Draft

ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

COMMENTS ON NIOSH'S "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" (2017)

Contract No. 211-2014-58081
SCA-TR-2018-SP002, Revision 0 PC-1

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June 2018

SC&A, INC.: ***Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program***

DOCUMENT TITLE:	Comments on NIOSH's "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" (2017)
DOCUMENT NUMBER/ DESCRIPTION:	SCA-TR-2018-SP002
REVISION NO.:	0 PC-1 (Draft)
SUPERSEDES:	0
EFFECTIVE DATE:	June 11, 2018
TASK MANAGER	Arjun Makhijani, PhD [signature on file]
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Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	4/20/2018	Initial issue
0 PC-1 (Draft)	6/11/2018	Corrects a typographical error in the document title on the title page

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ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
Ci	curie
CL	censor level
DTRA	Defense Threat Reduction Agency
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
EPA	U.S. Environmental Protection Agency
GM	geometric mean
GSD	geometric standard deviation
H+12	12 hours after detonation of a nuclear device
MDA	minimum detectable activity
MDL	minimum detectable level
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH OCAS Claims Tracking System
NRDS	Nuclear Rocket Development Station
NTS	Nevada Test Site
ORAUT	Oak Ridge Associated Universities Team
POC	probability of causation
SRDB	Site Research Database
Sv	sievert
TBD	technical basis document

1 INTRODUCTION

The primary issue behind the National Institute for Occupational Safety and Health's (NIOSH's) 2017 report, *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*, is quantification of beta dose to workers at the Nevada Test Site (NTS) during the period when personal dosimeters did not have the ability to record beta dose, but only gamma dose. Specifically, the period of interest in NIOSH (2017) is stated to be 1963–1966, so SC&A assumes here that NIOSH (2017) is intended to be included as part of the site profile analysis of occupational environmental dose (NIOSH 2012a). However, we note that the discussions of beta dose concerning workers at NTS are given in the technical basis documents (TBDs) related to occupational external dose (NIOSH 2007, 2010, 2012b). Attachment A presents an overview of the affected claimant population for 1963–1965.

In general, environmental occupational radiation dose during the 1963–1966 period is being reconstructed based on NIOSH's assumption that all such dose can be related to fallout from the Small Boy event that occurred on July 14, 1962 (NIOSH 2012a).

There are two reasons why the ratio of beta-to-gamma dose might change as a function of time following the deposition of nuclear explosion fallout on the ground. One is that the mixture of radionuclides changes with time following deposition, and the relative emissions of photons and betas also change. These changes in radionuclide mix as a function of time have been documented in calculations by H.G. Hicks (1981a–1981i, 1982, 1984, 1990). In addition, changes in the ratio of beta dose to gamma dose to the skin because of changes in the radionuclide mix have been documented in calculations by Barss and Weitz (2006) and by NIOSH (2007, 2010, 2012b).

The second and more important reason for a time-dependent change in the ratio of beta-to-gamma dose is that radionuclides deposited on a soil surface migrate into the soil column (see, e.g., the data in McArthur [1991] and in McArthur and Miller [1989]), and the emitted beta particles are more strongly absorbed by elements in soil than are the photons. There are no known tabulations showing the decrease in beta dose as a function of fallout weathering into soil; data for changes in photon exposure rate have been documented in Beck (1980). A commonly used assumption (UNSCEAR 1988) is that the relaxation depth of ground-deposited fallout is initially 0.1 cm (due to surface roughness), 1 cm at 1 month, and 3 cm at 1 year and thereafter. The relaxation depth comes from the assumption that fallout activity, *A*, is exponentially distributed with depth, *x*, in soil, as shown in Equation (1):

$$A(x) = A(0)\exp(-\alpha x), \qquad (1)$$

where the relaxation depth is equal to $1/\alpha$.

Four methods could be used to evaluate the beta doses in the 1963–1966 time period. One could do this by calculation with the use of the Hicks tables (Hicks 1981a–1981i, 1982, 1984, 1990) and an assumed time-varying rate of radionuclide migration into the underlying soil (method 1). These calculations would be complex and would require the use of sophisticated codes such as MCNP (LANL 2017) to follow the interaction of beta particles and photons with elements in soil. This might be the best approach, but it would also be laborious. Calculations would also be needed to transform the beta dose recorded by a personal dosimeter to the dose to the skin cells at risk and to other possible cells at risk, such as the lens of the eye. Thus, consideration should be given to shielding by clothing and the layer of dead skin (usually taken to be 7 mg cm^{-2}).

Two methods would depend upon empirical data in NIOSH (2015), which is a tabulation of gamma and beta doses for 1966 through 1986. The tricky part about using such data would be to carefully select data that would be known to have exposures to fallout of the same age that would be appropriate for the 1963–1965 time period. One possible method would be to select data known to be associated with fresh fallout laid down in the 1966–1986 period (method 2). Although aboveground testing had officially stopped at NTS with the Little Feller I event on July 17, 1962, the Plowshare program had been exempted, and there were also many unplanned releases. Table 1 lists unplanned releases during 1966–1970 that were detected off site (reproduced from Anspaugh [2008]). The fact that these releases were detected off site guaranties that large fallout deposits were on site.

Table 1. Unplanned Releases from Which Radionuclides Were Detected Off Site during the 1966 to 1970 Time Period

Event	Date	Release, Ci at H+12
Red Hot	Mar 5, 1966	1.0×10^{6}
Pin Stripe	Apr 25, 1966	2.2×10^{5}
Double Play	Jun 15, 1966	6.0×10^{5}
Derringer	Sep 12, 1966	1.2×10^{4}
Nash	Jan 19, 1967	6.9×10^{4}
Midi Mist	Jun 26, 1967	1.3×10^{3}
Umber	Jun 29, 1967	2.6×10^{4}
Door Mist	Aug 31, 1967	4.0×10^{5}
Hupmobile	Jan 18, 1968	1.2×10^{5}
Pod	Jan 29, 1969	3.9×10^{3}
Scuttle	Nov 13, 1969	2.1×10^{2}
Snubber	Apr 21, 1970	5.5×10^{4}
Mint Leaf	May 5, 1970	4.0×10^{5}
Baneberry	Dec 18, 1970	6.7×10^{6}

Source: Reproduced from Anspaugh (2008), Table 4, derived from data in Hicks (1981i).

