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SC&A's Evaluation of ORAUT-RPRT-0097, Revision 00, on Breathing Zone to General Area Air Concentration Ratios in Small Workrooms

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Prepared by

Syed F. Naeem, PhD

SC&A, Inc.
2200 Wilson Blvd., Suite 300
Arlington, VA 22201-3324

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Abbreviations and Acronyms

ABRWH	Advisory Board on Radiation and Worker Health
AC/hr	Air change per hour
BZ	breathing zone
CEA	Commissariat à l'Énergie Atomique
ft	foot
ft^2	square feet
GA	general area
GM	geometric mean
GSD	geometric standard deviation
kg	kilogram
LANL	Los Alamos National Laboratory
m^2	square meter
m^3	cubic meter
MMAD	mass median aerodynamic diameter
$\mu Ci/cm^3$	microcurie per cubic centimeter
µm	micrometer
NH_4OH	ammonium hydroxide
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
PAS	personal air sampler
ROS	regression on order statistics
s	second
SAS	stationary air sampler
SRDB	Site Research Database
T_C	transfer coefficient

1 Introduction and Background

In June 2022, the Advisory Board on Radiation and Worker Health tasked SC&A with a technical review of ORAUT-RPRT-0097, "Breathing Zone to General Area Air Concentration Ratios in Small Workrooms," revision 00, issued March 29, 2021 (ORAUT, 2021; "RPRT-0097"). In RPRT-0097, the National Institute for Occupational Safety and Health (NIOSH) evaluates the relationship between the general area (GA) and breathing zone (BZ) air concentrations for small workrooms for the purpose of determining inhalation intakes of workers when their respective bioassay data are not available. The air sample data are evaluated in terms of BZ air concentrations and room air concentrations measured from GA air samplers. The minimum workroom area evaluated in this report is 190 square feet (ft^2), and the maximum workroom area evaluated is 1,130 ft^2. BZ to GA (BZ:GA) ratio distributions are presented for these workroom areas to determine if adjustments to the GA air concentrations are needed to make them equivalent to the BZ air concentrations. NIOSH emphasizes that the workroom's height is usually less of a factor influencing the aerosol concentration (because of gravitational settling) than its other dimensions. Hence, room sizes are evaluated in terms of area for determining the applicability of the BZ:GA ratio information in this report to a specific room. Additionally, elevated releases are considered to be above the typical BZ elevations and can include releases originating at a lower elevation that are propelled above the typical BZ elevations (e.g., jet releases, over-pressurization releases, aerosol plumes lofted by heat source, etc.).

Two worker location scenarios are presented to make distribution of BZ:GA ratios. NIOSH summarized BZ:GA ratios for these scenarios by fitting BZ:GA ratio distribution datasets with lognormal models using regression on order statistics (ROS), generating a geometric mean (GM) and geometric standard deviation (GSD) for each model.

This report presents SC&A's evaluation of the technical approach, statistical methods, and documentation used by NIOSH in RPRT-0097 as follows. Section 2 outlines the methods used by NIOSH to evaluate BZ:GA concentration ratios, and section 3 presents a critical evaluation of the approach, statistical methods, and documentation used by NIOSH.

2 Overview of ORAUT-RPRT-0097

This section briefly describes RPRT-0097 to develop an understanding of statistical methods used by NIOSH to evaluate BZ:GA concentration ratios for various workroom areas.

2.1 Purpose and scope (RPRT-0097, section 1.0, p. 8)

The report states that its purpose is to evaluate the relationship between the GA and BZ air concentrations in the form of BZ:GA ratios for small radiological workrooms or test rooms. A "workroom" refers to a real workspace having a single distinguishable air space. A "test room" refers to a mockup of a real or hypothetical workspace having a single distinguishable air space. BZ air concentrations represent air breathed by workers, and GA air concentrations represent air in a workspace or a test room. BZ:GA ratios are used to determine if adjustments to the GA air concentrations are needed to make them equivalent to BZ air concentrations in a workspace. BZ air concentrations are used to determine inhalation intakes of workers when their bioassay data

are not available. The report presents a statistical evaluation of the potential ratios of the BZ air concentrations and the GA air concentrations. The use of BZ:GA air concentration ratio information should be justified on a case-by-case basis.

