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Subject Expert: Norman D. Rohrig

Approval:	Signature on File Daniel Mantooth, Document Owner	Approval Date:	12/12/2006
Approval:	Signature on File John M. Byrne, Task 3 Manager	Approval Date:	12/13/2006
Concurrence:	Signature on File Edward F. Maher, Task 5 Manager	Concurrence Date:	12/13/2006
Concurrence:	Signature on File Kate Kimpan, Project Director	Concurrence Date:	01/24/2007
Approval:	Brant A. Ulsh Signature on File for James W. Neton, Associate Director for Science	Approval Date:	01/31/2007

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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.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	anterior-posterior
cm	centimeter
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
HVL	half-value layer
Hz	hertz
ICRP	International Commission on Radiological Protection
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
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior
POC	probability of causation
s	second
SRS	Savannah River Site
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 for 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 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). INL 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 contractors and AEC personnel. Later, the service became the responsibility of the site prime contractor.

3.1.2 Scope

The examinations typically included 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 section discusses the various X-ray techniques and equipment used over the years at the INL. 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 prepared by Bechtel BWXT Idaho at INL at the request of NIOSH.

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 yr 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 thus favorable to claimants.

The Appendix to AEC Manual Chapter 0528 (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 yr (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 yr for workers under age 45 and every year for those over age 45 (Collings and Creighton 2002). On February 1, 1978, routine 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 yr (Collings and Creighton 2002). 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) for the posterior-anterior (PA; back to front) and lateral (LAT) chest exams.

The records indicate that none of the INL examinations used photofluorography (Creighton 2003; 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 fluoroscopic 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 have been beryllium with thickness equivalent to about 0.5 mm aluminum. 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 (HVL) at 90 kVp and 2.5 mm Al total 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 34 (1982), the HVL at 100 kVp and 2.5 mm Al total 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 PA image (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 times that of the PA view [1]. 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 yr 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 absence of particular information about collimation, this analysis assumed the dose conversion factors from 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 Report 102 (NCRP 1989) and the beam voltage, distance, and total filtration. Table 3-2 lists the skin entrance air kerma values in millirad.

Table 3-2. Skin entrance air kerma values (mrad).

Air kerma	PA	Lat
Pre-1954	200	NA
1954–1990	52	74
1990–present	53	76

Tables A2 to A9 of ICRP 34 (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. These dose conversion factor results are shown in Table 3-3. For the pre-1970 time period when collimation is uncertain, the values from Table 6-5 of OTIB-0006 (ORAUT 2005a) are 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 3-4 lists these other organs and the organs from ICRP 34 (1982), which were used to estimate the dose. For the eye and brain, dose conversion factors from OTIB-0006 (ORAU 2005a) are used.

Table 3-3. Dose Conversion Factors for ICRP 34 Organs.

ICRP 34 Organs		Dose Conversion Factors for INL (mrad/rad)							
Time Period	Geometry	Thyroid	Testes	Lungs	Breast	Ovary	Uterus Embryo	Bone Marrow	Skin
Before 1970[a]	PA	174	125	451	49	125	125	92	1250
1970 to 1990[b]	PA	34.2	0.0	464.4	52.2	1.1	1.5	96.0	1360
	LAT	117.9	0.1	227.5	260.1	0.6	0.6	38.8	1360
1990 to present[b]	PA	55.6	0.0	537.4	82.2	2.6	4.0	129.4	1400
	LAT	143.8	0.1	260	304.4	1.3	1.6	44	1400

a. Based on OTIB-0006 (ORAUT 2005a) and measurements by Webster therein (result/default kerma).
b Interpolated to actual HVL.

For organs where there is a difference for males and females, the larger values are used in Tables 3-3 and 3-5 to be favorable to the claimant. A linear interpolation applicable to the pre-1990 and post-1990 years was used between the dose ratios for HVLs of 2.5, 3.0, and 3.5 mm Al to the values of 2.58 and 3.3 mm Al [2]. 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 [3]. These distances account for body thickness and any other space between the person and the film. The dose to the skin is the product of the entrance skin exposure and a backscatter factor taken from Table B-8 of NCRP Report 102 (NCRP 1989).

Table 3-4. IREP organs not included in ICRP 34 (1982).

