DOE Review Release 04/17/2023

Y-12 Plant – Occupational Medical Dose

ORAUT-TKBS-0014-3 Rev. 02
Effective Date: 04/04/2023
Supersedes: Revision 01

Subject Expert(s): Stephanie L. Felch

Document Owner Approval:	Signature on File JoAnn M. Jenkins, Document Owner	Approval Date:	03/29/2023
Concurrence:	Signature on File John M. Byrne, Objective 1 Manager	Concurrence Date:	03/30/2023
Concurrence:	Signature on File Scott R. Siebert, Objective 3 Manager	Concurrence Date:	03/29/2023
Concurrence:	Vickie S. Short Signature on File for Kate Kimpan, Project Director	Concurrence Date:	03/29/2023
Approval:	Signature on File Timothy D. Taulbee, Associate Director for Science	Approval Date:	04/04/2023

**FOR DOCUMENTS MARKED AS A TOTAL REWRITE OR REVISION,
REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.**

☐ New ☒ Total Rewrite ☐ Revision

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
12/15/2003	00	New technical basis document for the Y-12 National Security Site – Occupational Medical Dose. First approved issue. Initiated by William E. Murray.
09/09/2004	00 PC-1	Deletes references to Kathren et al., to be published on pages 7, 11, 17 and 18. This document has not been published. Adds references on pages 7, 11, 17 and 18 for ORAU (Oak Ridge Associated Universities) 2003, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, ORAUT-OTIB-0006 Rev 00, Oak Ridge, Tennessee. November 14, 2003. First approved page change revision. Initiated by William E. Murray. Approval: Signature on File 09/08/2004 William E. Murray, TBD Team Leader Signature on File 08/27/2004 Judson L. Kenoyer, Task 3 Manager Signature on File 08/30/2004 Richard E. Toohey, Project Director Signature on File 09/09/2004 James W. Neton, Associate Director for Science
10/11/2005	00 PC-2	Page change initiated to incorporate the definition of U.S.C. on page 4 and details for the definition of a DOE facility on page 5. No sections were deleted. Second approved page change revision. Retraining is not required. Initiated by William E. Murray. Approval: Signature on File 10/06/2005 William E. Murray, TBD Team Leader Signature on File 10/04/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 10/04/2005 Richard E. Toohey, Project Director Signature on File 10/11/2005 James W. Neton, Associate Director for Science

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
04/18/2006	00 PC-3	Page change initiated to revise text in Table 3-5 on page 10 in Section 3.4 to remove reference that uterus is a surrogate for ovaries. No changes occurred as a result of formal internal review. No sections were deleted. Text on page 10 was revised in response to NIOSH formal review. Third approved page change revision. Retraining is not required. Initiated by William E. Murray. Approval: Signature on File 04/17/2006 William E. Murray, TBD Team Leader Judson L. Kenoyer Signature on File for 04/17/2006 John M. Byrne, Task 3 Manager Signature on File 04/14/2006 Edward F. Maher, Task 5 Manager Signature on File 04/18/2006 Kate Kimpan, Project Director Signature on File 04/18/2006 James W. Neton, Associate Director for Science
06/18/2007	01	Approved revision initiated to add Attributions and Annotations section and additional references in response to review. Added a Purpose and Scope subsection to the Introduction (Section 3.1). Incorporates formal internal and NIOSH review comments. This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by William E. Murray.
04/04/2023	02	Revision to remove X-ray dose tables and reference ORAUT-OTIB-0006 in their place. Updated dose reconstructor instructions and references. This revision results in a change in the assigned doses. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by John M. Byrne and authored by JoAnn M. Jenkins.

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AWE	Atomic Weapons Employer
cGy	centigray
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ENSD	entrance skin dose
GE	General Electric X-Ray Corporation
ICRP	International Commission on Radiological Protection
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
kVp	kilovolts-peak
mA	milliampere
mAs	milliampere-second
mGy	milligray
mm	millimeter
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
PA	posterior-anterior
PER	program evaluation report
PFG	photofluorographic
s	second
SEC	Special Exposure Cohort
SRDB Ref ID	Site Research Database Reference Identification (number)
SSD	source-to-skin distance
TBD	technical basis document
TEC	Tennessee Eastman Corporation
U.S.C.	*United States Code*
Y-12	Y-12 Plant
§	section or sections

3.1 INTRODUCTION

Technical basis documents (TBDs) and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular U.S. Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies), such as changing scientific understanding of operations, processes, or procedures involving radioactive materials. These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of individual dose reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA).

In this document the word “facility” is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an “AWE facility” or a “DOE facility.” The term “AWE facility” is defined in EEOICPA to mean “a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling.” 42 *United States Code* (U.S.C.) § 7384l(5). On the other hand, a DOE facility is defined as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located—(A) in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program); and (B) with regard to which the [DOE] has or had—(i) a proprietary interest; or (ii) entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services.” 42 U.S.C. § 7384l(12). The DOE determines whether a site meets the statutory definition of an AWE facility and the U.S. Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Under EEOICPA, a Part B cancer claim for benefits must be based on an energy employee’s eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility’s designated time period and location (i.e., a “covered employee with cancer”). After DOL determines that a claim meets the eligibility requirements under Part B of EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. 42 U.S.C. § 7384l(11). Also under EEOICPA, the types of exposure to be included in dose reconstructions for DOE employees are those radiation exposures incurred in the performance of duty. As such, NIOSH includes all radiation exposures received as a condition of employment at DOE facilities in its dose reconstructions for covered employees, which may include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. This is because NIOSH does not determine the fraction of total measured radiation exposure at a DOE facility that is contributed by the Naval Nuclear Propulsion Program at the DOE facility during a specified period of time for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees [NIOSH 2010]:

- Background radiation, including radiation from naturally occurring radon present in conventional structures, and
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons.

