DOE Review Release 08/26/2009

Document Title:	Document Number:	ORAUT-OTIB-0064
Coworker External Dosimetry Data for the Y-12 National Security Complex	Revision:	00
	Effective Date:	08/03/2009
	Type of Document	OTIB
	Supersedes:	None

Subject Expert(s): Janice P. Watkins, Edward L. Frome, George D. Kerr, William G. Tankersley

Site Expert(s): N/A

Approval:	Signature on File Janice P. Watkins, Document Owner	Approval Date:	06/22/2009
Concurrence:	Signature on File John M. Byrne, Objective 1 Manager	Concurrence Date:	06/22/2009
Concurrence:	Signature on File Edward F. Maher, Objective 3 Manager	Concurrence Date:	06/24/2009
Concurrence:	Signature on File Kate Kimpan, Project Director	Concurrence Date:	06/23/2009
Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	08/03/2009

☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/03/2009	00	Approved new technical information bulletin that provides background information on the Y-12 coworker external dosimetry data and includes tables with annual values that may be used in the process of assigning doses for unmonitored years of employment. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Janice P. Watkins.

TABLE OF CONTENTS

LIST OF TABLES

TABLE **TITLE** **PAGE**

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

ACRONYMS AND ABBREVIATIONS

CER	Center for Epidemiologic Research
DOE	U.S. Department of Energy
E (dose)	the expected value of dose in the statistical sense, i.e., the mean dose on the original scale
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
GM	geometric mean
GSD	geometric standard deviation
HP	health physics
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt (1,000 electron-volts)
K-25	Oak Ridge Gaseous Diffusion Plant
MDL	minimum detectable level
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
SRDB Ref ID	Site Research Database Reference Identification (number)
SSN	Social Security Number
TBD	technical basis document
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
wk	week
X-10	Oak Ridge National Laboratory
Y-12	Y-12 Plant, now the Y-12 National Security Complex
yr	year
§	section or sections

1.0 INTRODUCTION

Technical information bulletins (TIBs) 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). TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

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 of 2000 [42 U.S.C. § 7384l(5) and (12)].

2.0 PURPOSE AND SCOPE

The purpose of this TIB is to provide information that will enable Oak Ridge Associated Universities (ORAU) Team dose reconstructors to assign doses based on site coworker data to workers at the Y-12 Plant who have limited or no monitoring data. The data in this TIB are to be used in conjunction with ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment* (ORAUT 2008). This TIB is for use in reconstructions for the period from January 1950 to December 1979.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 8.0.

3.0 BACKGROUND

The ORAU Team is conducting a series of coworker data studies to permit dose reconstructors to complete cases for which external and/or internal monitoring data are unavailable or incomplete. Such cases can fall into one of several categories, as follows:

- The worker was unmonitored and, even by today’s standards, did not need to be monitored (e.g., a nonradiological worker).
- The worker was unmonitored but by today’s standards would have been monitored.
- It is possible that the worker was monitored, but if so the data are not available.
- There is some information available for the worker, but it is insufficient to permit a dose reconstruction.

The Union Carbide Corporation Nuclear Division assumed the management of the Y-12 Plant in May 1947, and the Plant mission changed from the electromagnetic enrichment of uranium using calutrons to the processing and fabrication of uranium and other nuclear materials (ORAUT 2007a). The first experience with the machining of uranium metal at the Y-12 Plant was in December 1947 in a shop in Building 9766 (Emlet 1952). In the spring of 1948, steps were taken for the transfer of certain weapon fabrication functions from Los Alamos to Y-12 Plant facilities, which were established in Building 9212 where chemical processing of uranium had long occurred. At that time, the responsibility for the study and monitoring of the uranium machining operations was transferred from a Special Hazards Group to a Health Physics (HP) Department in the Medical Division (Emlet 1952).

The HP Department started a film badge dosimetry program in 1948 to monitor external radiation exposures to Y-12 workers in the Assay Laboratories, Radiographic Shop, Spectrographic Shop, and Machine Shops, which handled uranium metals (Struxness 1948). The external monitoring data for 1948 and 1949 are not readily available by Social Security Number (SSN), and have not been supplied by Y-12 in response to requests under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) (Souleyrette 2003). A report of the external monitoring data for 1948 and 1949 that are available from previous epidemiological studies by the ORAU Center for Epidemiologic Research (CER) has been published (ORAUT 2005a). The CER data have been placed on the secure data server at the ORAU Cincinnati Operations Office for use in dose reconstructions for workers at the Y-12 facility. In addition, the data on the server have been linked to each worker's badge identification number and SSN (ORAUT 2005a).

An extensive documentation of the worker radiological programs beginning in the 1950s is provided in the *Recycled Uranium Mass Balance Project for the Y-12 National Security Complex Site Report* (BWXT Y-12 2000). The film badge dosimetry program was expanded in 1950 to include all Y-12 personnel who worked with (1) depleted uranium metal, (2) discrete sources of gamma rays or beta particles, (3) X-rays, and (4) materials that were contaminated with fission products (McLendon 1960). The external radiation dosimetry policy of monitoring only the Y-12 workers involved the four types of radioactive materials listed above (about 10% to 20%) was continued until 1961 (ORAUT 2005b). In 1961, a new policy was instituted that required all Y-12 workers to be monitored for external radiation exposure with film dosimeters, which were integrated into the worker's identification badges and contained components for both routine and accident-related dosimetry. The use of film dosimeters ended in 1979 when they were largely replaced by thermoluminescent dosimeters (TLDs) (McLendon et al. 1980; West 1993).

