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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
05/28/2004	00	New technical basis document for the Mound Site – Occupational Medical Dose. First approved issue. Initiated by Jeffrey S. Vollmer.
09/09/2004	01	Approved Issue of Revision 01. Initiated by Jeffrey S. Vollmer.
07/08/2005	01 PC-1	Approved page change revision. Page change initiated to correct organ dose estimates in Table 3-4 on page 7, in Section 3. No retraining is required. Initiated by Elyse M. Thomas. Document Owner: Signature on File 07/05/2005 Jeffrey S. Vollmer, TBD Team Leader Signature on File 07/05/2005 Judson L. Kenoyer, Task 3, Manager Signature on File 06/29/2005 Richard E. Toohey, Project Director Signature on File 07/08/2005 James W. Neton, Associate Director for Science
03/31/2006	01 PC-2	Approved page change revision. Page change initiated to include boilerplate language in Section 3.1 on pages 5 and 6. Makes changes to Tables 3-6, 3-7 and 3-8 on pages 9 and 10 as requested by NIOSH. No sections were deleted. Training required: As determined by the Task Manager. Initiated by Paul J. Demopoulos. Signature on File 03/17/2006 Paul J. Demopoulos, TBD Team Leader John M. Byrne Signature on File for 03/17/2006 Judson L. Kenoyer, Task 3 Manager Signature on File 03/17/2006 Edward F. Maher, Task 5 Manager Signature on File 03/22/2006 Kate Kimpan, Project Director Signature on File 03/31/2006 James W. Neton, Associate Director for Science
03/02/2009	01 PC-3	Approved page change initiated to remove information pertaining to Monsanto Chemical Company, the subject of a class of employees added to the Special Exposure Cohort. In Table 3-2 on page 7 in Section 3.2, a change was made in the first row to remove “Pre” from 1949. NIOSH required language was revised on pages 5 and 6 in Section 3.1. References were updated on pages 6 - 8, 15 in Sections 3.1, 3.2, 3.3, and Reference Section. Incorporates formal internal review comments. No changes occurred as a result of formal NIOSH review. No sections were deleted. Training required: As determined by the Task Manager. Initiated by Donald N. Stewart.

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ACRONYMS AND ABBREVIATIONS

cGy	centigray
cm	centimeter
ESE	entrance skin exposure
Gy	Gray
HVL	half-value layer
ICRP	International Commission on Radiological Protection
kVp	peak kilovoltage
LAT	lateral
Lucal	Lucite aluminum
mA	milliampere
mAs	milliampere-second
mGy	milligray
mm	millimeter
mR	milliroentgen
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
PA	posterior–anterior
R	roentgen
s	second
SID	source-to-image distance
SSD	source-to-skin distance
U.S.C.	United States Code
VCH	vertical cassette holder

3.1 INTRODUCTION

3.1.1 Purpose

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):

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

- 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

3.1.2 Scope

Diagnostic X-ray procedures were a contributor to the occupational radiation exposure of Mound workers. In general, the dose from such exposures was not measured, considered, or included as part of the overall occupational exposure of the employee, although it clearly was occupationally related. Diagnostic medical X-rays administered in conjunction with routine or special physical examinations required for employment are a valid source of occupational exposure. Unlike occupational exposures incurred during normal work processes, individual diagnostic medical X-ray exposures were not monitored, necessitating reconstruction of doses acquired in this manner. This section describes the technical aspects of dose reconstruction from medical X-rays administered prior to employment and periodically thereafter as a condition of employment. This discussion is based on ORAUT (2005).

3.2 EXAMINATION FREQUENCY, EQUIPMENT, AND TECHNIQUES

Employees at the Mound site received posterior–anterior (PA) chest X-rays as follows: A baseline at hiring, at specified intervals thereafter (Table 3-1), and at termination. In 1983, a policy modification required X-rays for terminating employees only if they had not had a chest X-ray within the previous 9 months (Mound 2002); this changed to a 6 months in 1988. In 1988, a lateral (LAT) view was required for women known to have undergone breast augmentations; the frequency of these examinations is not known (Mound 2002). Table 3-1 lists examination frequencies over the years for different groups based on information obtained from the Mound data files.

