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**ADVISORY BOARD ON
RADIATION AND WORKER HEALTH**

National Institute for Occupational Safety and Health

SC&A'S EVALUATION OF ORAUT-OTIB-0064, REVISION 02, COWORKER EXTERNAL DOSIMETRY DATA FOR THE Y-12 NATIONAL SECURITY COMPLEX

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ABBREVIATIONS AND ACRONYMS

ABRWH   Advisory Board on Radiation and Worker Health

Cd   cadmium

CER   Center for Epidemiologic Research

CTW   construction trade workers

DR   dose reconstruction

E(dose)   expected dose

GM   geometric mean

GSD   geometric standard deviation

HP   health physics

MDL   minimum detectable limit

mrem   millirem

NIOSH   National Institute for Occupational Safety and Health

ORAUT   Oak Ridge Associated Universities Team

OTIB   Occupational Technical Information Bulletin

ρ Pearson constant

R^2 Regression coefficient

R1   pocket ionization chamber reading

R2   sensitive film reading under open window of film badge (skin dose)

R3   sensitive film reading under 1-mm-thick Cd shield of film badge (deep dose)

R4   insensitive film reading under 1-mm-thick Cd shield of film badge (deep dose)

σ   sigma

SRDB   Site Research Database

μ   mu

1.0   INTRODUCTION AND BACKGROUND

At the Advisory Board on Radiation and Worker Health (ABRWH) meeting of January 25, 2017, SC&A was tasked with a technical review of ORAUT-OTIB-0064, *Coworker External Dosimetry Data for the Y-12 National Security Complex*, Revision 02, issued April 29, 2013 (NIOSH 2013a, referred to as "OTIB-0064"). In OTIB-0064, the National Institute for Occupational Safety and Health (NIOSH) used external gamma dose data from ORAUT-OTIB-0044, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Facility in Oak Ridge, Tennessee: Part 1 – Gamma Radiation*, Revision 01, issued April 29, 2013 (NIOSH 2013b, referred to as "OTIB-0044"), and external beta dose data from ORAUT-OTIB-0046, *Historical Evaluation of the Film Badge Dosimetry Program at the Y-12 Plant in Oak Ridge, Tennessee: Part 3 – Beta Radiation*, Revision 00, issued June 22, 2007 (NIOSH 2007, referred to as "OTIB-0046"), to derive the 50th and 95th percentile coworker gamma and beta doses during the period 1947–1979 for use in dose reconstruction (DR). This report presents SC&A's evaluation of the technical approach and statistical methods used by NIOSH in OTIB-0064.

2.0   OVERVIEW OF OTIB-0064

OTIB-0064 is a detailed document and, for evaluation purposes, it is advantageous to provide a brief outline as follows:

- **Purpose** – The purpose of the document was to provide external gamma and beta coworker dose data for assigning doses to Y-12 workers that should have been monitored, but had record gaps with no monitoring data, during the period 1947–1979.

- **Statistical Data** – Table 7-1a, page 13, provides a summary of the statistical data (μ, σ, geometric mean [GM], geometric standard deviation [GSD], and expected dose [E(dose)]) for 1947–1951 on a quarterly basis obtained from OTIB-0044 (Table 7-1, page 33) for gamma doses, and OTIB-0046 (Table 9-2, page 41) for beta doses.

- **Coworker Data** – Table 7-1b, page 15, provides a list of recommended 50th and 95th percentile gamma and beta doses for the period 1952–1979 on an annual basis. Table 7-1c, page 16, provides similar data for the period 1947–1951. These two tables contain the primary dose data used for purposes of DR.

- **CTW Coworker Data** – Table 7-2, page 17, provides a list of recommended 50th and 95th percentile gamma and beta doses for the period 1947–1979 on an annual basis for construction trade workers (CTW). These dose values have been modified according to guidance provided in ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers*, Revision 01 (NIOSH 2011).

