Draft

Advisory Board on Radiation and Worker Health
National Institute for Occupational Safety and Health

Review of ORAUT-OTIB-0081, Revision 04, "Internal Coworker Dosimetry Data for the Savannah River Site"

Contract No. 75D30119C04183
Document No. SCA-TR-2019-SEC004, Revision 1

Prepared by

Bob Barton, CHP
Ron Buchanan, PhD, CHP
Harry Chmelynski, PhD
Rose Gogliotti, MS
Joyce Lipzstein, PhD

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

March 13, 2020

SC&A, Inc. Technical Support for the Advisory Board on Radiation and Worker Health's Review of NIOSH Dose Reconstruction Program

Document Title	Review of ORAUT-OTIB-0081, Revision 04, "Internal Coworker Dosimetry Data for the Savannah River Site"
Document Number	SCA-TR-2019-SEC004
Revision Number	1 (Draft)
Supersedes	0 (Draft)
Effective Date	March 13, 2020
Task Manager	Joe Fitzgerald, MS, MPH [signature on file]
Project Manager	John Stiver, MS, CHP [signature on file]
Document Reviewer(s)	John Stiver, MS, CHP [signature on file] Joe Fitzgerald, MS, MPH [signature on file]

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	9/4/2019	Initial issue
1 (Draft)	3/13/2020	Finding 3 changed to an observation per discussion with NIOSH, the SRS Work Group, and the SEC Issues Work Group. Explanatory text added to section 5.2 and finding 5 (formerly finding 6) to clarify that the SC&A review of strata designation was a specifically targeted sampling of claimants rather than a representative sampling of the claimant population. Thus, the resulting analytical values are not subject to the established quality assurance criteria for the evaluation of coworker datasets.

Table of Contents

List of Tables

List of Figures

Abbreviations and Acronyms

ABRWH	Advisory Board on Radiation and Worker Health
Am	americium
Am/Cm/Cf	americium/curium/californium
Bq	becquerel
BRS	Board Review System
BS	bone surface
CATI	computer-assisted telephone interview
CCDF	complementary cumulative distribution functions
CL	censoring level
Co	cobalt
CoV	coefficient of variation
Cs	cesium
CTW	construction trade worker
CW	coworker
d	day
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
dpm	disintegrations per minute
dpm/d	disintegrations per minute per day
dpm/1.5L	disintegrations per minute per 1.5 liter
DTPA	diethylenetriamine pentaacetic acid
E&I	electrical and instrumentation
EE	energy employee
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FP	fission products
GM	geometric mean
GSD	geometric standard deviation
HP	health physicist
HPRED	Health Physics Radiological Exposure Database
ICRP	International Commission on Radiological Protection
ID	identifier

IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
L	liter
LCL	lower confidence limit
LOWESS	locally weighted polynomial
LTPD	lot tolerance percent defective
mBq	millibecquerel
MDA	minimum detectable activity
MFP	mixed fission products
mL	milliliter
MLE	maximum likelihood estimate
MPM	maximum possible mean
mR/hr	milliroentgen per hour
MSM	master slave manipulator
μCi/L	microcurie per liter
μg/L	microgram per liter
N/A	not applicable
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH OCAS Claims Tracking System
nonCTW	non-construction trade worker
Np	neptunium
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
pCi	picocurie
POC	probability of causation
PRID	payroll identification number
Pu	plutonium
QA	quality assurance
RBM	red bone marrow
ROS	regression on order statistics
RPRT	ORAUT report
SEC	Special Exposure Cohort

Sr	strontium
SRDB	Site Research Database
SRS	Savannah River Site
TWOPOS	time-weighted one-person-one-statistic
U	uranium
UCL	upper confidence limit
WBC	whole body count

1 Executive Summary

SC&A reviewed ORAUT-OTIB-0081, revision 04, “Internal Coworker Dosimetry Data for the Savannah River Site” (NIOSH, 2019a; hereafter “OTIB-0081”), with a focus on its adherence to the principles and guidance in the National Institute for Occupational Safety and Health (NIOSH) document, “Draft Criteria for the Evaluation and Use of Coworker Datasets (NIOSH, 2015a). These general criteria include data adequacy, data completeness, evaluation of the monitoring program, and stratification, as summarized in section 2 of this report.

SC&A’s primary concern in relation to data adequacy involves the treatment and manipulation of censored data (i.e., data that are listed less than the minimum detectable activity (MDA)). For certain contaminants, NIOSH employed an imputation method that resulted in modeled coworker excretion rates that were significantly lower than one-half the MDA in some cases (refer to finding 2 and observations 1–3). Similarly, data for trivalent actinides were reported at values much less than the MDA, which resulted in comparable coworker excretion rates below the MDA. In an individual dose reconstruction context for monitored workers, such data would be evaluated by applying missed dose methodologies at one-half the MDA. Use of different approaches for monitored and unmonitored workers raises the question of fairness and equitable treatment of workers under the auspices of the Energy Employees Occupational Illness Compensation Program Act (EEOICPA).

In addition, SC&A still has concerns about the observed variability in trivalent actinide bioassay data. Though SC&A recognizes that many of the observed samples would not be used due to the application of chelation techniques affecting that data, SC&A remains skeptical of the measurement technique, as even non-chelated samples showed nearly identical variation to the chelated samples. In addition, the reported MDA for trivalent actinides starting in 1971 was approximately a factor of 3 lower than the MDA reported in 1989 by the International Commission on Radiation Protection (ICRP) (refer to finding 1).

Regarding completeness, SC&A’s review of OTIB-0081 did not attempt to address whether the available internal monitoring data are sufficiently representative of the potentially exposed population as required by NIOSH (2015a). Determinations regarding the representativeness and completeness of the available dataset, specifically for workers on job-specific bioassay, is an ongoing issue that is currently being addressed in supplemental NIOSH evaluations that will undergo subsequent review by the Advisory Board on Radiation and Worker Health (ABRWH). However, there remain completeness items that are independent from the fundamental question of data representativeness and completeness that remain appropriate to OTIB-0081. Therefore, SC&A’s discussion of completeness as it relates to OTIB-0081 necessarily assumes, but does not affirm, that the available data are representative and complete for the purposes of this review only.

In evaluating completeness as it applies in this narrow context, SC&A notes that a substantial portion of the claimant population was not included in the original data analysis (refer to finding 3). Inclusion of such data would not only improve the completeness and accuracy of the coworker estimates but also may obviate the need to combine data for multiple years due to an insufficient number of bioassay results. Regarding the logbook data used for evaluation of trivalent and neptunium coworker intakes, SC&A also notes that some years had apparent gaps in the number of available monitoring results (refer to observation 4). While such gaps are not explicitly discussed in OTIB-0081, SC&A notes that a new report was recently issued by NIOSH concerning source term characterization of americium that may address the issue (NIOSH, 2019d).

SC&A's review of the monitoring protocol and stratification aspects of the coworker model details the difficulties in correctly designating construction trade workers (CTWs) from non-construction trade workers (nonCTWs) (refer to findings 4–5 and observation 7). However, the analysis of stratification presented in section 5 of this report does not directly address whether the chosen strata are appropriate in a Special Exposure Cohort (SEC) context. Specifically, this report does not address the issues associated with subcontract workers who were intended to be primarily monitored via the job-specific bioassay program versus those on a routine monitoring schedule. Additionally, statistically significant differences in strata between the operational workers, prime construction workers, and subcontract workers have not been established (refer to observation 5).

Such issues are currently under investigation by NIOSH, SC&A, and the Savannah River Site (SRS) work group via the recent issuance of ORAUT-RPRT-0092, "Evaluation of Bioassay Data for Subcontracted Construction Trade Workers at the Savannah River Site" (NIOSH, 2019c). Therefore, analysis and discussion beyond general commentary is beyond the purview of this report (refer to observation 6).

Finally, SC&A's evaluation of the quality assurance (QA) assessment provided in support of OTIB-0081 was favorable (refer to observation 8), with the added caveat that NIOSH is correct that the identified payroll ID errors did not materially affect the calculated coworker distributions.

A summary of the findings and observations resulting from SC&A's review of OTIB-0081, revision 04 is provided below for ease of reference:

Finding 1: Although SC&A recognizes that incident-based sampling involving chelation is not considered in final coworker modeling, the removal of DTPA-influenced samples from consideration in the analysis of the high variability observed in trivalent actinide bioassay results has not been justified sufficiently. Evidence suggests the variation among DTPA and non-DTPA samples is nearly identical. Furthermore, OTIB-0081 has not provided any reference to justify the assumption that DTPA causes heterogeneity among a single urinalysis voiding. (Refer to section 3.1.1.)

Finding 2: Use of imputed values that are less than one-half of the MDA raises a fundamental fairness issue in that monitored workers who have bioassay results that are less than the MDA are assigned a missed dose in accordance with ORAUT-OTIB-0060, "Internal Dose Reconstruction" (NIOSH, 2018). Per that guidance, bioassay values that are censored are assumed to be equal to one-half of the MDA rather than the use of an alternate imputed value (refer to section 3.2).

Finding 3: The coworker analysis uses the internal monitoring for claimants for which data were available to NIOSH in approximately August 2011 (~4,000 claims). Since that time, approximately 2,000 additional claims have been submitted that could be used to augment the coworker dataset. Inclusion of these data would be especially important for the two contaminants that required a combination of multiple years for analysis due to lack of a sufficient number of data points (uranium and cesium) (refer to section 4.1).

Finding 4: Classification of a "Machinist" as a nonCTW in OTIB-0081 is inconsistent with its classification in OCAS-PER-014, "Construction Trades Workers" (refer to section 5.2).

Finding 5: A targeted sampling comparing the OTIB-0081 strata designation (CTW or nonCTW) against two alternate sources for identifying worker job classification indicated that just over 9 percent of the entries appear to be in conflict when comparing the NIOSH and SC&A analyses. As this was a targeted subgroup of the monitored claimant population it does not represent the entirety of the monitored population and therefore is not subject to the established quality assurance criteria for evaluating coworker datasets (refer to section 5.2).

Observation 1: While the multiple imputation method is mathematically correct, it has the potential to result in biasing the simulated bioassay results unnecessarily low. Alternate approaches, such as the maximum possible mean method, which replaces censored data with the actual censoring limit (or alternately one-half the censoring limit), would solve the issues associated with datasets containing a large number of censored values in a claimant-favorable manner (refer to section 3.2).

Observation 2: A scoping assessment of the use of coworker bioassay data that are significantly less than the MDA versus an alternate missed dose approach concluded that, while intakes and doses are significantly higher using a missed dose approach in most of the sample calculations, the overall effect on resulting probability of causation (POC) values was relatively minor, and, in most cases, the coworker-derived POC bounded the missed dose evaluation. This appears to be due to the effect the statistical distribution has on resulting POC values, namely, the use of a triangular distribution for missed dose evaluation versus a lognormal distribution for coworker data (refer to section 3.3).

Observation 3: The sample comparison of coworker intakes to a missed dose method for uranium showed that the coworker model derived intakes were a factor of 4 or more higher than the missed dose approach. This illustrates the potential for inequity between the treatment of unmonitored workers assigned coworker intakes and monitored workers with results less than the detection limit in some situations (refer to section 3.3).

Observation 4: Available trivalent logbook data show notable differences with the number of reported samples taken in 1980 and 1982. These years, and any changes in operations, are not discussed specifically in OTIB-0081. However, it is noted that a future NIOSH report on americium exposure potential at SRS is pending that may address the apparent gaps in the data (refer to section 4.2).

Observation 5: OTIB-0081 does not provide a statistical comparison of the two stratified groups as prescribed in the coworker implementation guide. The various coworker models were stratified based on the a priori assumption that exposure potential between CTWs and nonCTWs was different (refer to section 5.1).

Observation 6: SC&A believes a quantitative assessment of available job plans, rather than a qualitative basis, is appropriate to determine that prime contractor and subcontractor CTWs are part of the same exposure strata. Such an assessment has been performed by NIOSH, and a report of their findings has recently been issued (NIOSH, 2019d) (refer to section 5.1).

Observation 7: SC&A acknowledges that there are inherent difficulties in correctly associating individual workers with the correct CTW/nonCTW strata. This is particularly true for job titles that could potentially be included in either stratum (e.g., General Service Operators, Assistants/Helpers, Foremen). SC&A suggests a scoping analysis in which such borderline job titles are removed to ascertain the effect on the resulting distributions. Such an analysis would help determine whether current strata designations are sufficient or a more rigorous approach to individual job classification is warranted (refer to section 5.2).

Observation 8: The results shown in attachment A of OTIB-0081 demonstrate a high degree of confidence that the acceptable error rates are within the goals established for each test. However, this conclusion is dependent on the assumption that payroll ID issues identified would not affect the resulting coworker distributions (refer to section 6.5).

2 Introduction and Background

NIOSH approved revision 04 of ORAUT-OTIB-0081, "Internal Coworker Dosimetry Data for the Savannah River Site," on March 13, 2019 (NIOSH, 2019a). Hereafter, this document is alternately referred to as "the coworker model" in this report. Per the publication record provided in the coworker model, revision 04 was initiated to provide coworker intake rates for plutonium, uranium, neptunium, cesium, cobalt, and mixed fission products (MFP) in accordance with the coworker development and implementation guidelines documented in NIOSH 2015a (hereafter referred to as the "implementation guide"). The previous revision of the coworker model (revision 03, NIOSH, 2016a) had developed similar coworker intake values for americium, thorium and tritium, which also appear in revision 04. SC&A previously reviewed revision 03 of the coworker model in March 2017 (SC&A, 2017a); attachment A discusses the resulting findings and observations from that review. Table 1 shows the date range for the calculated coworker intake values for each contaminant of interest.