Therefore, method 2 is to follow data from one or more of these large releases to examine the ratio of beta-to-gamma doses as a function of time. The activity related to the Baneberry event would be a good choice.

Another possible choice would be to examine data from more than one event, but of different ages of fallout deposition, to determine the change in beta-to-gamma dose ratios as a function of age of fallout (method 3).

For methods 2 and 3, it would still be necessary to correct the response of the personal dosimeter to dose to the skin (and perhaps other tissues) with consideration of shielding by clothing and the dead layer of skin.

Given the expected major change in the ratio of beta-to-gamma dose with time, it would not be useful to consider a large amount of data with no allowance for the dominating effect on the ratio of time since deposition due to weathering into soil.

A fourth method would be to plot the ratio of beta-to-gamma doses calculated from dosimeter data with positive beta and gamma doses (NIOSH 2015) on a log-probability plot, and to assume that the higher values represent values that could be associated with more recent fallout. Then, the assumption could be made that the ratio at the 95th or even higher percentile would be appropriate for extrapolation back to the 1963–1965-time period.

Because of the powerful effect of time since fallout deposition and the resultant rapid attenuation of beta dose due to weathering of fallout into soil, it would be extremely unfavorable to claimants to simply take the ratios of beta-to-gamma dose from the unselected 1966 and later time periods and to extrapolate those values backward in time. Nonetheless, in order to characterize the magnitude of actual observed beta-gamma empirical ratios, SC&A analyzed the individual dosimeter results from a semi-random sample of claimants during the period 1966–1972. Attachment A discusses the results of this analysis. As opposed to a back-extrapolation approach, it would be very claimant favorable to extrapolate values observed over fresh fallout and to extrapolate forward in time.

2 ESTIMATES OF THE RATIO OF BETA-TO-GAMMA DOSE AT THE NEVADA TEST SITE BEFORE THE NIOSH (2017) REPORT

The NIOSH (2017) report was not the first attempt to estimate the ratio of beta-to-gamma dose for persons exposed to fallout from nuclear weapons tests. A major activity was sponsored by the Defense Threat Reduction Agency (DTRA) to calculate beta and gamma doses to military personnel. The results of these activities have been documented by Barss and Weitz (2006). Calculations are presented for both the Pacific Proving Ground and NTS. The authors assumed that a microscopically thin layer of fallout is deposited upon the surface of an infinite flat plane of soil. They did not assume any effect due to surface roughness or weathering of the source into soil, so their calculations are claimant favorable. The calculations depended upon the radionuclide source terms provided by Hicks (1981a–1981h, 1982, 1984) and a code to calculate beta and gamma doses.

The results for NTS in Barss and Weitz (2006) for the ratios of beta-to-gamma dose to the skin at 100 cm above the plane source start at 10.8 at 0.5 hour, decrease to 8.9 at 2 hours, increase to 15.9 at 12 hours, decrease to 6.4 at 1 week, and then increase to reach a maximum of 96.1 at 2 years. Due to the weathering of fallout into the soil surface, it is extremely unlikely that the ratios calculated for time periods beyond 1 month would be realized.

NIOSH performed a similar type of calculation, but using somewhat independent tools, in Revision 01 to the occupational external dose TBD (NIOSH 2007, Attachment C). These calculations depended again upon the source terms calculated by Hicks (1981a–1981i, 1982, 1990), which provide estimates of radionuclide deposition density (microcuries per square meter) per 1.0 milliroentgen per hour at H+12 (12 hours after detonation). These deposition densities for each radionuclide were converted to estimates of beta and gamma dose by use of dose coefficients (sievert [Sv] per second per becquerel per square meter) calculated by Eckerman

(2006). The essential data from Eckerman apparently exist only in the form of an e-mail from Eckerman to R.V. Griffith of the Oak Ridge Associated Universities Team (ORAUT). Calculation of combined beta and gamma doses above an infinite plane are tabulated in the U.S. Environmental Protection Agency's (EPA's) *Federal Guidance Report No. 12* (EPA 1993). The only document where the doses are broken out separately by beta and gamma is Eckerman (2006).

The results obtained by NIOSH in the first revision to the NTS TBD for occupational external dose (NIOSH 2007) are quite similar to those obtained by Barss and Weitz (2006). NIOSH provided the results of an extensive series of calculations for individual events that occurred during Operation Ranger in 1951, Operation Buster-Jangle in 1951, Operation Tumbler-Snapper in 1952, Operation Upshot-Knothole in 1953, and the Sedan shot in 1962 (NIOSH 2007, page 108). Values are given for discrete time periods of 0, 1, 2, and 12 hours; 1, 10, 50, and 200 days; and 1, 2, 5, 10, 20, and 50 years post shot. The value for the first year for the 31 events considered varies from 18.9 to 32.9. As usual, these values are biased on the high side due to the lack of consideration of deposited radionuclides weathering into soil.

Table 2 summarizes NIOSH's results. Again, the results calculated for later times are not realistic because the weathering of fallout in soil is not considered. The main point of the calculations by Barss and Weitz (2006) and NIOSH (2007, Attachment C) is that beta dose to the skin at early times following an event can be an order of magnitude larger than the gamma dose.

NIOSH published the second revision to the NTS TBD for occupational external dose in 2010. This second revision contained basically the same information as prepared by NIOSH previously, as summarized in Table 2.

Table 2. Beta-Photon Ratios for Exposure from Surface Contamination

Elapsed time following the production event	Beta/photon (Sv/Sv)
0 to 50 d	10
50 to 365 d	25
1 to 5 yr	60
>5 yr	25

Source: Reproduced from NIOSH (2010), page 51.