- **Attachment A** – This attachment provides an in-depth comparison of film badge gamma and beta dose results retrieved from the period 1948–1949 to the expected gamma and beta doses for the same period derived from the regression approach using the dose data from 147 Y-12 workers monitored during the period 1956–1965. The result of the comparison indicates that the regression approach provides favorable-to-claimant dose assignments for the late 1940s.

3.0   SC&A'S EVALUATION OF OTIB-0064

The following is a summary of SC&A's evaluation of the approach, statistical analysis, and documentation used by NIOSH in developing OTIB-0064.

3.1   EVALUATION OF NIOSH'S APPROACH TO COWORKER DOSE

NIOSH's OTIB-0064 approach for developing 95th and 50th percentile coworker doses for DR purposes incorporates statistical data from OTIB-0044 for gamma and OTIB-0046 for beta exposures. The statistical parameters (μ, σ, GM, GSD, and E(dose)) for quarterly gamma doses listed in Table 7-1a, page 13, of OTIB-0064 represent only gamma doses for the period 1947–1951, rather than quarterly data for gamma doses throughout the entire period of 1947–1979, as presented in Table 7-1 of OTIB-0044. Likewise, the statistical parameters for quarterly beta doses in Table 7-1c of OTIB-0064 represent only the timeframe of 1947–1951, rather than the 1947–1979 beta dose data in Table 9-2 of OTIB-0046. It may have been because of the change in the method of excluding or including the missed doses that occurred between 1951 and 1952, as outlined on pages 14 and 15 of OTIB-0064, although this is not stated in the text. However, this did not affect the results in OTIB-0064, because more complete sets of statistical parameters were available in OTIB-0044 (Table 7-1) for gamma dose and OTIB-0046 (Table 9-2) for beta doses for use in deriving the percentile doses in Tables 7-1b and 7-1c of OTIB-0064.

NIOSH considered missed dose from badge readings less than the minimum detectable levels (MDLs) for 1952–1979, using MDL/2 multiplied by the badge exchange frequency. For 1947–1951, missed dose was included in the original analysis of these data in OTIB-0044.

OTIB-0064 does not provide the detailed steps used to derive the numerical value of the percentile doses listed in Tables 7-1b and 7-1c from the numerical statistical values of μ, σ, GM, GSD, and E(dose) listed in OTIB-0044 for gamma doses and OTIB-0046 for beta doses. The only reference made to these derivations was in Step 3 of Table 7-1b (1952–1979) in OTIB-0064 where it was stated:

> *The 50th- and 95th-percentile annual gamma and beta dose values were derived from the gamma and beta doses in Step 2* [on page 14] *by ranking the data and extracting percentiles for each year.*

And in Step 3 of OTIB-0064, Table 7-1c (1947-1951) where it is stated:

> *The 50th- and 95th-percentile annual gamma and beta dose values were derived from the resultant lognormal distributions from Step 1* [on page 15].

To perform an approximate comparison between dose values recommended in OTIB-0064 and those listed in OTIB-0044, SC&A calculated the sum[1] of the quarterly GM values for a given year from Table 7-1 of OTIB-0044, plus one-half the maximum potential missed dose (i.e., based on MDL/2) from Table 6-4, page 12, of OTIB-0064, for one-half the badge exchange cycles (considering that on an average one-half the exchange cycle had zero, or <MDL, readings

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[1] The calculated sum would be the total of the four quarter doses plus ½ the maximum missed dose 50% of the time; therefore, the total for any given year would be the sum of the quarter doses plus ¼ the maximum missed dose.

recorded). The resulting annual dose values were then compared to the 50th percentile gamma dose values in Table 7-1c for the period of 1947–1951, and Table 7-1b for the period 1952–1979. It was determined that the recommended 50th percentile dose values were generally close to, or slightly greater than, the GM values adjusted for missed dose (if applicable). Similar comparison results were obtained for beta doses.

SC&A did not identify any issues with the general approach used in OTIB-0064 to derive coworker doses for the period 1947–1979.

3.2   EVALUATION OF NIOSH'S STATISTICAL METHODS

SC&A evaluated the statistical methods employed by NIOSH in OTIB-0064 for developing coworker doses using data from OTIB-0044 for gamma and OTIB-0046 for beta exposures, as discussed below.