Table 1. Date ranges of coworker intakes by radionuclide in OTIB-0081, rev. 04

Contaminant of interest	Date range of coworker intakes	Relevant sections of OTIB-0081, rev. 04
Americium	1/1/1964–12/31/1989 (nonCTW and CTW)	4.1, 5.1, F.1
Tritium	1/1/1954–12/31/1990 (nonCTW and CTW)	4.2, 5.2
Plutonium	1/1/1955–12/31/1990 (nonCTW and CTW)	4.3, 5.3, F.2
Uranium (as U-234)	1/1/1953–12/31/1990 (nonCTW) 1/1/1955–12/31/1990 (CTW)	4.4, 5.4, F.3
Uranium (as U-233)	1/1/1961–9/30/1972 (nonCTW and CTW)	4.4, 5.4, F.3
Mixed Fission Products *	1/1/1955–12/31/1990 (nonCTW and CTW)	4.5, 5.5, 4.7, 5.7, F.4, F.6
Cobalt	1/1/1955–12/31/1970 (nonCTW and CTW)	4.6, 5.6, F.5
Cesium	1/1/1966–12/31/1990 (nonCTW and CTW)	4.7, 5.5, F.6
Neptunium	1/1/1961–12/31/1989 (nonCTW and CTW)	4.8, 5.8, F.7

Contaminant of interest	Date range of coworker intakes	Relevant sections of OTIB-0081, rev. 04
Thorium	10/1/1972–12/31/1989 (nonCTW and CTW)	4.9, 5.9, F.8

* Due to changing monitoring practices of MFPs at SRS, Sr-90 is used for intake assessment from January 1, 1955, to December 31, 1965, and Cs-137 is used for intake assessment from January 1, 1966 to December 31, 1990.

Although none of the intake assessments were extended past 1990, OTIB-0081 notes the following:

> The intake rates or dose for the last year listed may be extended to subsequent years as a measure favorable to the claimants. [NIOSH, 2019a, p. 90]

It is SC&A's understanding that this language was included so that the coworker methodology presented in OTIB-0081 could still be applied to the time period after 1990. This is common practice in dose reconstruction and is permitted provided it has been sufficiently established that doses did not increase following the coworker model. However, the potential for expansion of the coworker assessments into these later years will be considered by NIOSH pending acceptance of the current coworker methods in OTIB-0081.

As noted previously, revisions 03 and 04 of the coworker model were initiated to assess coworker intakes in accordance with the guidelines and criteria developed in NIOSH 2015a. As the first of such coworker models developed using these criteria, the methods and resulting intakes calculated in OTIB-0081 can be considered the pilot study of the coworker implementation guide.

The coworker implementation guide can be broken down into four main facets: data adequacy, data completeness, evaluation of the internal monitoring program, and worker stratification. These four facets, as described in NIOSH 2015a, are shown in table 2 with a brief description of the category as provided in that document.

Table 2. Description of the four main facets of the NIOSH coworker implementation guide

Category	Implementation guide description
Data adequacy	"The measurement techniques employed must be evaluated to ensure that they are capable of quantitatively measuring the exposure of interest" (NIOSH, 2015a, p. 4).
Data completeness	"The amount of available monitoring data must be evaluated to determine if there are sufficient measurements to ensure that the data are either bounding or representative of the exposure potential for each job/exposure category at the facility" (NIOSH, 2015a, p. 5).
Evaluation of monitoring program	"A review of the program should be conducted to determine the basis for the selection of program participants. It must be established who was monitored and why they were monitored" (NIOSH, 2015a, p. 8).
Worker stratification	"The distribution of a potentially more highly exposed population should be evaluated as a separate standalone distribution in situations where: 1) accurate job categories and/or descriptions can be obtained for all workers making up the general coworker dataset; 2) there is reason to believe that one of the job categories is more highly exposed; and, 3) there were unmonitored workers in this job category" (NIOSH, 2015a, p. 10).

SC&A's review of the coworker model is structured based on issues related to the four main facets of coworker model development rather than a radionuclide-specific review. However, radionuclide-specific issues are discussed under the individual coworker implementation categories as appropriate. Section 3 addresses standard data adequacy review concerning bioassay/in vivo measurement techniques. However, the adequacy issue also includes a substantive discussion of the use and manipulation of the available internal monitoring data in relation to the intended (and unintended) consequences under the auspices of the EEOICPA.

Section 4 evaluates and discusses the data completeness of the two primary data sources used in the coworker model development: claimant internal monitoring records and sitewide laboratory logbook records. Quality control related to data transcription and other issues is included as part of the coworker implementation guide under the category of data completeness. However, due to the extensive nature of QA procedures and reported results associated with the coworker model, the review of these methods is found separately in section 6.

Section 5 addresses both the issues of the monitoring program evaluation and worker stratification. However, it should be recognized that issues regarding the veracity of the available coworker data are highly dependent on a pending evaluation by NIOSH concerning the exposure potential and job-specific monitoring protocols for subcontractors. Therefore, issues specifically associated with monitoring protocols and data representativeness are only discussed in a cursory manner. The review in section 5 mainly concentrates on stratification issues that are independent of any potential issues related to the validity of the monitoring program.

Finally, attachments A and B discuss the findings and observations associated with previous SC&A reviews of revision 03 of the coworker model and ORAUT-OTIB-0075, “Use of Claimant Datasets for Coworker Modeling” (NIOSH, 2009), respectively (SC&A, 2017a; SC&A, 2010). These attachments are provided for ease of reference, with review comments and recommendations provided in the narrow context of their applicability to the SRS coworker models developed in OTIB-0081, revision 04.

3 Coworker Data Adequacy

This section discusses issues related to measurement techniques and evaluates the available dataset and its manipulation in arriving at the contaminant intake values presented in the coworker model. Section 3.1 provides an overview of the measurement techniques used for each contaminant of interest and also contains an in-depth discussion of the issue of observed variation among available measurements of trivalent actinides. This issue has been discussed multiple times by the SRS and SEC Issues Work Groups, including meetings in February 2014 (SRS Work Group, 2014b), March 2015 (SEC Issues Work Group, 2015), and August 2017 (SRS Work Group & SEC Issues Work Group, 2017).

Section 3.2 discusses the method used in the coworker model development of imputing bioassay values when a large portion of the dataset has been censored (i.e., a large portion of the available bioassay is reported as less than the MDA). Section 3.3 provides a set of sample calculations to evaluate the effect of using numerical values (whether imputed or actual reported values) that are significantly less than the MDA in comparison to missed dose approaches.

3.1 Instrumentation and measurement techniques

3.1.1 Americium

Urinalysis of trivalent actinides dates back to at least to the mid-1960s. The earlier reporting levels varied from 1 to 3 disintegrations per minute per 1.5 liter (dpm/1.5L). In 1964, solid-state surface barrier detectors replaced the previous counting method for using alpha track counting (NIOSH, 2019a). The value of 3 disintegrations per minute per day (dpm/d) (1.35 picocuries (pCi)/d or 0.05 becquerel (Bq)/d) is noticeably high. If the urine concentration is 3 dpm/d for a sample taken after continuous intake during 1 year of exposure, the corresponding committed equivalent dose to bone surface (BS) would be about 300 rem (also 17 rem to liver and 7 rem effective dose).

In 1971, gross alpha counting on solid-state detectors was used, and reporting levels were listed as 0.3 dpm/1.5L (0.135 pCi/d, 0.005 Bq/1.5L, or 3E-3Bq/L). This reporting level is much lower than the one referenced by ICRP Publication 54 (ICRP, 1989; hereafter "ICRP 54"), which suggests a detection limit of 1E-2 Bq/L in urine using alpha spectrometry. By comparison, the reported MDAs for other U.S. Department of Energy (DOE) sites are:

- 1.35 pCi/d at Los Alamos National Laboratory for 1958–1982 using chemical extraction and proportional counting (an order of magnitude higher than the reported SRS limit) (NIOSH, 2013)

- 0.34 pCi/d at Rocky Flats Plant for 1971–1977 (a factor of 3 higher than the reported SRS limit) (NIOSH, 2014a)

Such large differences between the reported measurement levels for SRS, ICRP 54, and other DOE sites is troubling for at least part of the 1970s.

In 1990, a change in radiochemical processing resulted in an MDA of 0.15 dpm/d (0.068 pCi/d, 0.0025 Bq/d, or 0.0017 Bq/L), which is even lower than the one specified in ICRP 54 (ICRP, 1989). In 1995, alpha spectrometry was used for routine samples, and the MDA was 0.064 dpm/L (1E-3 Bq/L or 0.029 pCi/L), the same as suggested in ICRP Publication 78 (ICRP, 1997; hereafter "ICRP 78").

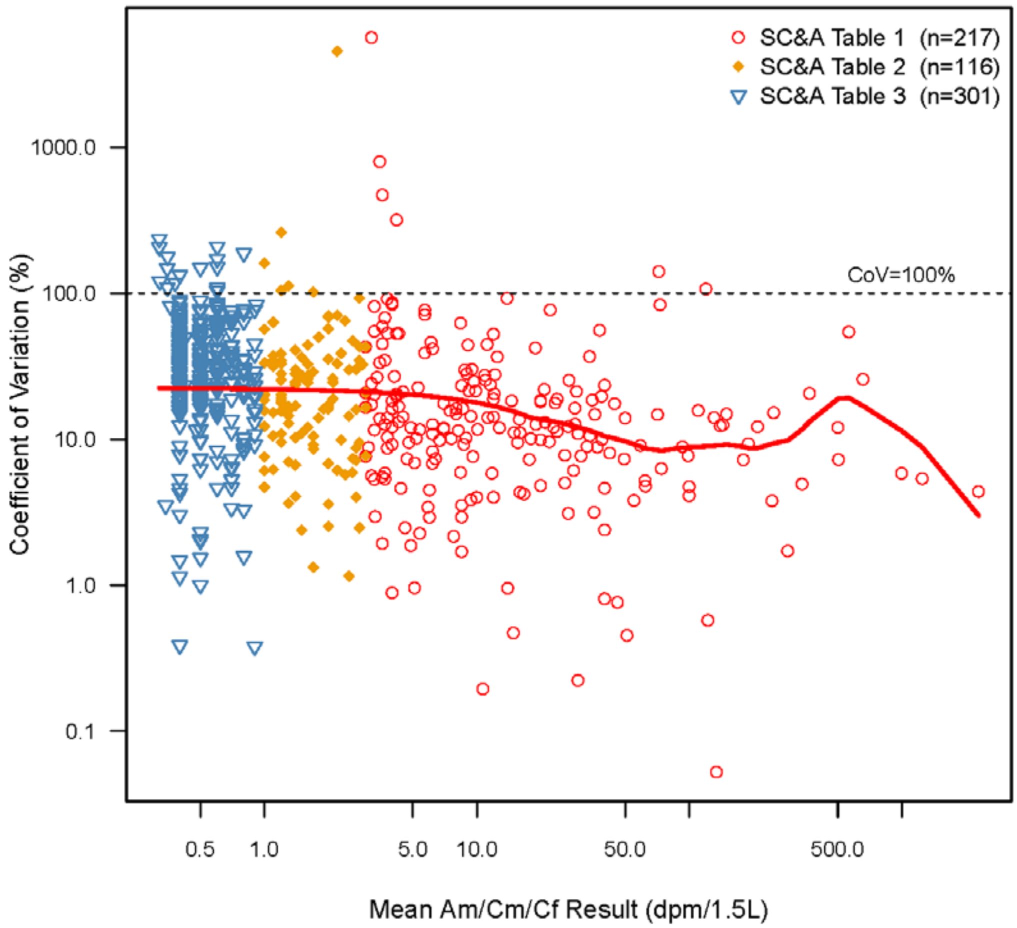
One very specific concern voiced in previous discussions of data adequacy is the observed variability in multiple measurements of the same aliquot among the trivalent actinide (i.e., americium/curium/californium (Am/Cm/Cf)) bioassay measurements. An SC&A memorandum of February 24, 2014, to the SRS Work Group contained an examination of the raw americium, curium, and californium urinalysis data used to calculate thorium intakes for the SRS internal dose coworker study (SC&A, 2014). The logbooks contain multiple counts for each urine sample beginning in 1969 and extending into the late 1980s. The examination focused on results greater than the MDA that exhibited a large variability between multiple counts of the same sample, or where the reported result was inconsistent with the individual sample counts.

The SC&A review noted that individual urine samples might be counted anywhere from 1 to 10 times, with 2 or 4 times being common. Large variability was observed in the results of these repeated counts of the same sample. SC&A also noted inconsistent reported results where the reported result does not match the average of the individual counts of the sample. The SC&A memorandum highlighted results with inconsistency or large variability in tables 1, 2, and 3 of the memorandum. Table 1 examined the counting data for recorded mean results greater than 3 dpm/1.5L; table 2 for recorded mean results between 1 and 3 dpm/1.5L; and table 3 for recorded mean results between 0.32 and 1 dpm/1.5L. The tables include all data with recorded means greater than the MDA

The log-log plot in figure 1 shows an overview of the variability of data in the SC&A tables with more than 1 count per sample. The coefficient of variation (CoV), defined as the ratio of the standard deviation to the mean, is commonly used as a measure of the variability. The CoV is plotted on the vertical axis and is expressed in percentage terms. The recorded mean results in each table are plotted on the horizontal axis on the figure.

The horizontal line at "CoV=100%" indicates a relatively high level of variability when the standard deviation of the counts is equal in size to the mean of the sample counts. Except for the data in table 3 with recorded mean result below 1 dpm/1.5L, only a small percentage of the samples show a CoV over 100 percent. The distribution of CoV is relatively constant at all levels of the mean.