2.2 Introduction (RPRT-0097, section 2.0, pp. 8–12)

In an ideal situation, the air concentration measured at any location within a room would be the same as having the BZ:GA ratio equal to 1. This means that the concentration of respirable airborne radioactive material would be homogenous throughout the airspace in a workroom when there is complete air mixing. However, complete air mixing rarely occurs, resulting in nonhomogeneous air concentrations measured at various locations within the room. Hence, the central tendency (median) of BZ:GA ratios distribution can shift away from 1 because of incomplete air mixing at various locations within the room. Incomplete air mixing can also increase the spread of the distribution denoted by GSD. The GA air concentration should be adjusted to account for the increased uncertainty in the BZ air concentration when the median of the BZ:GA ratio distribution becomes significantly greater than 1 or the GSD becomes large. NIOSH defines the term "significant" as "practically significant" as opposed to "statistically significant" (ORAUT, 2021, p. 8). Hence, the term "significant" in this report means that the difference is large enough to influence how a parameter is used or treated in practice.

As noted in section 2.1, the use of the BZ:GA air concentration ratio information should be justified on a case-by-case basis due to the large number of potential parameters and scenarios influencing BZ and GA air concentrations within a workroom. Hence, BZ:GA ratio information should be justified for a user-specific application.

NIOSH presented the relationship between the GA and BZ air concentrations by identifying parameters affecting the level of mixing of an aerosol and parameters only affecting the BZ:GA ratio. These parameters are discussed next.

2.2.1 Parameters affecting the level of mixing of an aerosol

There are a large number of parameters that affect the level of mixing of an aerosol within a workroom. Less aerosol mixing tends to lead to larger air concentration gradients, and more aerosol mixing tends to lead to smaller air concentration gradients. Air concentration gradients have a significant and direct effect on BZ:GA ratios and the GA air concentrations in a workroom. The analysis should consider the parameters affecting the level of mixing of an aerosol when looking to apply BZ:GA ratios to GA air concentrations to make them equivalent to BZ air concentrations for the workroom where the GA air samples are collected.

NIOSH emphasized the following four parameters that tend to have the most effect on the level of mixing: (1) room size (in terms of room area), (2) aerosol particle distribution (only respirable size particles with aerodynamic diameters < 20 micrometers (μm) because the presence of larger nonrespirable particles could result in an unreasonable overestimate of the worker's intake), (3) room ventilation rate, and (4) room complexity.

2.2.2 Parameters affecting the BZ:GA ratio

According to NIOSH, two dominant parameters affecting the BZ:GA ratio distribution are (1) sampler and release locations, and (2) low-number concentrations of dominant aerosol

particles in a workroom. For the first parameter, the radioactive aerosol release point location, worker location (BZ location), and GA air sampler location can have significant effects on the BZ:GA ratio distribution. For the second parameter, low-in-number radioactive particles have a relatively high specific activity and radiotoxicity, adversely impacting the collection of meaningful and reproducible air samples. Personal air samplers (PASs) are used as a statistical sampling device in an environment having only a few to few tens of particles per cubic meters (m^3). However, air sample data from workrooms with dominant particles are unreliable because of the stochastic nature of sampling low-number concentrations of airborne radioactive particles. For this reason, the Oak Ridge Associated Universities Team (ORAUT) does not recommend using air sample data from workrooms known to have dominant aerosol particles for developing BZ:GA ratios.

In addition to these two dominant parameters, NIOSH adds that there are many other parameters and factors that can affect BZ:GA ratio distribution and are "beyond the scope of this report" (ORAUT, 2021, pp. 10–11). An example given by NIOSH is the evaluation of the relationship between the GA and BZ air concentration by considering additional parameters, such as details about collection and analysis of individual samples, when these data are available. Continuing with the notion, SC&A suggests that the relationship between the GA and BZ air concentration could also be evaluated for GA sampler location with respect to the release point and the worker.