4.0 GENERAL APPROACH

As described in ORAUT (2008), the general approach to the application of coworker data to cases without external monitoring data involves two phases. Phase I permits the processing of cases when a "best-and-final" estimate of dose is not required for claim determination. Phase II facilitates the assignment of best-and-final estimates of dose, when necessary. This TIB provides coworker external dosimetry summary statistics applicable to Phase I dose reconstructions. Dose distributions applicable to Phase II dose reconstructions can be obtained from tables available in ORAUT-RPRT-0032, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Facility in Oak Ridge: Part 1 – Gamma Radiation* (ORAUT 2005b), for gamma doses and ORAUT-OTIB-0046, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Plant in Oak Ridge, Tennessee: Part 3 – Beta Radiation* (ORAUT 2007a), for beta doses.

5.0 APPLICATIONS AND LIMITATIONS

1. The coworker data and information in this report can be used only for dose reconstruction cases that do not require best-estimate calculations [1]. Such cases include evidently noncompensable cases for which a higher external dose can be assigned than that likely to have been actually received, or evidently compensable cases for which a lower external dose can be assigned than that likely to have been actually received. For cases that require a best-estimate analysis, recommended methods based on subgroup regression analyses are detailed in ORAUT (2005b) and ORAUT (2007a). These documents provide tables of geometric means (GMs) and geometric standard deviations (GSDs) that begin with the third quarter of 1947.

2. Some workers might have been employed at more than one of the major DOE sites in the Oak Ridge area (K-25, X-10, and Y-12). For some cases, employment information is provided in the NIOSH Office of Compensation Analysis and Support Claims Tracking System as a multiple site listing such as "K-25/Y-12/X-10," and the available information such as the DOE dosimetry records and claimant interview are insufficient to determine the actual work location(s), especially on an annual basis. Similarly, workers might have worked at more than one major site across the DOE complex during their employment history. Therefore, the data in this document must be used with caution to ensure, for evidently noncompensable and evidently compensable cases, that unmonitored external radiation exposures from multiple site employment have been overestimated and underestimated, respectively.

3. The summary statistics in this TIB extend from 1950 through 1979, the end of the film badge dosimetry program at the Y-12 Plant. The absence of data for 1980 and later (and subsequent development of other dose distributions) should not interfere with the processing of most Y-12 cases that have a lack of external dosimetry data because in recent years the TLD monitoring programs at Y-12 and the other Oak Ridge sites were sufficiently comprehensive to ensure that a dose reconstruction can be carried out for all workers with a potential for external exposure during the TLD dosimetry period [2].

4. The data in this TIB address gamma doses (i.e., the radiation doses from gamma rays and hard X-rays) and beta doses (i.e., the radiation from beta particles and soft X-rays). Neutron dose data are not presented. However, the locations at the Y-12 site at which neutron exposures were possible are limited (ORAUT 2005c), and neutron doses were monitored separately for Y-12 workers who had a potential for neutron exposure (Emlet 1956). Therefore, it is not likely that the lack of coworker data for external radiation exposure to neutrons in this TIB would negatively affect Y-12 dose reconstructions [3].

6.0 COWORKER DATA DEVELOPMENT

From 1978 through the early 1990s, the Y-12 site delivered electronic files of worker data to the ORAU CER as a resource for the Health and Mortality Studies for DOE and its predecessor agencies (Watkins et al. 1993). Files that were received on magnetic tapes contained records for more than 17,000 Y-12 workers. The records included doses from gamma, beta, and neutron exposures as well as other relevant information. Due to changes over time in recordkeeping practices and procedures at Y-12, the files were in several similar but not identical formats. CER transferred all the data from tape to disk and later constructed a carefully linked relational database with a standardized file format. Since 2002, the data have resided in a Structured Query Language database. The data that were used in this work consist of more than 425,000 records for 1950 through 1979. All records contain the data elements from original Y-12 files, which included first, middle, and last name; plant badge number; SSN; year; quarter; quarterly summations of dose readings for different monitoring periods (i.e., weekly, monthly, or quarterly); and other work history and demographic data. The quarterly summations give results in millirem for all beta, gamma, and neutron doses. Although each record has a flag to note an error condition, this flag is null for years before 1980 and so is not relevant for the film badge period. The external radiation doses that are being provided to NIOSH are effectively the same as those in the CER database.

The validity of the CER database was confirmed by a number of comparisons with summaries of film badge dose data in Y-12 internal correspondence and Y-12 HP progress reports [4]. The progress reports were produced with varying frequency (monthly, quarterly, and semiannually) and have been retrieved from as early as September 1947 (Murray 1947). Examples of such comparisons are provided in Table 6-1 and Figure 6-1. The left-hand portion of Table 6-1 lists the distribution of annual gamma doses and annual skin doses (i.e., annual gamma dose plus annual beta dose) to Y-12 workers during 1962 from a progress report for the fourth quarter of 1962 (UCNC 1963a). The right-

Table 6-1. Comparisons of distributions of annual gamma doses and annual skin doses (gamma plus beta radiation) in 1962.

HP progress report (UCNC 1963a)			CER database		
Dose range (mrem)	Number of workers		Dose range (mrem)	Number of workers	
	Gamma	Skin dose		Gamma	Skin dose
<1,000	5,787	5,108	0–1,000	5,771	4,990
2,000	6	324	1,001–2,000	20	403
3,000	1	173	2,001–3,000	2	197
4,000	0	91	3,001–4,000	1	98
5,000	0	40	4,001–5,000	0	43
6,000	0	25	5,001–6,000	0	28
7,000	0	15	6,001–7,000	0	16
8,000	0	9	7,001–8,000	0	10
9,000	0	6	8,001–9,000	0	6
10,000	0	2	9,001–10,000	0	2
11,000	0	0	10,001–11,000	0	1
12,000	0	1	11,001–12,000	0	0
>12,000	0	0	>12,000	0	0
Total	5,794	5,794	Total	5,794	5,794