Table 3-1. Frequency of required occupational PA chest X-rays.

Period	Frequency	Comment
1946 To 1959	Annually	All employees
1960 To 1979	Annually	Certain employees according to job category
	Biennially	Based on job category
1980 To 1988	Every 6 years	Employees under age 35
	Every 4 years	Employees between age 35 to 44
	Every 2 years	Employees age 45 and older
	Annually	Asbestos workers
	Annually	Any employee considered at risk in workplace (e.g., welders, etc).
1989 To 2003	Every 5 years	Employees under age 35
	Every 4 years	Employees between age 35 and 44
	Every 2 years	Employees age 45 and older
	Annually	Smoker, any age

Since at least 1980, the X-ray apparatus at Mound was a stationary enclosed unit with the control panel separated from the tube head by a wall. For the period before 1980, details about the X-ray apparatus and technique parameters are not known, and default values from ORAUT (2005) were used for entrance kerma. From 1980 through 2003, the equipment consisted of a single-phase, TWX-325 control unit with a Eureka Emerald 125 X-ray tube, Eureka Linear II automatic collimator, and S&S 1417B vertical cassette holder (VCH) used with no grid and 14- by 17-in. Kodak X-O-Matic Regular film. Actual measurement data obtained by the Ohio Department of Health were used. Tables 3-2 and 3-3 summarize technique parameters and entrance kerma for PA and LAT views,

respectively. For the period before 1980, no external collimation was assumed when converting entrance kerma to organ doses.

Table 3-2. Technique factors used for PA chest X-rays.

Period	Total filtration (mm Al)	Half-value layer (mm Al)	Current (mA)	Voltage (kVp)	Exposure time (s)	Entrance kerma (mGy)
1949-1970	Unknown	Unknown	Unknown	Unknown	Unknown	2.0[a]
1970-1979	Unknown	Unknown	Unknown	Unknown	Unknown	1.0[a]
1980-1987	3.0	2.5	Unknown	Unknown	Unknown	0.5[a]
1988-1994	3.3	3.0	200	84	1/20	0.5[a]
1995-1996	3.3	3.0	200	84	1/20	0.164
1997-1999	3.3	3.0	200	84	1/20	0.159
2000-2003	3.3	3.0	200	82	1/20	0.149

a. Default values from ORAUT (2005).

Table 3-3. Technique factors used for lateral chest X-rays.

Period	Total filtration (mm Al)	Half-value layer	Current (mA)	Voltage (kVp)	Exposure time(s)	Entrance kerma (mGy)
9/1988 to 2003	3.3	4.0	200	110	1/20	0.40[a]

a. Entrance kerma 2.5 times the PA entrance kerma for same period. 2.5 × 0.159 mGy = 0.4 mGy.

Although there is no specific evidence in the history data file (Mound 2002) to indicate the use of photofluorography at Mound, evidence suggests that General Electric mobile X-ray units might have been used at various U.S. Atomic Energy Commission, Energy Research and Development Administrations, or U.S. Department of Energy sites (NCRP 1989). A review of files from the 1940s and 1950s reveals that when photofluorography was used, an unusually large number of X-ray examinations would be performed in a given day. Thus, a larger than normal number of X-ray records for a given day might be a positive indicator of the use of photofluorography. However, in the absence of specific data on the use of photofluorography at Mound, or even that such equipment was present on site, this analysis assumes that photofluorography did not occur at Mound.

3.3 ORGAN DOSE CALCULATIONS

Organ doses are calculated by multiplying the entrance kerma listed in Table 3-2 by the appropriate organ dose conversion factor obtained from Tables A.2 to A.8 in International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982). The specific organ doses are shown in Tables 3-4 through 3-10 for PA X-ray procedures and Table 3-11 for LAT procedures. As noted above, the conservative default values from ORAUT (2005) were used for the period before 1988 for entrance kerma [entrance skin exposure (ESE)]. For the period from 1988 to 2003, data obtained by measurement by the State of Ohio were used.

