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☐ 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. |
| 12/18/2009 | 01 | Revision to modify Sections 4.0 and 5.0 to be consistent with current practices of applying coworker data. Table 7-1c and references to Tables 7-1a, 7-1b, and 7-1c were added in Section 7.0. Table 7-1c includes the 95th- and 50th-percentile annual doses derived from Table 7-1a. Adds details for Table 7-1c in Section 7.0. In Section 7.0, Table 7-2 was updated to include 1947 to 1949. Incorporates formal and NIOSH review comments. Updated Attributions and Annotations. Updated references. No sections were deleted. Training required: As determined by the Objective Manager. Initiated by Keith A. McCartney and Janice P. Watkins. |
| 04/29/2013 | 02 | Revision initiated to update Section 6.1 and add update of previous ORAUT-OTIB-0047, Rev 00 as Attachment A. No sections were deleted. No changes occurred as a result of formal internal review. Incorporates formal NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by George D. Kerr and Janice P. Watkins. |

## TABLE OF CONTENTS

**SECTION** **TITLE** **PAGE**



## LIST OF TABLES

**TABLE** **TITLE** **PAGE**

## LIST OF FIGURES

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CER | Center for Epidemiologic Research |
| DOE | U.S. Department of Energy |
| *E*(dose) | Expected value of dose in the statistical sense; i.e., the mean dose on the original scale |
| EU | enriched uranium |
| GM | geometric mean |
| GSD | geometric standard deviation |
| HP | health physics |
| hr | hour |
| ID | identifier |
| keV | kiloelectron-volt (1,000 electron-volts) |
| LANL | Los Alamos National Laboratory |
| MDL | minimum detectable level |
| MeV | megaelectron-volt, 1 million electron-volts |
| mm | millimeter |
| mR | milliroentgen, a unit of radiation exposure |
| mrem | millirem |
| NIOSH | National Institute for Occupational Safety and Health |
| NR | no reading/no response |
| ORAU | Oak Ridge Associated Universities |
| PIC | pocket ionization chamber |
| R1 | PIC reading |
| R2 | sensitive film reading under open window of film badge |
| R3 | sensitive film reading under 1-mm-thick cadmium shield of film badge |
| R4 | insensitive film reading under 1-mm-thick cadmium shield of film badge |
| SRDB Ref ID | Site Research Database Reference Identification (number) |
| SSN | Social Security Number |
| TEC | Tennessee Eastman Corporation |
| TBD | technical basis document |
| TIB | technical information bulletin |
| TLD | thermoluminescent dosimeter |
| UCC | Union Carbide Corporation |
| U.S.C. | United States Code |
| wk | week |

| | |
|---|---|
| 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 historical 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 2011a). This TIB is for use in reconstructions for the period from January 1947 to December 1979.

The purpose of Attachment A is to verify that the coworker data in Table 7-1a provide conservative but realistic estimates of the radiation doses to Y-12 workers who were not routinely monitored for exposure to external fields of gamma radiation and beta particles prior to 1952. This attachment analyzes the limited data available for Y-12 workers who were monitored for exposure to external radiation during 1948 and 1949.

Attributions and annotations within the text of this report are indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information. The attributions and annotations 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 2007). 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 1948a). 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 EEOICPA (Souleyrette 2003). Attachment A contains information about the external monitoring data for 1948 and 1949 that are available from previous epidemiological studies by the ORAU Center for Epidemiologic Research (CER). These 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 (see Attachment A).

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). This external radiation dosimetry policy of monitoring only the Y-12 workers who were involved with those four types of radioactive materials (about 10% to 20% of all workers) was continued until 1961 (ORAUT 2013). 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). The data in this TIB address penetrating gamma radiation and nonpenetrating electron and low-energy photon radiation.

## 4.0 GENERAL APPROACH

As described in ORAUT (2011a), the general approach to the application of coworker data to cases without external monitoring data is to assign either the 50th- or 95th-percentile doses with the intent that the assigned doses represent, but do not underestimate, the doses that would have been assigned had the worker been monitored.

## 5.0 APPLICATIONS AND LIMITATIONS

Some Y-12 workers could have worked at one or more other major sites in the DOE complex during their employment histories. Therefore, the data in this TIB must be used with caution to ensure that, for likely noncompensable cases, unmonitored external doses from multiple site employments have been overestimated. This typically requires the availability of the recorded doses or TIBs for external coworker dosimetry data for all relevant sites.

External onsite ambient dose should be applied as specified in the latest revision of ORAUT-PROC-0060, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites* (ORAUT 2006).

## 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 names; 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 [1]. 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-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 1952 to 1979.

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 |

## 6.1 ADJUSTMENT FOR MISSED DOSE

OCAS-IG-001, *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

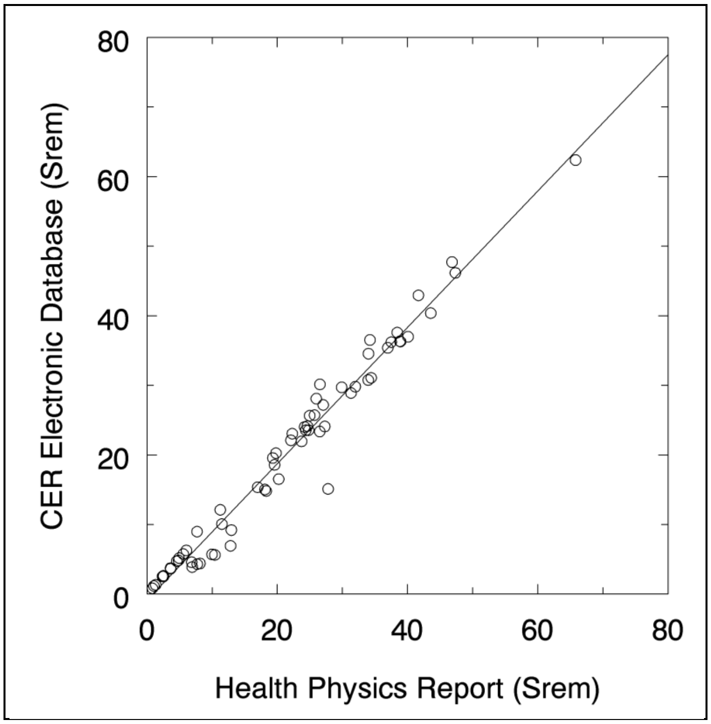


Figure 6-1. Comparison of cumulative skin doses in rem (Srem) from UCNC (1957) and the CER database for 65 foundry workers, 1952 to 1956.

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.

The assignment of missed doses for monitored workers is particularly significant for Y-12 workers, as Figures 6-2 and 6-3 show, 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 [2].

The magnitude of missed dose depended on both the exchange frequency and the MDL of the film badge dosimeters in use during the time of interest. Table 6-2 provides information of the exchange frequencies of the film badge dosimeters from 1948 through 1979, and Table 6-3 gives the MDLs along with the assigned MDL dose during the corresponding periods. It is important to note that the MDL and the assigned MDL dose to workers changed significantly with time. As noted, the dates in Table 6-2 and 6-3 are approximate because the changes did not occur for all Y-12 employees at the same time. During 1950 and 1951 the beta and gamma 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 doses for 148 monitored workers in 1950; 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).