3.2.1   Comparison of 1962 Health Physics Report and Center for Epidemiologic Research Doses

Table 6-1, page 9, of OTIB-0064 provided a comparison of the 1962 gamma and skin (gamma plus beta) doses from the Health Physics (HP) Report (UCNC 1963) and the Center for Epidemiologic Research (CER) database. SC&A found that the two sets of dose data are in good agreement, and the two distributions appear to be almost identical, as shown for skin doses in Figure 1.

Figure 1. Comparison of 1962 Skin Doses (data from OTIB-0064, Table 6-1)
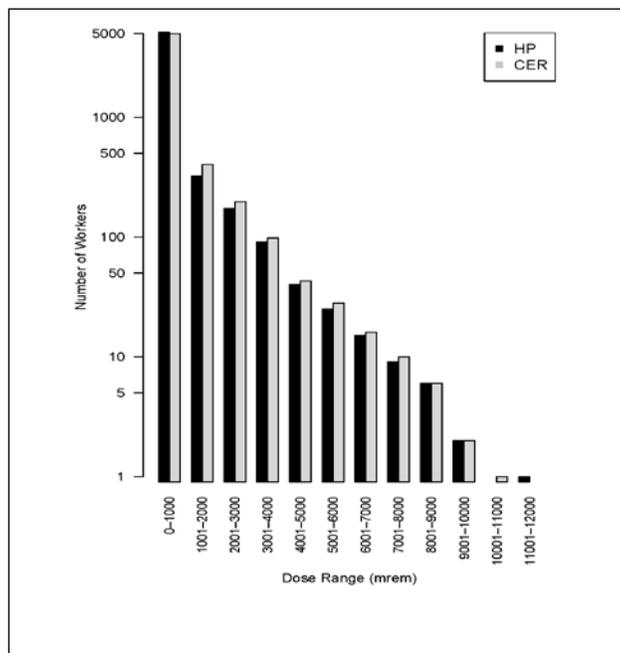
SC&A found no issues with the comparison of the HP Report and the CER database 1962 dose data.

3.2.2 Comparison of 1952–1956 Health Physics Report and Center for Epidemiologic Research Cumulative Skin Doses

On page 9 of OTIB-0064, it is stated:

> *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).*

SC&A analyzed these data and found that the value of the correlation cannot be determined from Figure 6-1 alone. The data for the individual doses of the 65 foundry workers used to derive the figure are required to verify the two correlations. Visual examination of the figure shows there is a very high degree of correlation, and the variances of the two variables are approximately equal. If the variances were equal, the slope of the regression line would be equal to the Pearson correlation. Examination of the figure shows that the slope is slightly less than 1. This indicates that the correlation is slightly less than 1. The reported Pearson constant (ρ) was only 0.841, so the regression coefficient (R^2) for regression is only 0.71, which is lower than would be expected given the high Spearman R^2 of 0.975. The one low outlier in Figure 6-1 is the likely cause of this discrepancy. The nonparametric Spearman estimate of the correlation appears more reasonable. The use of ranks in the calculation of the Spearman correlation reduces undue influence of the outlier. SC&A found no issues with the comparison of the HP Report (UCNC 1957) and the CER database cumulative 1952–1956 skin dose data.

3.2.3 Comparison of 1948–1949 Monitored Dose and Regression Approach

Attachment A, Section A.6, of OTIB-0064, pages 32–34, provides an evaluation of 1948 and 1949 recorded dose readings associated with four dose fields. These fields are represented by R1 = pocket ionization chamber, R2 = sensitive film under open window (skin dose), R3 = sensitive film under 1-mm-thick cadmium (Cd) (deep dose), and R4 = insensitive film under 1-mm-thick Cd (deep dose). The monitored doses are compared to the E(doses) derived from the lognormal distributions using the regression approach presented in Section 7.0, pages 31–33, and Table 7-1, of OTIB-0044 for gamma dose, and Section 9.0, pages 38 – 41, and Table 9-2, of OTIB-0046 for beta dose.