3.1.1 Purpose

This TBD documents historical occupational medicine practices at the Y-12 Plant and provides information needed for the reconstruction of occupational medical doses for workers.

3.1.2 Scope

This TBD contains supporting documentation to assist in the evaluation of occupational medical doses from screening chest X-rays provided to workers at the Y-12 Plant. The objective of this document is to provide supporting technical medical X-ray equipment data to reconstruct the occupational medical doses from these X-rays using assumptions that are favorable to the claimant.

3.1.3 Special Exposure Cohort

The Secretary of the U.S. Department of Health and Human Services has issued six designations of classes of Y-12 employees as additions to the SEC.

March 1, 1943, to December 31, 1947

> *Department of Energy (DOE) employees or DOE contractor or subcontractor employees who worked in uranium enrichment operations or other radiological activities at the Y-12 facility in Oak Ridge, Tennessee from March 1943 through December 1947 and who were employed for a number of work days aggregating at least 250 work days, either solely under this employment or in combination with work days within the parameters (excluding aggregate work day requirements) established for other classes of employees included in the SEC* [Leavitt 2005, p. 3].

NIOSH determined that it lacked access to sufficient information to estimate either the maximum radiation dose incurred by any member of the class or to estimate such radiation doses more precisely than a maximum dose estimate [NIOSH 2005].

A second designation extended the class to include all workers in all areas of Y-12 during this period:

> *All employees of the Department of Energy (DOE), its predecessor agencies, and DOE contractors or subcontractors who worked at the Y-12 Plant in Oak Ridge, Tennessee from March 1, 1943 through December 31, 1947 for a number of work days aggregating at least 250 work days occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort* [Leavitt 2008, p. 3].

NIOSH determined that it lacked the internal dosimetry data necessary to reconstruct the internal exposures from uranium enrichment and other radiological activities. In addition, NIOSH lacked external dosimetry or source term information about external exposures from other radiological activities at the facility during this period. Therefore, NIOSH found that it is not feasible to estimate with sufficient accuracy the radiation doses from internal and external radiation exposures workers could have received. In addition, NIOSH determined that, because exposure potential might not have been limited to only specific buildings or groups of workers at Y-12, the SEC class definition should include all employees in all areas of Y-12, and all employees of DOE, its predecessor agencies, and their contractors and subcontractors who worked at Y-12 during the period from March 1, 1943, to December 31, 1947 [NIOSH 2008]. NIOSH considers it feasible to adequately reconstruct the occupational medical dose for Y-12 workers for the covered period. Although no exposure data are available for the medical X-rays performed during this time, surrogate data were used to develop an exposure matrix for the Y-12 site profile [Oak Ridge Associated Universities (ORAU) Team (ORAUT) 2007].

January 1, 1948, to December 31, 1957

Department of Energy (DOE) employees or DOE contractor or subcontractor employees who were monitored or should have been monitored for:

(1) thorium exposures while working in Building 9201-3, 9202, 9204-1, 9204-3, 9206, or 9212 at Y-12 for a number of work days aggregating at least 250 work days from January 1948 through December 1957 or in combination with work days within the parameters (excluding aggregate work day requirements) established for one or more classes of employees in the SEC; or

(2) radionuclide exposures associated with cyclotron operations in Building 9201-2 at Y-12 for a number of work days aggregating at least 250 work days from January 1948 through December 1957 or in combination with work days within the parameters (excluding aggregate work day requirements) established for one or more classes of employees in the SEC [Leavitt 2006, p. 3].

NIOSH determined that the specific biological monitoring data, air monitoring information, process and radiological source information, and surrogate data from similar operations at other sites that would allow it to estimate, with sufficient accuracy, the potential internal radiological exposures to thorium and cyclotron radionuclides are not sufficient to complete dose reconstructions for the class [NIOSH 2006a,b].

A second designation extended the class to include all workers in all areas of Y-12 during this period:

All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Y-12 facility in Oak Ridge, Tennessee, during the period from January 1, 1948 through December 31, 1957, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort [Sebelius 2011, p. 3].

NIOSH determined that, due to undocumented worker movements across the site, limited worker-specific information about work locations, and a determination by DOL that employment records do not indicate work locations, it is unable to eliminate any specific worker from potential exposure scenarios based on assigned work location. NIOSH found that a determination cannot always be made about the specific area an employee worked in or whether an employee should have been monitored for radiological exposures. Accordingly, NIOSH determined that it was necessary to remove the area-specific and monitoring criteria from the class description associated with thorium and cyclotron exposures for the period. NIOSH determined that it was also necessary to expand the SEC class definition to include all employees and areas of Y-12 during this period [NIOSH 2011]. In its evaluation [NIOSH 2011], NIOSH found that internal exposure could be reconstructed for all employees from January 1, 1948, to December 31, 1957, with the exception of internal exposure to thorium and cyclotron radionuclides. NIOSH found that external exposure, including occupational medical doses, could be reconstructed for all employees between January 1948 and December 31, 1957.

January 1, 1958, to December 31, 1976

All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Y-12 Plant in Oak Ridge, Tennessee, during the period January 1, 1958, through December 31, 1976, for a number of work days aggregating at least 250 work days, occurring either solely under this employment

> *or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort* [Azar 2019a, p. 3].

