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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
09/09/2004	00	New Technical Basis Document for the Argonne National Laboratory – West – Occupational Medical Dose. First approved issue. Initiated by Norman D. Rohrig.
05/16/2005	00 PC-1	Approved page change revision. Replaces first paragraph of section 3.2 on page 4 and the associated table specifying x-ray /age requirements. Revises Table 3A-1 on page 11 to reflect these changes No changes were needed as a result of NIOSH formal review. No training required. Initiated by Norman D. Rohrig. Approval: Signature on File 05/10/2005 Norman D. Rohrig, Document Owner Signature on File 05/09/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 05/10/2005 Richard E. Toohey, Project Director Signature on File 05/16/2005 James W. Neton, Associate Director for Science
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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ANL-W	Argonne National Laboratory–West
AP	anterior-posterior
cm	centimeter
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
Hz	hertz
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
IREP	Interactive RadioEpidemiological Program
kerma	Kinetic Energy Released to Matter
kg	kilogram
kVp	kilovolts-peak, applied voltage
LAT	lateral
lb	pound
mA	milliampere
mAs	milliampere-second
mm	millimeter
mrad	millirad
ms	millisecond
NCRP	National Committee 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)
TBD	technical basis document
U.S.C.	United States Code
§	section or sections

3.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide 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) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute 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 contains an exclusion with respect to the Naval Nuclear Propulsion Program, 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 dosimetry monitoring results are considered valid for use in 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:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

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

3.1.1 Purpose

This TBD discusses the occupational medical dose workers received during employment at the Argonne National Laboratory–West (ANL-W), which has operated from February, 1951 to the present. The site required preemployment and periodic physical examinations as part of its occupational health and safety program. At first, the U.S. Atomic Energy Commission (AEC) provided these medical examinations for all onsite Federal and contractor personnel. Later, the examinations became the responsibility of the site prime contractor.

3.1.2 Scope

The examinations typically included diagnostic chest X-rays. The dose from these procedures depended not only on the characteristics of the X-ray machine and the procedure used, but also on the frequency of examinations. This document discusses various X-ray techniques and equipment used over the years at the Idaho National Laboratory (INL). ANL-W employees were a part of the Idaho National Laboratory medical program (Creighton 2003). The primary source of information on medical X-rays is a report that Collings and Creighton (2002) prepared at NIOSH request.

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

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 40 would receive an examination at a frequency influenced by several factors.
- Workers over 40 would receive an examination at least every 2 years (approximately annually when indicated).

The *1971 Annual Report of the Health Services Laboratory* (AEC 1972) stated that the schedule for examinations is “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 the frequency reported by Collings and Creighton (2002) and is assumed to apply from 1975 to 1976.

Beginning in 1976, physicals occurred every 2 years for workers under 45 and every year for those 45 and over (Collings and Creighton 2002). On February 1, 1978, INL eliminated routine chest X-rays during periodic physicals with the exception of high-risk individuals (as determined by the physician), in which case the examinations were performed every 4 years. Records from the exposures are reported in each worker’s medical file.

3.3 EQUIPMENT AND TECHNIQUES

The standard distance from source to image was 72 inches (183 cm).

The available information indicates that none of the INL examinations used fluoroscopic techniques (Creighton 2003). AEC (1972) identifies the use of a medical van for 22% of the 4,426 X-ray examinations. In addition, that report mentions that the Idaho Falls Navy dispensary performed X-ray examinations. Both of these facilities performed standard chest X-rays and did not do photofluoroscopy. A keyword search of the INL records system using the terms *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 0.0667 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. Based on Table A16 of International Commission on Radiological Protection (ICRP) Publication 34, *Protection of the Patient in Diagnostic Radiology* (ICRP 1982), the half-value layer at 90 kVp and 2.5-mm total aluminum filtration is 2.58 mm Al.

From February 1990 to the present, X-rays have been performed with a three-phase 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 (1982), the half-value layer at 100 kVp and 2.5-mm total aluminum filtration is 3.3 mm Al.

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 posterior-anterior (PA; back to front) image. From 1970 to 1978, the procedure consisted of both PA and lateral (LAT) projections. From 1978 to 1990, the LAT projection was dropped and only a PA projection was made. From 1990 to the present, there were both PA and LAT projections. The exposure time for LAT projections was about 1.25 times that of the PA projection. 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, Energy Research and Development Administration (ERDA) requirement for occupational medical programs (replaced in 1982) specified the minimum requirements for chest X-rays and a PA projection at least once every 5 years, as well as when a worker with cardiorespiratory system stress transferred to a different job (ERDA 1975).

Collimation and control of scatter for INL facilities generally followed the state of the medical art as it improved. However, in the absence of particular information about collimation, this TBD uses the dose conversion factors in Table 6-5 of 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. Table 3-1 lists air kerma values.

Table 3-1. Skin entrance air kerma values (mrad).

Air kerma	PA	LAT
Pre-1954	200	500
1954 to Jan 1990	52	74
Feb 1990 to present	53	76

Tables A2 to A9 of ICRP (1982) list Monte Carlo calculation results of the ratio of organ doses to air kerma for a 70-kg (154-lb) male or female for the thyroid, ovaries, testes, lungs, female breast, uterus (embryo), active bone marrow, and total body under different exposure conditions. For organs where there is a difference for males and females, the larger value is used. A linear interpolation, applicable to all years, was used between the dose ratios for half-value layers of 2.5, 3.0, and 3.5 mm Al to the values of 2.58 and 3.3 mm Al (ICRP 1982). The skin entrance surface was assumed to be 30 cm from the film for the PA projection and 40 cm from the film for the LAT projection (ORAUT 2005a). These distances account for body thickness and any space between the person and the film. The dose to the skin is the product of the entrance skin exposure and a backscatter factor from NCRP Report 102 (NCRP 1989, Table B-8).