Figure 1. Coefficient of variation (%) versus reported mean results for SC&A tables 1, 2, and 3 data with locally weighted polynomial (LOWESS) regression line



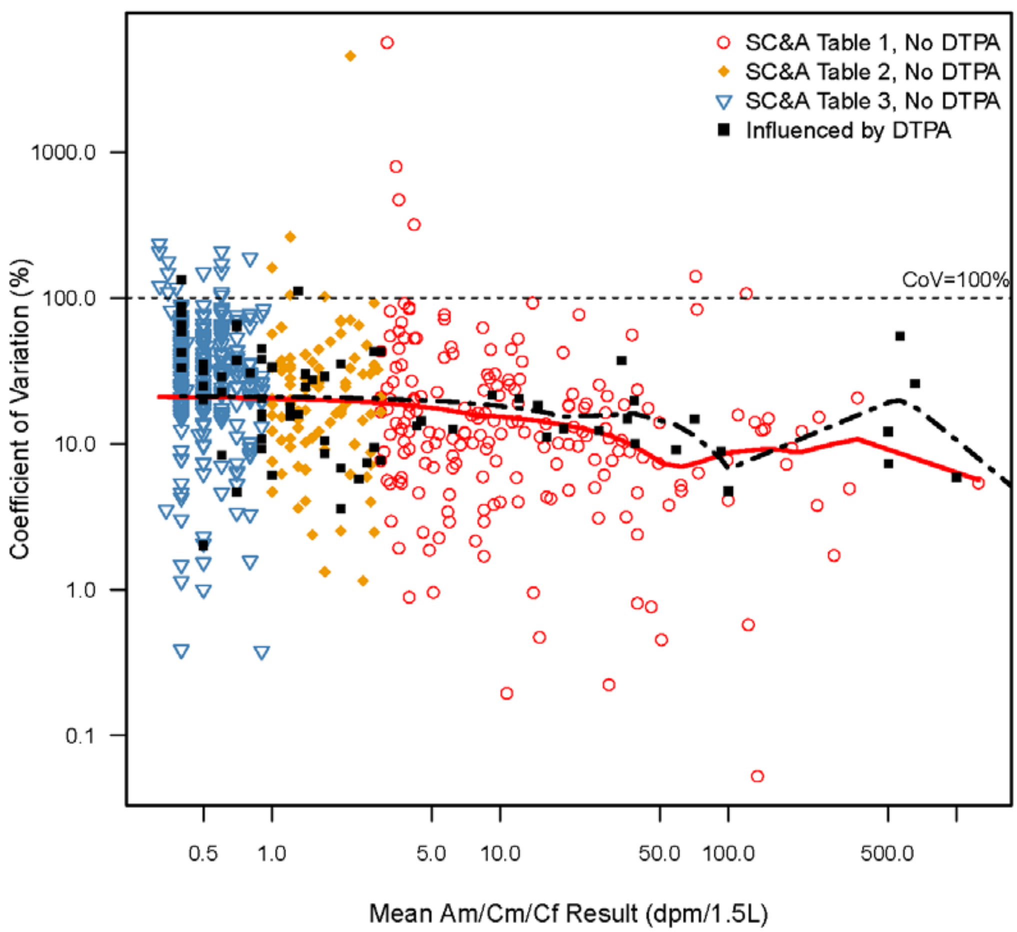
Attachment D of ORAUT-0081, revision 04 evaluates the results highlighted in the SC&A memorandum to determine the potential significance of this variability to the SRS coworker study. The evaluation addressed the impacts of removing data from chelated individuals. NIOSH summarized the rational for removing the chelated individuals as follows:

> Chelation accelerates the removal of actinides from the body by chemically binding with the actinide, which produces a chemical compound more readily eliminated through urine or feces (or both). This chemical process perturbs the normal bodily excretion of actinides and can also result in heterogeneity of the actinide concentration in the urine. SRS commonly analyzed small aliquots of urine samples using a sample volume of 5 or 10 mL. When a small aliquot is taken from a urine sample, this heterogeneity can result in markedly different radionuclide concentrations in comparison with a different aliquot from the same urine sample. . . .

> Urinalysis results influenced by administration of DTPA have been removed from this revision of the coworker study. Therefore, the data from any other individuals whose urinalysis results were influenced by administration of DTPA do not need any further evaluation because they are excluded. [NIOSH, 2019a, pp. 151, 152]

Figure 2 provides an overview of the variability of the diethylenetriamine pentaacetic acid (DTPA)-influenced samples versus the non-DTPA-influenced samples. The plot in figure 2 is similar to the one in figure 1, except the data are divided into two sub-populations: DTPA and non-DTPA samples. Although NIOSH argues that the exclusion of the DTPA-influenced samples is due to their variability, figure 2 shows that the variability of the DTPA-influenced samples appears almost identical to the variability of the non-DTPA samples.

Figure 2. Coefficient of variation versus reported mean results for SC&A non-DTPA tables 1, 2, and 3 data and separate DTPA dataset, with locally weighted polynomial (LOWESS) regression lines



After removing data from chelated workers, the NIOSH evaluation only looked at results significantly greater than the MDA (greater than 1 dpm/d) to identify results with significant variation in multiple counts from the same sample. Results with significant variability were investigated further to attempt to determine the reason for this variability.

The results of the analysis are presented in table D-1 of attachment D, reproduced here for convenience of the reader (table 3). This table summarizes a subset of the data SC&A reviewed that was greater than 1 dpm/d and had high variability.

Table 3. Summary of data >1 dpm/d

Sample type	Total # of samples	# of samples with high variability [(a)]
All samples >3 dpm/d	220	28
Samples > 3 dpm/d w/o chelation	21	2
All samples between 1 and 3 dpm/d	116	29 [(b)]
Samples between 1 and 3 dpm/d w/o chelation	31	0

Source: NIOSH, 2019a, table D-1
(a) Excluding high variability due to data entry issues.
(b) 14 of these 29 samples are from one person.

After exclusion of urinalysis results influenced by administration of DTPA, NIOSH reports that only 4 of the 52 samples that were >1 dpm/d and were unaffected by chelation had high variability. Two of those were characterized as highly variable due to data entry issues rather than with the site's bioassay program. The remaining two cases of high variability (less than 4 percent of samples that were above the MDA and not affected by chelation) had high variability due to potential issues with the site's bioassay program.

Based on this result, NIOSH concludes the following.

> The conclusion of the evaluation is that the occurrence of samples with significant intra-count variation is limited and that inclusion of these samples has an insignificant effect on the overall results. . . .
>
> This low percentage of individual disc variability and uncertainty is subsumed under the statistical analysis of all the samples collectively. All of the uncertainties discussed by SC&A are much less than the minimum GSD of 3.0 used for coworker study intakes. Therefore, the conclusion is that aliquot variability has an insignificant effect on the overall results and the data can be used as is. [NIOSH, 2019a, pp. 41, 153]

After removing all DTPA-related samples, NIOSH has reduced the scope of the variability review to a handful of samples with no clear evidence of a problem. It should be noted that SC&A's review of revision 03 of the coworker mode had requested that references be provided that demonstrate the effect of DTPA on the homogeneity of a single urinalysis voiding (refer to SC&A's previous observation 1 in attachment A from the review of revision 03 of OTIB-0081).

Finding 1: Although SC&A recognizes that incident-based sampling involving chelation is not considered in final coworker modeling, the removal of DTPA-influenced samples from consideration in the analysis of the high variability observed in trivalent actinide bioassay results has not been justified sufficiently. Evidence suggests the variation among DTPA and non-DTPA samples is nearly identical. Furthermore, OTIB-0081 has not provided any reference to justify the assumption that DTPA causes heterogeneity among a single urinalysis voiding.

Finally, SC&A notes that the MDA reported for trivalent actinides at SRS starting in 1971 was approximately a factor of 3 lower than the MDA reported by ICRP in 1989 and Rocky Flats up until 1977. The reported SRS MDA is also factor of 10 lower than that reported at Los Alamos National Laboratory. Based on these comparisons, such a low MDA should be only achievable from alpha spectrometry (refer to section 3.1.1).

3.1.2 Tritiated water

According to OTIB-0081, in 1958, liquid scintillation counting was initiated, and the reporting level was 1 microcuries per liter (µCi/L) until February 1981, when it was reduced to 0.5 µCi/L. The reporting level was further reduced to 0.1 µCi/L in January 1986. ICRP Publication 10 (ICRP, 1968; hereafter "ICRP 10") suggests the use of liquid scintillation counting for measurement of tritium, with a limit of detection of 0.1 µCi/L. The reporting level given in the 1990 technical basis manual is 0.02 µCi/L (740 Bq/L) (WSRC, 1990). ICRP 54 suggests a detection limit of 400 Bq/L for tritium (ICRP, 1989), and ICRP 78 suggests 100 Bq/L as the detection limit for tritium using liquid scintillation counting (ICRP, 1997).

3.1.3 Plutonium

According to OTIB-0081, in 1968 and in 1970, the positive result level was 0.1 dpm/1.5L (0.045 pCi/1.5L). ICRP 10 suggests a detection limit for plutonium-239 (Pu-239) of 0.06 pCi/d (ICRP, 1968), which is similar to the SRS positive result level. OTIB-0081 describes the use of alpha spectroscopy in the 1980s with reporting levels of 0.05 dpm/1.5L for Pu-238 (0.55E-3 Bq/L) and 0.07 dpm/1.5L (0.77E-3 Bq/L) for Pu-239. Those limits of detection are much lower than the ones suggested in ICRP 54 of 1E-2 Bq/L (ICRP, 1989) and similar to the ones suggested in ICRP 78 of 1E-3 Bq/L (ICRP, 1997). Today the typical detection limit for Pu-238 and Pu-239 using alpha spectrometry is 0.3 millibecquerel per liter (mBq/L) (European Commission, 2018).

3.1.4 Uranium

According to OTIB-0081, from the start up to the mid-1960s, uranium was measured in urine samples using gross alpha and alpha track counting with a reporting level of 0.15 dpm/1.5L (0.045 pCi/L), one half of the detection limit of 0.1 pCi/L suggested for uranium-233 (U-233), U-234, and U-235 in ICRP 10 (ICRP, 1968). The limits from the mid-1960s to 1982, using gross alpha on solid state detector, are more credible (1 dpm/1.5L or 0.3 pCi/L). From 1954 to 1982, both depleted and natural uranium were measured by fluorophotometric analysis, with a limit of detection similar to the one listed in ICRP 10 of 5 micrograms per liter (µg/L) (ICRP, 1968). From 1982 to 1986, delayed neutron analysis was adopted, but the detection limits for U-235 did not change (i.e. 1 dpm/L). From 1990 to 1994, the detection limit for enriched uranium was 0.4 pCi/L (0.015 Bq/L), which is similar to the detection limits from the mid-1960s to 1982, and similar to the detection limit suggested for U-235 in ICRP 54 of 0.01 Bq/L (ICRP, 1989). From 1994 to the present, the MDA is 0.036 pCi/L for U-235 and 0.032 pCi/L (0.0012 Bq/L) for U-234 and U-238 using alpha spectrometry. Those limits are similar to the ones suggested in ICRP 78, which reports 10 mBq/L for U-234, U-235, and U-238 (ICRP, 1997).

3.1.5 Fission products (strontium-90)

OTIB-0081 states that from 1959 to 1966, the reporting levels for strontium-90 (Sr-90) were 60 dpm/1.5L (1.8E-5 µCi/L). This reporting level is similar to the one suggested in ICRP 10 of 1E-5 µCi/L (ICRP, 1968).

3.1.6 Cobalt-60

OTIB-0081 gives the cobalt-60 (Co-60) MDA as 0.5 nanocurie (nCi)/1.5L (12 Bq/L) for 1966–1970, somewhat higher than the limit of 5 Bq/L suggested in ICRP 54 (ICRP, 1989). ICRP 10 does not give limits of detection for Co-60 in urine.

3.1.7 Cesium-137

According to OTIB-0081, cesium was measured using the SRS Whole Body Counting Facility, and the limit of detection was 1 nCi, which is 10 times lower than the limit of detection suggested in ICRP 10 (ICRP, 1968).

3.1.8 Neptunium

Neptunium was not really measured in urine at SRS after 1970. Up until 1970, the positive level was 0.1 dpm/1.5L (0.045 pCi/1.5L). ICRP 10 only gives whole body limits for neptunium detection. However, ICRP 78 gives a limit of detection of neptunium-237 (Np-237) in urine of 1E-3 Bq/L using alpha spectrometry (ICRP, 1997), which is equivalent to the positive level used at SRS.

3.2 Treatment of censored data using imputation methods

Bioassay results below a given threshold, which is often referred to as an MDA or a reporting threshold, are usually reported as less than that dose, or "less-than" doses. In statistics, the less-than-MDA or less-than-reporting threshold data are said to be "censored." Censored data are problematic because the result at a given time is not unambiguously defined if some of the data are censored. For example, table 4-5 of OTIB-0081, revision 04 lists the reporting levels of an enriched uranium urinalysis in the mid-1960s through 1982 to be 1 dpm/1.5 L. That means that results below the reporting threshold of 1 dpm/1.5 L were reported as <1 dpm/1.5 L, so if a true sample were 0.8 dpm/1.5L, it would be analyzed and reported as <1 dpm/1.5 L. When interpreting this result, it is impossible to know what the true concentration in a sample is because the "<" symbol indicates a range of possible values. Multiple censoring levels (CLs) are present in the coworker data.

To address the uncertainties introduced into the data due to the presence of censored data, NIOSH used a technique documented in ORAUT-RPRT-0096 (NIOSH, 2019b) for multiple imputation. Imputation is a technique that uses other values in the dataset and a model that incorporates random variation to predict the value of the censored result. Repeating this imputation step multiple times, then averaging the results is known as multiple imputation. The method specified in ORAUT-RPRT-0096 has not to SC&A's knowledge been applied to other internal coworker models in support the EEOICPA mission. ORAUT-RPRT-0096 was issued on January 24, 2019, and has not been formally reviewed by SC&A. Full review of this document is outside of the scope of this current evaluation; however, it was necessary to evaluate the method used in this document in the context that it is applied for developing the coworker models for

SRS in OTIB-0081, revision 04. Multiple imputation was used to model censored results for the uranium, plutonium, fission products, and neptunium—but not americium—models.

ORAUT-RPRT-0071, revision 00 (NIOSH, 2015b), first introduced the new procedure, utilizing multiple imputation methods for calculating external doses for workers who have censored data. ORAUT-RPRT-0071 applies the procedure to external coworker exposures. This document has not been reviewed by SC&A. ORAUT-RPRT-0096 applies the multiple imputation methodology to internal exposures at three example facilities: uranium activity data at Y-12 for 1950 to 1984; uranium mass data at Fernald for 1970 to 1985; and americium-241 data at SRS for 1994 to 2000.

