Determination of NTS Beta-to-Photon Ratio and Beta Dose for 1963–1966, and Determination of an Extremity to Whole-body Ratio Using Quantile Regression and Imputation Methods

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November 14, 2017

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INTRODUCTION

An updated method has been used to develop beta dose to Nevada Test Site (NTS) workers for 1963–1965 when no measurements of such dose are available. In addition, the relationship of extremity dose to whole body dose was determined for the same period. This was done to address questions regarding the limitations of the available dosimeter data, and its use for development of the current beta-photon ratio used in dose reconstruction. Dosimeter data for 1963 through 1987 were captured from Excel spreadsheets created for Energy Employee Occupational Illness Compensation Program Act (EEOICPA) claims. Use of monitoring results from coworkers to account for incomplete or missing data is considered the preferred method according to 42 CFR Part 82. The data were gathered into a single spreadsheet and used to determine beta and extremity dose relationships relative to photon dose. The data were also used to develop coworker dose values. The results can be used to estimate doses for the period 1963–1965 when beta and extremity doses were not measured, and for energy employees in the period 1963–1966 for which coworker dose should be applied.

BETA-PHOTON AND EXTREMITY-WHOLE BODY DOSE RELATIONSHIPS

NTS dosimeters did not measure beta dose prior to 1966. Utilizing EEOICPA claimant dosimeter data, a quantile regression analysis was performed to determine the relationships of beta-photon dose and extremity-whole body dose for NTS workers. Dosimeter data for years 1966–1972 were utilized for the analysis. These years were selected for their proximity to the period of 1963–1965 and the abundance of data during this time period. Although the data include dose values for all types of employees, an effort was not made to differentiate between different occupations or work areas. This aligns with past analyses that also do not differentiate between occupations, and is considered a reasonable level of effort for dose reconstruction within the Special Exposure Cohort (SEC) period at the NTS. The analysis followed the method used in *Neutron/Photon Ratios at Portsmouth* (SRDB Ref. ID 165497). This method estimates or "imputes" dose values when such values are censored (less than the limit of detection). A fit to the data is then developed using the quantile regression method and is shown in Figure 1, and the relationship of the beta dose (Y) to the photon dose is represented by the following formulas.

50^{th} percentile: $Y = 4.84 + 0.1893X$

95^{th} percentile: $Y = 41.429 + 1.8929X$

where

X = photon dose (mrem)

These results are based on the accumulated dosimeter data from 1966–1972. Separate analyses were also performed for each of these individual years but are not presented here. A determination was made that the results for the combined data were reasonable for dose reconstruction.

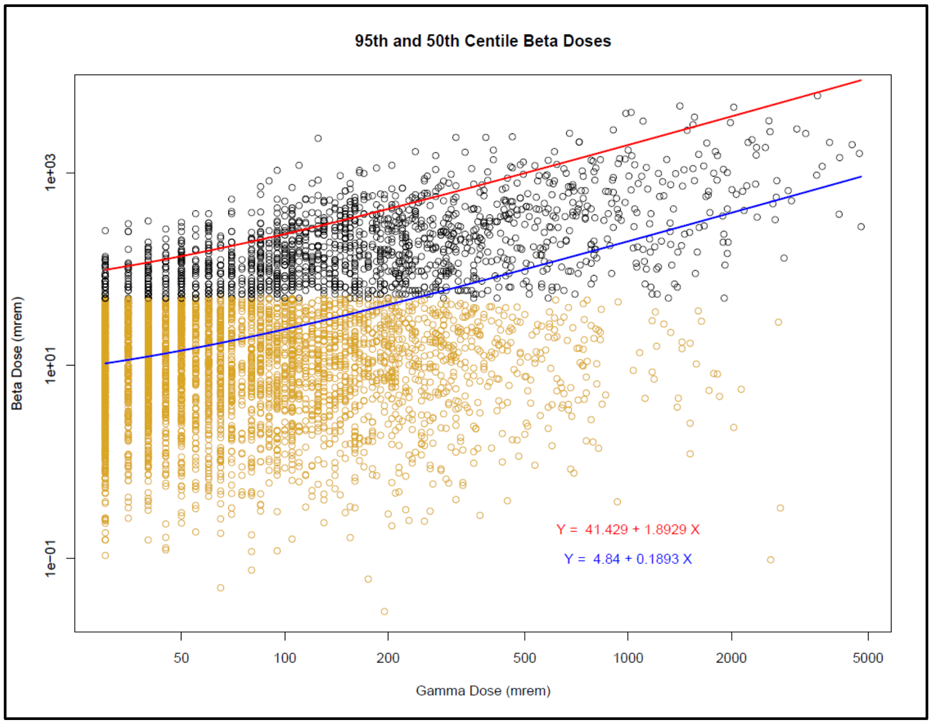

Figure 1. Beta Dose vs. Gamma Dose with 50th and 95th Percentile Fit

A similar process was performed to determine the relationship of the extremity-whole body dose. Data from the QC data files were used in the same manner as the beta-photon relationships presented above, and the extremity-whole body dose relationship is described by a fit to the data as shown in Figure 2. The 50th and 95th percentile extremity dose (Y) is represented by the following formulas.