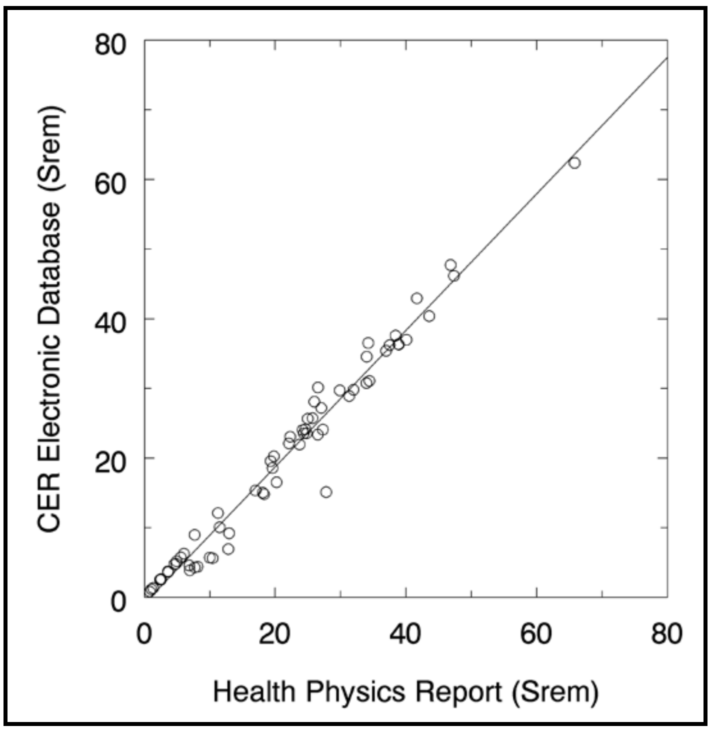

Figure 6-1. Comparison of cumulative skin doses in rem (Srem) from UCNC (1957) and the CER database for 65 foundry workers, 1952 to 1956.

hand portion of Table 6-1 lists the same annual dose distributions from the CER database. The two sets of annual dose distributions in Table 6-1 are in excellent agreement. The second example, shown in Figure 6-1, is from internal correspondence on the radiation doses to Y-12 foundry workers

(UCNC 1957). The open circles in Figure 6-1 represent a comparison of cumulative skin doses to 65 Y-12 foundry workers over the 5-year period from 1952 to 1956 from UCNC (1957) and those derived from sums of 194 person-years of recorded skin dose data over the same period and for the same 65 Y-12 foundry workers. The two sets of cumulative skin doses have high correlation as Figure 6-1 shows. The Pearson correlation coefficient, which assumes a bivariate normal distribution, is 0.841 (Pearson 1896), and the nonparametric Spearman (rank) correlation coefficient is 0.975 (Spearman 1904). Overall, the CER database was found to be acceptable for dose reconstruction purposes and for the development of coworker doses at the Y-12 Plant for 1950 to 1979.

6.1 ADJUSTMENT FOR MISSED DOSE

The *External Dose Reconstruction Implementation Guideline* (NIOSH 2007) states that missed doses are to be assigned for null dosimeter readings to account for the possibility that doses were received but either not recorded by the film badge dosimeter or not reported by the site. These missed doses are calculated by multiplying the minimum detectable level (MDL) of the dosimeters by the number of null badge readings and summing the results; these values are used as the 95th-percentile values of a lognormal distribution for calculating probability of causation for a specific cancer. Therefore, in the Interactive RadioEpidemiological Program (IREP), the calculated missed doses should be multiplied by 0.5 and entered in Parameter 1 (the GM), and 1.52 should be entered in Parameter 2 (the GSD).

The assignment of missed doses for monitored workers is particularly significant for Y-12 workers, as shown in Figures 6-2 and 6-3, because historically there was a high percentage of null dosimeter results for this site. The large number of null results in the monitoring data is largely due to the weekly exchange of film badge dosimeters for monitored workers in the early 1950s and to the monitoring of the entire Y-12 workforce with film badge dosimeters staring in 1961. Because Y-12 workers with null monitoring data should be assigned missed dose, including those workers who probably had no potential for exposure to external radiation during their employment, the assignment of doses to Y-12 workers with no monitoring data based on coworker data must also account for the assignment of missed dose [5].