The Ohio Department of Health made measurements during radiation safety and compliance surveys in 1995, 1997, and 2000. The analysis determined ESE values using a Lucite-aluminum (Lucal) chest phantom, representing a 23-cm-thick chest at a 183-cm source-to-image distance (SID). The values for 1995, 1997, and 2000 are 16.4 mR, 15.9 mR, and 14.9 mR, respectively. The 1995 measured value was used for 1995 and 1996; the 1997 value is used for 1997 to 1999, and the 2000 value was used for 2000 to 2003. Entrance kerma and doses are assumed to be numerically equal to the ESE (that is, 1 cGy is equal to 1 R is equal to 1 rem, which are claimant-favorable assumptions).

Table 3-4. Organ dose estimates for PA chest radiographs before 1970 assuming minimal collimation.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 2.5 mm Al HVL)[a]	Organ dose (rem)
Thyroid	174	3.48E-02
Eye/brain	32	6.40E-03
Ovaries	168	3.36E-02
Urinary/bladder	168	3.36E-02
Colon/rectum	168	3.36E-02
Testes	9.1	1.82E-03
Lungs	451	9.02E-02
Thymus	451	9.02E-02
Esophagus	451	9.02E-02
Stomach	451	9.02E-02
Bone surface	451	9.02E-02
Liver/gall bladder/spleen	451	9.02E-02
Remainder	451	9.02E-02
Breast	49	9.80E-03
Uterus(embryo)	149	2.98E-02
Bone marrow	92	1.84E-02
Skin[b]		2.70E-01

a. Dose conversion factors from ORAUT (2005), p. 18, p.21, and ICRP 34 (1982, Tables A.2 to-A.8).
b. Skin dose was determined by multiplying ESE by backscatter factors of 1.35., 1.39, and 1.4 for half-value layers (HVLs) of 2.5, 3.0, and 4.0 mm, Al respectively. From NCRP (1989, Table B-8).

Table 3-5. Organ dose estimates for PA chest radiographs from 1970 to 1979.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 2.5 mm Al HVL)[a]	Organ dose (rem)
Thyroid	32	3.20E-03
Eye/brain	32	3.20E-03
Ovaries	1	1.00E-04
Urinary/bladder	1	1.00E-04
Colon/rectum	1	1.00E-04
Testes	0.01	1.00E-06
Lungs	451	4.51E-02
Thymus	451	4.51E-02
Esophagus	451	4.51E-02
Stomach	451	4.51E-02
Bone surface	451	4.51E-02
Liver/gall bladder/spleen	451	4.51E-02
Remainder	451	4.51E-02
Breast	49	4.90E-03
Uterus(embryo)	1.3	1.30E-04
Bone marrow	92	9.20E-03
Skin[b]		1.35E-01

a. Dose conversion factors from ICRP (1982, Tables A.2 to A.8).
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.35 from NCRP (1989, Table B-8)

Table 3-6. Organ dose estimates for PA chest radiographs from 1980 to 1987.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 2.5 mm Al HVL)[a]	Organ dose (rem)
Thyroid	32	1.60E-03
Eye/brain	32	1.60E-03
Ovaries	1	5.00E-05
Urinary/bladder	1	5.00E-05
Colon/rectum	1	5.00E-05
Testes	0.01	5.00E-07
Lungs	451	2.26E-02
Thymus	451	2.26E-02
Esophagus	451	2.26E-02
Stomach	451	2.26E-02
Bone surface	451	2.26E-02
Liver/gall bladder/spleen	451	2.26E-02
Remainder	451	2.26E-02
Breast	49	2.45E-03
Uterus(embryo)	1.3	6.50E-05
Bone marrow	92	4.60E-03
Skin[b]		6.75E-02

a. Dose conversion factors from ICRP (1982) Tables A.2 through A.8.
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.35. From NCRP Report No. 102 (1989, Table B-8).