50th percentile: $Y = 450.137 + 0.3901X$

95th percentile: $Y = 1493.402 + 2.8247X$

where

X = photon dose

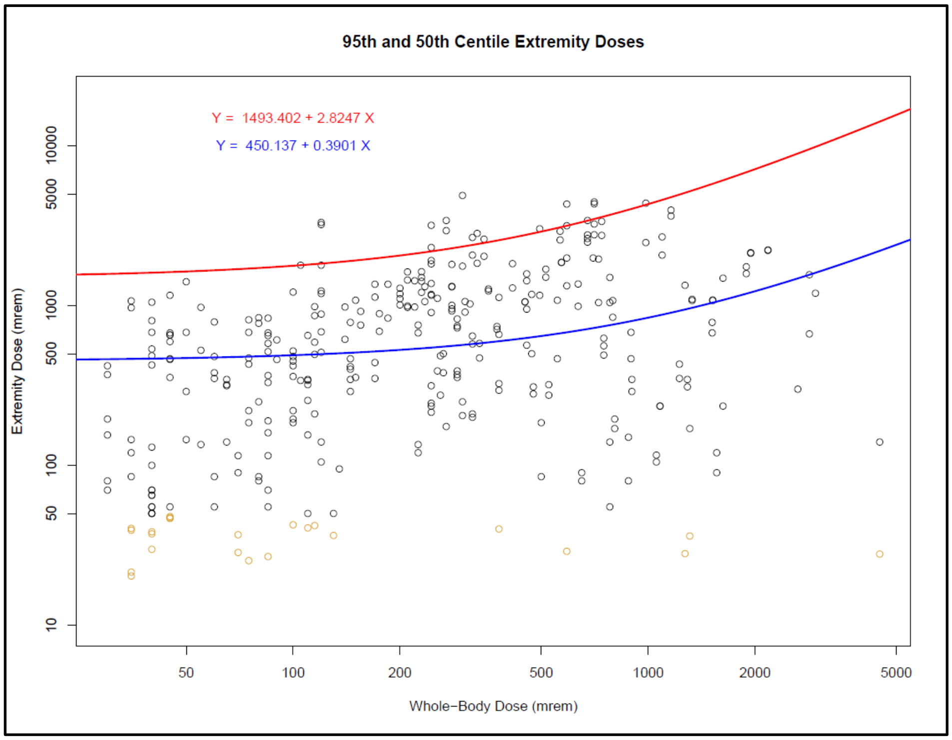

Figure 2. Extremity Dose vs. Whole Body Dose with 50th and 95th Percentile Fit

COWORKER DOSE 1963–1966

From 1963–1965 the beta dose is determined from the formulas derived above. In addition, a small number of workers who should have been monitored for dose from photon radiation may not have been, or – for monitored workers – photon dose may have been "zero" even though there was potential for a positive beta dose. Photon doses have been developed based on dosimeter results from monitored workers to account for this unmonitored dose. An imputation-based coworker study was performed of the available dosimeter data. Figure 3 illustrates the imputation model using the 1963–1966 dosimeter data.