NIOSH determined that it lacked sufficient information to allow it to estimate with sufficient accuracy the internal exposures to thorium (and associated progeny) for the period from January 1, 1958, to December 31, 1976, and ^{241}Pu for the period from January 1, 1958, to December 31, 1966 [NIOSH 2018].

Although NIOSH has determined that there are in vivo monitoring data for thorium (i.e., lung counts) during the period from January 1, 1958, to December 31, 1976, these data are recorded in total thorium mass. NIOSH is unable to use these data to determine the associated quantities of ^{232}Th, ^{228}Th, and ^{228}Ra. For this reason, NIOSH cannot determine with sufficient accuracy the internal exposures that might be represented by each thorium lung measurement. NIOSH has also evaluated the available gross alpha air monitoring data at the Y-12 Plant and determined that they cannot be used to accurately reconstruct internal exposure from thorium and associated progeny. NIOSH has not identified biological monitoring data specific to ^{241}Pu that can be used to reconstruct ^{241}Pu exposure during the period from January 1, 1958, to December 31, 1966. NIOSH has identified sufficient monitoring data to reconstruct ^{241}Pu beginning in 1967 [NIOSH 2018].

January 1, 1977, to July 31, 1979

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Y-12 Plant in Oak Ridge, Tennessee, during the period between January 1, 1977, and July 31, 1979, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort* [Azar 2019b, p. 3].

NIOSH determined that it lacked sufficient information to allow it to estimate with sufficient accuracy internal exposures to thorium (and associated progeny) for the period from January 1, 1977, to July 31, 1979, due to a lack of sufficient thorium-related lung count data for this period [NIOSH 2019].

Although NIOSH has determined that there are in vivo monitoring data for thorium (i.e., lung counts) during the period from January 1, 1977, to July 31, 1979, these data are recorded in total thorium mass. NIOSH is unable to use these data to determine the associated quantities of ^{232}Th, ^{228}Th, and ^{228}Ra. For this reason, NIOSH cannot determine with sufficient accuracy the internal exposures that might be represented by each thorium lung measurement. Air-sampling data specific to thorium for the period under evaluation (January 1, 1977, to December 31, 1994) are not available to NIOSH [NIOSH 2019, p. 42]. Consistent with its findings in the earlier Y-12 Plant evaluation reports, NIOSH finds that there is sufficient monitoring and source term information available to reconstruct external dose, including occupational medical dose, with sufficient accuracy for all Y-12 Plant employees during the period from January 1, 1977, to July 31, 1979.

SEC Classes Summary

Although NIOSH found that it is not possible to reconstruct radiation doses completely for the SEC classes, NIOSH intends to use any internal and external monitoring data that might become available, and can be interpreted using its existing dose reconstruction processes or procedures, for an individual claim. Therefore, for individuals employed at Y-12 during the period from March 1, 1943, to July 31, 1979, who do not qualify for inclusion in the SEC, dose reconstructions may be performed using these data as appropriate. All dose reconstructions for all workers having employment during an SEC period are considered partial dose reconstructions.

For the March 1, 1943, to December 31, 1947 period, NIOSH concludes that external doses for workers directly involved with the calutron uranium enrichment and the occupational medical dose for

all workers can be reconstructed [NIOSH 2005, 2008]. NIOSH found that external exposure, including occupational medical doses, can be reconstructed for all employees between January 1, 1948, and July 31, 1979, as determined in the evaluations of SEC-00018 [NIOSH 2005], SEC-00028 [NIOSH 2006a], SEC-00098 [NIOSH 2008], SEC-00186 [NIOSH 2011], SEC-00251 [NIOSH 2018], and SEC-00250 [NIOSH 2019].

3.2 EXAMINATION FREQUENCIES

The frequency of occupational examinations differed significantly over the years. Y-12 conducted preemployment and annual physical examinations as part of its occupational health program. These examinations typically included a chest X-ray. Most Y-12 employees received occupationally related X-rays annually for many years and at a lesser frequency in later years. The frequencies over time (1943 to present) for various groups of workers are shown in Table 3-1 for different age groups and for specific groups of workers through the years based on information provided by Y-12 [Wiley 2002]. Starting in July 1993, PA (posterior-anterior) chest X-rays were no longer a routine component of physical examinations [Wiley 2002]. Only photofluorographic (PFG) chest (1943 to 1947) and PA chest projections (1969 to present) are documented. No evidence was found that other screening X-rays were performed. This is further discussed in Section 3.3.

Table 3-1. Frequency of occupational PA chest X-rays at Y-12.[a,b,c]

Period	Frequency	Comment
1943–present	Preemployment	All employees
07/18/1988–03/1998	At termination	All employees
1943–07/18/1988	Annually	All employees
07/18/1988–present	Time of entry into hazardous job	Asbestos and beryllium workers and other jobs with potential pulmonary pathogens
07/18/1988–03/1998	Annually	Active and previous asbestos and beryllium workers
07/18/1988–06/30/1993	Every 10 years	Employees under 30 years old
07/18/1988–06/30/1993	Every 5 years	Employees aged 30–45 years old
07/18/1988–06/30/1993	Every 3 years	Employees over 45 years old
03/1998–present	Annually	Active asbestos workers
03/1998–present	Every 3 years	Previous asbestos workers; active and previous beryllium workers

a. Source: Wiley [2002].
b. Workers in certain occupations might have received chest X-rays more frequently. This information might be in the worker's file from DOE. This is discussed further below.
c. Preemployment PFG X-rays were performed from 1943 to 1947 [ORAUT 2003].