2.3 Methodology (RPRT-0097, section 3.0, pp. 12–15)

NIOSH evaluated the air sample data from the five air sampling studies for small rooms. The minimum room area evaluated in this report is 190 ft^2, and the maximum room area evaluated is 1,130 ft^2. Because only respirable size particles (i.e., < 20 µm) contribute to worker inhalation intakes, aerosol size particles up to 10.5 µm were evaluated. The worker location (BZ location) in a room is usually limited to the air volume intake that is in close proximity to a worker's head or face.

Two worker location scenarios are evaluated by NIOSH to adjust the site-specific GA air concentrations to make them equivalent to BZ air concentrations:

- **Scenario 1.** The worker and the aerosol release point are always located at the same *X*, *Y* coordinates in a room. This scenario generally applies to acute exposure and represents the worst-case scenario that yield the highest BZ:GA ratios.

- **Scenario 2.** The worker and the aerosol release point are not necessarily located at the same *X*, *Y* coordinates in a room. The potential BZ locations have the same probability of being located anywhere in the room. This scenario represents most radiological processing areas that have multiple workstations and workers moving around in a room. BZ:GA ratio distributions resulting from scenario 2 would usually be more appropriate for assessing chronic exposure scenarios.

For both scenarios, the *Z*-axis represent vertical aspects of various configurations in studies evaluated by NIOSH. NIOSH evaluated scenarios 1 and 2 in five studies presented next.

2.3.1 Gonzales et al. (1974)

This study was conducted by Los Alamos National Laboratory (LANL) in 1974 to evaluate the relationship between air sampling data from glove box work areas and inhalation risk to the worker. A simulated glovebox leak was used in a mockup plutonium test room to evaluate aerosol dispersal patterns in a 20- × 20- × 8-foot (ft) tall space.

Plutonium releases from the glovebox into the test room were simulated using a nonradioactive submicron tracer aerosol having mass median aerodynamic diameter (MMAD) aerosol particles ranging from 0.640 to 0.86 μm with GSDs ranging from 1.48 to 1.49. Test schemes were simulated for 6, 9, and 12 room air changes per hour (AC/hr) and 0°, 90°, and 180° airflow directions relative to the aerosol leak flow direction. A light-scattering photometer was used to measure room aerosol concentrations at several locations to determine the aerosol dispersal patterns from a given test scheme.

NIOSH evaluated this study using nine iso-concentration graphs from Gonzales et al. (1974) for the 1- and 2-ft-above aerosol leak-level elevations (4.75 and 5.75 ft above the floor). These elevations are selected because the radiological worker locations (BZ location) in most radiological processing areas are normally located above the glovebox leak levels. The evaluation for iso-concentration graphs was done using the Measurement Log feature in Adobe Photoshop CC 20.00 Release, in which iso-concentration graphs were divided into five potential air concentration regions for the following four assumed scenarios derived from two scenarios presented in section 2.3.

- **Scenario 1A.** The worker (BZ location) and the aerosol release point were always located at the same *X*, *Y* coordinates in a test room. Additionally, potential GA air samplers were randomly located anywhere in the room.

- **Scenario 1B.** The worker (BZ location) and the aerosol release point were always located at the same *X, Y* coordinates in a test room. Additionally, GA air samplers were randomly located anywhere in the room with the exception of the middle of the room. The exclusion area for the potential GA sampler locations was defined as a 4- × 6-ft area in the middle of the room.

- **Scenario 2A.** The worker (BZ location) and the aerosol release point were not necessarily located at the same *X, Y* coordinates in a test room. Additionally, potential GA air samplers were randomly located anywhere in the room.

- **Scenario 2B.** The worker (BZ location) and the aerosol release point were not necessarily located at the same *X, Y* coordinates in a test room. Additionally, GA air samplers were randomly located anywhere in the room with the exception of the middle of the room. The exclusion area for the potential GA sampler locations was defined as a 4- × 6-ft area in the middle of the room.

