the assigned uncertainty of 25%. Although the large uncertainty due to time does not apply to the high frequency Gendex machine, this uncertainty is included even though it only applies to the single phase machines.

[7] Rohrig, Norman. ORAU Team. Site Expert.
ICRP did not state an uncertainty, but scientific expertise implies there is one. A 5% value would be consistent with stating the results to 2 significant digits. Determining a significantly smaller uncertainty would increase the effort significantly. This uncertainty does not drive the total uncertainty.

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GLOSSARY

U.S. Atomic Energy Commission (AEC)

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy for military and civilian applications. The U.S. Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from the AEC in 1974. The U.S. Department of Energy succeeded the U.S. Energy Research and Development Administration in 1979.

anterior-posterior (AP)

In relation to radiography, orientation of the body in which the X-rays pass from the front to the back of the body to the film.

kerma

Measure in units of absorbed dose (usually grays but sometimes rads) of the energy released by radiation from a substance. Kerma is the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged particles per unit mass of a specified material. Free-in-air kerma refers to the amount of radiation at a location before adjustment for any external shielding from structures or terrain or backscatter from the body. The word derives from kinetic energy released per unit mass.

lateral (LAT)

In relation to radiography, orientation of the body in which the X-rays pass from one side of the body to the other.

posterior-anterior (PA)

In relation to radiography, orientation of the body in which the X-rays pass from the back to the front of the body to the film.

rad

Traditional unit for expressing absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium. A dose of 1 rad is equivalent to the absorption of 100 ergs per gram (0.01 joules per kilogram). The word derives from radiation absorbed dose. In the International System of Units (SI), the rad has been replaced by the gray (100 rads = 1 gray).

radiograph

Image produced on film by gamma rays or X-rays. Some of the rays (photons) can pass through parts of an item, while more opaque parts partially or completely absorb them and thus cast a shadow on the film. See *radiology*.

X-ray

(1) See *X-ray radiation*. (2) See *radiograph*.

X-ray radiation

Penetrating electromagnetic radiation (photons) of short wavelength (0.0005 to 10 nanometers) and energy less than 250 kiloelectron-volts. X-rays usually come from excitation of the electron field around certain nuclei. Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.

ATTACHMENT A
DOSES TO OTHER AREAS OF THE SKIN
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Before 1954

<1970 Chest				
Area of skin	**PA guidance**	**Dose (rem)**	**LAT (Left LAT) guidance**	**Dose (rem)**
R front shoulder	EXSD	5.9E-03	ENSD	6.75E-01
R back shoulder	ENSD	2.70E-01	ENSD	6.75E-01
L front shoulder	EXSD	5.9E-03	EXSD	3.0E-03
L back shoulder	ENSD	2.70E-01	EXSD	3.0E-03
R upper arm to elbow	ENSD	2.70E-01	ENSD	6.75E-01
L upper arm to elbow	ENSD	2.70E-01	EXSD	3.0E-03
L hand	ENSD	2.70E-01	10% ENSD	6.75E-02
R hand	ENSD	2.70E-01	10% ENSD	6.75E-02
L elbow, forearm, wrist	ENSD	2.70E-01	10% ENSD	6.75E-02
R elbow, forearm, wrist	ENSD	2.70E-01	10% ENSD	6.75E-02
R side of head (including ear)	10% ENSD	2.70E-02	Eye/Brain	6.85E-02
L side of head (including ear)	10% ENSD	2.70E-02	Eye/Brain	6.85E-02
Front left thigh	RSD (0.52m)	8.E-05	RSD (0.52m)	1.E-04
Back left thigh	RSD (0.52m)	8.E-05	RSD (0.52m)	1.E-04
Front right thigh	RSD (0.52m)	8.E-05	RSD (0.52m)	1.E-04
Back right thigh	RSD (0.52m)	8.E-05	RSD (0.52m)	1.E-04
L knee and below	RSD (0.86m)	3.E-05	RSD (0.86m)	4.E-05
R knee and below	RSD (0.86m)	3.E-05	RSD (0.86m)	4.E-05
L side of face	Eye/brain	6.4E-03	Eye/brain	6.85E-02
R side of face	Eye/brain	6.4E-03	Eye/brain	6.85E-02
L side of neck	ENSD	2.70E-01	Eye/brain	6.85E-02
R side of neck	ENSD	2.70E-01	Eye/brain	6.85E-02
Back of head	10% ENSD	2.70E-02	Eye/brain	6.85E-02
Front of neck	Eye/brain	6.4E-03	Eye/brain	6.85E-02
Back of neck	ENSD	2.70E-01	Eye/brain	6.85E-02
Front torso: Base of neck to end of sternum	EXSD	5.9E-03	Lung	1.10E-01
Front torso: End of sternum to lowest rib	EXSD	5.9E-03	Lung	1.10E-01
Front torso: Lowest Rib to iliac crest	EXSD	5.9E-03	Lung	1.10E-01
Front torso: Iliac crest to pubis	10% EXSD	5.9E-04	10% lung	1.10E-02
Back torso: Base of neck to mid-back	ENSD	2.70E-01	Lung	1.10E-01
Back torso: Mid-back to lowest rib	ENSD	2.70E-01	Lung	1.10E-01
Back torso: Lowest rib to iliac crest	ENSD	2.70E-01	Lung	1.10E-01
Back torso: buttocks (Iliac crest and below)	10% ENSD	2.70E-02	10% lung	1.10E-02
Right torso: Base of neck to end of sternum	ENSD	2.70E-01	ENSD	6.75E-01
Right torso: End of sternum to lowest rib	ENSD	2.70E-01	ENSD	6.75E-01
Right torso: Lowest Rib to iliac crest	ENSD	2.70E-01	ENSD	6.75E-01
Right torso: Iliac crest to pubis (R hip)	10% ENSD	2.70E-02	10% ENSD	6.75E-02
Left torso: Base of neck to end of sternum	ENSD	2.70E-01	EXSD	3.0E-03
Left torso: End of sternum to lowest rib	ENSD	2.70E-01	EXSD	3.0E-03
Left torso: Lowest Rib to iliac crest	ENSD	2.70E-01	EXSD	3.0E-03
Left torso: Iliac crest to pubis (L hip)	10% ENSD	2.70E-02	10% EXSD	3.E-04