However, occupational X-rays might have occurred more frequently than on the schedule indicated in Table 3-1, at least in the early years (1943 to 1947). The basis for specifying more frequent X-rays for these workers is taken from *Occupational Accidents and Diseases* [no date, p. 9]. Although this document is not dated, Sections 5 through 9 (pp. 11–17) are taken from a memorandum written by a physician in the United States Engineer Office in Oak Ridge, Tennessee, about the Y-12 X-Ray Department on February 23, 1945 [Wolf 1945]. Wolf [1945] specified more frequent physical examinations (including X-ray) for various occupational groups. A recommended procedure for routine medical examinations specified more frequent X-rays for the following occupational groups [Wolf 1945]:

- Food handlers and cafeteria workers – every 6 to 12 months.
- Alpha (calutron) workers – twice per year.
- Liquid phase workers exposed to uranium, phosgene, or carbon tetrachloride – three times per year.

It appears that the X-ray information is not provided in the records supplied by DOE. In addition, Y-12 has not provided this information. Therefore, the default information in this TBD should be applied in the absence of further information. However, the worker's files sometimes contain X-ray records [ORAUT 2017]. If information provided by Y-12 indicates more frequent X-rays than those described in the default assumptions, dose should be assigned accordingly.

3.3 EQUIPMENT AND TECHNIQUES

According to information from the Y-12 Medical X-Ray Department, preemployment chest X-rays were always taken with a conventional medical diagnostic X-ray machine using 14- by 17-in. film [Wiley 2002]. However, in reviewing the medical X-ray folders of workers from the 1940s, approximately 1,400 4- by 10-in. PFG chest X-ray films were found in the medical X-ray folders of workers who were employed at Y-12 from 1943 to 1947 [ORAUT 2003]. There are multiple references documenting the use of PFG machines and PFG film [Graham 1946; Tennessee Eastman Corporation (TEC) 1944–1947, p. 13; Wolf 1945, p. 4]. There is also a copy of a telegram from the Medical Director at Y-12 to General Electric X-Ray Corporation (GE) in Nashville requesting the installation of the PFG unit. William (Jack) Beck confirmed that PFG X-rays were taken only from 1943 to 1947 [ORAUT 2003].

In February 1945, a GE stereoscopic photoroentgen unit, a PFG X-ray machine, was listed as an equipment item in the Y-12 Medical Department [Wolf 1945]. Reexaminations and other chest films were done on conventional 14- by 17-in. films. On October 12, 1945, the TEC Medical Director sent a telegram to the GE X-Ray Corporation requesting that they set up a 4- by 10-in. photoroentgen unit [Leggo 1945]. In June 1946, TEC placed an order with the Oak Ridge Hospital for 6,000 Eastman single-coated 4- by 10-in. X-ray films for the period from August 1, 1946, to July 31, 1947 [Graham 1946]. Therefore, it is clear that preemployment chest X-rays were taken with a PFG unit from 1943 to 1947, as evidenced by the 4- by 10-in. films in the medical records and the purchasing records. All chest X-rays since then have been conventional 14- by 17-in. X-rays [Wiley 2002].

No record has been found to determine what type of X-ray machine was in use at Y-12 from 1948 until the GE machine mentioned below, which was used in the early 1960s. This date might not be correct either. In a meeting with the X-ray technologist who provided the information for that report, the technologist said that more recent documentation indicated that the GE-type machine was installed in 1969, not in the early 1960s [ORAUT 2003]. Therefore, it is not possible at this time to state with certainty what X-ray machine was used from 1948 to 1968. From 1969 until January 1982, the X-ray machine in use was similar to a GE Model DXD-350. This machine was replaced with a GE Model DSX-650II in February 1982 [Wiley 2002]. In June 2007, a Carestream DR 9000 X-ray machine was installed. The Carestream DR 9000 was operated until June 2020 when it was removed from service. From June 2020 through February 2021, there was not an operational X-ray machine at Y-12. Screening X-rays were performed off site during this period. A Carestream Ascend was installed in March 2021 and is currently in operation [ORAUT 2021].

A description of the X-ray equipment used at Y-12 is included in Table 3-2. The X-ray machines are grouped by type to account for the specific characteristics of the machines in use for each period. The specific technique factors for these machines are shown in Table 3-3.

Table 3-2. Description of X-ray equipment.

Machine	Period	Equipment
Type I	1943–1947	PFG unit at Oak Ridge Hospital or Y-12 Clinic[a]
Type II	1948–1968	Unknown
Type III	1969–01/1982	Similar to GE DXD-350 (exact model unknown)[b]
Type IV	02/1982–05/2007	GE DSX-650 II[b]
Type V	06/2007–05/2020	Carestream DR 9000[c]
Type VI	03/2021–present	Carestream Ascend[c]

a. Source: Graham [1946].
b. Source: Wiley [2002].
c. Source: ORAUT [2021].

Table 3-3. Technique factors used for each type of X-ray equipment.

Machine	Projection	mAs	Voltage (kVp)	Exposure time (s)
Type V[a]	PA	3.1 mAs	120	Phototimed
Type VI[a]	PA	6.25 mAs	120	Phototimed

a. Source: ORAUT [2021].