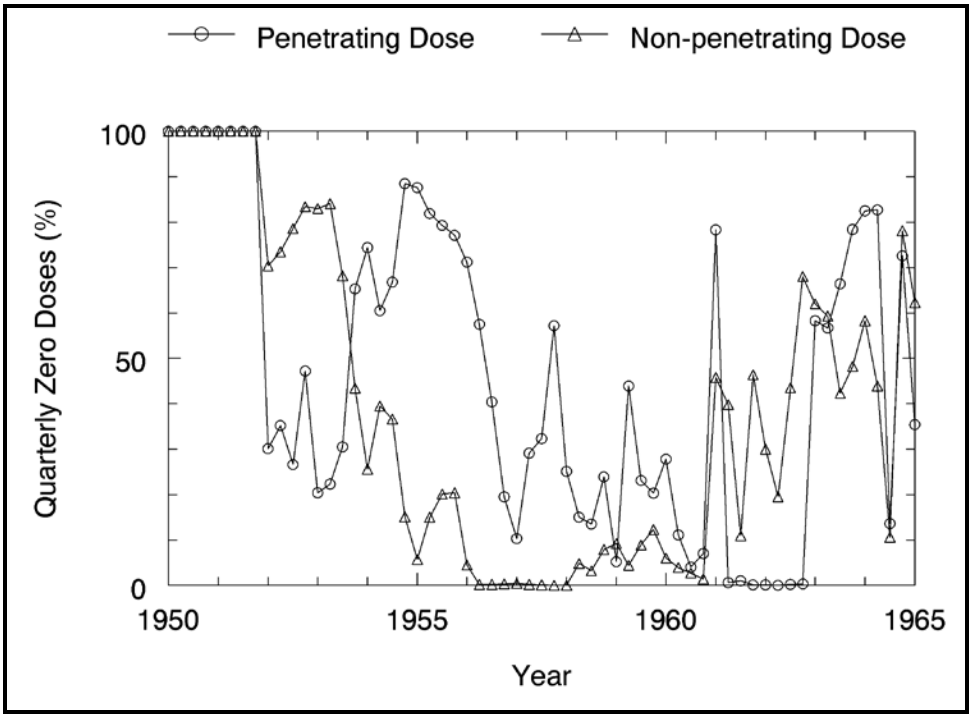

Figure 6-2. Percentage of null penetrating (gamma) and nonpenetrating (beta) doses among the recorded quarterly doses, 1950 to 1964.

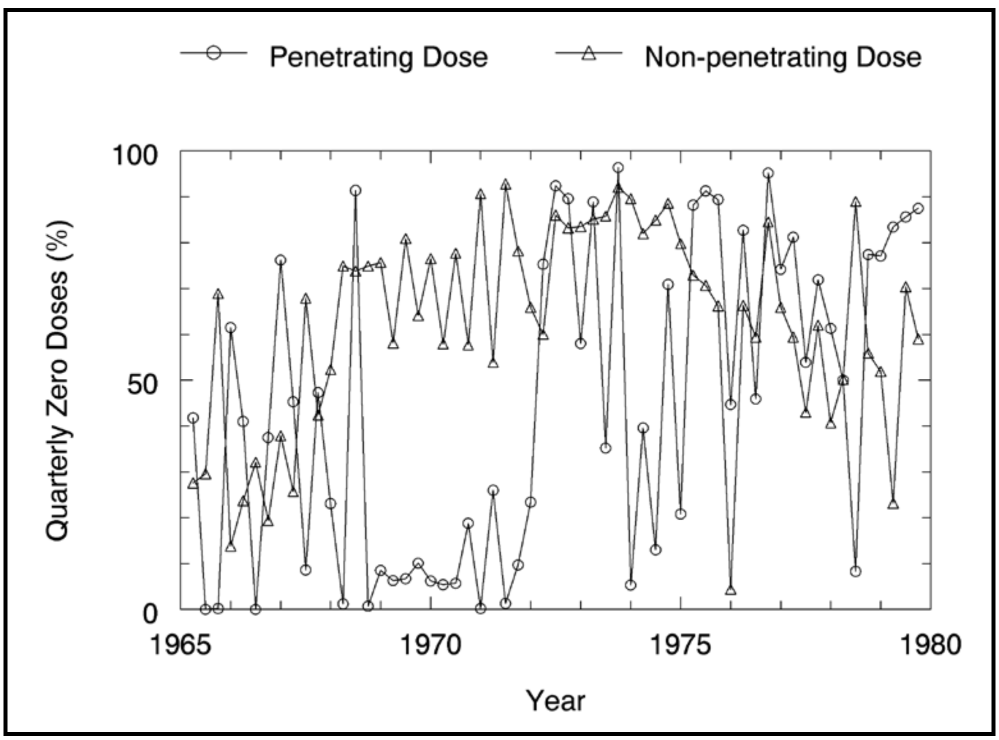

Figure 6-3. Percentage of null penetrating (gamma) and nonpenetrating (beta) doses among the recorded quarterly doses, 1965 to 1979.

The development of coworker data for the Y-12 Plant invoked a need to revise the MDLs and the exchange frequencies of the film badge dosimeters at the plant [6]. These revised dates for changes in the film badge exchange frequencies are provided in Table 6-2.

Table 6-2. Exchange frequencies for film badge dosimeters as a function of time.[a]

Period[b]	Exchange frequency
May 1948–September 1958	Weekly
October 1958–December 1960	Monthly
January 1961–December 1979	Quarterly

a. ORAUT (2005a), West (1993), McLendon (1958), and Reavis (1958).
b. Dates are approximate because changes did not occur for all employees at the same time.

The revised dates for changes in the estimated MDL of the film badge dosimeters are listed in Table 6-3. It is important to note that the MDL and the assigned MDL dose to workers changed significantly with time. As noted, the dates are approximate because the changes did not occur for all employees at the same time. In 1950 and 1951, doses were recorded as zero if they were less than the MDL of 30 mrem (see Table 6-3). As a result, there was only one positive gamma dose of 65 mrem among the 268 recorded quarterly doses for the 148 monitored workers in 1950, and no positive gamma doses were recorded for the 184 monitored workers in 1951. There were also no beta doses recorded for these monitored workers in either 1950 or 1951 (see Figure 6-2).

Table 6-3. MDLs and assigned MDL doses (mrem) for film used to measure gamma and beta doses.[a]

Period[b]	MDL	Assigned dose
May 1948–December 1949	30	30[c]
January 1950–December 1951	30	0
January 1952–September 1952	50	50[c]
October 1952–December 1952	43	43[c]
January 1953–June 1954	50	50[c]
July 1954–December 1954	30	30[c]
January 1955–December 1957	30	15[d]
January 1958–October 1979	30	Not applicable[e]

a. ORAUT (2005a); West (1993).
b. Dates are approximate because the changes did not occur for all employees at the same time.
c. Assigned to gamma dose for those workers with a high potential for exposure to gamma rays or to beta dose for those workers with a high potential for exposure to beta particles (or soft X-rays) if shielded and open-window film readings were less than the MDL.
d. Assigned to beta dose if shielded and open-window film readings were less than the MDL.
e. The actual shielded and open-window film readings were used to calculate the gamma and beta doses even when the film readings were less than the MDL.