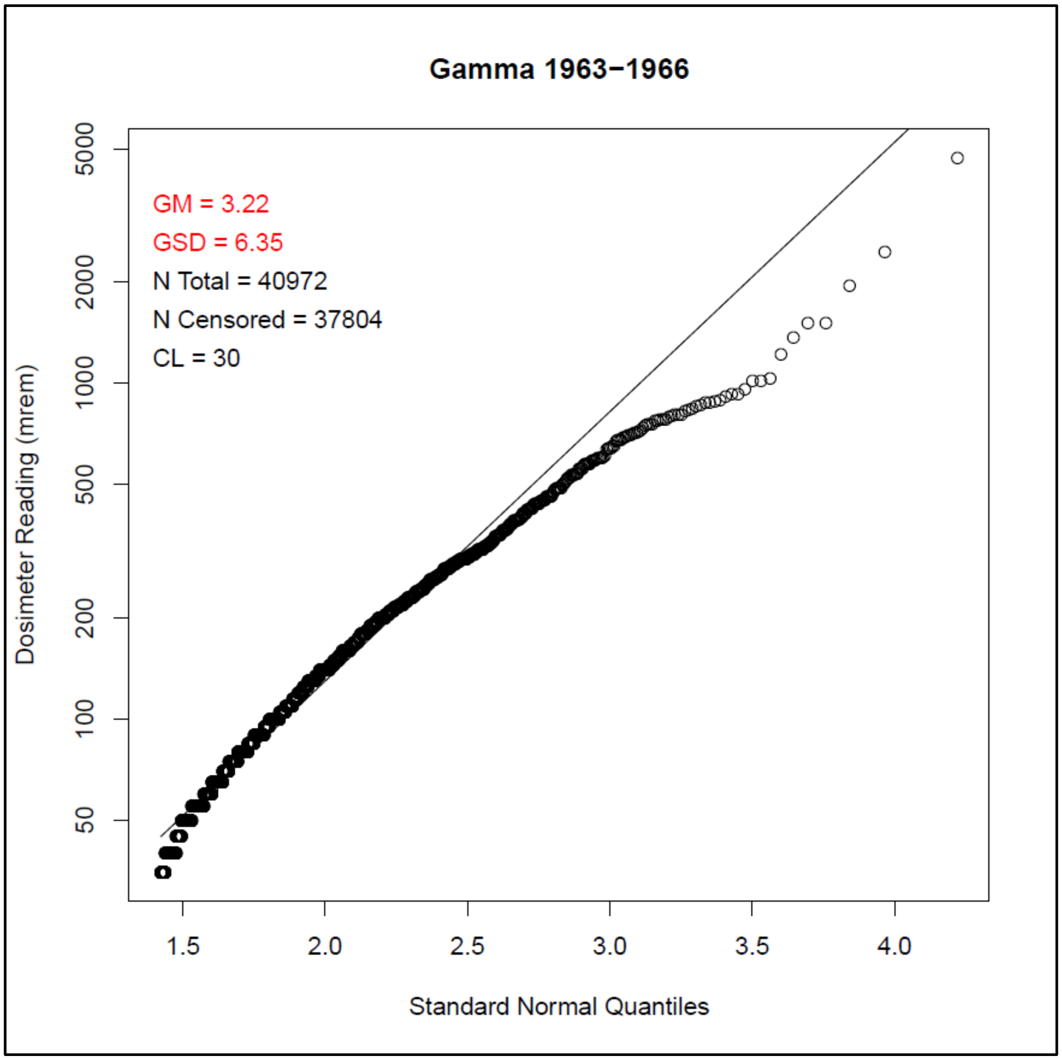

Figure 3. Imputation Model Results for NTS Photon Dose 1963–1966

This model was applied to the yearly data for 1963–1966 to determine the annual 50th and 95th percentile dose values with the results shown in the Table 1.

Table 1. NTS Coworker Dose 1963–1966.

Year	Geometric Mean (mrem)	Geometric Standard Deviation	50th % Photon (rem)	95th % Photon (rem)
1963	37.293	4.945	0.037	0.517
1964	44.172	3.7553	0.044	0.389
1965	50.662	4.7829	0.051	0.665
1966	55.299	4.3002	0.055	0.609

The results presented above are the predicted photon doses based on coworker dosimeter data. These values can be used to calculate beta dose by use of the beta-photon relationship previously developed. Similarly, extremity dose can be obtained by using the extremity-whole body dose relationship, since the whole body dose is also the photon dose based on the collected dosimeter data.

SUMMARY

The relationships between beta dose and photon dose, as well as extremity dose and whole body dose, have been derived for the years 1963–1965 using dosimeter data from 1966–1972. In addition, coworker photon dose has been derived for the years 1963–1966 using dosimeter data available in those years. The beta and extremity dose relationships to photon dose were developed using the quantile regression method after imputing values for readings below the censoring level. Coworker doses were developed by the imputation-based method resulting in a geometric mean and standard deviation for each year. These values were then used to calculate the 50th and 95th percentile coworker doses for each year from 1963–1966. To determine the beta dose for the purpose of dose reconstruction, the linear equations resulting from the quantile regression can be applied to measured dose if available, or the coworker dose. If a more individualized estimate of the beta dose is required, the data presented in Attachment C of ORAUT-TKBS-0008-6 can be used. The corresponding extremity-whole body equation developed by the quantile regression method should be applied when extremity dose is needed.

SC&A QUESTIONS/COMMENTS

The following items shown in italics were presented in a memorandum from SC&A, Inc. dated May 9, 2017. A response to each of these issues has been provided based on the work described above.

The NIOSH dose records used to develop the ratio of 1.16 are taken from badges used to monitor workers (i.e., empirical data), thus representing both the occupational and environmental external dose. The Hicks data in Appendix C to the TBD represent only environmental dose. The fact that the empirical data at least partially represent occupational dose suggests that the beta-gamma ratio may be influenced by specific projects, in different site areas, that are not associated with weapons tests.