However, there was additional material in the body of the report (NIOSH 2010, page 51):

> *No routine beta monitoring data exists for NTS prior to 1966. For the time period from 1966 to 1987, 368 data pairs were identified from 84 claim files with positive beta and gamma results (i.e., results higher than the applicable MDA). Based on these data, a lognormal distribution was calculated with a 50th percentile beta to gamma ratio of 1.04, a 95th percentile of 4.59, a geometric standard deviation (GSD) of 2.41, and a mode value between 0.5 and 1. Thus the use of the 50th percentile value on an annual basis is assumed to be reasonable, yet favorable to claimants. 42 CFR Part 82 allows claims to be completed using efficiency methods when precise estimates cannot realistically be developed due to all the variables that modify the potential for exposure to beta radiation.*

The recommendation was made to use this value for dose reconstruction for pre-1966 unless more specific data were available. The obvious problem with this approach is that no allowance was made for the fact that the dosimeter measurements were in general made many years after aboveground testing had ended in July 1962, and the beta doses recorded by the dosimeters would have been severely attenuated by movement of the fallout into the soil column.

The third revision to the NTS TBD for occupational external dose (NIOSH 2012b) contained much the same information. A ratio of 1.04 was again recommended, but the comment was made that, "*If a more precise estimate is required, the values in Attachment C can be adjusted and used*" (page 52). Attachment C contains the detailed calculations made by NIOSH (2007, Attachment C), which were discussed above.

At a meeting of the NTS Work Group of the Advisory Board on Radiation and Worker Health (ABRWH) on January 5, 2017 (ABRWH 2017), the issue of beta doses to the skin was discussed extensively. A request had been made to NIOSH to provide the basis for the beta-to-gamma dose ratio of 1.04. The representative from NIOSH stated that:

> *We had searched through several original files to derive a beta/gamma ratio of 1.04 to 1 originally and that original file could not be located. NTS data from 1966 to 1986 was reanalyzed using current EEOICPA data files and a value geometric mean of 1.16 with a GSD of 2.15 and a 95th percentile value of 4.09 was derived from the data.* [page 139]

The implication at that time was that NIOSH would use the ratio of 1.16 for their calculations of beta dose to the skin. Again, however, there is the same obvious problem that no allowance has been made for the fact that the measurements were made many years after the deposit of fallout, and that the later beta doses recorded by the dosimeters would have been severely attenuated by the movement of the fallout into the soil column.

3 THE NIOSH (2017) REPORT

The introduction to the NIOSH (2017) report states that, "*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*" (page 2). This NIOSH report considers two topics in sequence:

1. "Beta-Photon and Extremity-Whole Body Dose Relationships"
2. "Coworker Dose 1963–1966"

Although NIOSH first discusses the derivation of the relationship of beta dose to gamma dose, the analysis shown in Figure 1 of the report may have been done after they had dealt with coworker dose using a method similar to that shown in Figure 3 and Table 1 of the report. NIOSH states (page 2): "*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*." This Figure 1 contains several vertical columns where it appears that beta doses vary over three orders of magnitude while the gamma dose is constant. This may be due to the various levels of imputed gamma dose.

3.1 Coworker Dose 1963–1966

A problem with applying the concept of a beta-to-gamma dose ratio is that the process only works if there is a non-zero value of gamma dose. NIOSH (2017) explains a procedure for imputing a gamma dose based on an assumed distribution of the gamma doses in 1963–1966 and use of the non-zero values. NIOSH's Figure 3 demonstrates the individual results of the imputation process for all of the claimant gamma-dose data for 1963–1966. The figure includes the following information (page 5):

GM = 3.22
GSD = 6.35
N Total = 40972
N Censored = 37804
CL = 30

"GM" and "GSD" are assumed to represent the geometric mean and the geometric standard deviation of the fitted lognormal distribution. Although no units are given for the GM, the units must be in millirem (mrem). The distribution was fit to a highly censored distribution of 40,972 – 37,804 = 3,168 measurements that were left above the censor level (CL) of 30 [mrem]. Thus, the fit started at 37,804 / 40,972 = 0.92, or the 92nd percentile level. According to the abscissa of NIOSH's Figure 3, this would correspond to a "Standard Normal Quantile" of 1.40 (Pagano and Gauvreau 2000, Table A.3, page A-11).

NIOSH then uses the data for individual years to derive GMs and GSDs for each year, as shown in NIOSH's Table 1. A combination of the values above for the combined data for 1963–1966 and the values for each year are shown in Table 3.

Table 3. Summary of the Fits Reported by NIOSH (2017)

Year	Geometric mean (mrem)	Geometric standard deviation	50th % photon (rem)	95th % photon (rem)
1963–1966	3.22	6.35	0.00322	0.0674 [a]
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

[a] Calculated for this report by SC&A.

A major surprise from the now combined data reported in Table 3 is that the fit for all years produces a value that is more than an order of magnitude less than the values for each of the years from 1963 to 1965. This strongly suggests that the values are not fit well by a lognormal distribution. It is unfortunate that NIOSH did not display the graphs, such as in their Figure 3, for the individual years. The very high values of GSD also suggest a poor fit to all sets of data. Further, it is most peculiar that the GMs calculated by NIOSH for the individual years are above the censor level of 30 mrem. It is also obvious that the display of five significant digits is not defensible.

The bottom line for this method of computing coworker dose is that it is questionable and must be investigated further. It would be helpful if NIOSH would make this complete data file available for examination by SC&A.

3.2 Ratio of Beta Dose to Gamma Dose for Skin

The NIOSH (2017) report did not use any of the four possible methods recommended and discussed above. Rather, the report is based on all data on beta-to-gamma ratios available for the 1966–1972 time period and apparently includes "imputed" doses. The number of data points is not specified. No consideration is given by NIOSH for the extremely important time dependence of the beta-to-gamma ratios due to fallout weathering into soil. As would be expected with the neglect of the most important variable, NIOSH's Figure 1, which is a plot of beta dose versus gamma dose, shows a huge amount of scatter—about six orders of magnitude for beta dose and about three orders of magnitude for gamma dose.

There are several features of NIOSH's Figure 1 that are not understandable. First, individual data points are represented by small circles that are of two colors—black and yellow. There is no explanation of the meaning of the two colors. Second, the fit lines are said to be the result of a quantile regression analysis. The meaning of a quantile regression analysis is not explained, nor is a scientific reference provided.

NIOSH does offer the explanation that the analysis followed the method used in *Neutron/Photon Ratios at Portsmouth* (LaBone 2016). This paper is very sketchy, and about half of the seven-page document is taken up by the reproduction of computer code, which is not explained or even identified. We infer from other sources, including Chen (2005), that the code is written in the SAS language.