3.4 ORGAN DOSE CALCULATIONS

The medical practices at Y-12 are assumed to have followed the adoption of standards of radiology practice during the 1930s and 1940s to minimize skin dose to the patient [ORAUT 2019]. No actual X-ray beam measurements are available for Y-12 X-ray machines before June 2007. The provided X-ray technique factors might not be reliable because there is uncertainty about the types of X-ray machines at Y-12 and their operating parameters. Because no technique factors were identified by Y-12 for Type I equipment and the factors for Type II equipment are estimated based on conversations with employees, and because there is no supporting documentation, organ doses from ORAUT-OTIB-0006, *Dose Reconstruction From Occupational Medical X-Ray Procedures*, should be assigned [OTIB-0006; ORAUT 2019]. Type III equipment parameters are an estimate based on the GE DXD-350 X-ray machine because the Type III model is unknown. Further, because Type IV machines were phototimed, the exposure time is an estimate. Organ doses calculated using Type III and Type IV equipment parameters were initially calculated; however, the doses were considered low in comparison with OTIB-0006 organ doses. The decision was made to assign organ doses from OTIB-0006 both to account for estimates made in some of the Type III and Type IV equipment parameters and for consistency with earlier periods. Organ doses for Type V and Type VI equipment were calculated using the parameters from Y-12 and are shown in Tables 3-4 and 3-5. Because the X-ray units were 3-phase, the values from Figure A-1 of the International Commission on Radiological Protection (ICRP) Publication 34 were multiplied by a factor of 1.8 [ICRP 1982]. The data in Figure A-1 were corrected to a source-to-skin distance (SSD) of 154 cm and for the actual voltage, current, and phase of the machines for the various periods. An example calculation is shown below:

$$K_{a,i(2007-2020)} = K_{a,i(\text{ICRP 34})} \times Current(\text{mA}) \times ExposureTime(\text{s}) \times \left(\frac{100}{154}\right)^2 \times 0.1\,\text{cGy/mGy} \qquad (3\text{-}1)$$

where

$K_{a,i(2007\text{-}2020)}$ = incident air kerma in air (cGy)
$K_{a,i(\text{ICRP34})}$ = incident air kerma in air from ICRP Publication 34 (mGy/mAs)
Current = mA
Exposure Time = s

Therefore

$$K_{a,i\,(2007-2020)} = 0.170\,\frac{\text{mGy}}{\text{mAs}} \times 3.1\,\text{mAs} \times \left(\frac{100}{154}\right)^2 \times 0.1\,\text{cGy/mGy} = 0.022\ \text{cGy} \qquad (3\text{-}2)$$

where

$K_{a,i(2007\text{-}2020)}$ = incident air kerma in air for 2007 to 2020 (cGy)

Table 3-4. PA organ dose equivalents (rem) for chest projections.[a,b]

Organ	06/2007–05/2020	03/2021–present
Thyroid	1.74E−03	3.50E−03
Eye/brain	1.74E−03	3.50E−03
Ovaries	1.16E−04	2.33E−04
Urinary/bladder	1.16E−04	2.33E−04
Colon/rectum	1.16E−04	2.33E−04
Testes	2.23E−07	4.49E−07
Lung (male)	1.40E−02	2.82E−02
Lung (female)	1.50E−02	3.03E−02
Thymus	1.50E−02	3.03E−02
Esophagus	1.50E−02	3.03E−02
Stomach	1.50E−02	3.03E−02
Bone surface	1.50E−02	3.03E−02
Liver/gall bladder/ spleen	1.50E−02	3.03E−02
Remainder organs	1.50E−02	3.03E−02
Breast	2.58E−03	5.21E−03
Uterus	1.16E−04	2.33E−04
Bone marrow (male)	3.96E−03	7.99E−03
Bone marrow (female)	3.83E−03	7.72E−03
ENSD[c]	3.20E−02	6.45E−02

a. Source: ORAUT [2022].
b. ENSD = entrance skin dose.
c. ENSD is determined by multiplying the entrance air kerma in air by the backscatter factor of 1.44 for half-value layer of 4.6-mm Al, from National Council on Radiation Protection and Measurements (NCRP) Report 102 [NCRP 1989, Table B-8]. Skin doses for all areas of skin are provided in Table 3-5.

Table 3-5. PA skin dose equivalents (rem) for chest projections.[a]

Area of skin	06/2007–05/2020	03/2021–present
Right front shoulder	1.27E−03	2.55E−03
Right back shoulder	3.20E−02	6.45E−02
Left front shoulder	1.27E−03	2.55E−03
Left back shoulder	3.20E−02	6.45E−02
Right upper arm to elbow	3.20E−03	6.45E−03
Left upper arm to elbow	3.20E−03	6.45E−03
Left hand	3.20E−03	6.45E−03
Right hand	3.20E−03	6.45E−03
Left elbow, forearm, wrist	3.20E−03	6.45E−03
Right elbow, forearm, wrist	3.20E−03	6.45E−03
Right side of head including ear and temple	3.20E−03	6.45E−03
Left side of head including ear and temple	3.20E−03	6.45E−03
Front left thigh	1.39E−05	2.79E−05
Back left thigh	1.39E−05	2.79E−05
Front right thigh	1.39E−05	2.79E−05
Back right thigh	1.39E−05	2.79E−05
Left knee and below	5.06E−06	1.02E−05
Right knee and below	5.06E−06	1.02E−05
Left side of face	1.74E−03	3.50E−03
Right side of face	1.74E−03	3.50E−03
Left side of neck	3.20E−03	6.45E−03
Right side of neck	3.20E−03	6.45E−03
Back of head	3.20E−03	6.45E−03
Front of neck	1.74E−03	3.50E−03
Back of neck	3.20E−03	6.45E−03
Front torso: base of neck to end of sternum	1.27E−03	2.55E−03
Front torso: end of sternum to lowest rib	1.27E−03	2.55E−03
Front torso: lowest rib to iliac crest	1.27E−04	2.55E−04
Front torso: iliac crest to pubis	1.27E−04	2.55E−04
Back torso: base of neck to mid–back	3.20E−02	6.45E−02
Back torso: mid–back to lowest rib	3.20E−02	6.45E−02
Back torso: lowest rib to iliac crest	3.20E−03	6.45E−03
Back torso: buttocks (Iliac crest and below)	3.20E−03	6.45E−03
Right torso: base of neck to end of sternum	3.20E−02	6.45E−02
Right torso: end of sternum to lowest rib	3.20E−02	6.45E−02
Right torso: lowest rib to iliac crest	3.20E−03	6.45E−03
Right torso: iliac crest to pubis (right hip)	3.20E−03	6.45E−03
Left torso: base of neck to end of sternum	3.20E−02	6.45E−02
Left torso: end of sternum to lowest rib	3.20E−02	6.45E−02
Left torso: lowest rib to iliac crest	3.20E−03	6.45E−03
Left torso: iliac crest to pubis (left hip)	3.20E−03	6.45E−03