The multiple imputation procedure uses regression on order statistics (ROS) to fit a lognormal distribution to the uncensored data, then uses the fitted model to randomly impute values in the lower tail of the lognormal distribution as a substitute for the missing censored data. SC&A examined the R code that does the imputation and duplicated the algorithm on a Microsoft Excel spreadsheet to determine its suitability for coworker model dose estimates in the presence of censored data.

Figure 3 shows an example of using ROS to fit a lognormal distribution with no censored data. This plot is a logged version of the normal probability paper plots that were used before computers were available. After plotting the data, a line that best fits the data was drawn though the points to obtain estimates of the slope and the intercept of the regression line. In figure 3, Excel is used to obtain the same results. Table 4 shows the parameter estimates obtained with ROS, the true values of the parameters, and the maximum likelihood estimates (MLEs). There is good agreement between the MLEs and the ROS estimates.

Figure 3. Example of ROS for 100 lognormal[0, 1] samples with no nondetects

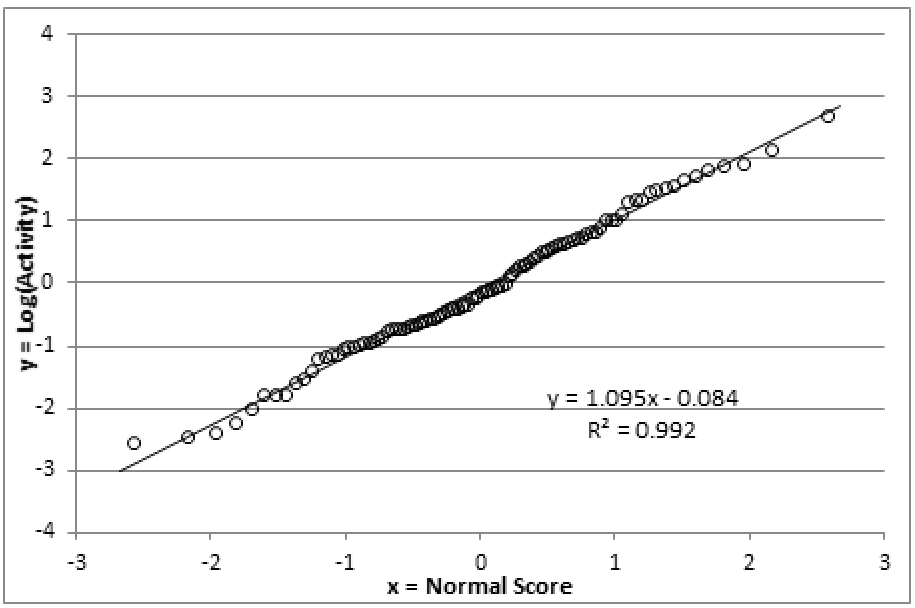


Table 4. ROS lognormal parameter estimates for example in figure 3 with true values and maximum likelihood estimates (MLEs)

Regression parameter	Estimate (log scale)	Lognormal parameter	ROS estimate	True value	MLE
Slope	1.095	GSD	2.990	2.718	2.998
Intercept	-0.084	GM	0.919	1	0.919

Figure 4 shows an example of the ROS regression in the presence of censored data below the limits of detection of the measuring device. This procedure is not based on maximum likelihood, but it can be used with censored data. Table 5 shows the parameter estimates obtained with ROS and the true values of the parameters. Note that the MLEs cannot be computed due to the missing data. Note that the R^2 for the regressions are not included in the tables because the x and y data pairs used in the ROS regression procedure are not independent. There is only one set of data, not two. The data have been sorted so that the y values (now called the "order statistics") are always non-decreasing, and the x values are a function of the ranks of the data. As a result, $y_i \mid x$ is not independent of $y_j \mid x$. If i < j, then $y_i <= y_j$ always, which is not the usual case for regression.

Figure 4. Example of ROS for 100 lognormal[0, 1] samples with 13 nondetects

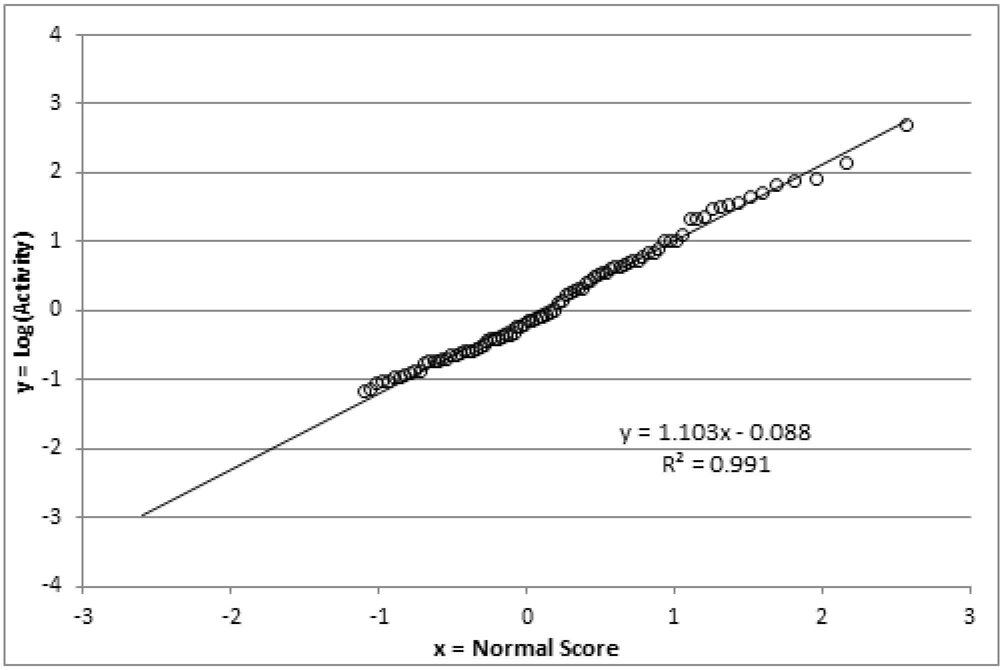


Table 5. ROS lognormal parameter estimates for example in figure 4 with true values

Regression parameter	Estimate (log scale)	Lognormal parameter	ROS estimate	True value	MLE
Slope	1.103	GSD	3.012	2.718	NA
Intercept	-0.088	GM	0.916	1	NA

Figure 5 shows an example of using the ROS regression estimates to randomly generate values in the lower tail of the fitted lognormal distribution as a substitute for censored data below the CL. The R code provided by NIOSH was used for the imputation. The triangles in the lower tail of the distribution show these imputed values. ORAUT-RPRT-0096 uses an iterative procedure where one random imputed value is substituted into the dataset in place of each censored value; the time weighted one-person-one-statistic (TWOPOS) calculations are done for each worker. The procedure is then repeated *K* times with different random imputed tail values in each iteration to obtain *K* TWOPOS estimates. These estimates are averaged for each worker to obtain the final TWOPOS results for use in the next step of intake modeling.

Figure 5. ROS plot with 13 imputed values plotted in lower tail (triangles)

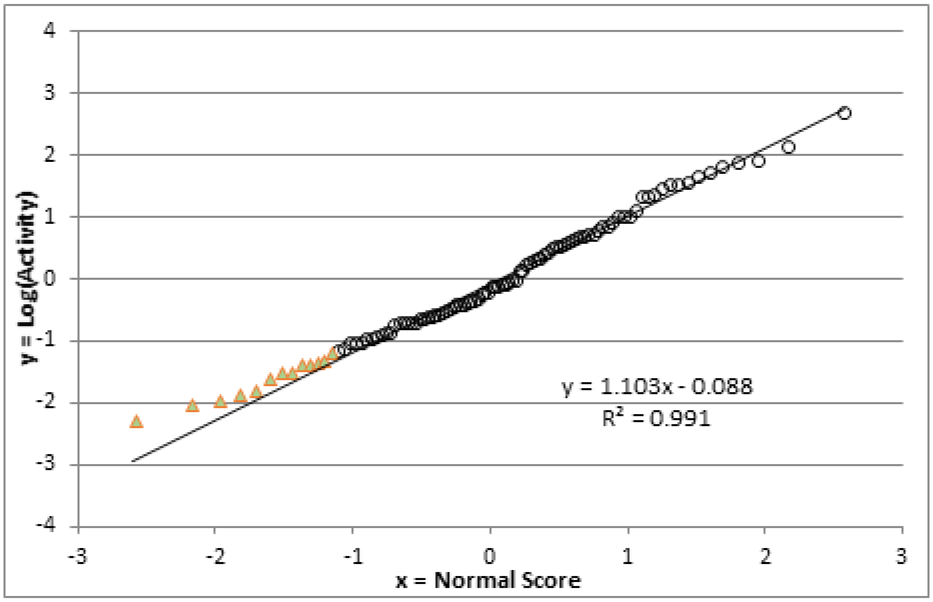


Figure 6 shows lognormal plots of simulated censored urinalysis data from two different hypothetical groups of 30 workers each over four quarters, for a total of 120 data points in each dataset. These groups may represent workers at two different facilities or in two different years at the same facility. Group 1 is assigned a lognormal[0, 1] distribution. The median for Group 2 is the same as the median for Group 1. The geometric standard deviation (GSD) for Group 2 was selected so the expected value for Group 2 is twice the expected value of Group 1. The data were censored at a CL of 0.5 dpm/1.5L, and only the uncensored data plotted in figure 6 are available to the intake modeling analyst.

Figure 6. ROS plot for quarterly urine samples observed in two different groups with 30 workers

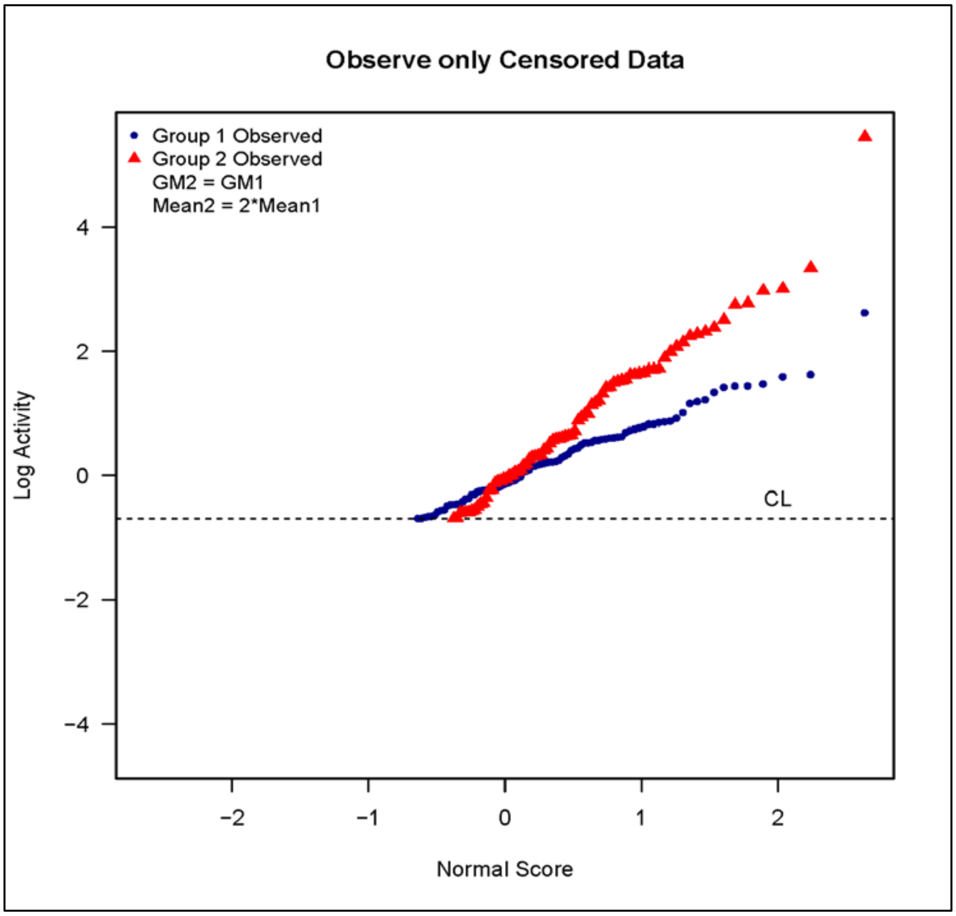
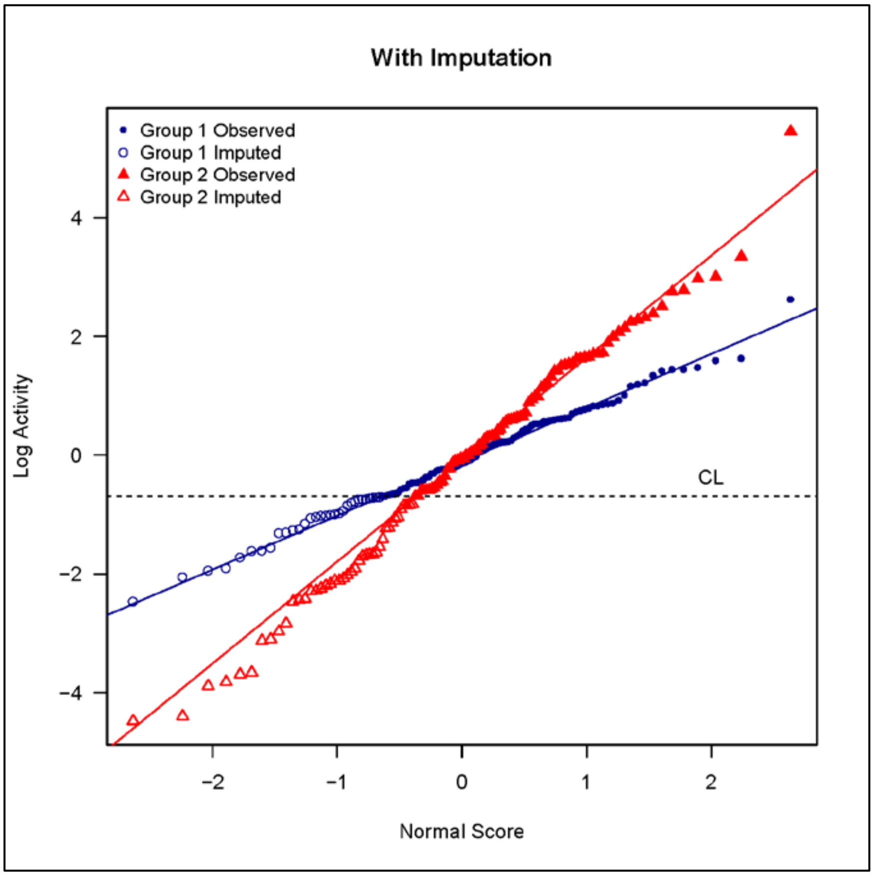


Figure 7 shows the application of the ROS multiple imputation procedure for these workers. Since these data were generated using a lognormal distribution, the regression lines fit the data very well. This is not usually the case. Although the shape of the distribution below the CL is unknown, the ROS procedure has the implicit assumption built in that the logarithm of the data is symmetrically distributed about the median. For example, if 5 percent of the workers are exposed at 10 times the median or higher in the upper tail of the distribution, NIOSH assumes, due to log-symmetry, that the 5 percent of workers in the lower tail of the distribution were exposed at a factor of 10 times below the median or lower. There is no obvious physical explanation for the assumption of log-symmetry.