SC&A found in Table A-7, page 33, of OTIB-0064 that the eight quarterly gamma lognormal dose distribution values from OTIB-0044 are almost identical for each quarter, with a small decrease in the expected value in each following quarter. The same is true for the eight beta lognormal dose distribution values from OTIB-0046. In Table A-7, the dose values E(R1), E(R2), E(R3), and E(R4) are compared with the expected lognormal distribution values. The reason for using the expected value to make a comparison is stated on page 32 as:

> *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 μ and the log of the geometrical standard deviation σ.*

However, this is not sufficient reason to select the expected value, since any percentile (other than the median) is also calculated using both the log of the GM μ and the log of the GSD σ. SC&A examined the Discussion Section (A.7) of Attachment A, which included the following summary statement:

> *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.* [emphasis added]

Comparison of 1948–1949 Beta Doses

In order to determine if the stated differences between the two sets of estimates for beta doses are correct, SC&A created Figures 2 and 3 that show the quarterly lognormal distributions (shaded area) for beta doses in 1948 and 1949, respectively. The expected median and mean values (dashed vertical lines) of each lognormal distribution are shown in the figures. The corresponding quarterly value of $E(R2)$ from Table A-7 is also shown in the figures (solid vertical line). Note that several quarters did not have estimates for $E(R2)$ in Table A-7. The $E(R2)$ beta dose values are all below the median and mean of the corresponding lognormal distributions.