The organ dose from a PA image is the product of the two table values, an inverse square correction, and the product of exposure current and time. Table 3-2 lists these values. For LAT images, a similar calculation was performed and added to the PA result. The first heading row in this table lists the organs identified in ICRP Publication 34 (ICRP 1982) and the second heading row lists the organs in IREP that are not listed in Publication 34.

Table 3-2. Organ doses from occupational medical exposures at ANL-W.

				Organ doses (mrad) from ANL-W chest X-ray						
		ICRP 34 organs		Thyroid	Testes	Lungs	Breast	Ovary Embryo	Bone marrow	
		Other organs		Eye Brain		Thymus Esophagus Stomach Bone surface Liver/spleen Gall bladder		Uterus Bladder Colon		Skin
Period	**Frequency**	**Geometry**								
Before 1954	No information		PA	69	1.8	93	10	34	19	272
	Assume annual									
1954–1974		New hires	PA	18	0.5	24	2.7	8	5	70
	Annual									
1975–1976		New hires	PA, LAT	10	0.008	41	22	0.1	8	171
	25, 30, 34, 37, 40									
	Biennial	40 to 62								
	Annual	>62								
1977–1978		New hires	PA, LAT							
	Biennial	<45								
	Annual	>45								
1979–Jan 1990		New hires	PA	1.8	0.001	24	2.7	0.1	5.0	70
	4 years	High risk								
Feb 1990–present		only	PA, LAT	14	0.008	53	27	0.3	11	180

Cancers in several other organs, as listed in the Interactive RadioEpidemiological Program (IREP), are compensable. 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 3-3 lists these other organs and the organs from ICRP Publication 34 (ICRP 1982), which were used to estimate the dose, in the third column.

3.5 UNCERTAINTY

Uncertainties in the occupational medical dose result from uncertainties in the current, voltage, and exposure time. In addition, organ doses are influenced by the size of the person. If an analog organ is used from the ICRP (1982) organs, the IREP organs are generally deeper in the body so the dose will be lower than that for the analog organ. No estimate is made of this one-sided uncertainty because it cannot lead to a larger dose.

Table 3-3. IREP organs not included in ICRP Publication 34 (ICRP 1982).

Anatomical location	ICRP (1982) reference organ	IREP organ analogs
Head	Thyroid	Eye Brain
Thorax	Lung	Thymus Esophagus Bone surface Stomach/spleen Liver/gall bladder
Abdomen	Ovaries	Urinary bladder Colon Uterus

The uncertainties assigned in the Savannah River Site (SRS) site profile (ORAUT 2005b) are generically valid for X-ray programs. The uncertainty at one sigma due to voltage was 9%, that due to current was 5%, and that due to time was 25%. The uncertainty for voltage assumes a 5% voltage uncertainty and, because the output has a $V^{1.7}$ dependence, results in a 9% uncertainty. Output is directly proportional to current, which is assumed to have a 5% uncertainty. 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 a short exposure time, this results in only a few pulses and thus a fairly large uncertainty due to time.

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 [1].

The error due to worker thickness has two components: (1) an increase for a larger person being closer to the source and (2) a decrease due to additional attenuation in the body. The Monte Carlo calculations in ICRP Publication 34 (ICRP 1982) assumed 70-kg (154-lb) male and female geometries. The 10% uncertainty assigned in the SRS TBD (ORAUT 2005b) was due to the first cause, but, because the effects counteract, that value is appropriate for the combined effect. This should be taken as 1 sigma on a normal distribution. These sources of uncertainty added in quadrature result in a combined uncertainty of ±30% at 1 sigma or 84% confidence [2].

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.

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. Mr. Rohrig continues to serve as a Site Expert for this document because he possesses or is aware of information relevant for reconstructing radiation doses experienced by energy employees who worked at the site. In all cases where such information or prior studies or writings are included or relied upon by the Document Owner, those materials are fully attributed to the source.

[1] Rohrig, Norman. ORAU Team. Health Physicist. June-September 2003.
ICRP (1982) did not state an uncertainty, but scientific expertise implies there is one. A 5% value would be consistent with stating the results to two significant digits. A significantly smaller uncertainty would increase the effort significantly. This uncertainty does not drive the total uncertainty.

[2] Rohrig, Norman. ORAU Team. Health Physicist. June-September 2003.
"Added in quadrature" refers to taking the square root of the sum of the squares of the individual error contributions, which are 9%, 5%, 25%, and 5%.

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GLOSSARY

U.S. Atomic Energy Commission
Original agency established for nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

anterior-posterior (AP)
Irradiation geometry in which the radiation passes from the front of a person to the back.

lateral (LAT)
Irradiation geometry in which the radiation passes from one side of a person to the other.

posterior-anterior (PA)
Irradiation geometry in which the radiation passes from the back of a person to the front.

rad
The unit for absorbed dose, 1 rad = 100 erg per gram.

X-ray
Ionizing electromagnetic radiation of external nuclear origin or an image generated by exposing a detector (e.g., film) to X-rays.