Figure 7. ROS plot with imputed samples for each group of workers

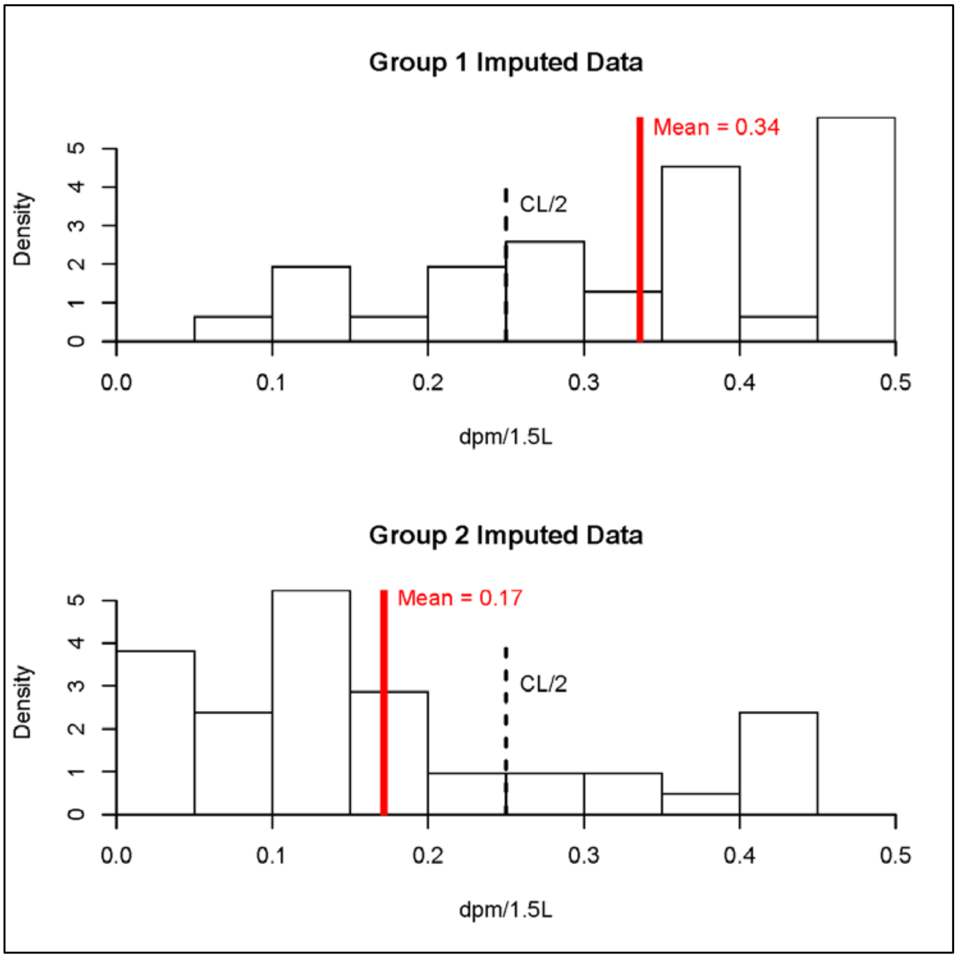


The imputation procedure is mathematically correct, if we assume that the unobserved values below the CL follow the same lognormal distribution that is fit to the detected values above the CL. Looking only at the detected values in plotted in figure 7, the assumption of symmetry about the median is not obvious. This crucial assumption of log-symmetry about the median is the basis for the imputation procedure.

The imputed data in the lower tail of the distribution are depicted with hollow circles and triangles. Note that due to the assumption of symmetry, the substituted values for the Group 2 workers are almost always below the substituted values for the Group 1 workers. Although the two groups of workers have the same median exposure, workers with censored data in Group 2 are assigned lower imputed values than workers with censored values in Group 1 simply because they worked with other workers who had high exposures. This illogical outcome is the direct result of the assumption of symmetry.

Figure 8 shows the distribution of imputed values for the two groups of workers. All values are below the CL of 0.5 dpm/1.5L. The value of CL/2 is shown with a broken line in the middle of the plots. The mean imputed value for the Group 1 workers is twice as high as the mean imputed value for the Group 2 workers. The outcome depicted in figure 8 is a result of one round of substituting an imputed value for each censored value for these workers.

Figure 8. Distribution of imputed data for each group of workers



The above example led to a comparison of the true mean values in the lower tails of the two lognormal distributions. The mean value of the lower tail of the lognormal distribution does not have a simple formula for direct calculation. SC&A performed a simulation by selecting 100,000 samples in the tail of each distribution and computing the sample mean for five different CL values. The procedure was repeated $K = 30$ times. Then, the average and standard deviations of the K mean values were calculated. The standard deviations were very small due to the large sample size used in the simulation. The resulting expected values for the lower tail of the two lognormal distributions and the ratio of these estimates are reported in table 6. At all CLs, the mean of the values imputed for Group 1 workers are about 30 percent higher than the mean of the values imputed for Group 2. Although these ratios are lower than the factor of 2 observed in the small-sample outcome in figure 7, the systematic bias of lower imputed values for Group 2 workers remains due to the assumption of symmetry.

Table 6. Simulated mean imputed values in lower tail of lognormal distributions for Group 1 and Group 2 ($n_1 = n_2 = 100{,}000$)

CL	Mean Group 1	Mean Group 2	Ratio of means (Group 1/Group 2)
0.1	0.0741	0.0582	1.273
0.25	0.169	0.130	1.300
0.5	0.305	0.233	1.309
0.75	0.422	0.323	1.307
1	0.523	0.404	1.295

A third group of workers with the same median as Groups 1 and 2 but with an expected value that is three times the expected value of Group 1 was created for this simulation. Table 7 shows a comparison of the results for Group 1 and Group 3. The higher expected value for Group 3 results in an increased disparity between these two groups. The ratios in the right-hand column indicate that the imputed values for the censored doses in Group 1 range from 40 percent to 45 percent greater than the imputed values for the censored doses in Group 3.

Table 7. Simulated mean imputed values in lower tail of lognormal distributions for Group 1 and Group 3 ($n_1 = n_3 = 100{,}000$)

CL	Mean Group 1	Mean Group 3	Ratio Group 1/Group 3
0.1	0.0741	0.0525	1.411
0.25	0.169	0.117	1.444
0.5	0.305	0.209	1.459
0.75	0.422	0.291	1.450
1	0.523	0.365	1.433

One scenario is that Group 1 and Group 2 are the same workers in two different years with the same median exposure in both years. Assume in the first year no workers had unusually high exposures, but in the second year some workers did have high exposures. The multiple imputation model will assign lower imputed doses to workers with censored data in the second year than to workers with censored data in the first year due to symmetry because a few coworkers had high doses in the second year. If a worker has censored data in both years, the average of the imputed values for the censored data in year 2 will be lower than in year 1, all due to the assumption of symmetry and that there were more coworkers with high exposures in year 2.

From a more distant perspective, imputing dose estimates below the MDA may lead to cases where a worker's unmonitored dose is unduly biased low because of the current imputation method. Use of the maximum possible mean (MPM) for TWOPOS, which was first introduced in ORAUT-RPRT-0053 (NIOSH, 2014b), is a more claimant-favorable approach. When applying TWOPOS with the MPM method, the CL is substituted for each censored value. Using the MPM solves the censored data problem in a very claimant-favorable way without imputing (i.e., substituting hypothetical simulated) numbers. Substituting the CL/2 for censored values is less claimant favorable, but both approaches would lead to more equitable treatment of workers in Groups 1 and 2.

Observation 1: While the multiple imputation method is mathematically correct, it has the potential to result in biasing the simulated bioassay results unnecessarily low. Alternate approaches, such as the maximum possible mean method, which replaces censored data with the actual censoring limit (or alternately one-half the censoring limit), would solve the issues associated with datasets containing a large number of censored values in a claimant-favorable manner.

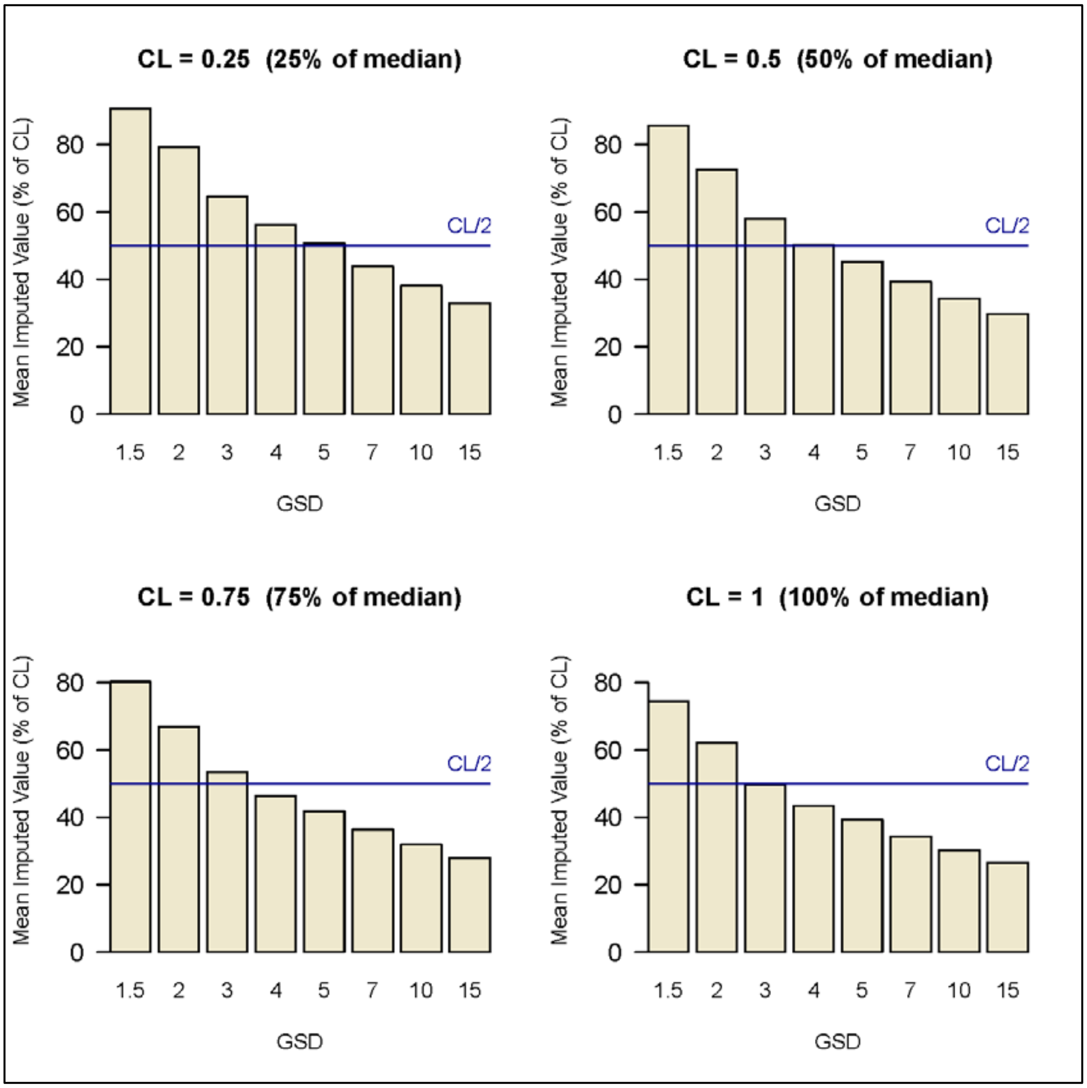
Aside from the evaluation of the imputation method itself, the use of such methods to derive coworker urinalysis results that are less than the MDA creates a basic conflict between how data are used and interpreted for monitored and unmonitored workers. The basic underlying concept of a coworker model is that the unmonitored worker *should have been monitored* and thus should be assigned equivalent unmonitored doses as for the monitored worker. For a monitored worker, bioassay values that are censored are treated as missed doses and are evaluated at one-half of the MDA rather than an imputed value that falls somewhere between zero and one-half of the MDA.

Finding 2: Use of imputed values that are less than one-half of the MDA raises a fundamental fairness issue in that monitored workers who have bioassay results that are less than the MDA are assigned a missed dose in accordance with ORAUT-OTIB-0060 (NIOSH, 2018). Per that guidance, bioassay values that are censored are assumed to be equal to one-half of the MDA rather than an alternate imputed value.

There is no simple closed-form solution for the mean value of the imputed values in the lower tail of a lognormal distribution below the CL. SC&A performed a Monte Carlo integration to determine the mean of the imputed values in the lower tail of a lognormal distribution with a median value of 1 and seven different GSDs. All lognormal distributions may be scaled to have a median of 1 with a corresponding scaling of the CL. The integration procedure used 100 iterations. In each iteration, 100,000 imputed values were selected randomly in the lower tail of the distribution. The 100 means of the imputed values from each iteration were then averaged to estimate the expected value. The mean values are bounded between 0 and the CL. Results are reported in figure 9, where the estimated mean is expressed as a percentage of the CL and is plotted as a function of the GSD for four CLs. The selected values of the CL range from 25 percent of the median up to 100 percent of the median.