Figure 2. Comparison of 1948 Beta Doses (data from OTIB-0064, Table A-7)
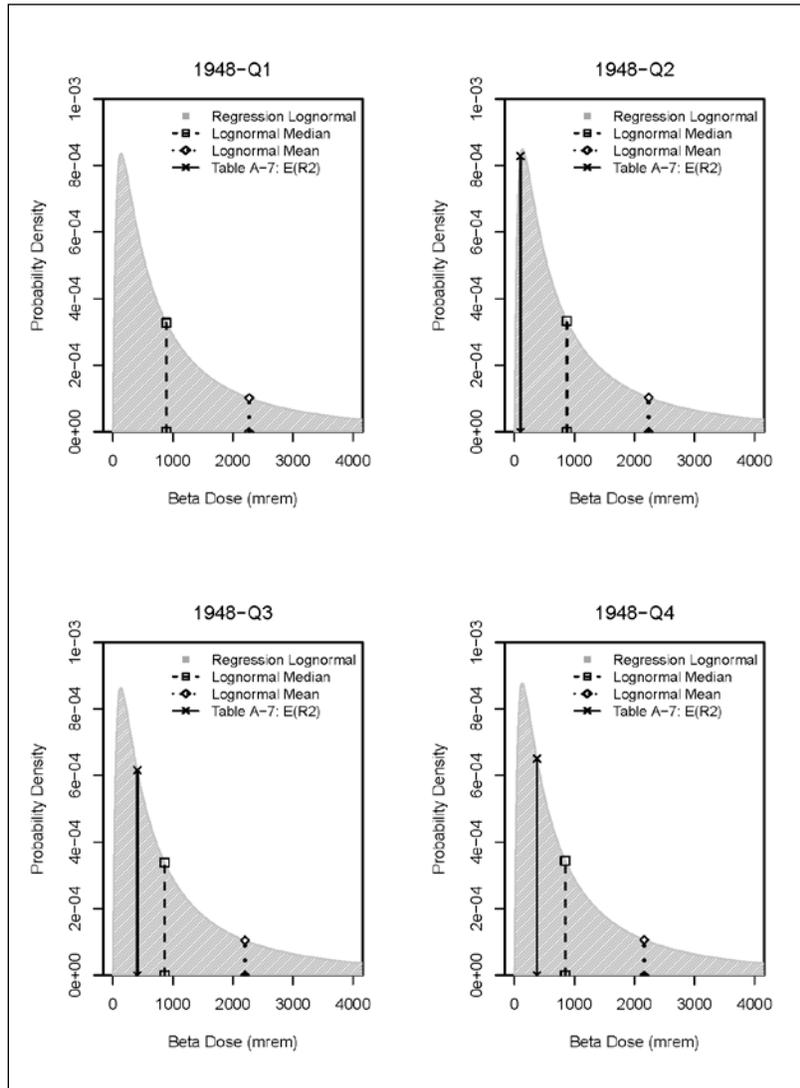
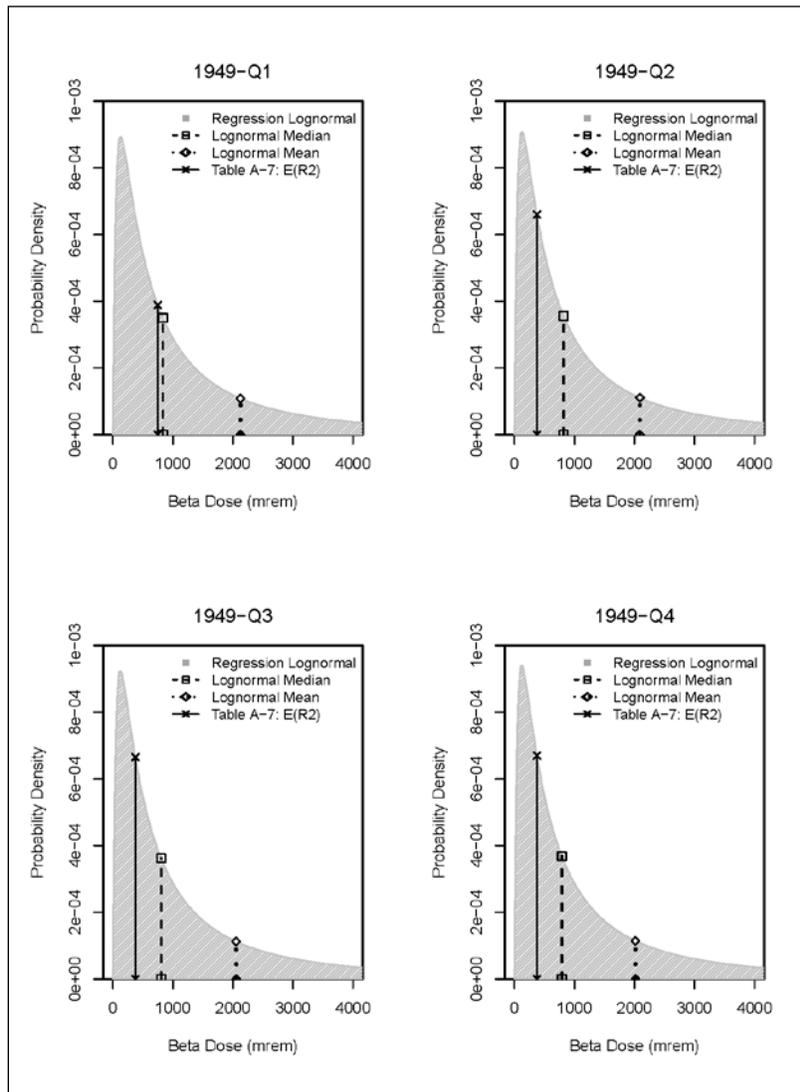**Figure 3. Comparison of 1949 Beta Doses (data from OTIB-0064, Table A-7)**

Table 1 shows the relative location of the recorded beta dose E(R2) as a percentile of the corresponding expected dose from the lognormal distribution (i.e., the total area under each of the curves in Figures 2 and 3 from regression analysis). The recorded beta dose exceeded the expected dose 6% to 47% of the time; conversely, the expected dose exceeded the recorded dose 94% to 53% of the time. Based on this comparison, the lognormal distribution would generally be more claimant favorable for assigning beta dose than using E(R2). However, only the second quarter in 1948 appears to be "ultra-conservative."