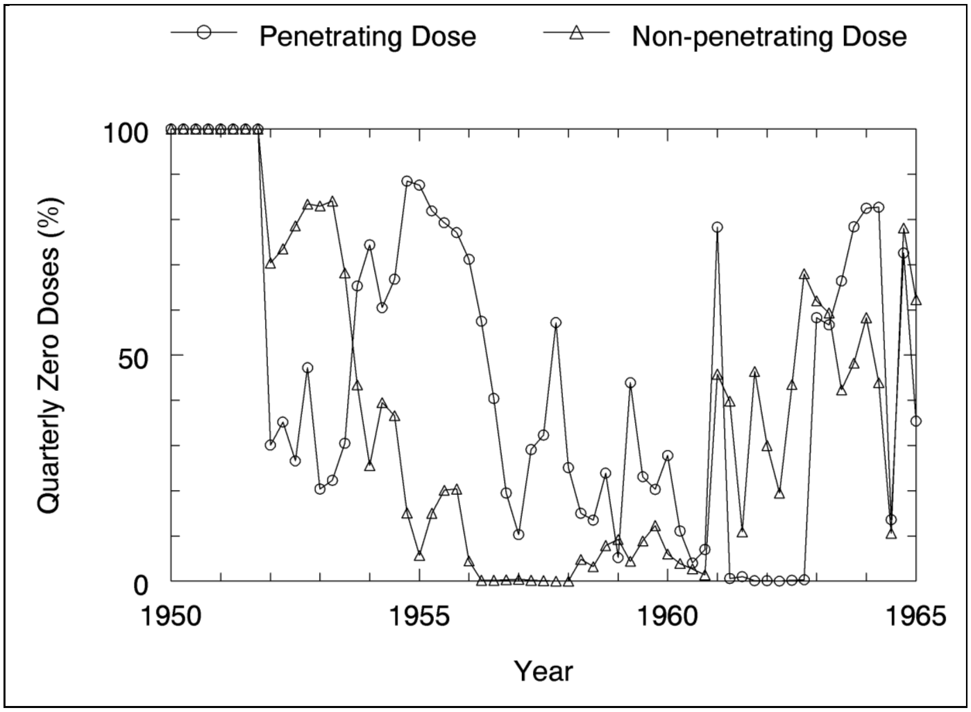


Figure 6-2. Percentage of null penetrating (gamma) and nonpenetrating (beta) doses among the recorded quarterly doses, 1950 to 1964.

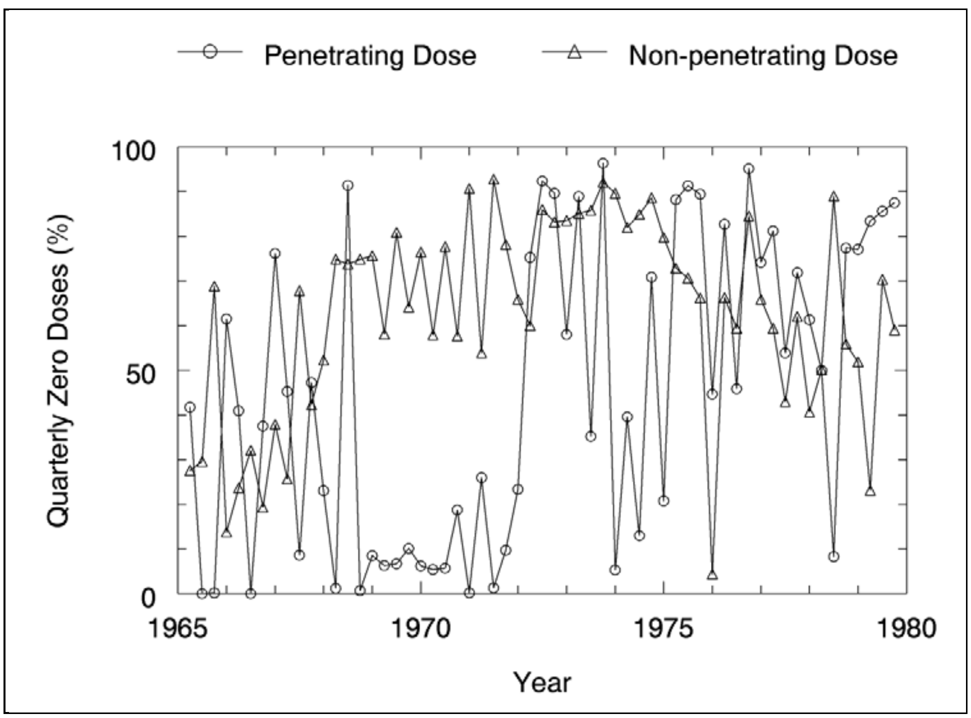


Figure 6-3. Percentage of null penetrating (gamma) and nonpenetrating (beta) doses among the recorded quarterly doses, 1965 to 1979.

The 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 2009a), the great majority of Y-12 workers were on the schedule 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 6-2. 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. Attachment A, West (1993), McLendon (1958), and Reavis (1958).
b. Dates are approximate because changes did not occur for all employees at the same time.

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. Attachment A; 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.

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 | 1,560 | 1,560 |
| Jan 1950–Dec 1951 | 30 | 30 | Weekly | 1,560 | 1,560 |
| Jan 1952–Sep 1952 | 50 | 50 | Weekly | 2,600 | 2,600 |
| Oct 1952–Dec 1952 | 43 | 43 | Weekly | 2,236 | 2,236 |
| Jan 1953–Jun 1954 | 50 | 50 | Weekly | 2,600 | 2,600 |
| Jul 1954–Sep 1958 | 30 | 30 | Weekly | 1,560 | 1,560 |
| 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 technical basis document (TBD) for the Y-12 site (ORAUT 2009a) 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 Section 7.0 describes, 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:

### Table 7-1a

Table 7-1a provides quarterly data for beta and gamma doses from the third quarter of 1947 through the fourth quarter 1951 based on subgroup regression analysis (ORAUT 2007, 2013). Percentile values in Table 7-1c are derived from these data.

Table 7-1a. Parameters for lognormal prediction density, 1947 to 1951.

| Year | Qtr | μ | σ | GM (mrem) | GSD | *E*(dose) (mrem) |
|---|---|---|---|---|---|---|
| **Gamma dose**[a] | | | | | | |
| 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 |
| 1950 | 1 | 4.9647 | 1.1703 | 143.2603 | 3.2228 | 284.1247 |
| | 2 | 4.9343 | 1.1702 | 138.9740 | 3.2226 | 275.6015 |
| | 3 | 4.9039 | 1.1701 | 134.8161 | 3.2224 | 267.3344 |
| | 4 | 4.8735 | 1.1701 | 130.7825 | 3.2222 | 259.3159 |
| 1951 | 1 | 4.8432 | 1.1700 | 126.8696 | 3.2220 | 251.5383 |
| | 2 | 4.8128 | 1.1699 | 123.0738 | 3.2217 | 243.9945 |
| | 3 | 4.7824 | 1.1699 | 119.3915 | 3.2216 | 236.6773 |

| Year | Qtr | μ | σ | GM (mrem) | GSD | *E*(dose) (mrem) |
|---|---|---|---|---|---|---|
| | 4 | 4.7520 | 1.1698 | 115.8194 | 3.2214 | 229.5801 |
| **Beta dose**[b] | | | | | | |
| 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 |
| 1950 | 1 | 6.6551 | 1.3687 | 776.76 | 3.9304 | 1,982.0 |
| | 2 | 6.6367 | 1.3687 | 762.56 | 3.9304 | 1,945.7 |
| | 3 | 6.6179 | 1.3687 | 748.35 | 3.9304 | 1,909.5 |
| | 4 | 6.5987 | 1.3687 | 734.15 | 3.9304 | 1,873.2 |
| 1951 | 1 | 6.5792 | 1.3687 | 719.94 | 3.9304 | 1,837.0 |
| | 2 | 6.5592 | 1.3687 | 705.73 | 3.9304 | 1,800.7 |
| | 3 | 6.5389 | 1.3687 | 691.53 | 3.9304 | 1,764.5 |
| | 4 | 6.5181 | 1.3687 | 677.32 | 3.9304 | 1,728.2 |

a. From ORAUT-OTIB-0044 (ORAUT 2013).
b. From ORAUT-OTIB-0046 (ORAUT 2007).

**Table 7-1b**

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 1952 to 1979. Consistent with the guidelines in ORAUT-OTIB-0020 (ORAUT 2011a), 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 3 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 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 in Table 7-1b are presented 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 2011a). The percentiles for beta doses should be applied only to Y-12 workers who were employed in areas with beta dose potential.

Table 7-1b. Annual coworker external doses (mrem) for 1952 to 1979 with gamma and beta doses adjusted for missed dose by the method in ORAUT-OTIB-0020 (ORAUT 2011a).

| Year | Gamma dose | | Beta dose | | Number of monitored workers |
|---|---|---|---|---|---|
| | 95th percentile | 50th percentile | 95th percentile | 50th percentile | |
| 1952 | 3,453 | 2,419 | 5,623 | 1,300 | 497 |
| 1953 | 4,216 | 1,300 | 7,429 | 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 |

**Table 7-1c**

1. The quarterly gamma and beta doses in Table 7-1a were combined into annual dose distributions using Monte Carlo techniques. Dose for 1947 was doubled to normalize the data to one full year of exposure.