The data in Tables 6-2 and 6-3 were used in the development of the data in Table 6-4, which lists the maximum annual missed gamma and beta doses by period. Although some workers might have been on a film dosimeter exchange cycle that was less or more frequent than the typical cycle (ORAUT 2006), the great majority of Y-12 workers were on the schedule listed in Table 6-2. Therefore, the values in Table 6-4 are appropriate for the adjustment of reported coworker doses to account for missed dose.

Table 6-4. Potential missed dose (mrem) from external radiation exposure during the film badge dosimetry program.

Period	Gamma MDL	Beta MDL	Exchange frequency	Maximum annual missed dose	
				Gamma (mrem)	Beta (mrem)
May 1948–Dec 1949	30	30	Weekly	1560	1560
Jan 1950–Dec 1951	30	30	Weekly	1560	1560
Jan 1952–Sep 1952	50	50	Weekly	2600	2600
Oct 1952–Dec 1952	43	43	Weekly	2236	2236
Jan 1953–Jun 1954	50	50	Weekly	2600	2600
Jul 1954–Sep 1958	30	30	Weekly	1560	1560
Oct 1958–Dec 1960	30	30	Monthly	360	360
Jan 1961–Dec 1979	30	30	Quarterly	120	120

6.2 OTHER CONSIDERATIONS

Certain aspects of the external dosimetry practices at the Y-12 Plant that are documented in the external radiation TBD for the Y-12 site (ORAUT 2006) were considered in the analysis of the site data. These include:

- In some cases, values less than the dosimeter MDL were reported by the site. A lower detection limit of approximately 10 mrem was possible if an experienced technician evaluated the exposed film with special care (Morgan 1961). Therefore, values as low as 10 to 20 mrem were reported even though the MDL was considered to be 30 mrem or more.

- Before 1961, dosimeter use was not expressly required for all workers. Badges were typically provided only to people who entered a radiation area, and the badges were worn based on an honor system rather than on a strict requirement. A review of worker data indicates that most workers did wear the badges when they were provided.

As described in Section 7.0, the approach for the development of coworker dose summaries was favorable to claimants, and this approach should account for any underestimates of doses to radiation workers at the Y-12 site based on these considerations.

7.0 COWORKER ANNUAL DOSE SUMMARIES

Based on the information and approaches described above, Y-12 coworker annual external dosimetry summaries were developed for use in the evaluation of external dose for workers who were potentially exposed to workplace radiation but for whom DOE could not provide monitoring data. These summaries were developed as follows:

1. The gamma and beta doses available from CER (see Section 6.0) were converted to annual data by summing the reported quarterly data for 1950 to 1979. Consistent with the guidelines in ORAUT-OTIB-0020 (ORAUT 2008), gamma and beta doses for individuals with fewer than 4 quarters of data for a particular year were converted to annual doses by extrapolation: One quarterly result was multiplied by 4; the sum of two quarterly results was multiplied by 2; and the sum of three quarterly results was multiplied by 1.333.

2. For the gamma doses, one-half of the year’s maximum possible annual missed dose was added to each annual dose from Step 1 using the MDLs and badge exchange frequencies in Tables 6-2 and 6-3. The added amount for a quarter was the MDL/2 multiplied by the badge exchange frequency. If a reported quarterly dose was positive, the badge exchange frequency

was reduced by 1 because it is not possible that all individual badge results were zero if a positive annual dose was reported. Note that this is not the procedure described in OCAS-IG-001 (NIOSH 2007, Section 2.1.2.3), which applies to situations in which the number of zero measurements cannot be determined, as occurs for Y-12 doses before 1961.

3. The 50th- and 95th-percentile annual gamma and beta dose values were derived from the gamma and beta doses in Step 2 by ranking the data and extracting percentiles for each year.

4. The results are presented in Table 7-1a and 7-1b for both gamma and beta doses. The gamma dose percentiles should be used for selected Y-12 workers with limited or no monitoring data using the methods in Section 7.0 of ORAUT-OTIB-0020 (ORAUT 2008). The percentiles for beta doses should be applied only to Y-12 workers who were employed in areas with beta dose potential.

Table 7-1a. Parameters for lognormal prediction density, 1947 to 1949.

Gamma dose[a]						
Yr	Qtr	μ	σ	GM(reg)	GSD(reg)	E(dose) (mrem)
1947	3	5.2684	1.1710	194.1093	3.2254	385.3264
	4	5.2380	1.1710	188.3017	3.2251	373.7602
1948	1	5.2077	1.1709	182.6679	3.2248	362.5419
	2	5.1773	1.1708	177.2026	3.2245	351.6610
	3	5.1469	1.1707	171.9009	3.2243	341.1072
	4	5.1165	1.1706	166.7578	3.2240	330.8709
1949	1	5.0862	1.1706	161.7685	3.2238	320.9423
	2	5.0558	1.1705	156.9285	3.2235	311.3123
	3	5.0254	1.1704	152.2334	3.2233	301.9717
	4	4.9950	1.1703	147.6787	3.2230	292.9120
Beta dose[b]						
Yr	Qtr	μ	σ	GM(reg)	GSD(reg)	E(dose) (mrem)
1947	3	6.8231	1.3687	918.82	3.9304	2,344.4
	4	6.8075	1.3687	904.61	3.9304	2,308.2
1948	1	6.7917	1.3687	890.41	3.9304	2,272.0
	2	6.7756	1.3687	876.20	3.9304	2,235.7
	3	6.7593	1.3687	862.00	3.9304	2,199.5
	4	6.7426	1.3687	847.79	3.9304	2,163.2
1949	1	6.7257	1.3687	833.59	3.9304	2,127.0
	2	6.7085	1.3687	819.38	3.9304	2,090.7
	3	6.6911	1.3687	805.17	3.9304	2,054.5
	4	6.6733	1.3687	790.97	3.9304	2,018.2

a. From ORAUT-RPRT-0032, Rev. 00 (ORAUT 2005b).
b. From ORAUT-OTIB-0046 (ORAUT 2007a).