The two linear fit lines shown in NIOSH's Figure 1 are for the 50th and 95th percentiles. It can be inferred from LaBone (2016) that the yellow data points shown in Figure 1 are the data for the 50th percentile fit, and the black data points were used for the 95th percentile fit. Examination of Figure 1 indicates that a curvilinear fit would have been a better treatment, especially for the lower values of beta dose.

The consistently lower values of beta dose at lower values of gamma dose are consistent with beta dose declining more rapidly than gamma dose, due to the stronger attenuation of beta dose due to fallout weathering into soil with time following deposition. The data shown in NIOSH's Figure 1 also display an unusual feature in that there are nine vertical columns indicating that for a single value of gamma dose, the beta doses vary over about three orders of magnitude. This may be partially due to the questionable "imputation" process used by NIOSH.

NIOSH states that separate analyses were done for each individual year for 1966–1972, and the results were similar for the combined data. It is unfortunate that the data for individual years were not shown. The results of NIOSH's analysis for the combined 1966–1972 years are as follows (page 2):

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

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

where *X* is photon dose in mrem, and *Y* is presumed to be beta dose in mrem. These results are rather peculiar in the sense that a beta dose-to-gamma dose ratio was the required entity, but the results are shown as a linear dependence with an intercept. Again, the lack of consideration of the most important variable probably accounts for the peculiar results. Also, the provision of up to five significant digits is not scientifically valid given the enormous spread in the data.

Another major reason to question the validity of these results for application to earlier times is the nature of the resulting fits. For example, if a gamma dose of 1,000 mrem is taken as an example, then the 50th percentile beta dose is calculated to be (4.84 + 189.3) mrem = 194 mrem, and the resulting ratio of beta dose-to-gamma dose would be 0.194. Based upon all the data and calculations before us, this would be an inappropriate value to be applied to the 1963–1965 time period.

None of the four preferred methods discussed in the Introduction to this paper have been employed, and the results are seriously impacted by the lack of consideration of the weathering of fallout into the soil surface. The fourth possible alternative method would be to plot the results of beta-to-gamma dose ratios on a log-probability plot, similar to that shown in NIOSH's Figure 3. Then a claimant-favorable ratio could be deduced from the plot (or fit to the plot) at whatever percentile might be chosen, perhaps 95th. This would be simple and far more defensible than the procedure used by NIOSH (2017).

3.3 Extremity-to-Whole Body Dose

It is not clear what is meant by "extremity dose." It is possible that high beta doses to fingers might have occurred due to handling of materials, and that so-called finger dosimeters might have been used. It should be clarified exactly what is meant by an extremity dose.

Again, there is a very large spread in the data shown in NIOSH's Figure 2. The fitted curves shown in Figure 2 are curvilinear, whereas the derived equations are given as linear (page 3):

$$50^{th}\ percentile:\quad Y = 450.137 + 0.3901X$$

$$95^{th}\ percentile:\quad Y = 1493.402 + 2.8247X$$

where *X* is gamma dose in mrem and *Y* is beta dose in mrem. In this case, a very low gamma dose could still provide a large beta dose, which might have occurred due to unique occupational exposures.

Rather than use this similarly complicated analysis given by NIOSH, it would be preferable to simply assume a lognormal distribution and plot the ratios on a log-probability scale to derive a 95th percentile value as a claimant-favorable value.

4 DISCUSSION OF THE RELEVANT CLAIMANT POPULATIONS

As part of its review, SC&A examined the two relevant claimant populations for the proposed beta-to-gamma approach. The first claimant population represents those energy employees employed from the 1963–1965 period who require application of the calculated beta-to-gamma formulas in NIOSH (2017); this population is referred to as "the affected claimant population."

The second claimant population represents those monitored claims from the 1966–1972 period that form the basis of the imputation method used in arriving at the beta-to-gamma formulas (this population is referred to as "the analyzed claimant population"). While the result of the claimant analysis is summarized here, the full analysis can be found in Attachment A.

Analysis of the affected population is useful in that it answers the question: "Who does this method really affect and what is the potential magnitude of assigned doses as a result of the proposed method?" Based on its analysis of the available entries in the NIOSH OCAS Claims Tracking System (NOCTS), SC&A determined that there were 252 claimants with covered employment during the period from 1963 through 1965, had a probability of causation less than 50%, and developed an illness requiring reconstruction of nonpenetrating radiation (i.e., beta dose). Although this only represents about 20% of the NTS claimant population during this time, it still is a relatively large number of claims affected by the beta-to-gamma methodology presented in NIOSH (2017).

Observed job types varied significantly and contained a large percentage of jobs (~80%) that could be considered "radiological workers" (e.g., drillers, miners, various construction trades, test engineers, etc.). Approximately 95% of the affected worker population was monitored externally during the period of interest, with roughly 15% of that monitored population accruing positive measured gamma doses. Observed maximum gamma doses ranged from 600 to 1,600 mrem; however, average annual doses were much less (25–63 mrem). As expected, the job categories of "engineer/scientist" and "driller/miner" had the highest percentage of positive measured doses among the affected population.

For the analyzed claimant population, SC&A determined that there were 1,593 claimants with covered employment during the period from 1966 through 1972. SC&A semi-randomly[1] selected 100 claims from this population for analysis. The number of monitored workers among these 100 claims ranged from 92.6% in 1971 to 99% in 1966. For the first 3 years during the period of interest, 26% to 29% of the monitored claims had positive measured doses (gamma, beta, or both). For the remaining years, the percentage of monitored claims with positive results ranged from 5.3% to 16.2%. However, the observed average empirical beta-to-gamma ratios on individual dosimetry cycles were higher in 1971 and 1972 (1.22 and 1.18, respectively) than in 1966 and 1967 (0.79 and 0.70, respectively). The maximum observed beta-to-gamma ratio was 10.21 in 1967. It is important to note that the rank ordering of the observed beta-to-gamma ratios shows that 26% of the data is less than 0.2, and 90% of the data is less than 2.00. These observed ratios can be compared with NIOSH (2017) beta-to-gamma ratios of 0.1893 and 1.893 at the 50th and 95th percentile, respectively.