2. Missed dose was not added to the resultant annual dose distributions from Step 1 above. The original analysis in ORAUT-OTIB-0044 (ORAUT 2013) includes an analysis of missed dose. Therefore, additional missed dose was not added to the quarterly dose distributions.

3. The 50th- and 95th-percentile annual gamma and beta dose values were derived from the resultant lognormal distributions from Step 1.

4. The results in Table 7-1c are presented 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 2011a). The percentiles for beta doses should be applied only to Y-12 workers who were employed in areas with beta dose potential.

Table 7-1c. Annual coworker external doses (mrem) for 1947 to 1951 based on combined quarterly results from Table 7-1a.

| | Gamma dose | | Beta dose | |
|---|---|---|---|---|
| **Year** | **95th percentile** | **50th percentile** | **95th percentile** | **50th percentile** |
| 1947 | 4,427 | 1,005 | 29,514 | 5,180 |
| 1948 | 3,345 | 1,089 | 23,471 | 6,222 |
| 1949 | 2,981 | 962 | 22,343 | 5,830 |
| 1950 | 2,592 | 851 | 20,713 | 5,487 |
| 1951 | 2,373 | 762 | 18,861 | 4,975 |

5. Beta dose 95th-percentile values for 1947 to 1951 might need adjustment for dose reconstruction. These values are above or in close proximity to the yearly radiological protection guidelines for that era, 25 rem for 1947 and 1948 and 15 rem for 1949 to 1951 (ORAUT 2007). There were no reported beta doses above these yearly radiation protection guidelines for 1947 to 1951 (Attachment A, ORAUT 2007).

Doses to organs that are affected only by gamma radiation (e.g., organs other than the skin, breast, and testes) should be calculated based only on the gamma dose columns in Table 7-1b and 7-1c in combination with the appropriate organ dose conversion factors (NIOSH 2007). Doses to the skin, breast, and testes (or any other cancer location that could be affected by beta radiation) should be determined based on both the gamma and beta columns. Gamma doses should be assigned as photons with energy ranges consistent with information in the external dosimetry TBD for the Y-12 site (ORAUT 2009a), and beta doses should be assigned as electrons with energy greater than 15 keV (or photons less than 30 keV if appropriate) with corrections to account for clothing attenuation or other relevant considerations (ORAUT 2005). Work with depleted uranium has been responsible for the majority of the beta (or nonpenetrating) doses at the Y-12 facility (UCNC 1963a,b; Henderson 1991; Ashley et al. 1995; ORAUT 2007).

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 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 2011b). These percentile values, which are based on the annual values in Tables 7-1b and 7-1c, 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 (ORAUT 2011b).

| Year | Gamma dose | | Beta dose | |
|---|---|---|---|---|
| | 95th percentile | 50th percentile | 95th percentile | 50th percentile |
| 1947 | 6,198 | 1,407 | 29,514 | 5,180 |
| 1948 | 4,684 | 1,525 | 23,471 | 6,222 |
| 1949 | 4,174 | 1,347 | 22,343 | 5,830 |
| 1950 | 3,629 | 1,191 | 20,713 | 5,487 |
| 1951 | 3,322 | 1,067 | 18,861 | 4,975 |
| 1952 | 4,324 | 2,877 | 5,623 | 1,300 |
| 1953 | 5,392 | 1,300 | 7,429 | 2,475 |
| 1954 | 4,542 | 1,300 | 11,843 | 3,039 |
| 1955 | 3,294 | 780 | 11,482 | 3,241 |
| 1956 | 2,227 | 1,039 | 8,404 | 2,541 |
| 1957 | 1,873 | 1,002 | 7,777 | 2,384 |
| 1958 | 2,210 | 1,185 | 4,470 | 1,745 |
| 1959 | 1,576 | 561 | 3,928 | 875 |
| 1960 | 1,508 | 526 | 5,093 | 894 |
| 1961 | 669 | 199 | 2,322 | 91 |
| 1962 | 708 | 221 | 2,257 | 101 |
| 1963 | 486 | 63 | 1,464 | 82 |
| 1964 | 538 | 83 | 1,578 | 97 |
| 1965 | 517 | 136 | 1,083 | 70 |
| 1966 | 651 | 104 | 1,185 | 118 |
| 1967 | 503 | 81 | 1,014 | 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 (SRDB).

[1] 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 (Ballenger 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).

[2] 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 to account for possible missed dose.

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**ATTACHMENT A**
**EXTERNAL RADIATION MONITORING AT THE Y-12 FACILITY DURING THE 1948–1949 PERIOD**


**SECTION** **TITLE** **PAGE**



**TABLE** **TITLE** **PAGE**

**FIGURE** **TITLE** **PAGE**



## A.1 PURPOSE

The purpose of this Attachment is to discuss and summarize the 1948–1949 external monitoring data that are now available for use in the NIOSH Dose Reconstruction Project for workers at facilities operated by the DOE and its predecessor agencies (NIOSH 2007). The 1948–1949 external monitoring data were made available to the ORAU Team, along with other data for use in epidemiological studies of workers at the Y-12 Plant and other DOE sites in Oak Ridge, Tennessee (Watkins et al. 1993, 1997). These 1948–1949 data have been placed on a secure data server at the ORAU Cincinnati Operations Center for use in dose reconstructions for workers at the Y-12 facility.

## A.2 BACKGROUND

The Y-12 Plant, now the Y-12 National Security Complex, was conceived in the fall of 1942 by engineers of the Manhattan Engineer District of the U.S. Army Corps of Engineers, and construction of the first building was completed in 1943 (Wilcox 2001; ORAUT 2009b). The Tennessee Eastman Corporation (TEC) operated Y-12 from 1943 to May 1947. During this period, operations primarily involved the use of the electromagnetic separation process to enrich uranium; the enriched product was shipped to Los Alamos National Laboratory (LANL) for use in the construction of nuclear weapons. Until the latter part of 1945, Y-12 converted $UO_3$ to $UCl_4$, which was enriched by the electromagnetic separation process using two calutron stages (“alpha” and “beta”). In the latter part of 1945, Y-12 discontinued the use of the alpha stage and began receiving $UF_6$ from the Oak Ridge Gaseous Diffusion Plant, also called the K-25 Plant. The $UF_6$ from K-25 was converted into $UCl_4$, enriched using the beta calutrons, converted to $UF_4$, and shipped to LANL. In these early days, TEC relied entirely on facility monitoring to measure and control occupational external and internal radiation exposures to workers. The nature of the work at the Y-12 facility in these early years primarily resulted in occupational internal exposure from uranium dust particles, which was a greater potential hazard than occupational external exposure (Dupree et al. 1994).

In May 1947, management of Y-12 was assigned to the Union Carbide Corporation (UCC) and the emphasis at Y-12 was directed from the enrichment of uranium to the fabrication of parts for nuclear weapons (Williams 1948; ORAUT 2009b). Numerous changes have occurred over the years in the fabrication procedures, but the general procedures have remained essentially the same. Enriched uranium (EU) typically was received at Y-12 in the form of $UF_6$, converted to $UF_4$, reduced to a metal, and fabricated into weapon parts. These fabrication processes involved casting, rolling, forming, and machining the EU metal and recycling the EU salvage. In addition to facility monitoring to measure and control radiation exposure to workers, an external dosimetry program was started in 1948 to monitor individual personnel working in the Assay Laboratories, Radiographic Shop, Spectrographic Shop, and the “Metal” Machine Shops. Other groups of workers were added in July 1948, January 1949, and July 1949. The occupational external monitoring since 1950 has been reviewed in ORAUT (2009b) and other ORAUT reports (ORAUT 2007, 2013).

## A.3 EXTERNAL RADIATION MONITORING DEVICES

Doses to the whole body from external radiation exposure at the Y-12 facility during 1948 and 1949 were measured using Victoreen pocket ionization chambers (PICs) exchanged on a daily basis and film badge dosimeters exchanged on a weekly basis (Souleyrette 2003; ORAUT 2009b). The MDLs for these dose measurements during this period were approximately 5 mrem for the PICs and 30 mrem for the sensitive film of the film badge dosimeters.