Table 3-7. Organ dose estimates for PA chest radiographs from 1988 to 1994.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 3.0 mm Al HVL)[a]	Organ dose (rem)
Thyroid	46	1.60E-03
Eye/brain	46	1.60E-03
Ovaries	1.8	5.00E-05
Urinary/bladder	1.8	5.00E-05
Colon/rectum	1.8	5.00E-05
Testes	0.01	5.00E-07
Lungs	535	2.26E-02
Thymus	535	2.26E-02
Esophagus	535	2.26E-02
Stomach	535	2.26E-02
Bone surface	535	2.26E-02
Liver/gall bladder/spleen	535	2.26E-02
Remainder	535	2.26E-02
Breast	69	2.45E-03
Uterus(embryo)	2.3	6.50E-05
Bone marrow	117	4.60E-03
Skin[b]		6.75E-02

a. Dose conversion factors from ICRP (1982, Tables A.2 to A.8).
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.39 from NCRP (1989, Table B-8).

Table 3-8. Organ dose estimates for PA chest radiographs from 1995 to 1996.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 3.0 mm Al HVL)[a]	Organ dose (rem)
Thyroid	46	7.54E-04
Eye/brain	46	7.54E-04
Ovaries	1.8	2.95E-05
Urinary/bladder	1.8	2.95E-05
Colon/rectum	1.8	2.95E-05
Testes	0.01	1.64E-07
Lungs	535	8.77E-03
Thymus	535	8.77E-03
Esophagus	535	8.77E-03
Stomach	535	8.77E-03
Bone surface	535	8.77E-03
Liver/gall bladder/spleen	535	8.77E-03
Remainder	535	8.77E-03
Breast	69	1.13E-03
Uterus(embryo)	2.3	3.77E-05
Bone marrow	117	1.92E-03
Skin[b]		2.28E-02

a. Dose Conversion Factors from ICRP 34 (1982, Tables A.2 to A.8).
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.39 from NCRP (1989, Table B-8).

Table 3-9. Organ dose estimates for PA chest radiographs from 1997 to 1999.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 3.0 mm Al HVL)[a]	Organ dose (rem)
Thyroid	46	7.31E-04
Eye/brain	46	7.31E-04
Ovaries	1.8	2.86E-05
Urinary/bladder	1.8	2.86E-05
Colon/rectum	1.8	2.86E-05
Testes	0.01	1.59E-07
Lungs	535	8.51E-03
Thymus	535	8.51E-03
Esophagus	535	8.51E-03
Stomach	535	8.51E-03
Bone surface	535	8.51E-03
Liver/gall bladder/spleen	535	8.51E-03
Remainder	535	8.51E-03
Breast	69	1.10E-03
Uterus(embryo)	2.3	3.66E-05
Bone marrow	117	1.86E-03
Skin[b]		2.21E-02

a. Dose conversion factors from ICRP (1982, Tables A.2 to A.8).
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.39 from NCRP (1989, Table B-8).

Table 3-10. Organ dose estimates for PA chest radiographs from 2000 to 2003.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 3.0 mm Al HVL)[a]	Organ dose (rem)
Thyroid	46	6.85E-04
Eye/brain	46	6.85E-04
Ovaries	1.8	2.68E-05
Urinary/bladder	1.8	2.68E-05
Colon/rectum	1.8	2.68E-05
Testes	0.01	1.49E-07
Lungs	535	7.97E-03
Thymus	535	7.97E-03
Esophagus	535	7.97E-03
Stomach	535	7.97E-03
Bone surface	535	7.97E-03
Liver/gall bladder/spleen	535	7.97E-03
Remainder	535	7.97E-03
Breast	69	1.03E-03
Uterus(embryo)	2.3	3.43E-05
Bone marrow	117	1.74E-03
Skin[b]		2.07E-02

a. Dose conversion factors from ICRP (1982, Tables A.2 to A.8).
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.39 from NCRP (1989, Table B-8).

Table 3-11. Organ dose estimates for LAT chest radiographs from 1988 to 2003.

Organ	Dose conversion factor (mGy/Gy air kerma) (beam quality for 4.0 mm Al HVL)[a]	Organ dose (rem)
Thyroid	164	6.56E-03
Eye/brain	164	6.56E-03
Ovaries	2.5	1.00E-04
Urinary/bladder	2.5	1.00E-04
Colon/rectum	2.5	1.00E-04
Testes	0.1	4.00E-06
Lungs	351	1.40E-02
Thymus	351	1.40E-02
Esophagus	351	1.40E-02
Stomach	351	1.40E-02
Bone surface	351	1.40E-02
Liver/gall bladder/spleen	351	1.40E-02
Remainder	351	1.40E-02
Breast	343	1.37E-02
Uterus(embryo)	2.1	8.40E-05
Bone marrow (male)	76	3.04E-03
Skin [b]		5.60E-02

a. Dose conversion factors from ICRP (1982, Tables A.2 to A.8).
b. Skin dose was determined by multiplying ESE by backscatter factor of 1.40 from NCRP (1989, Table B-8).