An analysis of the issue location associated with each of the positive dosimeter cycles showed that average beta-to-gamma ratios were above 1.00 for Area 23 (2.55), Area 16 (1.14), and U-16[2] (2.10). The remaining 19 observed locations had average beta-to-gamma ratios less than 1.00. The maximum observed beta-to-gamma ratio of 10.21 was for an unspecified issue location.

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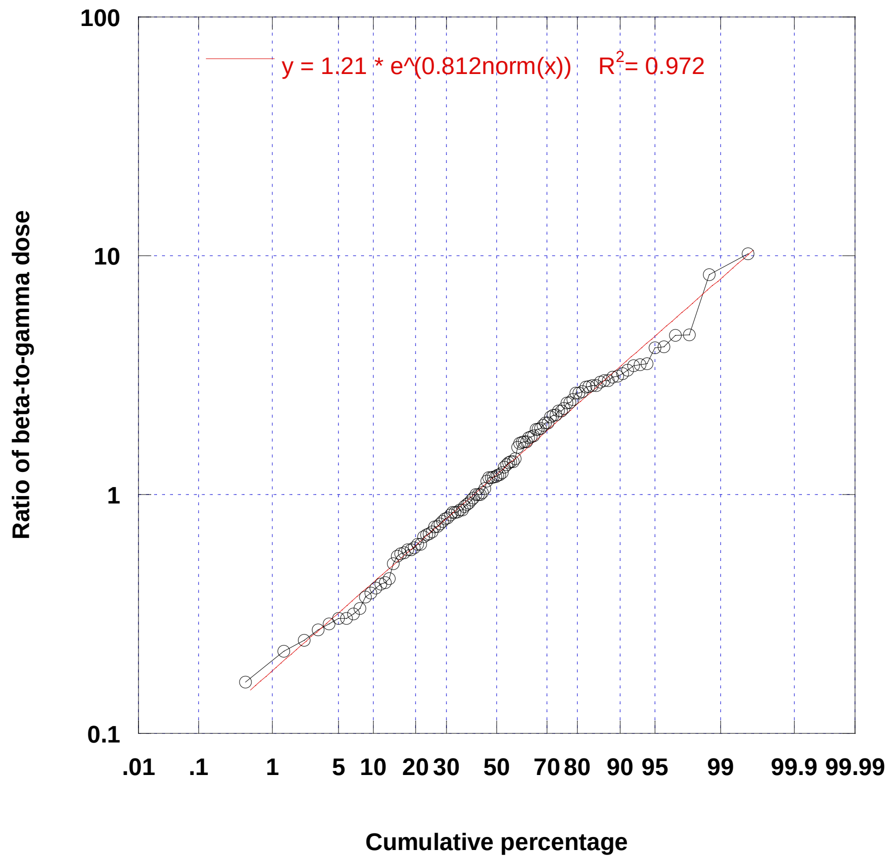
[1] As discussed in Attachment A, the claims were selected randomly for analysis. However, 11 originally selected claims were rejected from the analysis for having job types that were unlikely to have ever entered a radiological area at NTS.

[2] Assumed to represent an underground issue location.

There was no observed correlation between areas designated as "underground" and higher beta-to-gamma ratios as might be expected.

A plot of the 110 values examined that had positive results for both beta and gamma doses is shown in Figure 1, which is a modified version of Figure A2 in Attachment A. The data are well fit by a lognormal function with a GM of 1.21 and a GSD of exp(0.812) = 2.25. The 99th percentile of this distribution is equal to 8.0, which is reasonably close to the suggested value of beta-to-gamma dose of 10 computed by NIOSH (2007, Attachment C, and reproduced as Table 2 of this report).

Figure 1. Lognormal Fit Beta-to-Gamma Ratios Observed for 110 Positive Dosimeter Measurements Identified



5 CONCLUSIONS

SC&A's review of NIOSH (2017) concludes the following:

1. NIOSH's (2017) analysis of beta-to-gamma dose ratios has not considered the most important factor that causes the ratio to change with time: the weathering of fallout into soil with the subsequent stronger decrease in beta dose as compared to gamma dose.

2. Four alternate methods of deriving claimant-favorable values of beta-to-gamma dose ratios have been described by SC&A in this report (see Section 1 and Section 3.2) that should be discussed with NIOSH and the Work Group.

3. There may be serious errors in the evaluation of coworker dose for the years 1963–1966 (see Section 3.1).

4. SC&A described an alternate method of deriving claimant-favorable values of extremity dose-to-whole body dose ratios that should be discussed with NIOSH and the Work Group (see Section 3.3).

5. The dosimetry files used by NIOSH have not been specified, and the files have not been made available to SC&A as of the issuance of this report. It would be helpful for any potential future discussions to have those calculation files made available.

6. SC&A notes that beta doses for the years 1951–1962 can be calculated by using the data in NIOSH (2012b), Attachment C, as an alternative to methods developed by DTRA for military personnel.

6 REFERENCES

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ATTACHMENT A: OVERVIEW AND SAMPLING OF RELEVANT CLAIMANT POPULATIONS

OVERVIEW OF AFFECTED CLAIMANT POPULATION (1963–1965)

This attachment provides an overview of the NTS claimant population that would be affected by the proposed beta-to-gamma dose reconstruction methodology presented in NIOSH (2017). The purpose of this analysis is to answer the question: "Who does this method really affect and what is the potential magnitude of assigned doses as a result of the proposed method?" The affected claimant population, as defined in this section, consists of energy employees who have the following three characteristics:

- Covered employment at NTS during the 1963–1965 time period
- Covered illness that requires dose reconstruction from nonpenetrating radiation (the majority consisting of various skin cancers)
- Previous dose reconstruction resulting in a probability of causation (POC) below 50% (or alternately, no dose reconstruction has yet been performed)

Overall, there are 1,292 NTS claimants who were employed during 1963, 1964, and/or 1965 at NTS. Among this group of claimants, 474 (~37%) were diagnosed with a covered illness that required reconstruction of nonpenetrating external dose. Of these 474 claims, 252 did not have a dose reconstruction that resulted in a POC above 50%. These 252 claims are considered the affected claimant population for this analysis.