### A.3.1 Pocket Ionization Chambers

The Victoreen PICs were condenser-type ionization chambers that were used with a separate charger and charge reader (Price 1958; Handloser 1959). The PICs were charged to a known voltage by inserting them into the charger, which connected an internal power supply across the chambers. The charge reader, a string electrometer, indicated the charge. The PICs were the size of fountain pens and had clips similar to those on fountain pens so they could be carried securely in the pocket of a shirt or coverall. Exposure to ionizing radiation discharged the chamber, and the decrease in voltage provided a measurement of a worker's radiation exposure. The PICs were calibrated using integrated exposures of 100, 200, and 300 mR from a radium source (Struxness 1948a).

Properly operating PICs were not bothered by charge leakage over a period of a few days, but their use was generally restricted to 1 day (Price 1958; Handloser 1959). At Y-12 and most other DOE sites, it was general practice to provide each worker with two PICs, and the lower exposure reading was the significant reading because a malfunction of a PIC resulted in a charge decrease, indicating a higher exposure. Malfunctions of PICs were usually due to either charge leakage across the insulators or mechanical shock such as being dropped on the floor.

The energy response of the PICs, like film, was not flat but peaked at low X-ray energies (Price 1958; Handloser 1959). At photon energies of approximately 0.3 to 1.2 MeV, the energy response was linear, but it was about 1.4 times the linear response at an energy of approximately 0.1 MeV. Below 0.1 MeV, the response dropped rapidly because the photons underwent significant attenuation in the walls of the PICs. The readings were much less than the actual doses at energies below about 40 keV. The walls of the PICs were thin enough to allow some response to beta particles with energies of approximately 1 MeV or more.

### A.3.2 Film Badge Dosimeters

The film badge dosimeter used at Y-12 was the same badge used at the Oak Ridge National Laboratory in 1949 (ORAUT 2009b) and described by Thornton, Davis, and Gupton (1961). This was a U.S. Atomic Energy Commission Catalog Number PF-1B film badge manufactured by the A. M. Sample Machine Company in Knoxville, Tennessee (Patterson et al. 1957; ORAUT 2009b). The photographic film in the badge was encased in a protective cover of stainless steel with a clip for attachment to the pocket or collar of a shirt or coverall (Handloser 1959). One portion of the film (shielded window) was covered by a 1-mm-thick cadmium filter to determine the penetrating whole-body dose from photons (gamma rays and high-energy X-rays); the uncovered portion of the film (open window) was used to determine the skin dose from low-energy X-rays and beta particles (Handloser 1959).

The film badge dosimeters used at Y-12 from 1948 to 1963 contained DuPont type 552 film packets (Souleyrette 2003). These packets contained two film emulsions: (1) a so-called sensitive 502 emulsion with an effective dose range of approximately 30 mrem to 10 rem, and (2) a so-called insensitive 510 emulsion with an effective dose range of approximately 500 mrem to 20 rem (Craft, Ledbetter, and Hart 1953; Thornton, Davis, and Gupton 1961; Parrish 1979). Film badge dosimeters typically exhibited about the same sensitivity to beta and gamma radiation; that is, a 1-rem dose of beta particles yielded about the same response in the film as 1 rem of gamma rays (Auxier 1967). Thus, the MDLs of the film badge dosimeters were approximately the same for beta particles and gamma rays (ORAUT 2009b).

The DuPont 552 film packets were calibrated using X-rays, beta particles from a natural uranium slab, and gamma rays from a radium source (Struxness 1949). The gamma-ray calibrations used integrated exposures of 100, 250, 500, 750, and 1,000 mrem from the radium source (Struxness 1948a). The film badges were calibrated for beta particles by placing the film badge face down on the slab of natural uranium (Struxness 1949). The dose rate to skin from the beta particles at the surface of the natural uranium slab was taken to be 270 mR/hr (Murray 1948). The currently accepted value for the dose rate to skin from beta particles at the surface of a natural uranium slab is approximately 235 mrem/hr (DOE 2004). If one makes the common assumption that 1 mR/hr is approximately equal to 1 mrem/hr (Whyte 1959; NBS 1962), the beta-particle calibrations during the 1948–1949 period provide conservative estimates of a Y-12 worker's exposure to beta particles during that period.

## A.4 Y-12 EXTERNAL DOSE DATABASE

External monitoring records for 1950 to 1988 were provided by the Y-12 staff from 1978 through the early 1990s for use in epidemiologic studies by the Center for Epidemiologic Research of the Oak Ridge Associated Universities (Watkins et al. 1993, 1997). These records contained gamma, beta, and neutron monitoring records for individuals, summarized by quarters. For some time, it was assumed that no external monitoring records were available before 1950. After considerable investigation, including interviews with knowledgeable Y-12 staff members, it was discovered that a limited set of external monitoring data did exist for 1948 and 1949 (West 1980). Further investigation resulted in the retrieval of a single electronic file with 11,492 weekly monitoring records. Each record in the file included film badge identification (ID), date of weekly readings, four dose fields, and descriptive comments. The four dose fields consisted of the PIC dose reading and three photographic film dose readings. The PIC doses were the sum of the daily readings for the week and are referred to as R1. Doses from film badge readings of sensitive film with open window, sensitive film with shielding, and insensitive film with shielding are referred to as R2, R3, and R4, respectively.

Efforts were made to link the film badge ID in the Y-12 external monitoring file for 1948 and 1949 with Y-12 worker names and departments in the ORAU Team DOE facility database. A total of 229 distinct individuals were identified among the 11,492 records in the dataset. Each film badge ID in the Y-12 external monitoring file for 1948 and 1949 had 26, 52, 78, or 104 records, corroborating that monitoring results were recorded on a weekly basis during this period. As listed in Table A-1, there were 3,599 and 7,893 weekly records for 1948 and 1949, respectively. Based on four weekly monitoring records during some months and five weekly monitoring records during other months, the data in Table A-1 indicate that the total number of monitored Y-12 workers was approximately 26 during the first half of 1948, 107 during the second half of 1948, 141 during the first half of 1949, and 168 during the second half of 1949.

Although each record in the dataset had a value for all four dose fields (R1, R2, R3, and R4), many of the results were recorded as NR (no reading or no response). In fact, 7,876 or 69% of the 11,492 total records reported NR in each of the four dose fields. Therefore, only 3,616 of the records

Table A-1. Number of total and non-NR weekly records by month from Y-12 external monitoring file for 1948 and 1949.

| Month | 1948 Total records/ non-NR records[a] | 1949 Total records/ non-NR records[a] |
|---|---|---|
| January | 130/0 | 564/165 |
| February | 104/0 | 564/150 |
| March | 104/0 | 564/162 |
| April | 130/41 | 705/186 |
| May | 104/77 | 564/148 |
| June | 104/60 | 564/186 |
| July | 535/162 | 840/272 |
| August | 428/146 | 672/255 |
| September | 428/144 | 840/271 |
| October | 535/201 | 672/203 |
| November | 428/164 | 672/200 |
| December | 569/208 | 672/215 |
| **Total** | **3,599/1,203** | **7,893/2,413** |

a. At least one of the R1, R2, R3, or R4 values in the record was not NR (i.e., at least one of the R1, R2, R3, or R4 contained a number that represented a dose).

supplied information on occupational external doses. The information provided by these 3,616 records is summarized in the next section.

## A.5 EVALUATION OF 1948–1949 EXTERNAL DOSE DATA

Results in this section are based on all weekly records occurring in a month, although an individual worker could have provided multiple weekly records each month. Tables A-2 to A-5 present by month and year the number of non-null records and the number of these records equal to zero for R1, R2, R3, and R4, respectively. In addition, the number of these records with a dose of 30 mrem is listed for R2, R3, and R4. From January through March 1948, all dose field readings were blank. During the second half of 1948 and all of 1949, nearly all recorded doses for R2, R3, and R4 were set to 30 mrem. In 1949, R3 and R4 were generally not recorded because there were only 60 and 61 recorded doses, respectively, compared with 1,744 R2 doses, 99.5% of which equaled 30 mrem. Therefore, R2, R3, and R4 provided very few specific radiation doses, and 30 mrem was used as an upper bound on the actual dose received during the weekly monitoring period for film badges.