The probabilities for each potential BZ:GA ratio combination were evaluated using the area fractions for the five air concentration regions for every potential BZ location and GA air sampler location combination. A collective scenario 1 (by combining scenarios 1A and 1B) BZ:GA ratio distribution dataset for each airflow direction (0°, 90°, and 180°) was fitted with

lognormal models using ROS to generate a GM and GSD for each airflow direction. Similarly, a collective scenario 2 (by combining scenarios 2A and 2B) BZ:GA ratio distribution dataset for each airflow direction (0°, 90°, and 180°) was fitted with lognormal models using ROS to generate a GM and GSD for each airflow direction. Tables 1 and 2 show BZ:GA ratio GMs and GSDs evaluated by NIOSH for scenarios 1 and 2.

Table 1. BZ:GA ratio distributions evaluated by NIOSH for Gonzales et al. (1974) study (scenario 1)

Airflow direction	BZ:GA ratio GM	BZ:GA ratio GSD
0°	1.35	3.37
90°	1.59	4.13
180°	0.852	2.00

Source: ORAUT (2021), table 4-4.

Table 2. BZ:GA ratio distributions evaluated by NIOSH for Gonzales et al. (1974) study (scenario 2)

Airflow direction	BZ:GA ratio GM	BZ:GA ratio GSD
0°	1.06	3.86
90°	1.04	6.80
180°	1.08	2.28

Source: ORAUT (2021), table 4-5.

2.3.2 Charuau (1987)

This French study was conducted by the Commissariat à l'Énergie Atomique (CEA) in 1987. NIOSH analyzed these contamination transfer study data for a plutonium laboratory to determine BZ:GA ratio GMs and BZ:GA ratio GSDs for two different particle size aerosols, one with a MMAD of 2.3 µm and the other with a MMAD of 10.5 µm. Plutonium releases were simulated in a 49- × 23- × 15-ft tall laboratory with multiple gloveboxes and workstations. Nonradioactive tracer gas and tracer aerosol (helium gas and a fluorescent aerosol) were used to simulate plutonium releases. The average ventilation rate in the CEA study was 10 AC/hr. A gas and aerosol source release point and 10 sampling locations were located at an elevation of 4.9 ft above the floor. The units of air concentrations at sampling locations were reported in terms of transfer coefficient T_C (seconds per cubic meter (s/m^3)), defined as the ratio of the locally measured concentration of gas (m^3/m^3) or aerosols (kilograms (kg)/m^3) to the emission flux from the source of gas (m^3/s) or aerosols (kg/s).

NIOSH evaluated BZ:GA air concentration ratio distributions using the two BZ location scenarios described in section 2.3. A lognormal model was fitted to the dataset using ROS, generating a GM and GSD for each scenario. Additionally, NIOSH used lognormal models for the 2.3 µm and 10.5 µm that were combined using Monte Carlo simulation to create a single lognormal model for each scenario. Table 3 summarizes BZ:GA ratio distributions for scenarios 1 and 2.

Table 3. BZ:GA ratio distributions evaluated by NIOSH for Charuau (1987) study

Scenario for aerosols	BZ:GA ratio GM	BZ:GA ratio GSD
Scenario 1	4.92	2.50
Scenario 2	1.00	2.94

Source: ORAUT (2021), table 5-3.

2.3.3 Munyon and Lee (2002)

This 2002 air sampling study was performed at Argonne National Laboratory-East during the decommissioning of a previously active plutonium glovebox facility in a 28- × 12- × 8-ft tall enclosure. The workroom portion of the enclosure was 16- × 12- × 8-ft tall with a reported 90 AC/hr. Stationary air samplers (SASs) were used to measure the work area GA activity concentrations, whereas PASs were used to measure BZ activity concentrations of workers. The study was unique because BZ data were collected from actual workers. Both PASs and SASs were located at approximately 4.5 ft above the floor. The average activity median aerodynamic diameter of aerosol particles was 3 µm with a corresponding average GSD of 2.4.

NIOSH only evaluated BZ:GA air concentration ratio distributions for scenario 2 (variable worker location relative to the release point described earlier in section 2.3). A lognormal model was fitted to the dataset using ROS, generating a GM of 1.08 and a GSD of 5.40.