The mean air kerma for a chest LAT view is calculated at a distance of 144 cm, which is the source to skin distance (SSD). The SSD is calculated using the following equation:

$$SSD = SID - \text{Chest thickness} - VCHd$$
$$SSD = SID - CT - 5 = 183 - 34 - 5 = 144 \text{ cm}$$

where

SID = 183 cm;
VCHd = 5.0 cm; the distance between the VCH and the worker
CT = 34 cm; lateral chest thickness for a typical worker

The average air kerma is obtained from Figure 10.1 of the *Handbook of Health Physics and Radiological Health* (Shleien, Slaback, and Birky 1998) for a single-phase unit at 3.3-mm Al total filtration at 100 cm from the source per 100 mAs using the corresponding lateral technique factors listed in Table 3-3. Use of a 3.3-mm Al total filtration is based on data provided by beam quality analyses performed by the Ohio Department of Health and Human Services (Mound 2002). The air kerma value was 0.082 cGy. The analysis applied a geometric correction using the inverse square distance law to calculate air kerma at 144 cm. The calculated geometric correction factor was 0.48. The mean air kerma for the LAT view was 0.04 cGy. All values are listed in Table 3-3.

Organ doses were calculated by multiplying entrance kerma by the corresponding dose conversion factor. Tables 3-4 through 3-11 list organ doses.

3.4 UNCERTAINTY ANALYSIS

Error (deviation from the correct, true, or conventionally accepted value of a quantity) and uncertainty (defined in terms of the potential range of a stated, measured, assumed, or otherwise determined value of a quantity) provide an indication of the confidence of the dose estimates. Error implies knowledge of the correct or actual value, which in this case is, of course, not known. Therefore, the more appropriate factor is uncertainty, which is expressed in terms of a confidence level (e.g., a 99% confidence level indicates that the correct or true value, although not actually known, has a 99% probability of falling within the range cited). Uncertainty includes both precision and reproducibility of the measurement and accuracy, or how close the measurement or estimate of dose comes to the actual or correct value.

In theory, a large number of factors can introduce uncertainties or affect X-ray machine output intensity and dose to the worker. In practice, however, only five factors can reasonably have an impact on dose uncertainty:

1. Measurement error
2. Variation in applied kilovoltage (kVp)
3. Variation in beam current (mA)
4. Variation in exposure time
5. Distance from the worker to the source of the X-rays [source-to-skin distance (SSD)]

The influence of such other factors as the use of screens, grids, reciprocity failure, film speed, and development, while potentially variable, would not affect the beam output intensity.

Medical X-ray doses, when measured, were derived largely from actual measurements of X-ray machine output with R-meters or similar ionization chamber devices designed for measurement of

photons in the medical X-ray energy range. If properly calibrated and used, R-meters and similar instruments typically and historically have had an uncertainty of ±2% for photon energies below 400 keV (Kathren and Larson 1969). Although more recent versions of these instruments might provide a somewhat smaller uncertainly, perhaps on the order of ±1% (NBS 1985, 1988), for conservatism, dose reconstructors should apply the uncertainty range of ±2% to measurements of X-ray intensity.

Theoretically, for a given set of machine settings and parameters, X-ray output is constant and unvarying. In practice however, output is essentially constant unless focal spot loading occurs, as could be the case when the power rating of the machine is exceeded. It is unlikely that power ratings were ever exceeded because such an event would be difficult to achieve in practice and could result in damage to the X-ray tube. However, even with the use of constant voltage transformers to control line voltages, slight variations can occur in line voltage input or other internal voltages, which in turn can alter the kVp of the output beam. In general, for a given kVp setting, variation in kVp falls within ±5% of the machine setting. Beam intensity is approximately proportional to the 1.7 power of the kilovoltage; this translates to an uncertainty of approximately ±8.6% with respect to output beam intensity in the 80 to 100 kVp used for diagnostic radiographs. For conservatism, this is rounded up to ±9%.