a. Source: ORAUT [2022].

The use of proxy data is based on the idea that the Y-12 Plant, like other DOE sites, used the standard radiological procedure of the time. The X-ray doses in OTIB-0006 should be assigned for all periods before June 2007 [ORAUT 2019] and if projections other than PA are found in the worker's records.

The tissue at risk for chronic lymphocytic leukemia is the B-lymphocytes. The dose to the B-lymphocytes was determined using the method in ORAUT-RPRT-0064, *Medical Dose to the B-Lymphocytes* [ORAUT 2014], site-specific information, and ICRP Publication 34 dose conversion factors [ICRP 1982]. Table 3-6 provides dose distributions and statistical parameters for input into the Interactive RadioEpidemiological Program (IREP) for determining dose to the B-lymphocytes.

Table 3-6. IREP dose distributions and statistical parameters for the dose to the B-lymphocytes.[a]

Period	IREP distribution	Parameter 1	Parameter 2	Parameter 3
06/2007–05/2020	Weibull 3	2.102371	0.006472	2.3408 E-05
03/2021–present	Weibull 3	2.101702	0.013231	4.77381 E-05

a. Source: ORAUT [2022].

3.4.1 Dose Reconstruction Guidance

The information below summarizes instructions for dose reconstructors in determining organ doses from occupational medical X-ray procedures. For the purpose of evaluating probability of causation, X-ray doses are always considered acute and to reflect photons with energies in the range from 30 to 250 keV. X-ray doses are assigned in IREP with a normal distribution in IREP Parameter 1 and the product of the organ dose multiplied by an uncertainty of 0.3 in Parameter 2 for the purpose of calculating probability of causation [ORAUT 2017].

3.4.1.1 Maximizing Approach

To maximize X-ray dose, preemployment and annual X-rays should be assigned unless there is evidence of more frequent X-ray examinations. Refer to OTIB-0006 for PFG and PA chest X-ray examination doses before June 2007 [ORAUT 2019] and Tables 3-4 and 3-5 thereafter. Refer to OTIB-0006 for examination doses for examinations other than PA chest X-rays if found in the worker's records and determined to be occupational in nature.

3.4.1.2 Best-Estimate Approach

The dose reconstructor may use a frequency other than annual if the actual frequency is known and apply the guidance in Table A-1 of ORAUT-PROC-0061, *Occupational Medical X-Ray Dose Reconstruction* [ORAUT 2017]. X-ray records can be requested from the site on an as-needed basis. Refer to OTIB-0006 for PFG and PA chest X-ray examination doses before June 2007 [ORAUT 2019] and Tables 3-4 and 3-5 thereafter. Refer to OTIB-0006 for examination doses for examinations other than PA chest X-rays if found in the worker's records and determined to be occupational in nature.

3.5 UNCERTAINTY

Although many factors can introduce uncertainty and error into X-ray dose estimates, five factors contribute the most: measurement error, variation in peak kilovoltage, variation in beam current, variation in exposure time, and distance from the worker to the source of the X-rays (source-to-skin distance) [ORAUT 2019]. Other variables such as the use of screens and grids, reciprocity failure, and film speed and development would not affect the beam output intensity [ORAUT 2019].

There is no apparent reason to believe that practices at Y-12 were different from those at other facilities or from recommended standards of the medical community at the time. Therefore, use of default estimates and reliance on information from other DOE sites when site-specific information is unavailable is likely to closely approximate X-ray performance at Y-12. Therefore, for a derived dose equivalent to an individual organ, a total combined standard uncertainty of ±30% can be assumed. Dose reconstructors should, therefore, input the organ dose equivalent as the mean of a normal distribution, with a standard uncertainty of ±30% [ORAUT 2019].