Table 7-1b. Annual coworker external doses (mrem) for 1950 to 1979 with gamma and beta doses adjusted for missed dose by the method in ORAUT-OTIB-0020.

	Gamma dose (mrem)		Beta dose (mrem)		Number of monitored workers
Year	95th percentile	50th percentile	95th percentile	50th percentile	
1950	780	780	780	780	148
1951	780	780	780	780	184
1952	3,453	2,419	5623	1,300	497
1953	4,216	1,300	7429	2,475	386
1954	3,608	1,300	11,843	3,039	681
1955	2,572	780	11,482	3,241	623
1956	1,810	961	8,404	2,541	729
1957	1,556	934	7,777	2,384	795
1958	1,797	1,065	4,470	1,745	995
1959	1,173	448	3,928	875	1,265
1960	1,124	423	5,093	894	1,335
1961	491	155	2,322	91	5,869
1962	519	171	2,257	101	5,793
1963	360	58	1,464	82	5,789
1964	397	72	1,578	97	5,592
1965	382	110	1,083	70	5,138

1966	478	87	1,185	118	4,730
1967	372	71	1,014	81	5,016
1968	271	141	897	48	5,580
1969	364	127	624	52	6,319
1970	366	122	863	53	7,122
1971	325	110	469	47	7,055
1972	208	57	586	48	6,880
1973	198	53	510	60	6,503
1974	366	93	614	60	5,836
1975	171	54	613	60	5,282
1976	179	58	410	89	5,062
1977	158	52	350	57	5,360
1978	219	86	385	57	5,573
1979	156	60	571	71	5,964

Doses to organs that are affected only by gamma radiation (e.g., organs other than the skin, breast, and testes) are calculated based only on the gamma dose columns in Table 7-1a and 7-1b in combination with the appropriate organ dose conversion factors (NIOSH 2006). Doses to the skin, breast, and testes (or any other cancer location potentially affected by beta radiation) are determined based on both the gamma and beta columns; gamma doses are assigned as photons with energy ranges consistent with information in the external dosimetry TBD for the Y-12 site (ORAUT 2006), and beta doses are assigned as electrons with energy greater than 15 keV (or photons with less than 30 keV if appropriate) with corrections to account for clothing attenuation or other relevant considerations (ORAUT 2005d). Work with depleted uranium has been responsible for the majority of the beta (or non-penetrating) doses at the Y-12 facility (UCNC 1963a,b; Henderson 1991; Ashley et al. 1995; ORAUT 2007a).

As footnoted in Table 6-3 and demonstrated in the example in Section 6.2, significant amounts of missed dose were already added to the recorded dose of Y-12 workers in the late 1940s and early 1950s. With the addition of more missed dose to these workers' recorded doses as outlined above, the amount of missed dose that was added to some of these workers' recorded doses from January 1952 to September 1952 and from January 1953 to June 1954 could be as large as 75 mrem/wk, or 3.9 rem/yr. Therefore, the Y-12 coworker doses in this report are expected to be extremely favorable to claimants for the period before the start of the monthly and quarterly exchange of the film badge dosimeters in the late 1950s and early 1960s (see Table 6-2).

Table 7-2 contains the 50th- and 95th-percentile values of the gamma dose for construction trade workers who meet the criteria in Section 3.0 of ORAUT-OTIB-0052 (ORAUT 2007b). These percentile values, which are based on the annual values in Table 7-1, were calculated using the guidance in Section 8.0 of ORAUT-OTIB-0052 and should not be used for workers who do not meet the specified criteria.

Table 7-2. Annual coworker external doses (mrem) with gamma and beta doses modified for construction trade workers in accordance with ORAUT-OTIB-0052.

	Gamma dose (mrem)		**Beta dose (mrem)**	
Year	**95th percentile**	**50th percentile**	**95th percentile**	**50th percentile**
1950	780	780	780	780
1951	780	780	780	780
1952	4,324	2,877	5623	1300
1953	5,392	1,300	7429	2475

1954	4,542	1,300	11843	3039
1955	3,294	780	11482	3241
1956	2,227	1,039	8404	2541
1957	1,873	1,002	7777	2384
1958	2,210	1,185	4470	1745
1959	1,576	561	3928	875
1960	1,508	526	5093	894
1961	669	199	2322	91
1962	708	221	2257	101
1963	486	63	1464	82
1964	538	83	1578	97
1965	517	136	1083	70
1966	651	104	1185	118
1967	503	81	1014	81
1968	362	179	897	48
1969	492	160	624	52
1970	494	153	863	53
1971	437	136	469	47
1972	273	62	586	48
1973	259	56	510	60
1974	494	112	614	60
1975	221	58	613	60
1976	233	63	410	89
1977	203	55	350	57
1978	289	102	385	57
1979	200	60	571	71

8.0 ATTRIBUTIONS AND ANNOTATIONS

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

[1] Watkins, Janice P. Oak Ridge Associated Universities. Biostatistician. March 2007.
As discussed in ORAUT-RPRT-0032, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Facility in Oak Ridge: Part 1 – Gamma Radiation* (ORAUT 2005b), for gamma dose and ORAUT-OTIB-0046, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Plant in Oak Ridge, Tennessee: Part 3 – Beta Radiation* (ORAUT 2007a), for beta doses, standard statistical distributions, including the lognormal, do not fit either the gamma or beta recorded doses well before 1957. Therefore, dose reconstructions that require best-and-final dose estimates should be based on tables of GMs and GSDs that were obtained from regression analysis based on a subgroup of workers with numerous doses both before and after 1961. The results of these regression analyses allow for the estimation of radiation doses to workers starting in May 1948 when the Union Carbide Corporation Nuclear Division assumed management of the Y-12 Plant and the Plant mission changed from the electromagnetic enrichment of uranium to the processing of uranium and other nuclear materials (ORAUT 2005b, 2007a).