Table 1. Beta Dose E(R2) as a Percentile of the Corresponding Lognormal Distribution

Year	Quarter	E(R2)	Percentile of Lognormal Distribution
1948	1	No data	No data
1948	2	99.75	6%

Year	Quarter	E(R2)	Percentile of Lognormal Distribution
1948	3	407.25	29%
1948	4	375	28%
1949	1	748.13	47%
1949	2	375	28%
1949	3	375	29%
1949	4	375	29%

Comparison of 1948–1949 Gamma Doses

The same comparison was performed for gamma doses. Figures 4 and 5 show the quarterly lognormal distributions (shaded area) for gamma doses for 1948 and 1949, respectively. The expected median and mean values (dashed vertical lines) of each lognormal distribution are shown in the figures. The corresponding quarterly value of E(R3) from Table A-7 is also shown in the figures (solid vertical line). Two of the E(R3) gamma dose values were greater than the mean and median values of the corresponding lognormal distributions, and one E(R3) value, the second quarter of 1948, was less than the lognormal mean and median values.

Figure 4. Comparison of 1948 Gamma Doses (data from OTIB-0064, Table A-7)
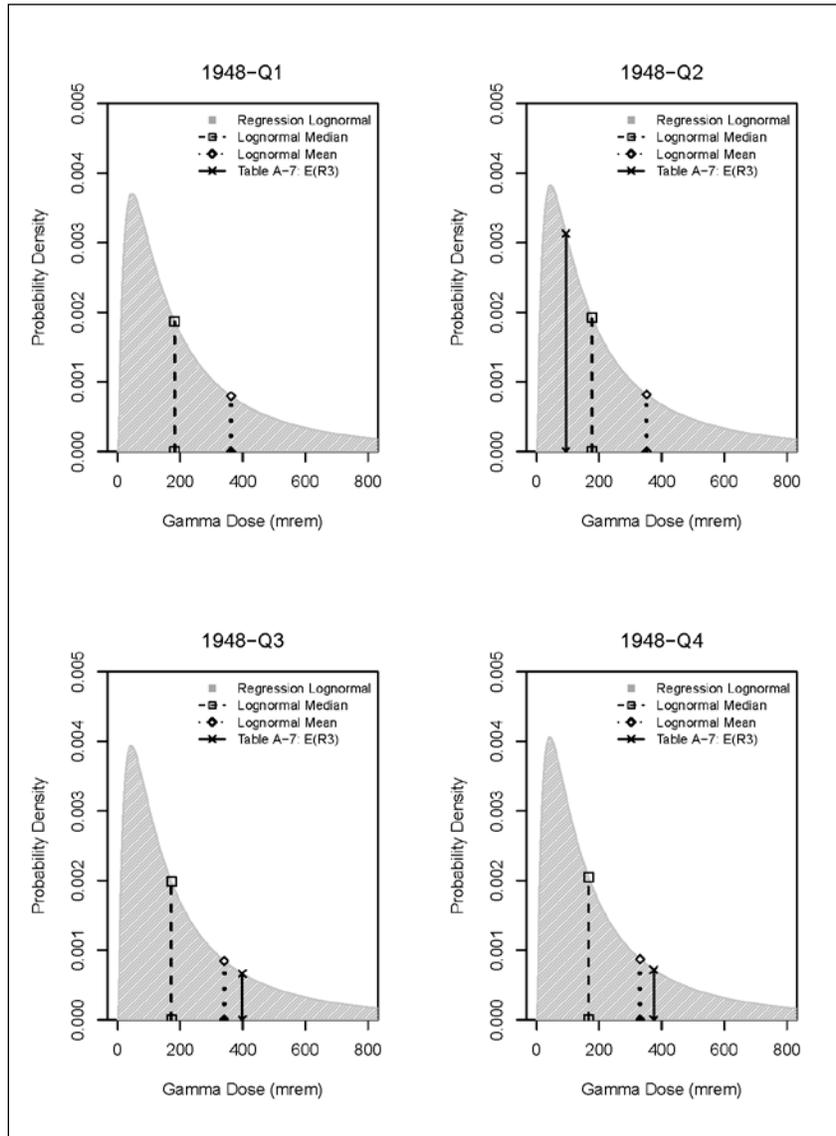
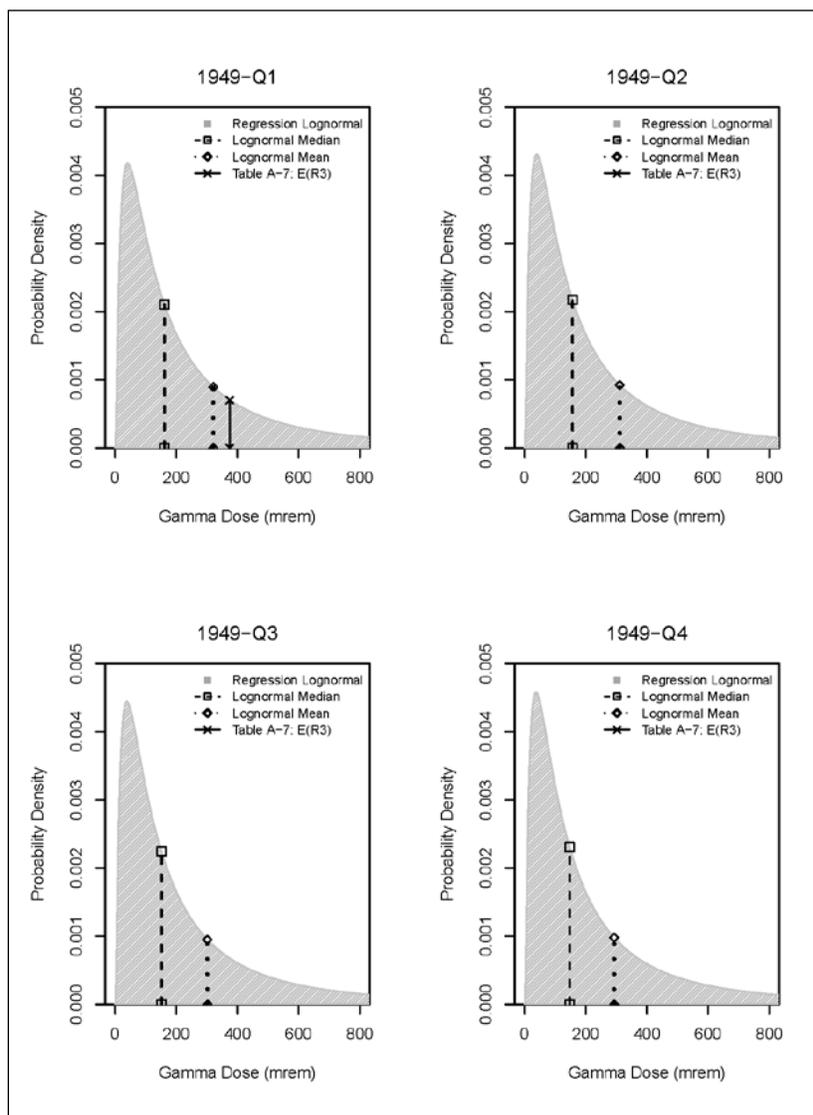**Figure 5. Comparison of 1949 Gamma Doses (data from OTIB-0064, Table A-7)**

Table 2 shows the relative location of the recorded gamma dose E(R3) as a percentile of the corresponding expected dose from the lognormal distribution (i.e., the total area under each of the curves in Figures 4 and 5 from regression analysis). The recorded gamma dose exceeded the expected dose 29% to 76% of the time; conversely, the expected dose exceeded the recorded dose 71% to 24% of the time. Based on this comparison, the lognormal distribution may be appropriate for assigning gamma dose, but not necessarily claimant favorable. In three of the four quarters shown in Table 2, only the upper quartile of the lognormal distribution exceeded the value of E(R3) derived from the 65 foundry workers. In all three of these cases, E(R3) exceeds the mean and median values of the corresponding lognormal dose distribution as shown in Figures 4 and 5.