REFERENCES

Azar AM II [2019a]. U.S. Department of Health and Human Services designation of additional members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act of 2000 designating a class of employees from Y-12 Plant Oak Ridge, Tennessee. Washington, DC: U.S. Department of Health and Human Services, Office of the Secretary. SEC-00251, February 26. [SRDB Ref ID: 178555]

Azar AM II [2019b]. U.S. Department of Health and Human Services designation of additional members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act of 2000 designating a class of employees from Y-12 Plant Oak Ridge, Tennessee. Washington, DC: U.S. Department of Health and Human Services, Office of the Secretary. SEC-00250, October 25. [SRDB Ref ID: 184330]

Graham WH [1946]. X-ray film. Letter to Dr. F.T. Rogers, Oak Ridge Hospital. Clinton Engineer Works, Oak Ridge, TN: Tennessee Eastman Corporation. June 26. [SRDB Ref ID: 186978]

ICRP [1982]. ICRP 34 - Protection of the patient in diagnostic radiology. ICRP Publication 34. Ann ICRP *9*(2/3). [SRDB Ref ID: 32466]

Leavitt MO [2005]. HHS designation of additional members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act designating a class of employees from Y-12 Plant Oak Ridge, Tennessee. Washington, DC: U.S. Department of Health and Human Services, Office of the Secretary. August 25. [SRDB Ref ID: 168093]

Leavitt MO [2006]. HHS designation of additional members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act designating a class of employees from Y-12 Plant Oak Ridge, Tennessee. Washington, DC: U.S. Department of Health and Human Services, Office of the Secretary. August 8. [SRDB Ref ID: 184331]

Leavitt MO [2008]. HHS designation of additional members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act designating a class of employees from Y-12 Plant Oak Ridge, Tennessee. Washington, DC: U.S. Department of Health and Human Services, Office of the Secretary. August 15. [SRDB Ref ID: 168094]

Leggo C [1945]. Telegram to E.C. Evans, GE X-Ray Corporation. Clinton Engineer Works, Oak Ridge, TN: Tennessee Eastman Corporation. October 12. [SRDB Ref ID: 186979]

NCRP [1989]. Medical X-ray, electron beam and gamma-ray protection for energies up to 50 MeV (equipment design, performance and use). Bethesda, MD: National Council on Radiation Protection and Measurements. NCRP Report 102, June 30. [SRDB Ref ID: 32467]

NIOSH [2005]. Special Exposure Cohort petition evaluation report petition SEC-00018 Rev. 0 Y-12 Plant qualified February 3, 2005. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00018 Rev. 0, June 13. [SRDB Ref ID: 100832]

NIOSH [2006a]. Special Exposure Cohort petition evaluation report petition SEC-00028 Rev. 0 Y-12 Plant qualified April 29, 2005. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00028 Rev. 0, April 7. [SRDB Ref ID: 100833]

NIOSH [2006b]. Special Exposure Cohort petition evaluation report petition SEC-00028 Supplement Rev. 0 Y-12 Plant qualified April 29, 2005. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00028 Supplement Rev. 0, June 9. [SRDB Ref ID: 176736]

NIOSH [2008]. Special Exposure Cohort petition evaluation report petition SEC-00098 Rev. 0 Y-12 Plant qualified September 24, 2007. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00098 Rev. 0, June 6. [SRDB Ref ID: 100834]

NIOSH [2010]. Radiation exposures covered for dose reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DCAS-IG-003 Rev. 1, October 5. [SRDB Ref ID: 88929]

NIOSH [2011]. Special Exposure Cohort petition evaluation report petition SEC-00186 Rev. 0 Y-12 Plant qualified April 28, 2011. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00186 Rev. 0, July 18. [SRDB Ref ID: 100831]

NIOSH [2018]. Special Exposure Cohort petition evaluation report petition SEC-00251 Rev. 0 Y-12 Plant qualified November 16, 2018. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00251 Rev. 0, November 27. [SRDB Ref ID: 176735]

NIOSH [2019]. Special Exposure Cohort petition evaluation report petition SEC-00250 Rev. 0 Y-12 Plant qualified March 6, 2019. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Petition SEC-00250 Rev. 0, July 17. [SRDB Ref ID: 180255]

Occupational accidents and diseases [no date]. [SRDB Ref ID: 4685]

ORAUT [2003]. Beck's notes on Y-12 Plant medical X-rays. E-mail to William E. Murray. Oak Ridge, TN: Oak Ridge Associated Universities Team. August 13. [SRDB Ref ID: 8634]

ORAUT [2007]. Y-12 National Security Complex – occupational medical dose. Oak Ridge, TN: Oak Ridge Associated Universities Team. ORAUT-TKBS-0014-3 Rev. 01, June 18. [SRDB Ref ID: 32461]

ORAUT [2014]. Medical dose to the B-lymphocytes. Oak Ridge, TN: Oak Ridge Associated Universities Team. ORAUT-RPRT-0064 Rev. 00, June 3. [SRDB Ref ID: 132772]

ORAUT [2017]. Occupational medical x-ray dose reconstruction. Oak Ridge, TN: Oak Ridge Associated Universities Team. ORAUT-PROC-0061 Rev. 04, June 6. [SRDB Ref ID: 166910]

ORAUT [2019]. Dose reconstruction from occupational medical x-ray procedures. Oak Ridge, TN: Oak Ridge Associated Universities Team. ORAUT-OTIB-0006 Rev. 06, September 27. [SRDB Ref ID: 178310]

ORAUT [2021]. Y-12 response to data request. Documented communication with Paige Hurst. Oak Ridge, TN: Oak Ridge Associated Universities Team. October 11. [SRDB Ref ID: 190380]

ORAUT [2022]. ORAUT-TKBS-0014-3 Rev 02 support files. Zip file. Oak Ridge, TN: Oak Ridge Associated Universities Team. March 22. [SRDB Ref ID: 194914]

Sebelius K [2011]. HHS designation of additional members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act designating a class of employees from Y-12 Plant Oak Ridge, Tennessee. Washington, DC: U.S. Department of Health and Human Services, Office of the Secretary. October 18. [SRDB Ref ID: 168097]