[2] Kerr, George D. Oak Ridge Associated Universities. Health Physicist. March 2007.
The film badge period ended in 1979 as film dosimeters at the Y-12 site and other Oak Ridge sites were largely replaced by TLDs (McLendon et al. 1980; Souleyrette 2003; ORAUT 2007a). The practice of monitoring all employees was continued during the TLD monitoring program, the TLD dosimeters were exchanged quarterly, and the MDL was approximately 10 mrem (Souleyrette 2003; ORAUT 2006). Therefore, the TLD data from the Y-12 site and other Oak Ridge sites are sufficiently comprehensive to ensure that a dose reconstruction can be carried out for all workers with a potential for external exposure during the TLD dosimetry period.

[3] Kerr, George D. Oak Ridge Associated Universities. Health Physicist. March 2007.
There were very few locations at the Y-12 Plant where neutron exposures were routinely possible; in these cases, personnel monitoring was provided by neutron-sensitive films (Emlet 1956). During 1952 to 1956, for example, there were only 375 positive quarterly neutron doses among 143 Y-12 workers. If a worker had no positive neutron doses before 1962, it is unlikely that the worker experienced any neutron exposure at the Y-12 Plant (ORAUT 2005c).

[4] Tankersley, William G. Oak Ridge Associated Universities. Industrial Hygienist. March 2007.
Comparisons were made between the CER database and original plant documents in relation to total number of workers monitored by year and department, cumulative annual doses for individuals and groups, magnitude of particularly outstanding results, specific years of monitoring for individuals, count of doses within or exceeding regulatory limits, average annual exposures for multiple years, count of monitoring results within dose ranges, and others. Results of the comparisons provided strong evidence of the reliability and completeness of the CER database. Specific documents that contained the data with which comparisons were carried out included the following:

- *Y-12 Plant Health Physics Progress Report for Period July 1 1951 to December 31, 1951* (UCNC 1952);
- *Y-12 Plant Quarterly Health Physics Report, Third Quarter CY 1962* (UCNC 1963b);
- *Y-12 Plant Quarterly Health Physics Report, Fourth Quarter CY 1962* (UCNC 1963a); and
- “Cumulative External Radiation Exposures” (McLendon 1957).

[5] Watkins, Janice P. Oak Ridge Associated Universities. Biostatistician. March 2007.
The *External Dose Reconstruction Implementation Guideline* (NIOSH 2007) mandates the assignment of missed dose for periods of employment when badge readings were zero regardless of whether the worker’s tasks involved potential for external radiation exposure. To maintain consistency, doses based on coworker data for unmonitored periods of employment should also be augmented for possible missed dose.

[6] Kerr, George D. Oak Ridge Associated Universities. Health Physicist. March 2007.
Recently, two documents were found that provided new information on the changes in frequency of film badge exchange. These documents, McLendon (1958) and Reavis (1958), were not available when some previous Y-12 reports were written.

REFERENCES

Ashley, J. C., J. E. Turner, M. L. Souleyrette, R. S. Bogard, and K. L. McMahan, 1995, *A Technical Study or TLD Beta Calibration Factor for Exposure to Depleted Uranium*, Y/DQ-59, Y-12 Plant, Oak Ridge, Tennessee, June. [SRBD Ref ID: 16474].

BWXT Y-12, 2000, *Recycled Uranium Mass Balance Project Y-12 National Security Complex Site Report*, Y/LB-16,036, Rev. 1, Y-12 National Security Complex, Oak Ridge, Tennessee, December. [SRBD Ref ID: 16500].

Emlet, L. B., 1952, "Contamination Control: Appendix A – Health Physics Aspects," letter to R. C. Armstrong (U.S. Atomic Energy Commission, Oak Ridge Operations), Union Carbide Nuclear Corporation, Oak Ridge, Tennessee, July 21. [SRDB Ref ID: 20122]

Emlet, L. B., 1956, "Radiation Protection at UCNC Production Facilities," letter to S. R. Sapirie (U.S. Atomic Energy Commission), Union Carbide Nuclear Company, Oak Ridge, Tennessee, August 29. [SRDB Ref ID: 23616]

Henderson, M. D., 1991, *Evaluation of Radiation Exposure in Metal Preparation Depleted Uranium Process Areas*, Y/DQ-5/R1, Y-12 Plant, Oak Ridge, Tennessee, May. [SRDB Ref ID: 8538]

McLendon, J. D., 1957, "Cumulative External Radiation Exposures," memorandum to J. S. Reece et al., Union Carbide Nuclear Company, Oak Ridge, Tennessee, July 1. [SRDB Ref ID: 23622]

McLendon, J. D., 1958 , "Change in Y-12 Film Badge Program," memorandum to E. W. Bailey et al., Union Carbide Nuclear Company, Oak Ridge, Tennessee, March 31. [SRDB Ref ID: 20093]

McLendon, J. D., 1960, "Personnel Radiation Exposure Data," memorandum to G. W. Flack, Union Carbide Nuclear Company, Y-12 Plant, Oak Ridge, Tennessee, August 25. [SRDB Ref ID: 3694]

McLendon, J. D., R. G. Affel, A. G. Bailey, K. A. Davis, and E. D. Gupton, 1980, *External Radiation Monitoring of Union Carbide Nuclear Division Personnel*, Y/DD-268, Union Carbide Corporation, Y-12 Plant, Oak Ridge, Tennessee, March 23. [SRDB Ref ID: 8589]