Table 2. Gamma Dose E(R3) as a Percentile of the Corresponding Lognormal Distribution

Year	Quarter	E(R3)	Percentile of Lognormal Distribution
1948	1	No data	No data
1948	2	94.13	29%
1948	3	398.25	76%
1948	4	375	76%
1949	1	375	76%
1949	2	No data	No data
1949	3	No data	No data
1949	4	No data	No data

Comparisons Incorporating Nondetects

OTIB-0064 presents the results of another comparison of the E(R2) and E(R3) values and the beta and gamma lognormal distributions in Table A-8, page 34, of OTIB-0064. In that comparison, the value of MDL/2 was used to calculate E(R2) and E(R3). SC&A did not find this comparison credible because two sets of data only should be compared using the same treatment of nondetects (i.e., readings of zero or less than the MDL values). Table 3-3, page 12, of OTIB-0044, and Table 3-2, page 12, of OTIB-0046 indicate that an MDL of 30 millirem (mrem) was used for 1948 and 1949 for film badge gamma and beta measurements.

3.3   EVALUATION OF DOCUMENTATION IN OTIB-0064

SC&A's review of OTIB-0064 identified seven observations, as discussed below, where clarification or correction of errors would facilitate understanding and application of the document for DR purposes.

Observation 1. Page 9: The reference of "UCNC (1957)" maybe be incorrect. It appears that it should read "McLendon (1957)."

Observation 2. Page 10: The reference of "UCNC (1957)" in the title for Figure 6-1 maybe be incorrect. It appears that it should read "McLendon (1957)."

Observation 3. Page 13: It is not obvious why Table 7-1a only covers the period 1947–1951, instead of the complete period under review of 1947–1979. It may have been because of the change in the method of excluding or including the missed doses that occurred between 1951 and 1952, as outlined on pages 14 and 15 of OTIB-0064, although this is not stated in the text.

Observation 4. Pages 15 and 16: It is not obvious why Table 7-1b and Table 7-1c are separated between the years 1951 and 1952, when the most likely method would be to separate the two tables into two periods of 1947–1956 (when the regression model was used) and then 1957–1979, when the Y-12 coworker badge data from the CER were used. In addition, the statement on page 14, "*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.*" adds to the confusion of

the source of the data in Tables 7-1b and 7-1c (i.e., were the 1952–1956 data derived from the regression model, or from the CER coworker data?). According to Section 7.3, page 35, and Section 8.0, page 41, of OTIB-0044, it is clearly stated that the gamma dose data used in the tables for the period 1947–1956 were from the regression analyses, and that the data used for the period 1957–1979 were from the coworker data. This is also stated for the appropriate time periods in Section 9.3, page 42, and Section 10.0, page 46, of OTIB-0046 for beta doses.

Observation 5. Page 15: It was indicated in Step 2 that missed dose was not added to the resultant gamma doses from OTIB-0044 for the period 1947–1951 in Table 7-1c, because missed dose had already been included. Does this also apply to OTIB-0046 beta doses for 1947–1951?

Observation 6. Page 16: In Step 5 it is stated, "*Beta dose 95th-percentile values for 1947 to 1951 might need adjustment for dose reconstruction.*" However, there are no definite instructions to the dose reconstructor concerning the necessary steps to adjust these dose values to ensure consistence in DR.

Observation 7. Pages 33 - 34: The units of mrem need to be added to Tables A-6 and A-7, and A-8, as appropriate.

4.0   SUMMARY AND CONCLUSIONS

SC&A found the approach used to derive recommended Y-12 coworker doses in OTIB-0064 to be reasonable and technically correct.

SC&A's analysis of the statistical methods used to derive coworker doses were found to be acceptable, with some clarification and limits as discussed by SC&A in Section 3.2.

In Section 3.3 of this report, SC&A identified seven observations that would facilitate the document's readability and help to clarify the methods used to derive the coworker data, and make OTIB-0064 consistent with OTIB-0044 and OTIB-0046.

5.0   REFERENCES

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