2.3.4 Scripsick et al. (1979a, 1979b)

The study was conducted at LANL in 1979 to measure the dilution of contaminants between worker BZ and GA air concentrations in a typical workroom inside a plutonium-handling facility. Aerosol releases were simulated from 20 potential release locations inside a 30- × 21- × 13-ft tall workroom. Plutonium-related work was performed in gloveboxes. A solution of fluorescein in NH_4OH was used to generate the test aerosol, which was detectable at an air concentration of 0.1 $\mu g/m^3$. Furthermore, the generated aerosol had a count median aerodynamic diameter of 0.35 µm with a GSD of 2.1. The ventilation rate for the workroom was 12 AC/hr. Fixed and continuous GA area samplers were used to measure workroom air concentrations. Fixed area samplers along the glovebox faces were located at ~6.6 ft above the floor, whereas continuous air samplers were located at 3.2 ft above the floor. The BZ location was 1.3 ft above the release location, i.e., 5.6 ft above the floor. Workroom floorplan with ventilation system components and air sampler locations can be seen in RPRT-0097, figure 7-1. Release locations used in the study can be seen in RPRT-0097, figure 7-2.

NIOSH evaluated BZ:GA air concentration ratio distributions using the two BZ location scenarios described earlier in section 2.3. A lognormal model was fitted to the dataset using ROS, generating a GM and GSD for each scenario. Additionally, lognormal models for the 2.3 µm and 10.5 µm were combined using Monte Carlo simulation to create a single lognormal model for each scenario. Table 4 summarizes BZ:GA ratio distributions for scenarios 1 and 2.

Table 4. BZ:GA ratio distributions evaluated by NIOSH for Scripsick et al. (1979a, 1979b) study

Scenario for aerosols	BZ:GA ratio GM	BZ:GA ratio GSD
Scenario 1	30.5	3.31
Scenario 2	1.43	3.64

Source: ORAUT (2021), table 9-1, table 9-4.

2.3.5 Whicker and Moxley (2001)

The study was conducted by LANL personnel in 2001 at the Savannah River Site C-Lab used as a low-level plutonium chemistry workroom. The workroom dimensions were approximately 20- × 13- × 10-ft tall with a ventilation rate of approximately 15 AC/hr. The workroom contained multiple workstations, hoods, and gloveboxes. Radioactive aerosol releases were simulated with a nontoxic oil (dioctyl sebacate) having 0.01 to 2 μm size range from six potential release locations R1–R6 in the form of 60-seconds "puff-type" releases. A total of 18 simulated releases resulting from three separate releases at each of the six locations were used to measure the variability of the aerosol dispersion. Aerosol concentrations at 16 sampling locations were measured with 16 laser particle counters.

NIOSH once again evaluated BZ:GA air concentration ratio distributions using the two BZ location scenarios described in section 2.3. A lognormal model was fitted to the dataset using ROS, generating a GM and GSD for each scenario. Additionally, lognormal models for scenario 2 were combined using Monte Carlo simulation to create a single dataset in order to perform a lognormal model fit on the new dataset using ROS. Table 5 summarizes BZ:GA ratio distributions for scenarios 1 and 2.

Table 5. BZ:GA ratio distributions evaluated by NIOSH for Whicker and Moxley (2001) study

Scenario for aerosols	BZ:GA ratio GM	BZ:GA ratio GSD
Scenario 1	2.28	3.18
Scenario 2	1.02	4.31

Source: ORAUT (2021), table 8-2.

2.4 Statistical analysis and conclusions (RPRT-0097, sections 9.0 and 10.0, pp. 54–61)

Monte Carlo simulations were performed to combine datasets from each study to create a single dataset for BZ location scenarios 1 and 2. The scenario 1 dataset was subdivided into open and obstructed workspaces in the middle of the room to understand their impact on GZ:GA ratios. A lognormal model was then fitted to each dataset using ROS, generating BZ:GA ratio GMs and GSDs (RPRT-0097, table 10-1, ratios reproduced here in table 6) from the fitted lognormal distribution. In the quantile-quantile plots, the quantiles are from the fitted lognormal distribution, and the horizontal lines are the 50th, 84th, and 95th percentiles for the plotted data (ORAUT, 2020).