ATTACHMENT A
DOSES TO OTHER AREAS OF THE SKIN
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1954–1969

<1970 Chest				
Area of skin	**PA Guidance**	**Dose (rem)**	**LAT (Left LAT) Guidance**	**Dose (rem)**
R front shoulder	EXSD	1.5E-03	ENSD	9.96E-02
R back shoulder	ENSD	7.02E-02	ENSD	9.96E-02
L front shoulder	EXSD	1.5E-03	EXSD	4.E-04
L back shoulder	ENSD	7.02E-02	EXSD	4.E-04
R upper arm to elbow	ENSD	7.02E-02	ENSD	9.96E-02
L upper arm to elbow	ENSD	7.02E-02	EXSD	4.E-04
L hand	ENSD	7.02E-02	10% ENSD	1.0E-02
R hand	ENSD	7.02E-02	10% ENSD	1.0E-02
L elbow, forearm, wrist	ENSD	7.02E-02	10% ENSD	1.0E-02
R elbow, forearm, wrist	ENSD	7.02E-02	10% ENSD	1.0E-02
R side of head (including ear)	10% ENSD	7.0E-03	Eye/brain	1.01E-02
L side of head (including ear)	10% ENSD	7.0E-03	Eye/brain	1.01E-02
Front left thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
Back left thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
Front right thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
Back right thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
L knee and below	RSD (0.86m)	7.E-06	RSD (0.86m)	6.E-06
R knee and below	RSD (0.86m)	7.E-06	RSD (0.86m)	6.E-06
L side of face	Eye/brain	1.7E-03	Eye/brain	1.01E-02
R side of face	Eye/brain	1.7E-03	Eye/brain	1.01E-02
L side of neck	ENSD	7.02E-02	Eye/brain	1.01E-02
R side of neck	ENSD	7.02E-02	Eye/brain	1.01E-02
Back of head	10% ENSD	7.0E-03	Eye/brain	1.01E-02
Front of neck	Eye/brain	1.7E-03	Eye/brain	1.01E-02
Back of neck	ENSD	7.02E-02	Eye/brain	1.01E-02
Front torso: base of neck to end of sternum	EXSD	1.5E-03	Lung	1.62E-02
Front torso: end of sternum to lowest rib	EXSD	1.5E-03	Lung	1.62E-02
Front torso: lowest rib to iliac crest	EXSD	1.5E-03	Lung	1.62E-02
Front torso: iliac crest to pubis	10% EXSD	2.E-04	10% lung	1.6E-03
Back torso: base of neck to mid-back	ENSD	7.02E-02	Lung	1.62E-02
Back torso: mid-back to lowest rib	ENSD	7.02E-02	Lung	1.62E-02
Back torso: lowest rib to iliac crest	ENSD	7.02E-02	Lung	1.62E-02
Back torso: buttocks (iliac crest and below)	10% ENSD	7.0E-03	10% lung	1.6E-03
Right torso: base of neck to end of sternum	ENSD	7.02E-02	ENSD	9.96E-02
Right torso: end of sternum to lowest rib	ENSD	7.02E-02	ENSD	9.96E-02
Right torso: lowest rib to iliac crest	ENSD	7.02E-02	ENSD	9.96E-02
Right torso: iliac crest to pubis (r hip)	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Left torso: base of neck to end of sternum	ENSD	7.02E-02	EXSD	4.E-04
Left torso: end of sternum to lowest rib	ENSD	7.02E-02	EXSD	4.E-04
Left torso: lowest rib to iliac crest	ENSD	7.02E-02	EXSD	4.E-04
Left torso: iliac crest to pubis (l hip)	10% ENSD	7.0E-03	10% EXSD	4.E-05