Morgan, K. Z., 1961, "Dosimetry Requirements for Protection from Ionizing Radiation," *Selected Topics in Radiation Dosimetry, Proceedings of the Symposium on Selected Topics in Radiation Dosimetry, Sponsored by and Held in Vienna 7-11 June 1960*, International Atomic Energy Agency, Vienna, Austria, pp. 3–23. [SRDB Ref ID: 8345]

Murray, R., 1947, *Y-12 Plant Health Physics Progress Report*, September 1-30, 1947, Y-40, Union Carbide and Carbon Chemicals Corporation, Y-12 Plant, Oak Ridge, Tennessee, October 16. [SRDB Ref ID: 8602, p. 495]

NIOSH (National Institute for Occupational Safety and Health), 2007, *External Dose Reconstruction Implementation Guideline*, OCAS-IG-001, Rev. 3, Office of Compensation Analysis and Support, Cincinnati, Ohio, November 21.

ORAUT (Oak Ridge Associated Universities Team), 2005a, *External Radiation Monitoring at the Y-12 Facility During the 1948-1949 Period*, ORAUT-OTIB-0047, Rev. 00, Oak Ridge, Tennessee, September 20.

ORAUT (Oak Ridge Associated Universities Team), 2005b, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Facility in Oak Ridge, Tennessee: Part 1 – Gamma Radiation*, ORAUT-RPRT-0032, Rev. 00, Oak Ridge, Tennessee, April 13.

ORAUT (Oak Ridge Associated Universities Team), 2005c, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Facility in Oak Ridge, Tennessee: Part 2 – Neutron Radiation*, ORAUT-RPRT-0033, Rev. 00, Oak Ridge, Tennessee, April 13.

ORAUT (Oak Ridge Associated Universities Team), 2005d, *Interpretation of Dosimetry Data for Assignment of Shallow Dose*, ORAUT-OTIB-0017, Rev. 01, Oak Ridge, Tennessee, October 11.

ORAUT (Oak Ridge Associated Universities Team), 2006, *Technical Basis Document for the Y-12 National Security Complex – Occupational External Dosimetry*, ORAUT-TBKS-0014-6, Rev. 00, PC-3, Oak Ridge, Tennessee, May 11.

ORAUT (Oak Ridge Associated Universities Team), 2007a, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Plant in Oak Ridge, Tennessee: Part 3 – Beta Radiation*, ORAUT-OTIB-0046, Rev. 00, Oak Ridge, Tennessee, June 22.

ORAUT (Oak Ridge Associated Universities Team), 2007b, *Parameters to Consider When Processing Claims for Construction Trade Workers*, ORAUT-OTIB-0052, Rev. 00 PC-1, Oak Ridge, Tennessee, January 16.

ORAUT (Oak Ridge Associated Universities Team), 2008, *Use of Coworker Dosimetry Data for External Dose Assignment*, ORAUT-OTIB-0020, Rev. 02, Oak Ridge, Tennessee, December 4.

Pearson, K., 1896, “Mathematical Contributions to the Theory of Evolution; III. Regression, Heredity and Panmixia,” *Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character, Volume 187*, pp. 253–318, pp. 253–318.

Reavis, J. P., 1958, “Frequency of Film Badge Analysis,” memorandum to C. M. West, Union Carbide Nuclear Company, Oak Ridge, Tennessee, October 8. [SRDB Ref ID: 20094]

Souleyrette, M. L., 2003, *Y-12 National Security Complex, Summary of Historical Monitoring Techniques Provided to NIOSH for EEOICPA Data Requests*, Rev. 0, BWXT Y-12, Y-12 National Security Complex, Oak Ridge, Tennessee, February 18. [SRDB Ref ID: 8586]

Spearman, C. E., 1904, “General Intelligence, Objectively Determined and Measured,” *American Journal of Psychology*, volume 15, number 2, pp. 201–293.

Struxness, E. G., 1948, *Health Physics - Industrial Hygiene Progress Report, May 1 - 31, 1948*, Y-181/1R, Y-12 Plant, Oak Ridge, Tennessee, June 16. [SRDB Ref ID: 8602, p. 457]

UCNC (Union Carbide Nuclear Company), 1952, *Y-12 Plant Health Physics Progress Report for Period July 1, 1951 to December 31, 1951*, Y-858, Y-12 Plant, Oak Ridge, Tennessee, March 15. [SRDB Ref ID: 13055]

UCNC (Union Carbide Nuclear Company), 1957, "December Health Physics Report – Mechanics Operation Division," Y-B94-8 (Excerpt), letter to J. M. Case, Oak Ridge, Tennessee, January 24. [SRDB Ref ID: 23626]

UCNC (Union Carbide Nuclear Company), 1963a, *Y-12 Plant Quarterly Health Physics Report, Fourth Quarter CY 1962*, Y-KB-26, Y-12 Plant, Oak Ridge, Tennessee, March 20. [SRDB Ref ID: 23618]

UCNC (Union Carbide Nuclear Company), 1963b, *Y-12 Plant Quarterly Health Physics Report, Third Quarter CY 1962*, Y-KB-24, Y-12 Plant, Oak Ridge, Tennessee, February 7. [SRDB Ref ID: 23167]

Watkins, J. P., J. L. Reagan, D. L. Cragle, E. L. Frome, C. M. West, D .J. Crawford-Brown, and W. G. Tankersley, 1993, *Data Collection, Validation, and Description for the Oak Ridge Nuclear Facilities Mortality Study,* ORISE 93/J-42, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee, October. [SRDB Ref ID: 10133]

West, H. [C. M.], 1993, “Brief History of the Y-12 External Monitoring Program,” internal memorandum to D. Cragle, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee, June 7. [SRDB Ref ID: 8532]