Similarly, slight variations in tube current are normal; as a tube ages, or heats from use, current can change and typically drops. With all other factors constant, beam intensity is reduced in direct proportion to the change in tube current. Typically, the reduction in beam output from current variation is not more than a few percent under normal operating conditions; large decreases are readily detectable and result in maintenance on the machine to restore the output or, as a temporary measure, an increase in the current or kVp to provide the necessary intensity for proper radiography. There is no evidence to suggest that such temporary measures were ever used at Mound. For a given kVp setting, the output of the beam is a function of the tube current, which in turn is measured by an ammeter, which measures average tube current. The measurement is subject to uncertainties; there might be minor changes in output as the tube heats from normal use. Because these variations are typically small, the estimated uncertainty in beam output attributable to current variation is ±5%.

Another parameter that has potential to affect the dose from a diagnostic radiograph, perhaps significantly, relates to the time of exposure. A full-wave rectified machine produces 120 pulses per second of X-rays. In an exposure time of 1/20 of a second, only six pulses would result. A small error in the timer that resulted in a change of only ±1 pulse would correspondingly affect the output by ±17%. For an exposure time of 1/30 of a second, the change in output corresponding to a deviation of ±1 pulse is ±25%. Early mechanical timers were notoriously inaccurate; accuracy improved significantly with the introduction of electronic timers. Other than measurements of reproducibility made by the State of Ohio, there are no data on which to base an evaluation of the accuracy and precision of the timers on the Mound X-ray apparatus. The measurements made by the State suggest that the timers, and indeed the entire X-ray output from 1995 on, were reasonably constant. In addition, because the same apparatus was used since 1980, it is reasonable to conclude that timer errors since then were small. However, for conservatism, the assumed uncertainty in beam output attributable to timers is ±25%.

The final factor likely to affect worker dose is the SSD, which is a determinant of the ESE. For a given individual, the SSD will be determined largely by the body thickness of the worker and the accuracy of the positioning. For a typical worker, the estimated variation in SSD is no more than a few centimeters, with an upper limit of perhaps 7.5 cm. Using inverse square, this indicates an uncertainty of ±10% from this source.

There are two approaches to determine the combined uncertainty from the five listed, potential sources of uncertainty. The first, and most conservative in that it gives the greatest range, is to assume that the uncertainties are additive, which yields an uncertainty range of 2 + 9 + 5 + 25 + 10 = +51%. However, a more reasonable approach would be to assume that the uncertainties are in fact random, and to compute the statistical root mean square value. That value is simply the square root of the sum of the squares and computes as ±28.9%. Rounding this up to ±30% would seem to provide an adequate and suitably conservative indication of uncertainty. Thus, for an individual ESE or derived organ dose, dose reconstructions should assume an uncertainty of ±30% at the 99% confidence level. To further ensure claimant favorability, reconstructions should assume that errors are all positive (that is, only +30% should be used).

3.5 INSTRUCTION GUIDE FOR DOSE RECONSTRUCTORS

Summarized below are instructions for dose reconstructors determining organ doses from required medical diagnostic X-ray procedures at Mound. In the absence of measurement data or other specific information, dose reconstructors can calculate organ doses for LAT view by multiplying the entrance kerma for the PA view by a default value of 2.5 and using this value along with the ICRP (1982) tables to compute the appropriate organ dose. Entrance kerma should be used to compute the organ doses associated with the LAT view; multiplying the organ doses obtained for the PA view by a factor of 2.5 will result in erroneous results. For evaluation purposes, X-ray doses are always considered acute with photon energies in the range of 30 to 250 keV. Tables 3-4 to 3-11 list organ doses from PA and LAT chest radiography. The doses listed in the tables are per X-ray procedure. In absence of specific data, dose reconstructors should assume frequencies as listed in Table 3-1, but review of medical or other records could lead the dose reconstructor to determine that the actual frequency could have been greater or smaller. If so, the reconstructions should adjust annual doses accordingly.