Table 6. Summary of the combined BZ:GA ratio distributions evaluated by NIOSH

Scenario for aerosols	BZ:GA ratio GM	BZ:GA ratio GSD
Scenario 1 – open workspaces	1.39	3.27
Scenario 1 – obstructed workspaces	12.0	4.11
Scenario 1 – open and obstructed workspaces	2.95	5.03
Scenario 2 – open and obstructed workspaces	1.08	4.02

Source: ORAUT (2021), table 10-1.

2.4.1 NIOSH's conclusions

NIOSH's evaluation had the following conclusions:

- Table 6, row 1: BZ:GA ratios for scenario 1 did not indicate a significant difference between the BZ:GA ratios when the room is generally open in the middle.

- Table 6, row 2: BZ:GA ratios for scenario 1 can be significantly higher when the room has a lot of obstructions in the middle.

- Table 6, row 3: BZ:GA ratios for scenario 1 indicated a significant difference between the BZ:GA ratios when the room is generally open in the middle rather than when the room has significant obstructions in the middle. Therefore, it might be more appropriate to use a BZ:GA ratio based only on the data from rooms with obstructions in the middle.

- Table 6, row 4: BZ:GA ratios for scenario 2 did not indicate a significant difference between the BZ:GA ratios when the room is generally open in the middle versus when the room has a lot of obstructions in the middle. No special consideration is warranted for this scenario.

- Individual and combined BZ:GA ratio distributions for scenarios 1 and 2 indicate that ventilation rates for six different air change rates (6, 9, 10, 12, 15, and 90 AC/hr) have no significant effect on the BZ:GA ratio distribution.

2.5 BZ:GA ratio application (RPRT-0097, section 11.0, pp. 61–64)

Section 11.0 provides guidance to the dose reconstructor on the appropriate application of the BZ:GA ratio data. The use of the BZ:GA ratio information is limited to radiological releases with relatively long-lived radionuclides in workrooms. The uses of the BZ:GA ratio information need to be justified on a case-by-case basis. The justification should consider five key parameters in the application of the generic BZ:GA ratio distributions from table 10-1 of RPRT-0097 to site-specific GA air sample results as follows: (1) room size, (2) aerosol particle distribution, (3) room ventilation rate, (4) room complexity, and (5) the presence of dominant particles.

To assist the dose reconstructor in determining whether the BZ:GA ratios are appropriate for various site-specific applications, NIOSH provides expanded guidance on the five key parameters as follows:

1. **Room size:** Due to the potentially high variability in the term "small workroom," NIOSH specifies that the ratios should be used for room sizes that are reasonably comparable to those evaluated in the studies, which ranged from 17.6 to 105.0 square meters (m^2) (190–

1,130 ft^2). The BZ:GA ratios should not be used for rooms greater that 105.0 m^2 (1,130 ft^2). In addition, these ratios should not be used for scenarios with elevated releases considered to be above the BZ elevation.

2. **Particle size:** If particle size distribution is known for the GA air samples, consideration should be given to adjusting the workroom's GA air sample results to exclude the nonrespirable fraction before applying the BZ:GA ratio.

3. **Ventilation rate:** The studies showed that room air change rates (AC/hr) did not have a significant effect on the BZ:GA ratio distribution. Therefore, NIOSH recommends that these ratios can be used in all rooms except for the most extreme air change rates.

4. **Room complexity:** The largest effect on BZ:GA ratio distributions resulted from the complexity of the room and ventilation flow patterns, but this effect was primarily limited to scenario 1 when there are obstructions in the middle of the room. When evaluating exposures similar to scenario 2, the BZ:GA ratio data are likely applicable to all small workrooms.

5. **Dominant particles:** Air sample data from workrooms with dominant particles are very unreliable, and using these data should be avoided when possible. If using these data is unavoidable, intake distributions should be calculated instead of point estimate.

If the use of the BZ:GA ratio distribution can be justified, NIOSH provides guidance to the dose reconstructor to select the most appropriate ratio distribution from table 10-1 of RPRT-0097 based on whether the exposure scenario is best represented by scenario 1 or scenario 2. The GA air sample result for a workroom is then multiplied by the appropriate BZ:GA ratio distribution to make the measured air concentrations equivalent to BZ air concentrations in a radiological workroom.