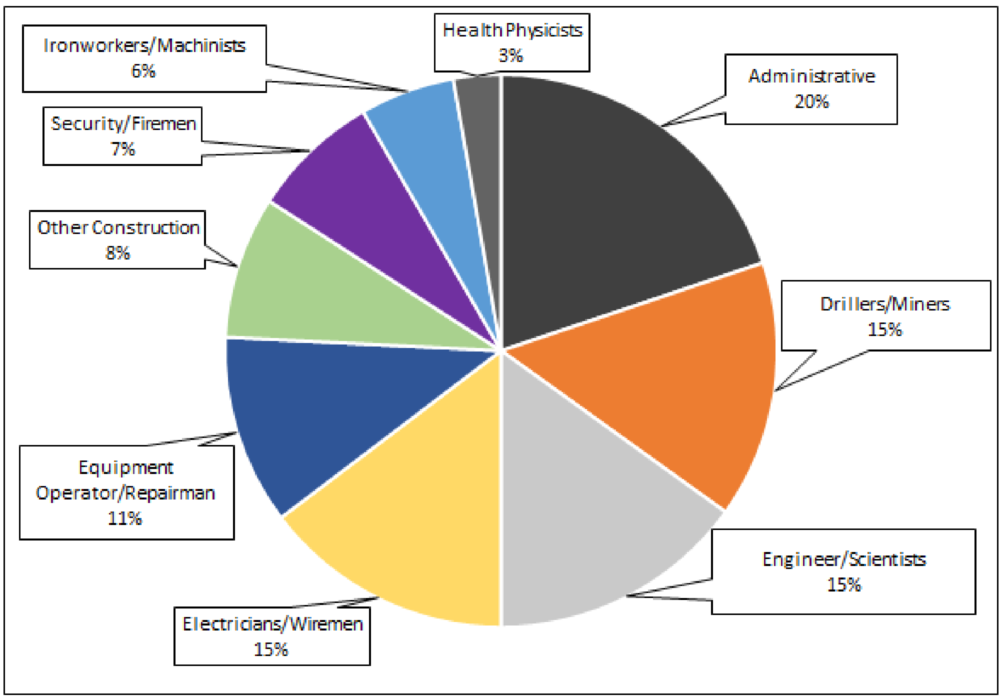
There were 178 different job titles observed among the affected population; however, many were simply variants on the same general job category (e.g., metal worker, sheet metal worker, ironworker, etc.). Therefore, SC&A used professional judgment and categorized the 178 job titles into nine general categories, as shown in Table A1 and Figure A1. As seen in this table and figure, the "administrative" category made up the largest portion of the affected claimant population (~20%), which may be a reflection of the lower exposure potential expected for workers with POCs less than 50%. However, the category "drillers/miners" and "engineers/scientists" also made up a significant portion of the affected claimant population. This category of workers would likely experience the highest exposure potential because they would be directly involved in drill-back and reentry activities post shot. The remaining job categories would also likely enter radiological areas on at least a part-time basis and, thus, the development of a claimant-favorable method for assigning beta dose would likely have a direct effect on approximately 80% of the affected claimant population.

SC&A also analyzed the dosimetry records for the 252 claimants in the affected population to determine the relative magnitude of annual gamma doses from 1963–1965 (see Table A2). As seen in the table, the percentage of monitored workers and those with positive recorded photon dose is remarkably consistent for each of the three years of interest. For the former category, generally 95% of the affected population was monitored, and roughly 15% of those monitored workers accrued positive gamma exposures. This indicates that while a large portion of the affected population was monitored externally, only a small portion of that workforce was exposed to measurable levels of external photon dose.

Table A1. Categorization of the Affected Population by Job Title

SC&A job title	Total claims	Percent of total
Administrative	50	19.8%
Drillers/Miners	38	15.1%
Engineer/Scientists	38	15.1%
Electricians/Wiremen	37	14.7%
Equipment Operator/Repairman	28	11.1%
Other Construction	21	8.3%
Security/Firemen	19	7.5%
Ironworkers/Machinists	14	5.6%
Health Physicists	7	2.8%
Total	**252**	**100%**

Figure A1. Job Categorization for 252 Claimants in the Affected Population



Recorded gamma doses were generally low on average (<100 mrem), with rank-order 95th percentile doses ranging from 157 mrem to 412.5 mrem annually. The maximum observed annual dose was 1,600 mrem (1.6 rem) for a heavy-duty truck driver in 1965. The breakdown by job category of those workers who accrued positive gamma dose during the period from 1963 through 1965 is shown in Table A3. Not surprisingly, the categories of "drillers/miners" and "engineers/scientists" made up the largest portions of affected claims with positive gamma measurements. However, somewhat surprising is the number of "administrative" workers who accrued positive gamma dose during the period of interest.

Table A2. Overview of Dosimetry Records among the Affected Claimant Population

Category	1963	1964	1965
# claims in year	149	174	205
# of monitored workers (% of total)	142 (95.3%)	165 (94.8%)	200 (97.6%)
# with positive gamma dose (% of monitored total)	22 (15.5%)	25 (15.2%)	31 (15.5%)
Average gamma dose (mrem)	29.3	24.7	62.8
Ranked 95th percentile (mrem)	211	157	412
Maximum photon dose (mrem)	1,105	610	1,600

Table A3. Breakdown by Job Title for Affected Claimants with Positive Accrued Dose (1963–1965)

SC&A job title	Total claim years with positive dose (1963–1965)	Percent of total
Engineers/Scientists	19	24.4%
Drillers/Miners	16	20.5%
Electricians/Wiremen	12	15.4%
Administrative	9	11.5%
Equipment Operator/Repairman	9	11.5%
Health Physicists	7	9.0%
Ironworkers/Machinists	3	3.8%
Security/Firemen	3	3.8%
Total	**78**	**100%**

In summary, the affected claimant population is relatively large (over 250 claimants). A significant portion of that population (95% or more) was monitored externally for gamma dose; however, only a small portion (~15 percent) accrued any measurable dose. The affected claimant population contained many workers who would be considered "radiological workers," such as miners, drillers, engineers, and various construction trades. However, even those workers classified as "administrative" sometimes accrued positive doses (9 of 50, or approximately 18%, accrued positive dose during the period of interest). Accrued gamma doses were low on average and are approximately equivalent to the limit of detection for one or two badging cycles. However, 95th percentile doses could be several hundred millirem, with maximum annual doses above 1 rem.