Figure A-1 shows the sum of all weekly records by month for R1 to R4. In 1948, the monthly dose sums were nearly identical for R2, R3, and R4, with the exception of a slightly lower R4 dose in July. The monthly sums for the PIC readings starting in July 1948 were generally about one-third as large as film badge sums for R2, R3, and R4. In 1949, the monthly PIC sums were about one-third or less of the R2 sums, with the exception of the period from March through June, when the R2 sums dipped much lower. Sums for R3 and R4 in 1949 were at or near zero except for January.

Figures A-2 to A-5 show descriptive statistics by month and year for R1 to R4, respectively, based on all weekly recorded doses excluding the NRs. The 75th percentile for R1 was near 30 mrem for the entire period from April 1948 through December 1949, indicating that approximately three-fourths of the PIC weekly readings each month had a value of 30 mrem or less. However, maximum R1

**ATTACHMENT A**
**EXTERNAL RADIATION MONITORING AT THE Y-12 FACILITY DURING THE 1948–1949 PERIOD**


Table A-2. Number of PIC (R1) weekly records from Y-12 monthly external monitoring file for 1948 and 1949 and number of these records equal to zero.

| | **1948** | | **1949** | |
|---|---|---|---|---|
| **Month** | **N** | **N = 0** | **N** | **N = 0** |
| January | 0 | | 127 | 35 |
| February | 0 | | 123 | 23 |
| March | 0 | | 119 | 23 |
| April | 3 | 1 | 138 | 14 |
| May | 54 | 23 | 97 | 9 |
| June | 46 | 11 | 94 | 14 |
| July | 115 | 33 | 104 | 19 |
| August | 111 | 27 | 97 | 25 |
| September | 118 | 43 | 118 | 30 |
| October | 147 | 44 | 86 | 23 |
| November | 111 | 42 | 80 | 20 |
| December | 136 | 50 | 81 | 27 |
| **Total R1** | **841** | **274 (32.6%)** | **1,264** | **262 (20.7%)** |

Table A-3. Number of sensitive film–open window (R2) weekly records from Y-12 monthly external monitoring file for 1948 and 1949 and number of these records equal to zero and to 30 mrem.

| | 1948 | | | **1949** | | |
|---|---|---|---|---|---|---|
| Month | N | **N = 0** | **N = 30** | **N** | **N = 0** | **N = 30** |
| January | 0 | | | 98 | 0 | 94 |
| February | 0 | | | 93 | 0 | 90 |
| March | 0 | | | 100 | 0 | 99 |
| April | 40 | 14 | 0 | 102 | 0 | 102 |
| May | 76 | 29 | 0 | 101 | 0 | 101 |
| June | 60 | 7 | 5 | 139 | 0 | 139 |
| July | 142 | 0 | 124 | 232 | 0 | 232 |
| August | 140 | 0 | 140 | 196 | 0 | 196 |
| September | 137 | 0 | 136 | 200 | 0 | 200 |
| October | 200 | 0 | 200 | 158 | 0 | 158 |
| November | 161 | 0 | 161 | 156 | 0 | 156 |
| December | 200 | 0 | 200 | 169 | 0 | 169 |
| **Total R2** | **1,156** | **50 (4.3%)** | **966 (83.6%)** | **1,744** | **0 (0%)** | **1,736 (99.5%)** |

readings were generally above 60 mrem after October 1948. Beginning in July 1948, the R2 values of the 25th percentile, median, and 75th percentile were all 30 mrem, suggesting that a dose of 30 mrem was likely to be assigned if a weekly badge reading during the month fell below the MDL. For R3 from July 1948 through March 1949, it appears that a dose of 30 mrem was assigned if a weekly badge reading was below the MDL, and beginning in April 1949 the weekly badge reading was listed as NR if the reading was below the MDL. For R4 it appears that 30 mrem was assigned based on the MDL of R2 and R3 during the same period. Several very high maximum doses were recorded for R2, including 760 mrem in July 1948 and 2,500 mrem in both January and February 1949 (see Figure A-3). With the exception of one R3 dose of 640 mrem in July 1948, R3 and R4 have weekly doses of only 30 mrem from July 1948 through March 1949 and then no additional dose records except one R4 dose of 30 mrem in November (see Figures A-4 and A-5). Figure A-5 shows that 30 mrem was the maximum recorded dose for R4 throughout 1948 and 1949.

**ATTACHMENT A**
**EXTERNAL RADIATION MONITORING AT THE Y-12 FACILITY DURING THE 1948–1949 PERIOD**


Table A-4. Number of sensitive film–cadmium shielded (R3) weekly records from Y-12 monthly external monitoring file for 1948 and 1949 and number of these records equal to zero and to 30 mrem.

| | 1948 | | | 1949 | | |
|---|---|---|---|---|---|---|
| **Month** | **N** | **N = 0** | **N = 30** | **N** | **N = 0** | **N = 30** |
| January | 0 | | | 56 | 0 | 56 |
| February | 0 | | | 3 | 0 | 3 |
| March | 0 | | | 1 | 0 | 1 |
| April | 40 | 14 | 0 | 0 | | |
| May | 76 | 29 | 0 | 0 | | |
| June | 60 | 7 | 5 | 0 | | |
| July | 142 | 0 | 124 | 0 | | |
| August | 140 | 0 | 140 | 0 | | |
| September | 137 | 0 | 137 | 0 | | |
| October | 200 | 0 | 200 | 0 | | |
| November | 161 | 0 | 161 | 0 | | |
| December | 200 | 0 | 200 | 0 | | |
| **Total R3** | **1,156** | **50 (4.3%)** | **966 (83.6%)** | **60** | **0 (0%)** | **60 (100%)** |

Table A-5. Number of insensitive film–cadmium shielded (R4) weekly records from Y-12 monthly external monitoring file for 1948 and 1949 and number of these records equal to zero and to 30 mrem.

| | 1948 | | | 1949 | | |
|---|---|---|---|---|---|---|
| **Month** | **N** | **N = 0** | **N = 30** | **N** | **N = 0** | **N = 30** |
| January | 0 | 0 | 0 | 56 | 0 | 56 |
| February | 0 | 0 | 0 | 3 | 0 | 3 |
| March | 0 | 0 | 0 | 1 | 0 | 1 |
| April | 40 | 19 | 0 | 0 | | |
| May | 76 | 35 | 0 | 0 | | |
| June | 60 | 8 | 0 | 0 | | |
| July | 142 | 0 | 142 | 0 | | |
| August | 139 | 0 | 139 | 0 | | |
| September | 143 | 0 | 143 | 0 | | |
| October | 200 | 0 | 200 | 0 | | |
| November | 161 | 0 | 161 | 1 | | 1 |
| December | 200 | 0 | 200 | 0 | | |
| **Total R4** | **1,161** | **62 (5.3%)** | **985 (84.8%)** | **61** | **0 (0%)** | **61 (100%)** |

The two very high weekly R2 doses in Figure A-3 in January and February 1949, which occurred in one worker, suggest a large skin dose that might not have been detected by the PICs. These two high R2 doses do not appear to be due to beta particles because the ratio of R2 to R3 of approximately 100:1 is much larger than the expected beta-to-gamma dose ratio from exposure to uranium. These two high readings are more likely the result of exposure to very-low-energy photons leaking from an X-ray spectrograph or other devices, a problem that was noted in early Health Physics reports (Struxness 1948b,c). The R2 readings from the 502 sensitive film under the open window of a film badge show a response to photons with energies less than 0.1 MeV that is as much as 15 to 20 times greater than the response to photons of higher energies (Handloser 1959; Thornton, Davis, and Gupton 1961). However, PICs have trouble detecting photons with energies less than 0.1 MeV because they are heavily attenuated in the wall materials of the PICs, as discussed in