For actual dose calculations, reconstructors should assume a normal distribution with an uncertainty of ±30% at the 99% confidence interval. However reconstructions should use only the positive uncertainty and multiply the doses listed in Tables 3-4 through 3-11 by a factor of 1.3 to include uncertainty at the 99% confidence interval.

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GLOSSARY

absorbed dose
The energy imparted per unit mass by ionizing radiation to matter at a specified point. The SI unit of absorbed dose is joule per kilogram (J/kg). The special name for this unit is gray (Gy). The previously used special unit of absorbed dose, rad, is being replaced by the gray. 1 rad = 0.01 Gy. 1 Gy = 100 rad.

alternating electric current
Electric current that changes in magnitude and direction.

ampere
Electric current unit. One ampere is equal to one coulomb per second.

beam quality
The quality of an x-ray beam refers to its ability to penetrate matter.

centigray (cGy)
0.01 gray. 1 cGy equals one rad.

dose conversion factor
The ratio of dose equivalent in tissue or organ to entrance Kerma at the surface of the x-rayed person.

dose equivalent
The product of the absorbed dose in tissue, quality factor and all other necessary modifying factors at the location of interest. The SI unit for dose equivalent is the sievert. The historical unit for dose equivalent is the rem. The ICRP defines dose equivalent as equivalent dose.

entrance kerma
Refers to air kerma without backscatter.

exposure
A measure of the quantity of x or gamma radiation based upon its ability to ionize air through which it passes. The SI unit for exposure is coulomb per kilogram. The historical unit for exposure is Roentgen (R).

film
A medium used to record an image.

filtration
Material in the useful beam that usually absorbs preferentially the less penetrating radiation.

fluorography
The production of a photographic record of the image formed on the output phosphor of an image intensifier by the action of x-rays transmitted through the patient.

frequency
Number of cycles per second of alternating current.

gray (Gy)
The special name for SI unit of absorbed dose, Kerma, and specific energy imparted equal one joule per kilogram. One gray equals to one joule per kilogram.

electric current
The amount of charge per unit time passing a point in a conductor.

half-value layer (HVL)
Thickness of a specified substance which, when introduced in the path of a given beam of radiation, reduces the Kerma rate by one –half.

image
The pattern formed in the film due to beam interaction in the film composition after passage through the x-rayed person target of interest.

image quality
Refers to the visibility and sharpness of the images of structural details.

kerma
The sum of the initial kinetic energies of all charged ionizing particles liberated by uncharged ionizing particles per unit mass of a specified material. Kerma is measured in the same units as absorbed dose. The SI unit of kerma is joule per kilogram and its special name is gray (Gy). Kerma can be quoted for any specified material at a point in free space or in an absorbing medium.

milligray (mGy)
0.001 gray. 1 mGy = 10 rad.

phantom
An object used to simulate the absorption and scatter characteristics of the patient's body for radiation measurement purposes.

radiography
The production of images on film by the action of x-rays transmitted through the patient.

rad
Historical unit for absorbed dose. One rad equals 100 ergs per gram. The word derives from *radiation absorbed dose*.

roentgen (R)
The previously used special unit of exposure. An exposure of one roentgen will produce 2.58 $x10^{-4}$ coulomb of ions of either sign per kilogram in air.

rem
Historical unit of dose equivalent. The word derives from *roentgen equivalent (in) man.*

sievert (Sv)
The special name for the SI unit of dose equivalent. One Sievert equals one joule per kilogram. One sievert is equal to 100 rem.

source-to-image-distance (SID)

The distance measured along the central ray from the center of the front of the surface of the source (x-ray focal spot) to the surface of the image detector.

source to skin distance (SSD)

The distance measured along the central ray from the center of the front surface of the source (x-ray focal spot) to the surface of the irradiated object or patient.

technique factors

Refer to x-ray machine settings used in an examination or procedure. The factors include such terms as kilovolt peak, milliampere, and exposure time.

voltage

Electrical potential energy per unit charge. The SI unit is volt (V). One volt is equal to joule per coulomb.