Sampling of Analyzed Claimant Population Used in Beta-to-Gamma Ratio Development (1966–1972)

Unlike the previous section, where the affected claimant population is discussed, this section analyzes a sample of the claimant population from 1966 through 1972, which NIOSH (2017) uses to impute the gamma-dose values used to formulate the proposed beta-to-gamma methodology (this claimant population is referred to as the "analyzed claimant population"). From available NOCTS data, SC&A determined there were 1,582 claimants who had covered employment during the period of interest. From this population, SC&A semi-randomly[3] selected 100 claimants for sampling analysis, with a bias toward claims for 1966 (the first year in which beta dose was measured by the dosimetry system at NTS).

Table A4 presents an overview of the badging practices among the sampled claims. As seen in the table, the number of externally monitored claimants among those reviewed ranged from 93% to 99%, which generally comports with the observed monitoring percentage for the affected population (see Table A2). In general, the average number of dosimeters per claim in a year was between 9 and 10, which suggests that most of the sampled population was on a monthly exchange schedule. The number of sampled claims with positive recorded dose (beta, gamma, or both) ranged from approximately 5% to nearly 30%. The highest proportion of positive recorded doses occurred in the first 3 years during the analyzed period of interest (1966–1968).

Table A4. Overview of the Sampled Claimant Population

Year	# sampled claimants employed in year	# monitored claimants (% of total)	Total badges in year	Average # dosimeters per claimant per year	# sampled claims with positive result in year (% of monitored total)
1966	100	99 (99.0%)	1,041	10.4	26 (26.3%)
1967	95	91 (95.8%)	966	10.2	26 (28.6%)
1968	89	83 (93.3%)	935	10.5	23 (27.7%)
1969	81	76 (93.8%)	749	9.1	4 (5.3%)
1970	72	68 (94.4%)	659	9.0	11 (16.2%)
1971	68	63 (92.6%)	689	10.1	9 (14.3%)
1972	63	59 (93.7%)	581	9.2	4 (6.8%)

Table A5 shows an analysis of the individual dosimeters that recorded positive doses. As seen in the table, the number of positive badges per year was around 10% for the first 2 years in the period of interest, at which point it drops to approximately 6% or less. Interestingly, the number of dosimeters in which a positive gamma (photon) dose was reported but the beta component was zero (231 total) far exceeds the number of dosimeters in which a positive beta was recorded but the gamma component was zero (only three total). This, at least partially, addresses the

[3] Eleven of the original random sample were rejected as not being germane to the study due to job types associated with cafeteria work (5), general administration (5), or because they were not actually at NTS during the period of interest (1).

concern raised during the January 2017 Work Group meeting (ABRWH 2017) concerning the potential for positive beta dose coupled with zero gamma dose in the empirical dose records.

Table A5. Overview of Dosimeters with Positive Results by Year

Year	Total badges in year	Total positive badges in year (% of total)	# dosimeters with positive beta and zero gamma	# dosimeters with positive gamma and zero beta
1966	1,041	114 (11.0%)	1	68
1967	966	97 (10.0%)	0	64
1968	935	50 (5.3%)	0	42
1969	749	12 (1.6%)	0	10
1970	659	38 (5.8%)	1	27
1971	689	23 (3.3%)	1	14
1972	581	10 (1.7%)	0	6
All Years	5,620	344 (6.1%)	3	231

Table A6 shows the observed beta-to-gamma ratios by year for the sampled claimant population. For situations in which there was a positive measurement in one of the dose elements (beta or gamma) but a zero measurement in the other element, the zero element was adjusted to the minimum detectable level (MDL) divided by two. As seen in the second column of Table A6, the total summed beta-to-gamma ratio for all years was less than 1. On average, the individual dosimeters with positive measurements displayed a beta-to-gamma ratio less than 1 for all years except 1971 and 1972. The maximum beta-to-gamma ratio by year ranged from approximately 3 to 10. Figure A2 displays the rank-ordered beta-to-gamma ratios for all dosimeters measuring a positive dose among the sampled claimant population. As seen in this figure, approximately 90% of the observed beta-to-gamma ratios were less than 2 (which can be compared with the 95th percentile beta-to-gamma ratio of 1.893 in NIOSH 2017). However, only approximately 26% of the observed beta-to-gamma ratios were less than 0.2 (which can be compared to the 50th percentile beta-to-gamma ratio 0.1893 in NIOSH 2017).

Table A6. Overview of Beta-to-Gamma Ratios Observed by Year for 1966–1972

Year	Total summed beta-to-gamma for year	Minimum individual dosimeter beta-to-gamma	Maximum individual dosimeter beta-to-gamma	Average of individual dosimeter beta-to-gamma
1966	0.60	0.05	5.00	0.79
1967	0.88	0.03	10.21	0.70
1968	0.54	0.04	8.33	0.72
1969	0.57	0.07	3.14	0.67
1970	0.46	0.05	7.67	0.69
1971	0.93	0.06	9.33	1.22
1972	0.84	0.13	4.67	1.18
All Years	0.69	0.03	10.21	0.78

Note: Beta/gamma ratios calculated assuming MDL/2 is situations of zero recorded dose in one of the elements.