# ATTACHMENT A
# EXTERNAL RADIATION MONITORING AT THE Y-12 FACILITY DURING THE 1948–1949 PERIOD



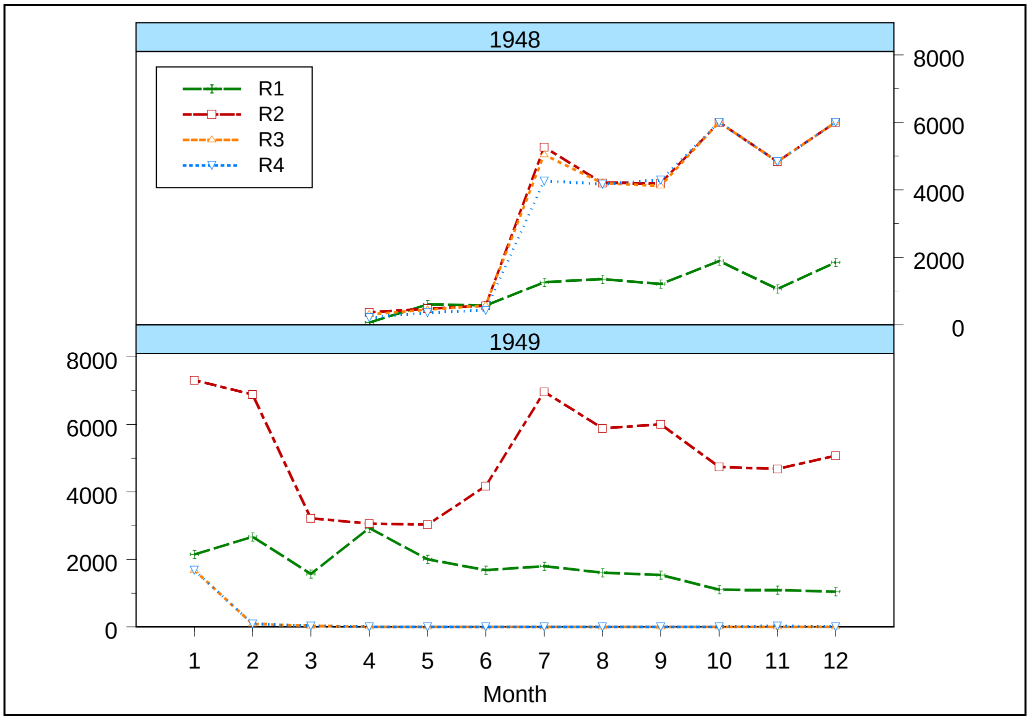


Figure A-1. Sums of Y-12 weekly recorded doses (mrem) by month and year for 1948 and 1949.

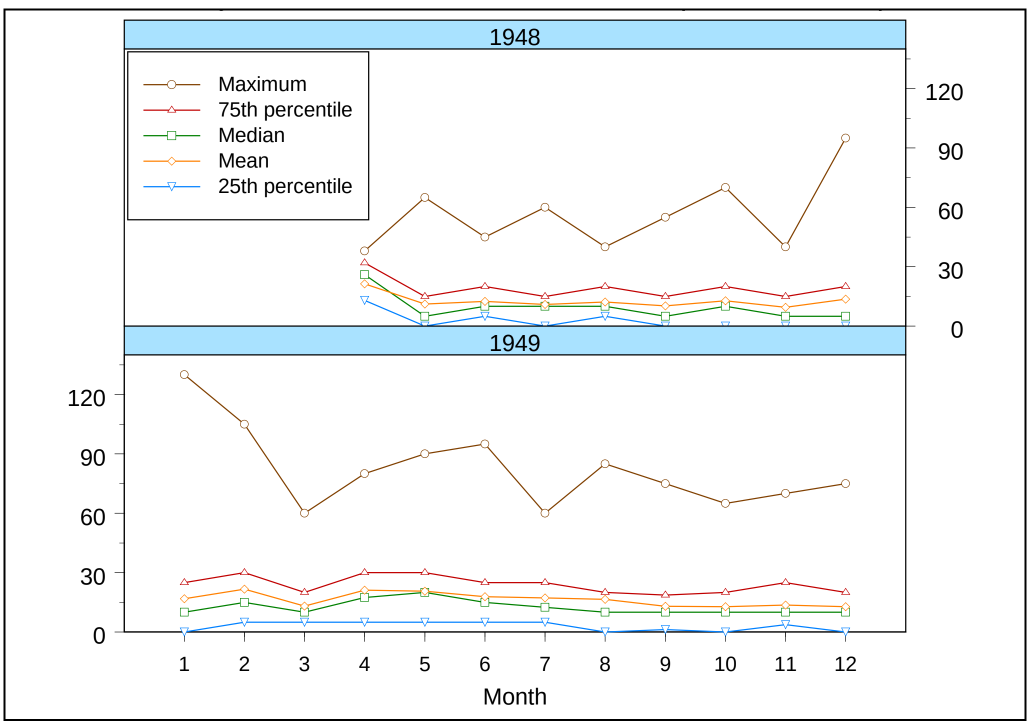


Figure A-2. Statistics for Y-12 weekly R1 doses (mrem) by month and year (NRs excluded).

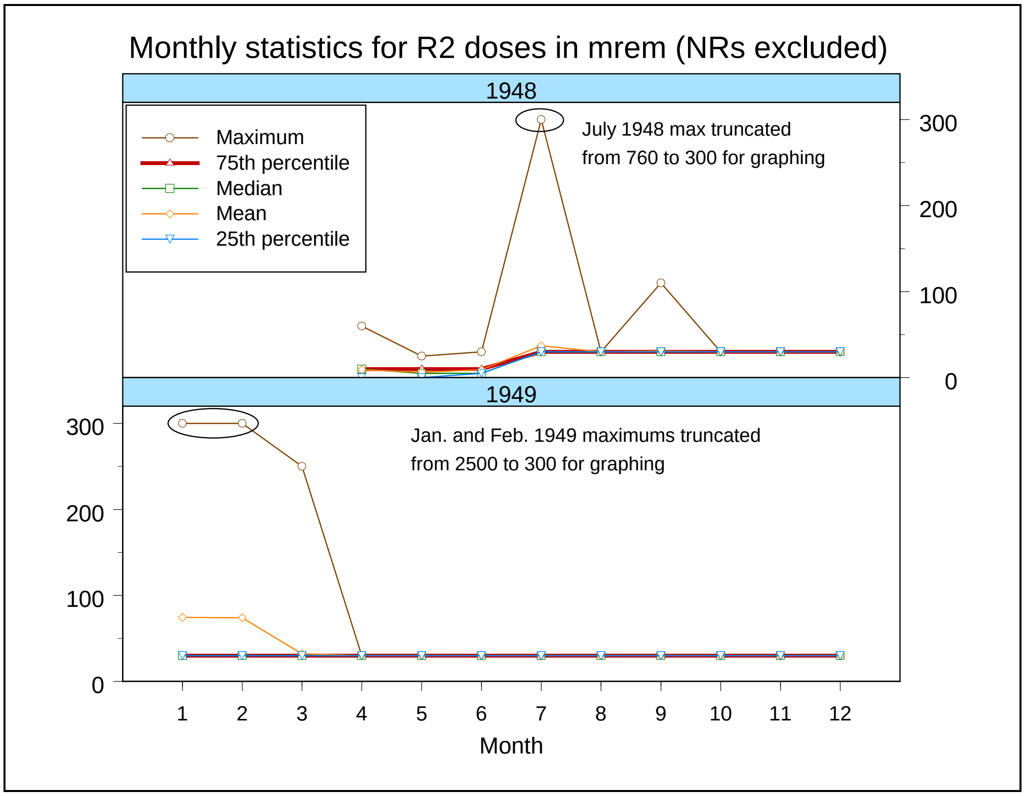


Figure A-3. Statistics for Y-12 weekly R2 doses (mrem) by month and year (NRs excluded).