ATTACHMENT A
DOSES TO OTHER AREAS OF THE SKIN
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1970–1990

>1970 Chest				
Area of skin	**PA Guidance**	**Dose (rem)**	**LAT (Left LAT) Guidance**	**Dose (rem)**
R front shoulder	EXSD	1.5E-03	ENSD	9.96E-02
R back shoulder	ENSD	7.02E-02	ENSD	9.96E-02
L front shoulder	EXSD	1.5E-03	EXSD	4.E-04
L back shoulder	ENSD	7.02E-02	EXSD	4.E-04
R upper arm to elbow	10% ENSD	7.0E-03	ENSD	9.96E-02
L upper arm to elbow	10% ENSD	7.0E-03	EXSD	4.E-04
L hand	10% ENSD	7.0E-03	10% ENSD	1.0E-02
R hand	10% ENSD	7.0E-03	10% ENSD	1.0E-02
L elbow, forearm, wrist	10% ENSD	7.0E-03	10% ENSD	1.0E-02
R elbow, forearm, wrist	10% ENSD	7.0E-03	10% ENSD	1.0E-02
R side of head (including ear)	10% ENSD	7.0E-03	10% ENSD	1.0E-02
L side of head (including ear)	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Front left thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
Back left thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
Front right thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
Back right thigh	RSD (0.52m)	2.E-05	RSD (0.52m)	2.E-05
L knee and below	RSD (0.86m)	7.E-06	RSD (0.86m)	6.E-06
R knee and below	RSD (0.86m)	7.E-06	RSD (0.86m)	6.E-06
L side of face	Eye/Brain	1.7E-03	10% ENSD	1.0E-02
R side of face	Eye/Brain	1.7E-03	10% ENSD	1.0E-02
L side of neck	10% ENSD	7.0E-03	10% ENSD	1.0E-02
R side of neck	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Back of head	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Front of neck	Thyroid	1.7E-03	10% ENSD	1.0E-02
Back of neck	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Front torso: base of neck to end of sternum	EXSD	1.5E-03	Lung	1.62E-02
Front torso: end of sternum to lowest rib	EXSD	1.5E-03	Lung	1.62E-02
Front torso: lowest rib to iliac crest	10% EXSD	2.E-04	10% lung	1.62E-02
Front torso: iliac crest to pubis	10% EXSD	2.E-04	10% lung	1.6E-03
Back torso: base of neck to mid-back	ENSD	7.02E-02	Lung	1.62E-02
Back torso: mid-back to lowest rib	ENSD	7.02E-02	Lung	1.62E-02
Back torso: lowest rib to iliac crest	10% ENSD	7.0E-03	10% lung	1.62E-02
Back torso: buttocks (iliac crest and below)	10% ENSD	7.0E-03	10% lung	1.6E-03
Right torso: base of neck to end of sternum	ENSD	7.02E-02	ENSD	9.96E-02
Right torso: end of sternum to lowest rib	ENSD	7.02E-02	ENSD	9.96E-02
Right torso: lowest rib to iliac crest	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Right torso: iliac crest to pubis (r hip)	10% ENSD	7.0E-03	10% ENSD	1.0E-02
Left torso: base of neck to end of sternum	ENSD	7.02E-02	EXSD	4.E-04
Left torso: end of sternum to lowest rib	ENSD	7.02E-02	EXSD	4.E-04
Left torso: lowest rib to iliac crest	10% ENSD	7.0E-03	10% EXSD	4.E-04
Left torso: iliac crest to pubis (l hip)	10% ENSD	7.0E-03	10% EXSD	4.E-05