To illustrate how to use the various BZ:GA ratio distributions to convert GA air concentrations into equivalent BZ air concentrations for determining inhalation intakes of workers when their respective bioassay data are not available, NIOSH provides three examples in section 11.0. The following examples use a BZ:GA ratio distribution with a GM of 1.08 and GSD of 4.02 from table 10-1 of RPRT-0097 evaluated for the scenario 2 model (refer to section 2.3 of this report).

2.5.1 GA air concentration (lognormal distribution)

Equations 1 and 2 (equations 11-1 and 11-2 in RPRT-0097) are used to calculate the equivalent GM_{BZ} and GSD_{BZ} when the GA air concentration has a lognormal distribution with a GM_{GA} and GSD_{GA}. The BZ:GA ratio distribution is also used to make the applicable BZ:GA ratio distribution equivalent to the probability distribution for the BZ air concentration.

$$GM_{BZ} = exp\left(ln(GM_{GA}) + ln(GM_{BZ:GA})\right) \quad (1)$$

$$GSD_{BZ} = exp\left(\sqrt{ln(GSD_{GA})^2 + ln(GSD_{BZ:GA})^2}\right) \quad (2)$$

In these equations, GM_{BZ} represents the GM of the BZ air concentration distribution, GSD_{BZ} represents the GSD of the BZ air concentration distribution, $GM_{BZ:GA}$ represents the GM of the

applicable BZ:GA ratio distribution, $GSD_{BZ:GA}$ represents the GSD of the applicable BZ:GA ratio distribution, GM_{GA} represents the GM of the GA air concentration distribution, and GSD_{GA} represents the GSD of the GA air concentration distribution.

For example, if GM_{GA} = 10 µCi/cm^3 and GSD_{GA} = 4.0, then using $GM_{BZ:GA}$ and $GSD_{BZ:GA}$ values presented in the last paragraph in section 2.5 of this report, the GM_{BZ} = 11 µCi/cm^3 and GSD_{BZ} = 7.1.

2.5.2 GA air concentration (constant)

Equations 3 and 4 (equations 11-5 and 11-6 in RPRT-0097) are used to calculate the equivalent GM_{BZ} and GSD_{BZ} when the GA air concentration is a constant, denoted by C_{GA}. Additionally, the BZ:GA ratio distribution is used to make the applicable BZ:GA ratio distribution equivalent to the probability distribution for the BZ air concentration.

$$GM_{BZ} = C_{GA} \times GM_{BZ:GA} \tag{3}$$

$$GSD_{BZ} = GSD_{BZ:GA} \tag{4}$$

For example, if C_{GA} = 10 µCi/cm^3, then using $GM_{BZ:GA}$ and $GSD_{BZ:GA}$ values in the last paragraph in section 2.5 of this report, the GM_{BZ} = 11 µCi/cm^3 and GSD_{BZ} = 4.02.

2.5.3 GA air concentration (not constant)

The BZ:GA ratio distribution is multiplied to the GA air concentration distribution using Monte Carlo techniques when the GA air concentration distribution is not constant. That is, the GA air concentration has a distribution other than a lognormal distribution (e.g., a normal distribution with an arithmetic mean and standard deviation).

3 SC&A's Review of ORAUT-RPRT-0097

The following is a summary of SC&A's confirmation of the approach, statistical analysis, application, and documentation used by NIOSH to develop RPRT-0097.

3.1 Review of NIOSH's approach to BZ:GA concentration ratios

The studies evaluated by NIOSH are limited to a minimum workroom area of 190 ft^2 and a maximum workroom area of 1,130 ft^2. Additionally, NIOSH stated that as the workroom size increases beyond the maximum workroom area evaluated, there is a point where it will no longer be appropriate to use the BZ:GA ratio information presented in this report.

SC&A is satisfied that NIOSH's selection of studies is adequate and representative of the population of available data. Additionally, SC&A did not identify any issues with the general approach used in RPRT-0097 to determine BZ:GA concentration ratios in small workrooms.