Figure A2. Rank Order of Observed Beta-to-Gamma Ratios for Individual Positive Dosimeters among Sampled Claimants (1966–1972)

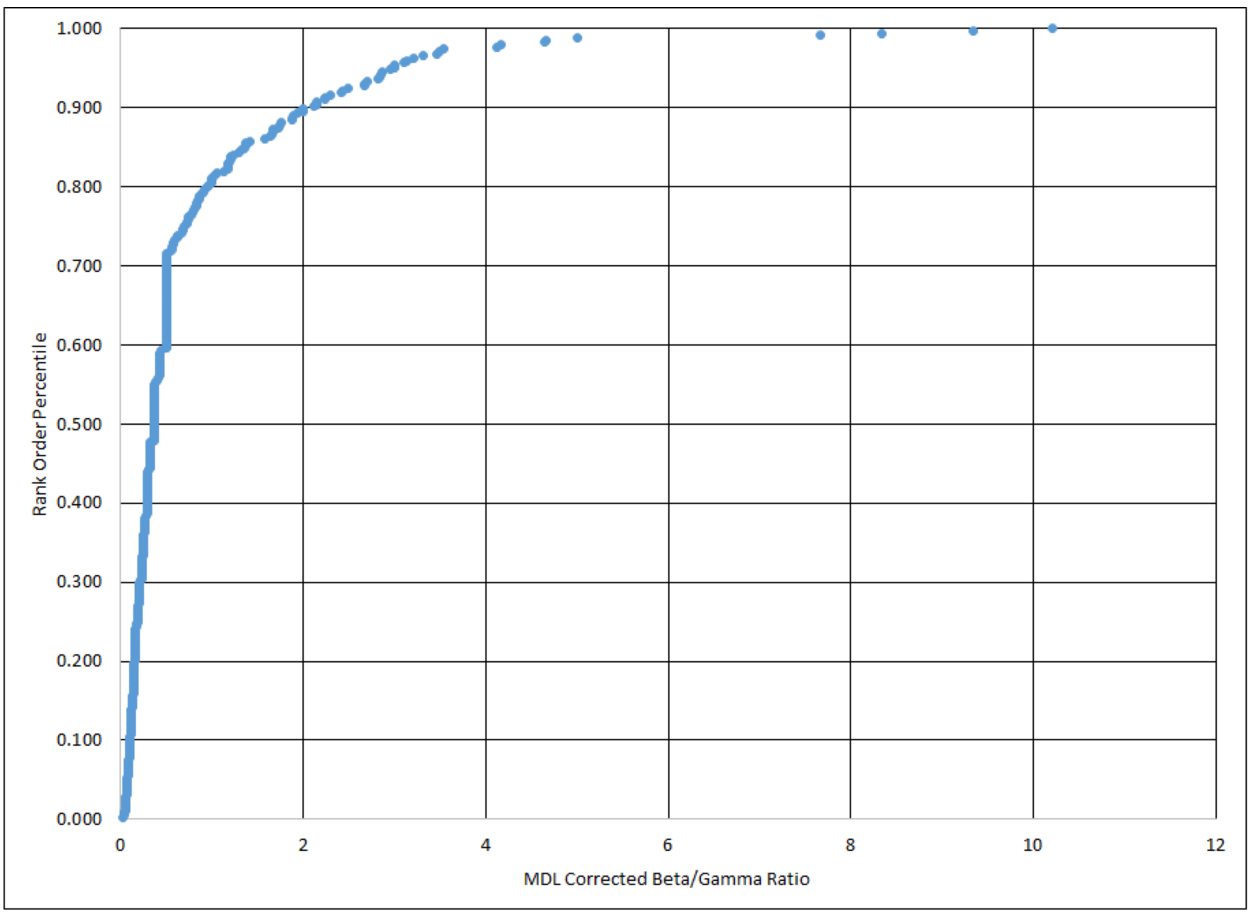


Table A7 shows an analysis of the observed beta-to-gamma ratios by the area associated with the individual badges. On average, the observed beta-to-gamma ratios were less than one in 19 of 22 locations (including the unspecified location). There does not appear to be a specific trend related to underground issue locations (assumed to be specified with a "U" preceding the area number) versus aboveground locations. Notably, Area 16 had some of the higher average beta-to-gamma ratios; however, the maximum observed beta-to-gamma ratio was for an unspecified location. Ironically, Area 23, which includes the headquarters town of Mercury, had the highest average ratio of beta-to-gamma dose.

Table A7. Observed Beta-to-Gamma Ratios by Area

Area designation on badge	Total badges	Minimum individual dosimeter beta/gamma	Maximum individual dosimeter beta/gamma	Average individual dosimeter beta/gamma
23	2	0.43	4.67	2.55
U-16	14	0.27	8.33	2.10
16	15	0.29	4.17	1.14
Unspecified	86	0.05	10.21	0.92
BLDG 1000	31	0.03	4.13	0.84
12	36	0.11	4.64	0.80
U-5	1	0.68	0.68	0.68
NRDS	58	0.09	3.32	0.64
U-12	45	0.06	3.47	0.62
E Tunnel	10	0.11	1.76	0.43
CP-2	16	0.07	1.18	0.38
3	1	0.38	0.38	0.38
5	1	0.38	0.38	0.38
2	4	0.17	0.50	0.28
U-10	4	0.09	0.50	0.28
U-2	4	0.04	0.38	0.27
9	3	0.09	0.43	0.25
U-20	1	0.21	0.21	0.21
24	1	0.17	0.17	0.17
8	2	0.06	0.25	0.16
20	7	0.04	0.27	0.14
U-11	2	0.07	0.08	0.07

Note: Ratios calculated by assuming MDL/2 in situations of zero recorded dose in one of the elements.

In summary, a semi-random sample of 100 claimants during the period of interest showed that a higher percentage of monitored claims accrued positive measured doses during the first 3 years (1966–1968) than in the latter 4 years (1969–1972). However, observed beta-to-gamma ratios during these years were lower on average than later years (1971–1972). Overall, 80% of the individual dosimeter beta-to-gamma results were less than 1, and 90% were less than 2. However, only 8% of the observed beta/gamma ratios were less than 0.1, which is essentially the 50th percentile ratio proposed in NIOSH (2017). A location-specific analysis of positive dosimeter badges did not indicate a bias toward either underground or aboveground issue locations.

It is very important to keep in mind that the results of the ratio of beta to gamma doses discussed in this attachment were measured in 1966–1972—many years after the atmospheric testing of nuclear weapons had stopped in July 1962. Because fallout deposited on the ground surface weathers into the soil and because beta particles are attenuated much more strongly than are gamma rays, the values of recorded ratios of beta to gamma doses should be considered as minimal values. The goal at hand is to evaluate the beta doses that could have been received by persons during the 1963–1965 period, when no such measurements were available and before more severe weathering had taken place.

Currently, it is not possible to specify why some of the ratios of beta to gamma doses were much higher than average—up to a ratio of 10. Such high values could have been due to exposure to fresh fallout resulting from leaks of underground tests. Underground tests continued to take place until September 1992.