ATTACHMENT A
DOSES TO OTHER AREAS OF THE SKIN
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1990–present

>1970 Chest				
Area of skin	**PA Guidance**	**Dose (rem)**	**LAT (Left LAT) Guidance**	**Dose (rem)**
R front shoulder	EXSD	2.2E-03	ENSD	1.06E-01
R back shoulder	ENSD	7.42E-02	ENSD	1.06E-01
L front shoulder	EXSD	2.2E-03	EXSD	7.E-04
L back shoulder	ENSD	7.42E-02	EXSD	7.E-04
R upper arm to elbow	10% ENSD	7.4E-03	ENSD	1.06E-01
L upper arm to elbow	10% ENSD	7.4E-03	EXSD	7.E-04
L hand	10% ENSD	7.4E-03	10% ENSD	1.06E-02
R hand	10% ENSD	7.4E-03	10% ENSD	1.06E-02
L elbow, forearm, wrist	10% ENSD	7.4E-03	10% ENSD	1.06E-02
R elbow, forearm, wrist	10% ENSD	7.4E-03	10% ENSD	1.06E-02
R side of head (including ear)	10% ENSD	7.4E-03	10% ENSD	1.06E-02
L side of head (including ear)	10% ENSD	7.4E-03	10% ENSD	1.06E-02
Front left thigh	RSD (0.52m)	3.E-05	RSD (0.52m)	2.E-05
Back left thigh	RSD (0.52m)	3.E-05	RSD (0.52m)	2.E-05
Front right thigh	RSD (0.52m)	3.E-05	RSD (0.52m)	2.E-05
Back right thigh	RSD (0.52m)	3.E-05	RSD (0.52m)	2.E-05
L knee and below	RSD (0.86m)	1.E-05	RSD (0.86m)	7.E-06
R knee and below	RSD (0.86m)	1.E-05	RSD (0.86m)	7.E-06
L side of face	Eye/brain	3.3E-03	10% ENSD	1.06E-02
R side of face	Eye/brain	3.3E-03	10% ENSD	1.06E-02
L side of neck	10% ENSD	7.4E-03	10% ENSD	1.06E-02
R side of neck	10% ENSD	7.4E-03	10% ENSD	1.06E-02
Back of head	10% ENSD	7.4E-03	10% ENSD	1.06E-02
Front of neck	Thyroid	3.3E-03	10% ENSD	1.06E-02
Back of neck	10% ENSD	7.4E-03	10% ENSD	1.06E-02
Front torso: base of neck to end of sternum	EXSD	2.2E-03	Lung	2.36E-02
Front torso: end of sternum to lowest rib	EXSD	2.2E-03	Lung	2.36E-02
Front torso: lowest rib to iliac crest	10% EXSD	2.E-04	10% lung	2.4E-03
Front torso: iliac crest to pubis	10% EXSD	2.E-04	10% lung	2.4E-03
Back torso: base of neck to mid-back	ENSD	7.42E-02	Lung	2.36E-02
Back torso: mid-back to lowest rib	ENSD	7.42E-02	Lung	2.36E-02
Back torso: lowest rib to iliac crest	10% ENSD	7.4E-03	10% lung	2.4E-03
Back torso: buttocks (iliac crest and below)	10% ENSD	7.4E-03	10% lung	2.4E-03
Right torso: base of neck to end of sternum	ENSD	7.42E-02	ENSD	1.06E-01
Right torso: end of sternum to lowest rib	ENSD	7.42E-02	ENSD	1.06E-01
Right torso: lowest rib to iliac crest	10% ENSD	7.4E-03	10% ENSD	1.06E-02
Right torso: iliac crest to pubis (r hip)	10% ENSD	7.4E-03	10% ENSD	1.06E-02
Left torso: base of neck to end of sternum	ENSD	7.42E-02	EXSD	7.E-04
Left torso: end of sternum to lowest rib	ENSD	7.42E-02	EXSD	7.E-04
Left torso: lowest rib to iliac crest	10% ENSD	7.4E-03	10% EXSD	7.E-05
Left torso: iliac crest to pubis (l hip)	10% ENSD	7.4E-03	10% EXSD	7.E-05