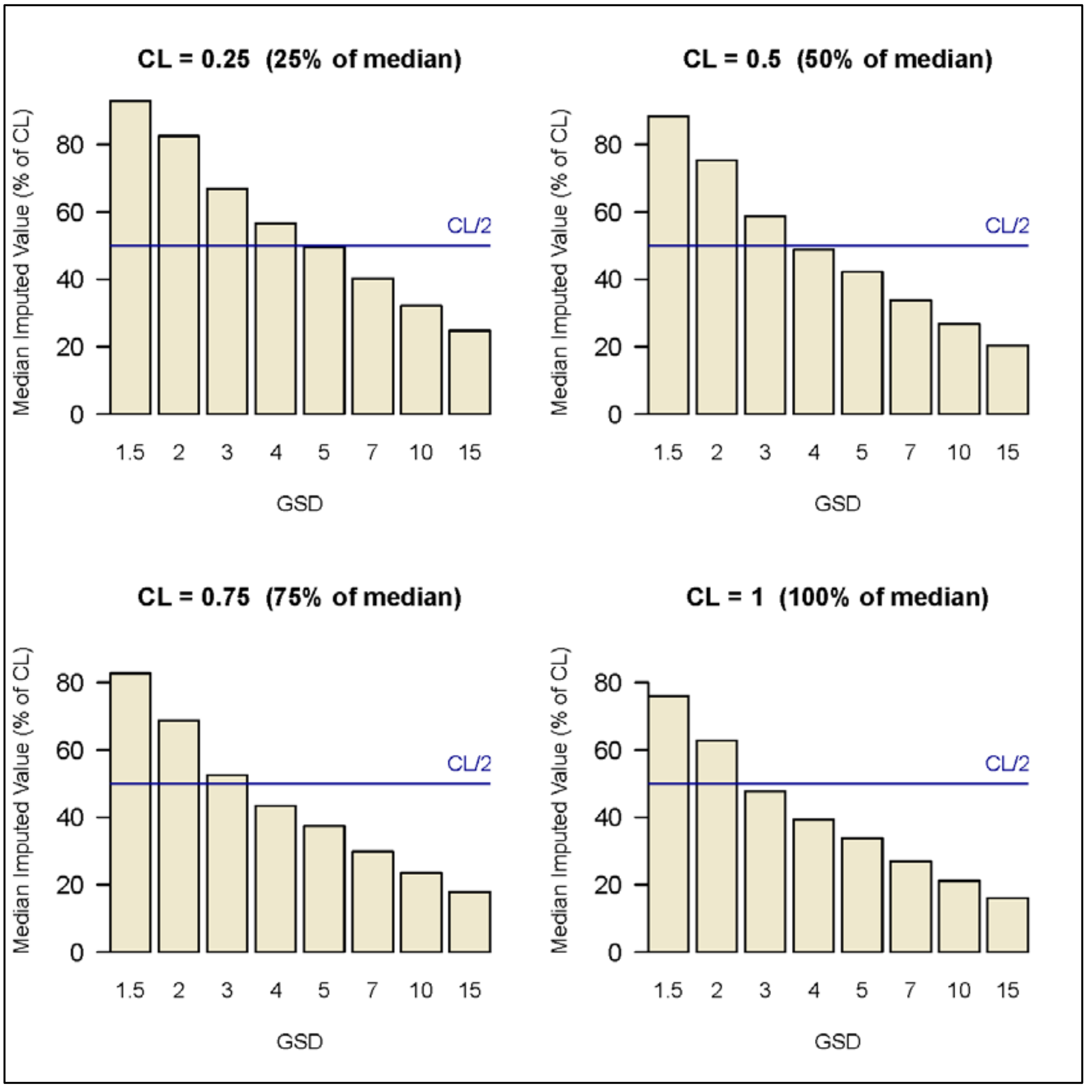
The upper two plots are for CLs equal to 25 percent or 50 percent of the median. The two lower plots are for CLs equal to 75 percent or 100 percent of the median. The estimated mean is expressed as a percentage of the CL and is plotted as a function of the GSD. The mean of imputed values is higher than one-half of the CL for GSDs less than or equal to 3, and less than one-half of the CL for GSDs greater than or equal to 4 (or greater than or equal to 5 for CL = 0.25). Note that the mean imputed value always decreases as a function of the GSD at all CLs. The mean imputed value at a GSD of 15 is much smaller than the mean imputed value at a GSD of 1.5 or 2 at all CLs. This result corroborates the results noted in the Group 1/Group2 analysis above. If there are two groups of workers with the same median, the workers with missing data in the group with a lower GSD will be assigned higher imputed values on average than workers with missing data in the group with a higher GSD.

Figure 9. Mean of imputed values in the lower tail of a lognormal distribution as percentage of the censoring level for eight geometric standard deviations (GSD) and four censoring levels (CL)



SC&A performed another simulation to evaluate the median imputed values. The results of this analysis are shown in figure 10. In the upper two plots for CLs equal to 25 percent or 50 percent of the median imputed values are higher than CL/2 except for GSD = 5 in the upper right-hand plot. The lower two plots are for CLs equal to 75 percent or 100 percent of the median. The median imputed values are higher than CL/2 for GSDs of 3 or less and are less than CL/2 for the higher GSDs. Again, the median imputed value always decreases as a function of the GSD at all CLs. The median imputed value at a GSD of 15 is much smaller than the mean imputed value at a GSD of 1.5 or 2 at all CLs. At the higher GSDs, the median imputed value is less than CL/5 (i.e., less than 20 percent of the CL).

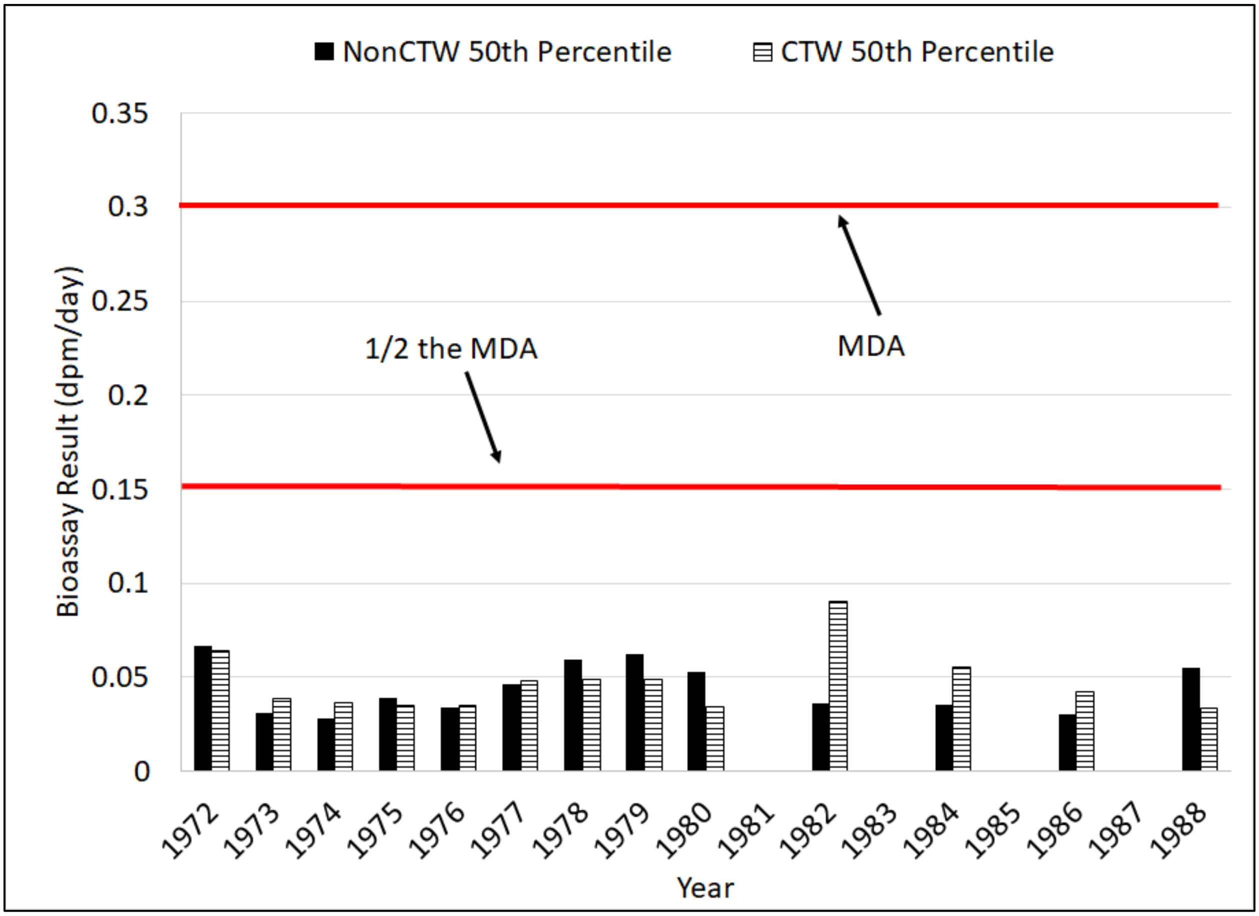
Figure 10. Median of imputed values in the lower tail of a lognormal distribution as percentage of the censoring level for eight geometric standard deviations (GSD) and four censoring levels (CL)



3.3 Use of data less than the minimum detectable activity

As discussed previously in section 3.2, NIOSH has developed methods to impute numerical bioassay values when the data are reported as less than the limit of detection. In addition to imputed values for uranium, plutonium, fission products, neptunium, trivalent actinide data (Am/Cm/Cf) were reported in the source records at values less than the detection limit. The use of imputed values and recorded values that are less than the detection limit results in estimates of coworker excretion rates that are sometimes much less than the detection limit. For example, figure 11 shows the calculated coworker excretion rates for Am/Cm/Cf at the 50th percentile as compared to the MDA. For individual dose reconstructions involving monitored workers, bioassay values that are less than the limit of detection are treated as a “missed dose” per the guidelines in ORAUT-OTIB-0060 (NIOSH, 2018).

Figure 11. Trivalent coworker bioassay values during the SEC evaluation period compared to the minimum detectable activity



To better understand the effect of using bioassay values less than the detection limit (whether imputed or actual), SC&A performed sample calculations using the coworker data developed in OTIB-0081 compared to the alternate method of evaluating missed dose as outlined in ORAUT-OTIB-0060. This section summarizes SC&A's analyses of coworker verses missed intakes, doses, and POC values for several radionuclides and target organs.

To compare the results of using coworker data versus assigning missed dose in a potential dose reconstruction process for workers at SRS, SC&A used coworker data and one-half the recorded bioassay MDA values in the Integrated Modules for Bioassay Analysis (IMBA) program to predict intakes. SC&A then used these predicted intakes in IMBA to derive annual organ doses and then used these organ doses in Interactive RadioEpidemiological Program (IREP) tables to determine POC values. SC&A performed these analyses for two hypothetical workers at SRS working side by side for the same time period: one without any bioassay data (i.e., coworker data would be used in a dose reconstruction for this worker), and one monitored yearly with all results <MDA for the radionuclide of interest (i.e., missed dose would be assigned in a dose reconstruction for this worker). SC&A analyzed a beta emitter (Sr-90), a gamma/beta emitter (Co-60), and alpha emitters (Np-237, uranium, and plutonium). SC&A used CTW and nonCTW data. SC&A used a variety of target organs, both systemic and nonsystemic. SC&A performed the following steps in these analyses.

3.3.1 Derivation of intake values

CW data: SC&A used annual urine excretion 50th percentile values from OTIB-0081 tables 4-7, 4-8, and 4-11 for Sr-90, Co-60, and Np-237, respectively, as bioassay data input into IMBA to confirm NIOSH’s coworker intake values in table F-14 for Sr-90, table F-17 for Co-60, and table F-21 for Np-237. Intake values for uranium and plutonium were selected from table 5-8, table 5-11, and table 5-4. The isotopic composition of plutonium was assumed to be 10 percent 12-year aged plutonium using guidance from table 4.1.1-3 of the SRS site profile (NIOSH, 2005).

Missed intakes using MDA data: SC&A used one-half the most appropriate (and/or averaged) MDA values from recorded bioassay data for 1955–1969 that were available in the SRS files on the ABRWH server as bioassay input into IMBA to derive the projected annual intake values for Sr-90, Co-60, and Np-237 for a worker with all bioassay results less than the MDA value. Additionally, SC&A modeled intakes from 1955–1990 using half of the reporting values from the SRS site profile table 4.1.1-4 assuming 100 percent U-234 and table 4.1.1-1 for 10 percent 12-year aged plutonium (NIOSH, 2005).

The missed intakes derived using one-half the MDA values were approximately 1.5 to 2.5 times the value derived using coworker data, depending on the radionuclide.

3.3.2 Derivation of organ dose

CW data: SC&A used the derived Sr-90 intake values for CTWs (table 4-7 of OTIB-0081) for the period 1955–1965 to calculate the annual doses and total dose to the red bone marrow (RBM), BS, colon, and skin. SC&A used the derived Co-60 intake values for CTWs (table 4-8 of OTIB-0081) for the period 1955–1965 to calculate the annual doses and total dose to the RBM, BS, liver, and kidneys. SC&A used the derived Np-237 intake values for nonCTWs (table 4-11 of OTIB-0081) for the period 1961–1969 to calculate the annual doses and total dose to the RBM, liver, colon, and skin.

SC&A used the derived Type S uranium 50th percentile intake rates from table 5-8 (for nonCTW) and table 5-11 (for CTW) for 1955 through 1990 to calculate the annual organ doses assuming a diagnosis date 10 years following the last exposure. Similarly, SC&A used the 50th percentile Type M plutonium intake values for nonCTWs and CTWs from table 5-4 for 1955 through 1990 to calculate the annual organ doses assuming a diagnosis date 10 years following the last exposure. Dose was modeled to the skin, RBM, colon, and kidney for both uranium and plutonium exposures.