When coworker dosimeter results are available, they are to be used as the first approach for reconstructing dose as specified in section 1.3 of OCAS-IG-001. A new beta-photon relationship has been developed based on a quantile-regression method using coworker data. The relationship is developed from a large population of dosimeter results and includes potential dose from various activities. As such, it is not a perfect representation of any single person, but is considered a reasonable estimate. The use of Appendix C of the TBD remains an option for specific circumstances.

If a higher BG ratio is found to be appropriate (such as from Appendix C and/or Barss and Weitz 2006), then the beta doses could easily be on the order of rems. This is particularly important for claims involving cancers to the skin, lips, testes, and breasts for which shallow doses are assessed.

The relationship between the beta and gamma doses developed as part of this analysis will result in higher doses to organs affected by beta radiation relative to the original ratio of 1.04 or the updated ratio of 1.16.

SC&A understands that dosimeter measurements typically represent the most "desirable" data source for determining occupational external dose in terms of the hierarchy of data for use in DR. Nonetheless, in this case, the approach to DR of using the empirical data appears to be questionable and not claimant favorable. Given that the source term for beta dose at NTS during this period is predominantly from fallout from nuclear device debris, it would appear that the data in Appendix C to the TBD and/or the ratios provided in Barss and Weitz (2006) would be more appropriate and certainly more claimant favorable. If NIOSH decides not to use these ratios, NIOSH should explain why it believes that its measured ratios are appropriate, given that they are so much lower than would be expected based on Appendix C and Barss and Weitz.

The use of measurement data as a first option is mandated by law and a new general relationship for the beta-photon dose has been developed using coworker dosimeter results. The Barss and Weitz values are calculated in a manner that includes conservative assumptions and are not verified against measured values. However, Appendix C guidance remains an available method when a more individualized estimate is required.

It appears that most of the empirical data derived from film badge readings in the post-1966 period have zero recorded gamma dose (below detection level). This calls into question the quality and appropriateness of the data for developing BG ratios for use in DR. The proportion of badges post-1966 with no recorded gamma needs to be quantified. If the data derived from post-1966 badges are to be used to assess pre-1966 beta dose, NIOSH needs to develop a methodology for accounting for the sub-method-detection-limit (sub-MDL) gamma readings.

The sub-method-detection-limit photon doses were addressed by imputing the dose when a result of zero was observed. These imputed values were used in the quantile regression analysis for determining the beta-photon relationship. The analysis refers to these results as censored which is another way of describing values below the limit-of-detection.

The potential for situations where the badging records indicate a positive beta dose with a deep dose below the detection limit has not been evaluated. NIOSH should investigate this potential source of negative bias.

The new analysis imputes dose values for situations where the dosimeter record indicates zero dose so that doses below the detection limit are not neglected in the evaluation of the beta-photon relationship.

The NIOSH data are from post-1966, when there was only underground weapons testing (with venting being an issue) with intervening periods of no testing. The pre-1966 time frame represents *both atmospheric testing and underground testing; therefore, the NIOSH data may not be representative of the diverse external dose potential. NIOSH needs to provide a clear explanation of why it believes that these post-1966 data are appropriate for back extrapolation, given the widely different activities and source terms. SC&A suggests that NIOSH determine the proportion of pre-1966 badges that recorded no measurable gamma dose and compare that to the proportion of post-1966 dose records with sub-MDL readings. Such a comparison might help in determining whether post-1966 data are appropriate for back-extrapolation to pre-1966 exposures. Such investigations are consistent with the guidance in the March 2015 NIOSH white paper, Draft Criteria for the Evaluation and Use of Coworker Datasets,* Revision 4.1 (NIOSH 2015b).

Data from 1966–1972 were used to develop the new beta-photon relationship. The new analysis is for reconstructing dose in the time period of underground testing from 1963 through 1965 when beta dose was not measured. Periods of above ground testing may be addressed by the methods utilized for reconstructing dose to military personnel under the Defense Threat Reduction Agency (DTRA).

The potential for the empirical data being skewed by badge results dominated by certain claimants or groups of claimants has not been investigated. The issue of data dominance was one of the central reasons why NIOSH developed the time-weighted one person, one statistic approach to coworker model development. It would be beneficial for NIOSH to quantify how many claimants make up the proposed dataset to determine if data dominance may be an issue. It would also be beneficial for NIOSH to record their occupation and work locations, if possible, to see if the data are dominated by certain occupational groupings at certain times. Furthermore, NIOSH has proposed a single BG ratio for the entire period under consideration. Analysis and discussion of temporal, work location, and occupational variations would appear warranted and is consistent with the coworker criteria described in NIOSH 2015b.

The 1966–1972 dosimeter data used for the analysis include dose values for all types of employees, an effort was not made to differentiate between different occupations or work areas. This aligns with past analyses that do not differentiate between occupations, and is considered a reasonable level of effort for the Special Exposure Cohort (SEC) period at the NTS.