3.2 Review of NIOSH's statistical methods

SC&A evaluated the statistical methods employed by NIOSH in RPRT-0097 for evaluating the relationship between the GA and BZ air concentrations in the form of BZ:GA ratios to determine if adjustments to the GA air concentrations are needed to make them equivalent to BZ air

concentrations in a workspace. However, the evaluated BZ:GA ratio distributions are limited to small radiological workrooms in which BZ air concentrations represent air breathed by workers and GA air concentrations represent air in a radiological workspace.

BZ air concentrations are calculated using equations presented in section 2.5 of this report and used to determine inhalation intakes of workers when their bioassay data are not available.

3.2.1 Parameters affecting the relationship between the GA and BZ air concentrations

SC&A agreed with the methodology employed by NIOSH for establishing the relationship between the GA and BZ air concentrations, including the following parameters affecting the level of mixing of an aerosol and parameter only affecting the BZ:GA ratio:

- The parameters that tend to affect the level of mixing the most are (1) room size, (2) aerosol particle distribution (only respirable size particles with aerodynamic diameters <20 μm), (3) room ventilation rate, and (4) room complexity.

- The parameter that tends to affect the BZ:GA ratio is the presence of low-number concentrations of dominant aerosol particles in air sample data. Both ORAUT and NIOSH do not recommend using this parameter for developing BZ:GA ratios.

3.2.2 Scenarios for acute and chronic radiation exposures

SC&A agrees with the two worker location scenarios summarized in section 2.3 of this report to adjust the site-specific GA air concentrations to make them equivalent to BZ air concentrations.

3.2.3 BZ:GA, GM, and GSD

SC&A reviewed air sample data analyzed by NIOSH from the five air sampling studies for small workrooms. BZ:GA ratios for acute and chronic radiological exposure scenarios in table 10-1 of RPRT-0097 are the result of fitting BZ:GA ratio distributions datasets with lognormal models using ROS. This generates a GM and GSD for each scenario and is accomplished by performing Monte Carlo simulations to combine datasets from each study to create a single dataset for BZ location scenarios for acute and chronic exposures.

SC&A found NIOSH's statistical methods in RPRT-0097 for developing the BZ:GA ratio distributions to generate GM and GSD values to be appropriate.

3.3 Evaluation of guidance for applying the BZ:GA ratio data in RPRT-0097

SC&A recognizes that dose reconstructors will encounter a variety of exposure scenarios that will likely require considerable professional judgement to justify and select the appropriate BZ:GA ratio distribution. Although SC&A acknowledges that RPRT-0097 provided the user with some guidance to assist in making these decisions, SC&A had the following two concerns.

Observation 1: Needs guidance for when data are insufficient to select a scenario

Based on SC&A's knowledge of the dose reconstruction process, SC&A questions whether the dose reconstructor will have access to the data required to make a reasonable decision about the appropriate scenario to use on a case-by-case basis. If sufficient data are not available to the dose reconstructor, RPRT-0097 should instruct the user to select the most claimant-favorable values.

Observation 2: Needs guidance to document professional decision

NIOSH in section 11 of RPRT-007 specified that it is the responsibility of the dose reconstructor to justify their decisions. The guidance in RPRT-0097 should explicitly state that this professional decision be included in the dose reconstruction documentation.

3.4 Review of documentation in ORAUT-RPRT-0097

SC&A's review of RPRT-0097 did not identify any notable documentation or clarification issues. The report provides adequate data to understand NIOSH's approach and methods for developing the BZ:GA ratios.

4 Summary and Conclusions

SC&A found the approach used in RPRT-0097 to develop a sampling plan to be reasonable and technically correct.

SC&A found the statistical methods used in the sampling plan to be acceptable. In section 3.2 of this review, SC&A provides an expanded discussion of the effects that changes in variable parameters could have on the results.

SC&A did not identify any documentation issues that would affect the readability or application of the sampling plan.

However, SC&A did have two observations about the applicability of RPRT-0097 in the dose reconstruction process (refer to section 3.3).

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