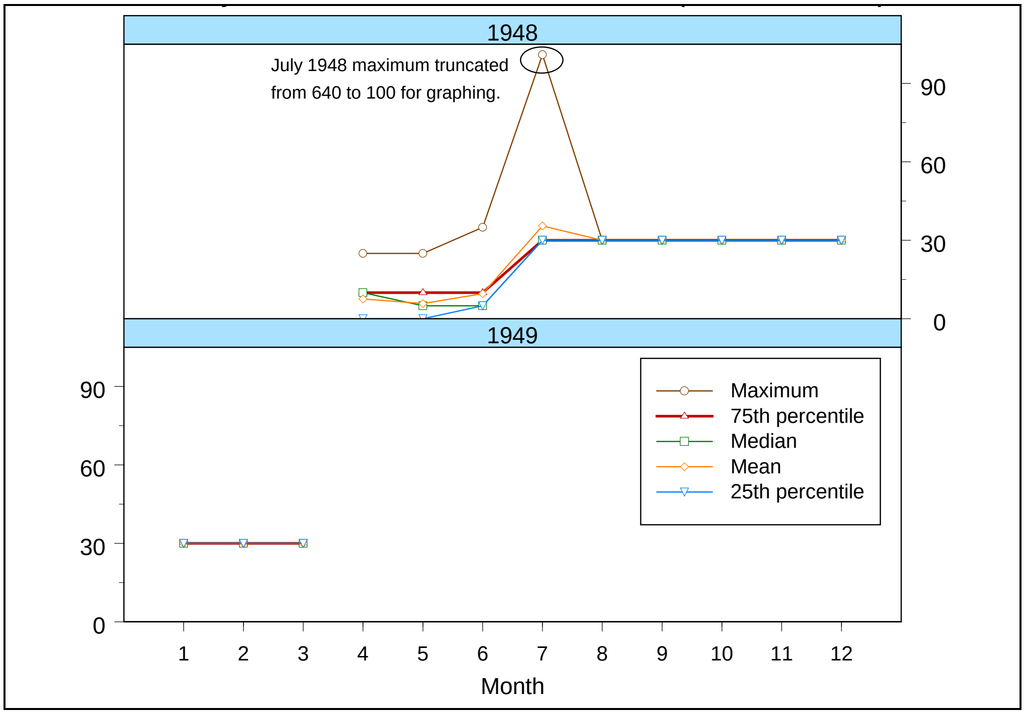


Figure A-4. Statistics for Y-12 weekly R3 doses (mrem) by month and year (NRs excluded).

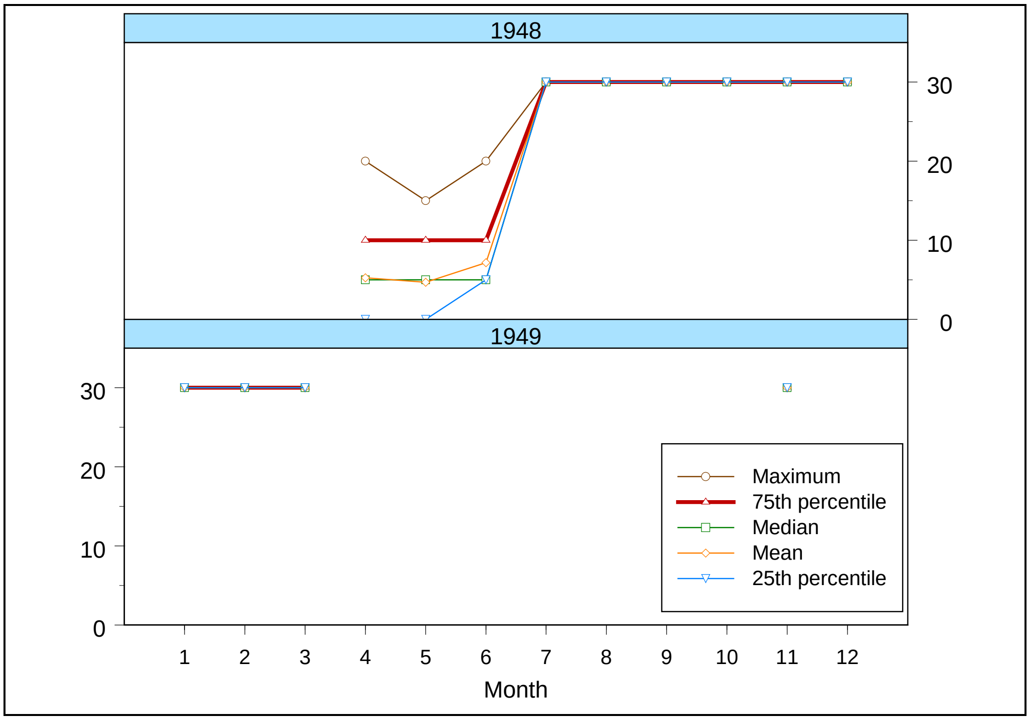


Figure A-5. Statistics for Y-12 weekly R4 doses (mrem) by month and year (NRs excluded).

Section 3.1. The high R2 reading for another worker in July 1948 appears to be an artifact because: (1) the R2 and R3 readings for the skin and whole-body doses are nearly equal (see Figures A-3 and A-4), and (2) the high R3 reading of 640 mrem for the whole-body dose is not observed in the R1 or R4 readings for the worker (see Figures A-2 and A-5).

## A.6 COMPARISON WITH REGRESSION APPROACH ESTIMATES FOR 1948–1949 QUARTERLY DOSES

In this section the means of the weekly R1, R2, R3, and R4 doses from the Y-12 external monitoring file for 1948 and 1949 are calculated and then scaled to full quarter values to be compared with corresponding mean quarterly doses that were estimated using the regression approach for gamma and beta doses discussed in ORAUT (2013) and ORAUT (2007) respectively. The purpose of this comparison is to examine whether the regression approach provides realistic estimates that are favorable to claimants for dose reconstruction purposes. The mean dose was selected as the most appropriate comparison statistic from the regression approach because it is calculated using both the log of the geometrical mean $\mu$ and the log of the geometrical standard deviation $\sigma$. Specifically, for a given quarter the mean dose on the original scale (arithmetic mean) from regression is calculated as follows:

$$E(dose) = \exp(\mu + 0.5\sigma^2) \quad \text{(A-1)}$$

The weekly mean doses for R1, R2, R3, and R4 were calculated directly with all NRs deleted before calculation to ensure that results were not lowered, and are listed in Table A-6. It is important to note that each dose entry in the Y-12 external monitoring file for 1948 and 1949 represents the dose per

**ATTACHMENT A**
**EXTERNAL RADIATION MONITORING AT THE Y-12 FACILITY DURING THE 1948–1949 PERIOD**


week in the specified quarter and not the dose per quarter. In order to make a valid comparison with the regression results, weekly means must be scaled up to represent the dose over an entire quarter. Table A-7 lists the average weekly dose from Table A-6 multiplied by 12.5 weeks per quarter, assuming 50 working weeks and 2 vacation weeks per year. R3, the sensitive film reading under the 1-mm-thick cadmium shield of film badge, can be compared to the regression approach quarterly gamma dose estimates, *E*(gamma dose), in the next to last column of the Table A-7. For R2, the sensitive film reading under the open window of the film badge, comparison can be made to *E*(beta dose) from the regression approach, which is the last column of the table.

Table A-6. Means of weekly recorded doses in the quarter from Y-12 external monitoring file, 1948 and 1949.

| | | **Means of weekly doses in each quarter** | | | |
|---|---|---|---|---|---|
| **Year** | **Quarter** | ***E*(R1)** | ***E*(R2)** | ***E*(R3)** | ***E*(R4)** |
| 1948 | 1 | ----- | ---- | ---- | ---- |
| | 2 | 12.03 | 7.98 | 7.53 | 5.65 |
| | 3 | 11.09 | 32.58 | 31.86 | 30.00 |
| | 4 | 12.20 | 30.00 | 30.00 | 30.00 |
| 1949 | 1 | 17.29 | 59.85 | 30.00 | 30.00 |
| | 2 | 20.12 | 30.00 | ---- | ---- |
| | 3 | 15.49 | 30.00 | ---- | ---- |
| | 4 | 13.10 | 30.00 | ---- | 30.00 |

Table A-7. Comparison of mean weekly doses from Table A-6 scaled up to a full quarter and mean quarterly dose estimates from regression approach.

| | | **Weekly means scaled to full quarter** | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Quarter** | ***E*(R1)** | ***E*(R2)** | ***E*(R3)** | ***E*(R4)** | ***E*(gamma dose)[a]** | ***E*(beta dose)[b]** |
| 1948 | 1 | ----- | ---- | ---- | ---- | 362.54 | 2,272.0 |
| | 2 | 150.36 | 99.75 | 94.13 | 70.63 | 351.66 | 2,235.7 |
| | 3 | 138.63 | 407.25 | 398.25 | 375.00 | 341.11 | 2,199.5 |
| | 4 | 152.50 | 375.00 | 375.00 | 375.00 | 330.87 | 2,163.2 |
| | **Total** | **441.49** | **882.00** | **867.38** | **820.63** | **1,386.18** | **8,870.4** |
| 1949 | 1 | 216.13 | 748.13 | 375.00 | 375.00 | 320.94 | 2,127.0 |
| | 2 | 251.50 | 375.00 | ---- | ---- | 311.31 | 2,090.7 |
| | 3 | 193.63 | 375.00 | ---- | ---- | 301.97 | 2,054.5 |
| | 4 | 163.75 | 375.00 | ---- | 375.00 | 292.91 | 2,018.2 |
| | **Total** | **825.01** | **1873.13** | **375.00** | **750.00** | **1,227.14** | **8,290.4** |

a. See Table 7-1a in this document and Table 7-1 in ORAUT (2013) for gamma dose arithmetic means from regression approach to *E*(R3).
b. See ORAUT (2007, Table 9-2) for beta dose arithmetic means from regression approach to *E*(R2).