TEC [1944–1947]. Purchase orders x-ray film. Clinton Engineer Words, Knoxville, TN: Tennessee Eastman Corporation. [SRDB Ref ID: 12326]

Wiley SW [2002]. NIOSH request for description of x-ray protocols. Letter to J. Newton, National Institute for Occupational Safety and Health. Y-12 National Security Complex, Oak Ridge, TN: BWXT Y-12. April 1. [SRDB Ref ID: 8394]

Wolf BS [1945]. X-ray department at Y-12, as of 23 February 1945. Memorandum for the files. Oak Ridge, TN: Army Service Forces, United States Engineer Office, Manhattan District. February 23. [SRDB Ref ID: 4691]

GLOSSARY

accuracy
Closeness of agreement between a measured quantity value and the true quantity value of a measurand. Accuracy is a qualitative term unless the true quantity value is known. See *measurand* and *uncertainty*.

calutron
Accelerator that separates isotopes (e.g., ^{235}U from ^{238}U) according to their masses using strong magnetic fields. The name derives from California University cyclotron.

entrance skin dose (ENSD)
Dose equivalent to the skin surface in the primary X-ray beam on the entrance side of the body.

error
Difference between the correct, true, or conventionally accepted value and the measured or estimated value. Error is a qualitative term unless the true value is known. Sometimes used to mean estimated uncertainty. See *accuracy* and *uncertainty*.

film speed
Measure of the sensitivity of film to X-rays or light.

gray
International System unit of absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium; 1 gray equals 1 joule per kilogram or 100 rad. Gray is also the plural.

grid
Device that consists of a series of thin, closely spaced lead strips that is placed between the person being X-rayed and the X-ray film to reduce interaction of scattered radiation with the film.

Interactive RadioEpidemiological Program (IREP)
Computer program that uses a person's calculated annual organ doses and other information (e.g., gender, age at diagnosis, and age at exposure) to calculate the probability of causation of a specific cancer from a given pattern and level of radiation exposure.

kerma
Measure in units of absorbed dose (usually gray but sometimes rad) of the energy released by radiation from a given amount of a substance. Kerma is the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged ionizing particles (neutrons and photons) 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. The word derives from kinetic energy released per unit mass.

kiloelectron-volt (keV)
Unit of particle energy equal to 1,000 (1×10^3) electron-volts.

measurand
Quantity intended to be measured.

National Council on Radiation Protection and Measurements (NCRP)
Private U.S. public service organization chartered by the U.S. Congress to formulate and disseminate information, guidance, and recommendations on radiation protection and measurements.

photofluorography
Historical radiographic technique to produce chest images for screening a large number of people in a short period of time. The X-ray image produced on a fluorescent screen was photographed on 4- by 5-inch film. Photofluorography was the primary method of screening large populations for tuberculosis before the advent of nonradiographic screening methods. Also called fluorography or mass miniature radiography. Not to be confused with *fluoroscopy*.

photon
Quantum of electromagnetic energy generally regarded as a discrete particle having zero rest mass, no electric charge, and an indefinitely long lifetime. The entire range of electromagnetic radiation that extends in frequency from 10^{23} cycles per second (hertz) to 0 hertz.

posterior-anterior (PA)
Physical orientation of the body relative to a penetrating directional radiation field such that the radiation passes through the body from the back to the front.

preemployment X-ray
An X-ray, usually of the chest, taken before hire or assignment to a specific job. The purpose of preemployment X-rays was to screen for active disease such as tuberculosis.

probability of causation
For purposes of dose reconstruction for the Energy Employees Occupational Illness Compensation Program Act of 2000, the percent likelihood, at the 99th percentile, that a worker incurred a particular cancer from occupational exposure to radiation.

pulmonary
Of or relating to the lungs.

radiograph
Static images produced on radiographic film by gamma rays or X-rays after passing through matter. In the context of the Energy Employees Occupational Illness Compensation Program Act of 2000, radiographs are X-ray images of the various parts of the body used to screen for disease. See *radiology*.

radiology
Medical science and specialty of producing images on radiographic film or other media, which are used to identify, diagnose, and or treat diseases, injuries, or other conditions.

screen
Fluorescent material in X-ray film cassettes that absorbs X-rays and converts them into light to expose the X-ray film. Also called intensifying screens.

source-to-skin distance
Distance from the X-ray machine target (anode) to the skin of the person being radiographed. This distance varies with the size of the person being radiographed.

technique
Combination of X-ray machine settings (technique factors) used to produce radiographs, which consists of the kilovoltage, tube current (milliamperes), and exposure time (seconds). The last two parameters are often multiplied to yield the electric charge that has crossed the X-ray tube during the exposure in units of milliampere-seconds. Any combination of time and tube current that produces a given product in milliampere-seconds produces the same exposure for a fixed peak kilovoltage. Also called technic.

termination X-ray
X-ray, usually of the chest, taken when an employee separates from the company.

tube current
Average electrical current measured in milliamperes flowing from the cathode to the anode of an X-ray tube during operation of the tube.

uncertainty
Nonnegative parameter characterizing the dispersion of the quantity values being attributed to the quantity being measured, based on the information used. See *accuracy* and *error*.

variable
In a mathematical formula, a quantity or function that can assume any given value or set of values.

X-ray
See *radiograph*.

X-ray tube
Evacuated electronic tube in which electrons are accelerated by an applied voltage to strike an anode or target and produce X-rays.