Missed dose: SC&A used the derived Sr-90 intake values for CTWs (derived from using one-half the recorded bioassay MDA values) for the period 1955–1965 to calculate the annual doses and total dose to the RBM, BS, colon, and skin. SC&A used the derived Co-60 intake values for CTWs (derived from using one-half the recorded bioassay MDA values) for the period 1955–1965 to calculate the annual doses and total dose to the RBM, BS, liver, and kidneys. SC&A used the derived Np-237 intake values for nonCTWs (derived from recorded bioassay MDA values) for the period 1961–1969 to calculate the annual doses and total dose to the RBM, liver, colon, and skin. SC&A used the intake values derived from the reporting levels for uranium and plutonium CTW and nonCTWs from 1955 through 1990 to calculate the annual doses and the total dose to the skin, RBM, colon, and kidneys.

The organ missed dose values calculated using one-half the MDA or reporting level values were approximately 0.12 to 5.1 times the organ dose values calculated using coworker data, depending on the radionuclide and organ involved (a summary of this information is provided in tables 1 through 7).

3.3.3 Derivation of POCs

POCs from CW data: SC&A used the calculated annual dose values (from coworker data) for each organ in an IREP table in conjunction with NIOSH-IREP v.5.8.1 to derive the POC for each organ for each radionuclide. The doses were assigned with a lognormal distribution with an uncertainty of 3 (OTIB-0081, section 5.0, p. 90) in the IREP tables.

POCs from missed dose: SC&A used the calculated annual missed dose values (derived from one-half the MDA values in the recorded bioassay data) for each organ in an IREP table in conjunction with NIOSH-IREP v.5.8.1 to derive the POC for each organ for each radionuclide. The doses were assigned as a triangular distribution with a minimum of 0, a mode based on one-half the MDA, and a maximum based on the MDA (ORAUT-OTIB-0060, section 2.5.2, p. 14) in the IREP tables.

Tables 8–14 summarize the results of SC&A's analyses of the total dose and POC values obtained using coworker data verses total dose and POC values obtained from missed dose using one-half the recorded bioassay MDA values for various organs and radionuclides.

Table 8. Sr-90 Type F gross beta urinalyses 1955–1965 50th percentile CTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	0.085	0.210	2.5	0.11%	0.13%	1.2
Bone	0.183	0.452	2.5	0.33%	0.41%	1.2
Skin	3.13E-04	7.76E-04	2.5	0.00%	0.00%	1.0
Colon	2.04E-03	5.05E-03	2.5	0.01%	0.01%	1.0

As shown in table 8, the Sr-90 POC values derived using missed dose were the same, or slightly greater, than the POC values derived using coworker data, even though the doses using coworker data were a factor of 2.5 higher.

Table 9. Co-60 Type M gross beta urinalyses 1955–1965 50th percentile CTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	1.90E-03	9.72E-03	5.1	0.00%	0.01%	N/A
Bone	1.77E-03	9.04E-03	5.1	0.00%	0.01%	N/A
Liver	3.81E-03	1.95E-02	5.1	0.04%	0.09%	2.3
Kidneys	1.85E-03	9.49E-03	5.1	0.00%	0.01%	N/A

Table 9 indicates that the Co-60 POC values derived using either missed dose or coworker data were so low (near zero) that a meaningful comparison was not possible for the organs analyzed. In general, the POC values derived using missed dose were the same, or slightly greater, than the POC values derived using coworker data. It should be noted that the doses using the missed dose method were over a factor of 5 higher than the coworker estimates.

Table 10. Np-237 Type F gross alpha urinalyses 1961–1969 50th percentile nonCTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	1.628	2.305	1.4	3.20%	2.71%	0.8
Liver	6.654	9.481	1.4	49.81%	44.70%	0.9
Skin	0.050	0.072	1.4	0.14%	0.12%	0.9
Colon	0.051	0.073	1.4	0.23%	0.18%	0.8

Table 10 shows that the POC values derived for Np-237 using missed dose were all slightly less than the POC values derived using coworker data.

Table 11. 10% enriched 12-year aged Type M plutonium 1954–1990 50th percentile CTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	2.424	4.515	1.86	4.87	4.73	0.97
Kidney	0.243	0.456	1.88	1.16%	1.13%	0.97
Skin	0.080	0.144	1.81	0.26	0.24	0.92
Colon	0.081	0.146	1.81	0.37	0.35	0.95

Table 12. 10% enriched 12-year aged Type M plutonium 1954–1990 50th percentile nonCTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	2.842	4.515	1.59	5.68%	4.73%	0.83
Kidney	0.285	0.456	1.60	1.35%	1.13%	0.84
Skin	0.094	0.144	1.54	0.31%	0.24%	0.77
Colon	0.095	0.146	1.54	0.43%	0.35%	0.81

As shown in tables 11 and 12, the POC values derived for plutonium using missed dose were all slightly less than the POC values derived using coworker data, even though the calculated doses for the missed dose method were approximately 50–90 percent higher than the coworker doses.

Table 13. Uranium Type S 1954 through 1990 50th percentile CTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	0.041	0.032	0.77	0.09%	0.03%	0.08
Kidney	0.165	0.137	0.83	0.82%	0.32%	0.39
Skin	0.011	0.006	0.59	0.04%	0.01%	0.25
Colon	0.036	0.029	0.82	0.24%	0.08%	0.33

Table 14. Uranium Type S 1954 through 1990 50th percentile nonCTW

Organ	CW data total dose (rem)	Total missed dose (rem)	Dose ratio missed/CW	CW data POC	POC based on missed dose	POC ratio missed dose/CW
RBM	0.186	0.032	0.17	0.46%	0.03%	0.07
Kidney	0.691	0.137	0.20	3.91%	0.32%	0.08
Skin	0.054	0.006	0.12	0.29%	0.01%	0.03
Colon	0.116	0.029	0.25	0.75%	0.08%	0.11

Tables 13 and 14 indicate that for uranium, the POC values derived using missed dose were each less than the POC values derived using coworker data. The difference in POC values derived using MDA and coworker data were even more pronounced in the sample calculation because the uranium coworker intakes were actually greater than those derived from MDA values in those examples.

Except for uranium, the derived intake and dose values were greater using missed dose from recorded bioassay data compared to using coworker data. However, assigning a triangular distribution for missed dose values and assigning a lognormal distribution for coworker dose at the 50th percentile resulted in the *POC values being similar* for the conditions, radionuclides, and organs used in these analyses. The coworker intakes for uranium for both CTW and nonCTW were generally greater than half the MDA values; therefore, the resulting doses and POC values were consistently greater when compared to those derived using MDA data. Examination of several of the previous scenarios using the 95th percentile derived coworker intakes with the doses assigned as a constant resulted in greater POC values than using either the 50th percentile coworker intakes or a missed dose approach. It is important to note that individual claim conditions have a large impact on the dose and POC assigned in a case. The above scenarios do not encompass the range of conditions seen in the dose reconstruction process and are intended to quantify the impact for sample scenarios.

Observation 2: A scoping assessment of the use of coworker bioassay data that are significantly less than the MDA versus an alternate missed dose approach concluded that, while intakes and doses are significantly higher using a missed dose approach in most of the sample calculations, the overall effect on resulting POC values was relatively minor and, in most cases, the coworker-derived POC bounded the missed dose evaluation. This appears to be due to the effect the statistical distribution has on resulting POC values, namely, the use of a triangular distribution for missed dose evaluation versus a lognormal distribution for coworker data.

Observation 3: The sample comparison of coworker intakes to a missed dose method for uranium showed that the coworker model derived intakes were a factor of 4 or more higher than the missed dose approach. This illustrates the potential for inequity between the treatment of unmonitored workers assigned coworker intakes and monitored workers with results less than the detection limit in some situations.

4 Coworker Data Completeness

As noted in section 3.1 of OTIB-0081, two main data sources were used in the development of coworker intake assignments:

1. individual claimant internal monitoring data as found in the NIOSH OCAS Claims Tracking System (NOCTS)

2. laboratory logbooks containing americium and neptunium urinalysis results

For the case of the first dataset, NIOSH assumed the portion of the available claimant records used is a representative sample of the full dataset of worker monitoring records for SRS per the conclusions of ORAUT-OTIB-0075[1] (NIOSH, 2009). Section 4.1 discusses the completeness of the NOCTS dataset. For the second dataset, the laboratory logbooks are considered the complete set of available monitoring records for the entire SRS worker population and are discussed in section 4.2.

4.1 Completeness of NOCTS data

Individual claimant records in NOCTS were evaluated for coworker assignment in OTIB-0081 for six of the eight contaminants of interest: tritium, plutonium, uranium, MFPs, Co-60, and cesium-137 (Cs-137). As stated in section 3.1 of the coworker model, claimant records were used because a sitewide electronic database of internal monitoring records is not available for SRS until approximately 1991, which corresponds to the advent of the Health Protection Radiation Exposure Database. While the NOCTS compilation is not a complete set of SRS worker data, OTIB-0081 notes that NOCTS was "the best available compilation of data in a usable form (i.e., electronic spreadsheet or database)" (NIOSH, 2019a, p. 25).

It was noted in OTIB-0081 that claim numbers for SRS up to Claim 34999 were used in the coworker analysis. This corresponds to a total of 4,117 claimants; however, some claimants in this total would not be included due to the lack of internal monitoring or the temporal constraints of the covered employment (e.g., employed after 1990). This cutoff point was likely chosen based on the number of claims with internal dosimetry files available at the time the coworker assessment was first undertaken and corresponds to roughly August 2011.

As of the writing of this report, an additional 2,133 claims have been submitted for SRS with individual monitoring records compiled and supplied by DOE. At face value, this could potentially represent a 50 percent increase in the available internal monitoring data for analysis in the coworker model. Therefore, it is important to understand the covered years of employment

[1] Some findings related to ORAUT-OTIB-0075 are still under discussion by the SRS and SEC Issues Work Groups. These findings are provided in attachment B for ease of reference.

and potential internal monitoring coverage represented by this latter group of claims. SC&A compared the covered employment years for both the analyzed group of claims (Claims 0–34999) and the latter group of claims that could potentially be used to augment the coworker analysis (Claims 35000+). Figure 12 shows the number of years of covered employment for each group; figure 13 displays the same data as a percentage of the total for both groups. Interestingly, the number of claims with covered employment per year in the original group remained somewhat consistent throughout the period of interest, while the latter group of claims remained consistent until the early 1970s, when a significant increase in covered years was observed for each subsequent year. While one might expect that claims filed more recently would have covered employment that was slightly biased toward later years, the significant increase in frequency is more likely driven by the granting of SEC Petition 103, which extends from January 1, 1953, through September 30, 1972. During the years after the SEC, the percentage of the total covered years of employment represented by the latter group ranged from roughly 18 percent in 1973 to over 44 percent in 1990.