When the weekly doses are scaled up to a full quarter as listed in Table A-7, most of the quarterly means based on the monitoring data for 1948 and 1949 in column *E*(R3) tend to slightly surpass the gamma dose estimates based on the regression approach. However, the vast majority of the R3 dose records in the Y-12 external monitoring file for 1948 and 1949 had a recorded value of 30 mrem (see Table A-4), which was probably assigned to a worker when the film badge reading was below the MDL, and represented a bounding dose to the worker for that week. In early 1948, a zero was entered instead to indicate a film badge reading of less than the MDL (see Table A-4). It is clear that the quarterly regression approach estimates are reasonable estimates of the gamma doses received by workers in these 2 years. In contrast, the quarterly beta dose comparisons of *E*(R2) to the regression

approach reveal that backwards extrapolation of beta doses provides ultraconservative dose estimates for workers in 1948 and 1949. The source of this discrepancy for beta doses is that in 1948 and 1949 machining at Y-12 mainly involved EU, which was reflected in R2 doses that differed little from R3 doses. It was not until 1950 that the monitoring program was expanded and included workers with exposure to natural and depleted uranium because machining process began to involve less highly enriched uranium (ORAUT 2007). The regression approach was based on beta doses for 1956 to 1965 when machining processes mainly involved natural and depleted uranium. Figure 4-1 of ORAUT (2007) illustrates the increasing dose rate of beta particles as the percent of enrichment of uranium declines.
To assess the possible impact of the dose entries listed as “less than the MDL,” the dose records for R2, R3, and R4 with values of zero or 30 mrem were changed to half of the MDL or 15 mrem, as recommended by NIOSH (2007). Table A-8 lists the recalculated means scaled up to a full quarter. There were a few dose entries that had non-zero values that were less than the MDL. It is likely that these represent film readings with a detection limit that was deemed more accurate than the typical MDL of 30 mrem (Morgan 1961). These values were not adjusted in the analysis in Table A-8, though it is clear that adjusting these values by half would further reduce the mean quarterly doses derived from the Y-12 external monitoring file for 1948 and 1949.

Table A-8. Comparison of mean weekly doses from Table A-6 with an adjustment for doses assigned when below MDL and mean quarterly dose estimates from regression approach.

| Year | Quarter | Y-12 dose files for 1948–1949[a] | | | | *E*(gamma dose)[b] | *E*(beta dose)[c] |
|---|---|---|---|---|---|---|---|
| | | ***E*(R1)** | ***E*(R2)** | ***E*(R3)** | ***E*(R4)** | | |
| 1948 | 1 | ----- | ---- | ---- | ---- | 362.54 | 2272.0 |
| | 2 | 150.74 | 147.73 | 143.11 | 136.72 | 351.66 | 2235.7 |
| | 3 | 142.81 | 228.22 | 218.38 | 187.50 | 341.11 | 2199.5 |
| | 4 | 157.92 | 187.50 | 178.50 | 187.50 | 330.87 | 2163.2 |
| | **Total** | **457.46** | **563.45** | **548.99** | **511.72** | **1386.18** | **8870.4** |
| 1949 | 1 | 222.98 | 565.72 | 187.50 | 187.50 | 320.94 | 2127.0 |
| | 2 | 250.00 | 187.50 | ---- | ---- | 311.31 | 2090.7 |
| | 3 | 196.22 | 187.50 | ---- | ---- | 301.97 | 2054.5 |
| | 4 | 167.38 | 187.50 | ---- | 187.50 | 292.91 | 2018.2 |
| | **Total** | **836.59** | **1128.22** | **187.50** | **375.00** | **1227.14** | **8290.4** |

a. Doses below MDL, listed as 0 or 30 mrem, were set to 15 mrem (half the R2 and R3 MDL) as recommended in NIOSH (2007).
b. See Table 7-1a in this document and Table 7-1 in ORAUT (2013) for gamma dose arithmetic mean from regression approach to *E*(R3).
c. See ORAUT (2007, Table 9-2) for beta dose arithmetic mean from regression approach to *E*(R2).

Table A-8 indicates that when dose entries of 0 or 30 mrem are adjusted to half of the MDL, the resulting mean doses in column *E*(R3) all fall below the comparable quarterly results from the regression approach, *E*(gamma dose). This comparison provides further evidence that the quarterly gamma doses from the regression approach are valid estimates of worker dose during this period. Quarterly beta doses from the regression approach are again ultraconservative, reflecting the difference in sources of beta dose exposure in 1948 and 1949 than in later years.

## A.7 DISCUSSION

The Y-12 external monitoring data for 1948 and 1949 have been reviewed in this report and appear to be useful in a variety of ways for dose reconstructions of Y-12 workers. In an earlier study, for

**ATTACHMENT A**
**EXTERNAL RADIATION MONITORING AT THE Y-12 FACILITY DURING THE 1948–1949 PERIOD**


example, gamma-ray dose data for Y-12 workers from 1950 to 1979 were reviewed, and a method was developed for estimating gamma-ray dose starting with the UCC management change in the third quarter of 1947 (ORAUT 2013). During the 1948–1949 period, PICs and film badge dosimeters were used at Y-12 (Souleyrette 2003; ORAUT 2009a), and the PICs appear to provide the doses of record. This is consistent with practices at other DOE facilities such as the Oak Ridge National Laboratory and Hanford Site (Ostrouchov, Frome, and Kerr 2000). Initially, PICs were considered the primary device for monitoring worker exposures, and film badge dosimeters were considered a valuable adjunct (Hart 1966). Eventually, the film badge dosimeters were considered as providing the dose of record, and the PICs became the day-to-day means of monitoring worker exposures (Wilson et al. 1990). The switch from PICs to film badge dosimeters to provide the doses of record occurred in 1950 at Y-12 (ORAUT 2013).

Pre-1950 film badge data have been considered questionable because of frequently changed procedures and a perceived general lack of monitoring quality control during this period (Tankersley 1982). For example, for R2, R3, and R4 in the Y-12 data, it appears that from April through June 1948, 0 was assigned to below-MDL weekly readings while 30 mrem was assigned to such readings for the remainder of 1948 and for 1949 (see Tables A-2 to A-4). In addition, the very large doses observed in the R2 and R3 film badge responses were sometimes absent in the PIC data (see Figures A-2 to A-4). The PIC data were obtained with devices that were very simple to use; they should have provided reliable data about whole-body doses from gamma rays and high-energy beta particles during the 1948–1949 period. Several R2 readings suggest high exposures to the skin from very low-energy photons that might not have been detected by the PICs (see Figure A-3).

Gamma doses have been the focus of this TIB because of the possible link between these doses and most of the cancers relevant to dose reconstruction. This investigation of the Y-12 external monitoring data for 1948 and 1949 has clearly demonstrated that backwards extrapolation from the regression approach provides a reasonable method that is favorable to claimants for use in the reconstruction of potential whole-body doses from photon exposures to workers at the Y-12 facility during the late 1940s and early 1950s. Although gamma doses were the major interest, beta doses were also investigated. It was found that backwards extrapolation from 1956 to 1965 beta doses to the 1948 to 1949 period furnishes ultraconservative doses because of the continuing shift from mainly highly enriched uranium before 1950 to principally natural and depleted uranium by 1960.