Anatomical Location	ICRP 34 (1982) Reference Organ	IREP Organ Analogues
Thorax	Lung	Thymus Esophagus Bone surface Stomach/Spleen Liver/Gall Bladder
Abdomen	Ovaries	Urinary Bladder Colon Uterus

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 3-5 lists these values and the frequencies. When there was also a LAT image, a similar calculation was performed and added to the PA result in Table 3-5. Row 2 in Table 3-5 lists the organs identified in ICRP 34 (1982), and row 4 lists the organs identified in IREP that are not in ICRP 34 (1982).

Table 3-5. Organ doses (mrad) from occupational medical exposures at the INL.

Period	Frequency information		Geometry	ICRP 34 Organs								
				Thyroid	Testes	Lungs	Breast	Ovary	Uterus Embryo	Bone Marrow		
				Other Organs								
						Thymus Esophagus Stomach Bone Surface Liver/Spleen Gall Bladder		Bladder Colon			Skin	Eye Brain
Before 1954	No information; assume annual		PA	35	25	93	10	25	25	19	272	6
1954 to 1969	*New hires*		PA	9	6.5	24	2.7	6.5	6.5	5	70	1.7
	Rad workers											
	Every 4 yr	18-24										
	Triennial	25-39										
	Biennial	40 - 49										
	Annual	over 50										
	Nonrad workers											
	Every 5 yr	30-39										
	Triennial	40-49										
	Biennial	50-59										
	Annual	over 60										
1970 to 1976	*New hires*		PA, LAT	10	0.008	41	22	0.1	0.1	8	171	12
	25, 30, 34, 37, 40											
	Biennial	40 to 62										
	Annual	>62										
1977 to 1978	*New hires*		PA, LAT									
	Biennial	<45										
	Annual	>45										
1979 to Jan 1990	*New hires* 4 yr High risk only		PA	1.8	0.001	24	2.7	0.1	0.1	5.0	70	1.7
Feb 1990 to 2006			PA, LAT	14	0.008	53	27	0.2	0.3	11	180	12

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 person [4]. For IREP organs where an analogue organ is used from the ICRP 34 (1982) organs, the IREP organs are generally deeper in the body so the dose will be lower than the analogue organ. No estimate is made of this one-sided uncertainty because it cannot lead to a larger dose [5].

The uncertainties assigned in the site profile for the Savannah River Site (SRS) (ORAUT 2005b) are generically valid for X-ray programs. The uncertainty at 1 sigma 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 [6]. 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 [7].

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 34 (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 [8].

The error due to an individual's thickness has two causes: (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 34 (1982) assumed 70-kg (154-lb) male and female geometries. The 10% uncertainty assigned in the SRS site profile (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.

3.6 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in the preceding text, 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 again in the Attributions and Annotations section of the document with information provided to identify the source and justification for each associated item. Conventional references are provided in the next section of this document, linking data, quotations, and other information to documents available for review on the Oak Ridge Associated Universities (ORAU) Team servers.

[1] Rohrig, Norman. ORAU Team. Site Expert. July 8, 2003.
Stated in phone conversation by Dr. Paul Creighton, INL Medical Director.

[2] Rohrig, Norman. ORAU Team. Site Expert.
HVLs determined from ICRP 34 as noted in § 3.3. Linear interpolation used to get intermediate values since a relatively small change was involved.

[3] Rohrig, Norman. ORAU Team. Site Expert.
Chest thickness for reference man is 23 cm. These values allow for some leeway which will result in a value favorable to the claimant.

[4] Rohrig, Norman. ORAU Team. Site Expert.

Because radiation is attenuated by the body, the dose conversion factor is reduced for a larger person. Operators may increase the voltage slightly to compensate, which could increase the dose to an organ.

[5] 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.

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

[7] Rohrig, Norman. ORAU Team. Site Expert.
For the early machine, the exposure time was 1/15 sec 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%.

[8] 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. Getting a significantly smaller uncertainty would increase the effort significantly. This uncertainty does not drive the total uncertainty.

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Vivian, K. A., and Rockhold, L. E., 2003, "Transmittal of Medical Documents from the INEEL," letter to N. Rohrig (Intrepid Technology and Resources), CCN 46313, Bechtel BWXT Idaho, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho, November 18. [SRDB Ref ID: 7975]

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

posterior-anterior (PA)
In relation to radiology, orientation 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
Photographic 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.