Figure 12. Total number of covered employment years for each claimant group

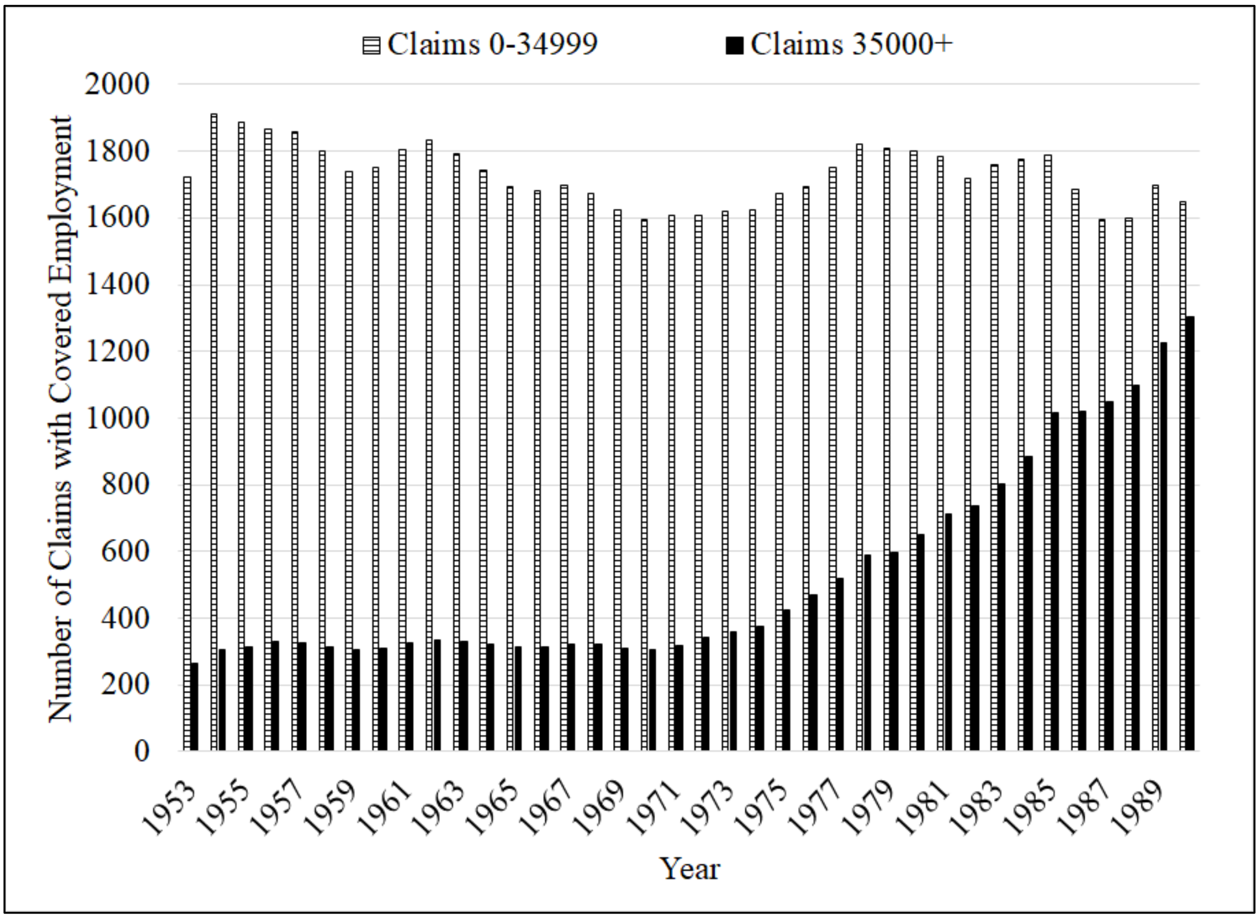
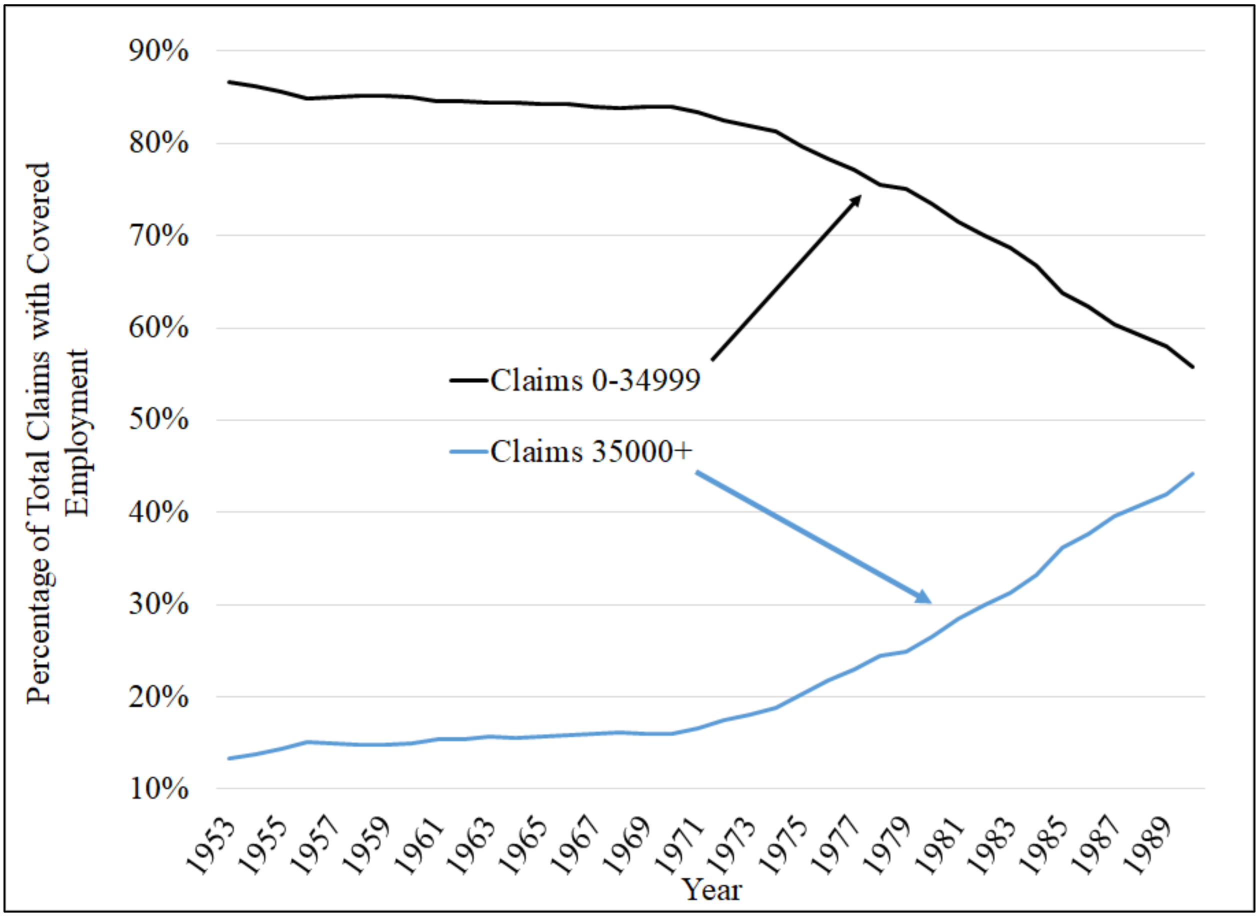


Figure 13. Percentage of total covered employment years for each claimant group



In addition to the comparison of covered employment between the original analyzed group (Claims 0–34999) and the latter group (Claims 35000+), SC&A performed a scoping tally of the number of claims in each group that had internal monitoring records during the period of interest. Similar to figures 12 and 13, figures 14 and 15 show the total number of claims with internal monitoring by year for each group and also the percentage of the total internally monitored years for both groups combined. SC&A did not attempt to parse the available internal monitoring data by contaminant or monitoring method (urinalysis versus whole body count). Not surprisingly, the trends in monitoring data closely mirror the observed trends in covered employment.

While the effect of adding the additional claimant data since August 2011 to the current coworker distributions is not possible to quantify at this time, the evaluation of such data would clearly be beneficial from a completeness standpoint, given that a full analysis of the SRS monitored population is not currently feasible prior to 1991. Furthermore, claimant data in NOCTS are already in an electronically useable format for analysis per OTIB-0081 (cited at the start of this section).

Finally, the inclusion of additional claimant data into the coworker analysis may obviate the need to combine multiple years for evaluation. This is especially true for CTW analysis of uranium data in the 1980s because the additional claimant monitoring data are biased toward these later years. The additional data may also have an effect on the analysis of whole body counts for cesium, though the years with limited data for that contaminant and analysis were prior to 1974. Evaluating coworker data on a year-by-year basis, or a shorter period if available, is preferable to combining years for analysis due to an insufficient number of workers in a given period.

Figure 14. Approximate total number of internally monitored employment years for each claimant group

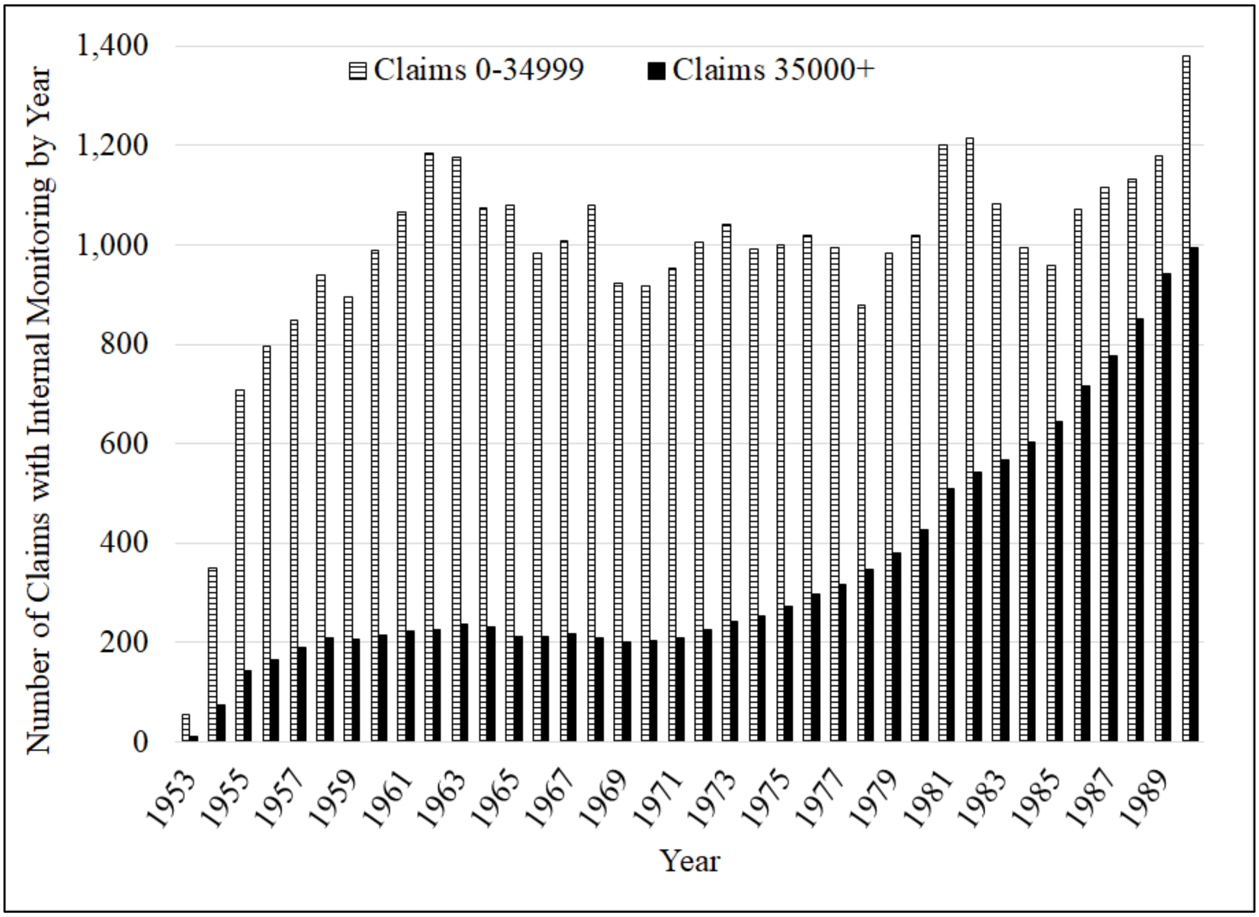
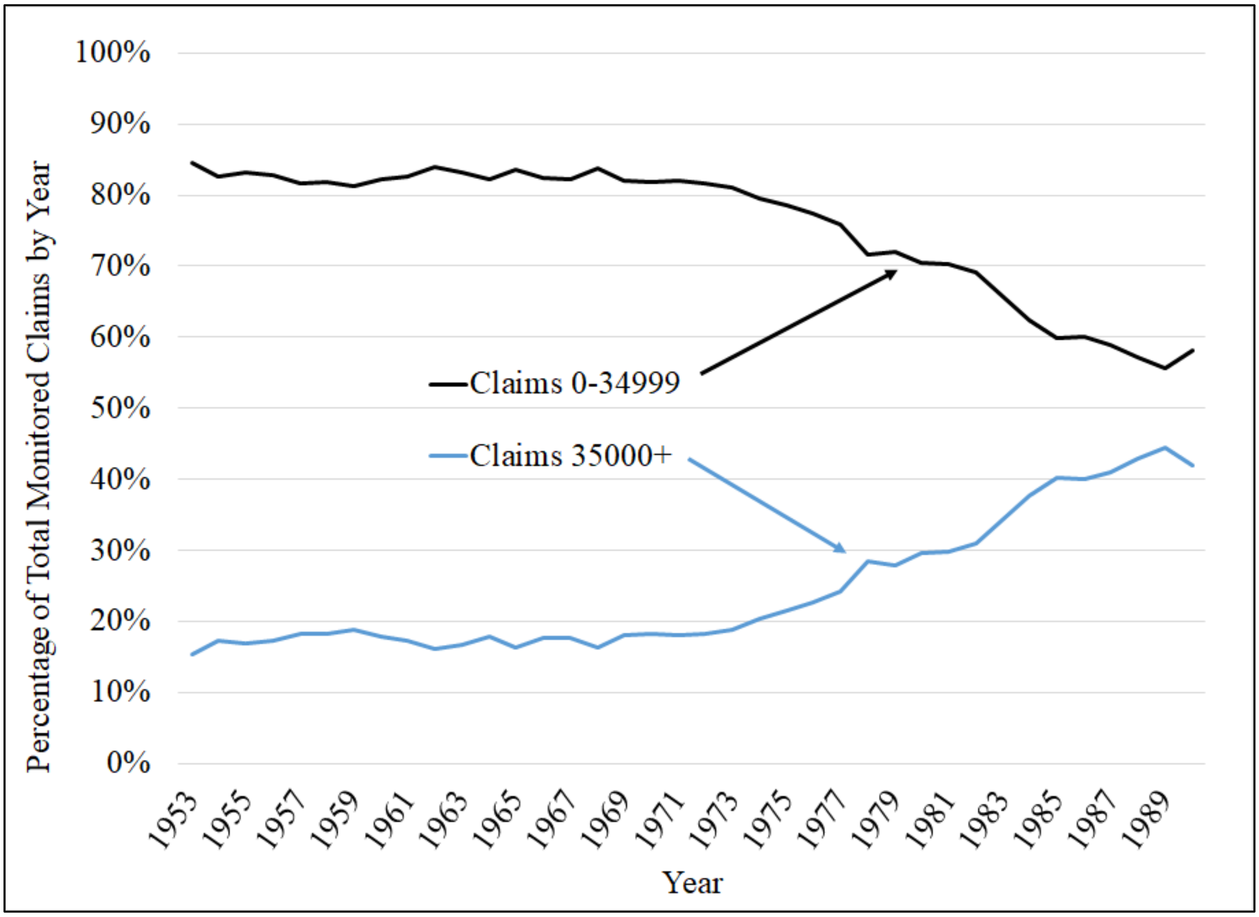


Figure 15. Percentage of total covered employment years for each claimant group



Finding 3: The coworker analysis uses the internal monitoring for claimants for whom data were available to NIOSH in approximately August 2011 (~4,000 claims). Since that time, approximately 2,000 additional claims have been submitted that could be used to augment the coworker dataset. Inclusion of these data would be especially important for the two contaminants that required a combination of multiple years for analysis due to lack of a sufficient number of data points (uranium and cesium).

4.2 Completeness of laboratory logbook data

Laboratory logbook results were used in OTIB-0081 for coworker modeling of trivalent actinides (Am/Cm/Cf) and also for a portion of the period when neptunium monitoring was performed primarily by urinalysis (up to 1969). As opposed to the completeness issues associated with using only claimant internal monitoring records, the use of laboratory logbooks should contain a complete dataset of the entire monitored population at SRS.

The most informative completeness test is to compare the number of bioassay results available for analysis to the number of bioassays that were reported to have been conducted during a given year. Figure 16 shows this comparison for trivalent actinides, and figure 17 for neptunium.

Figure 16. Comparison of available trivalent logbook data versus the reported number of analyzed bioassay samples

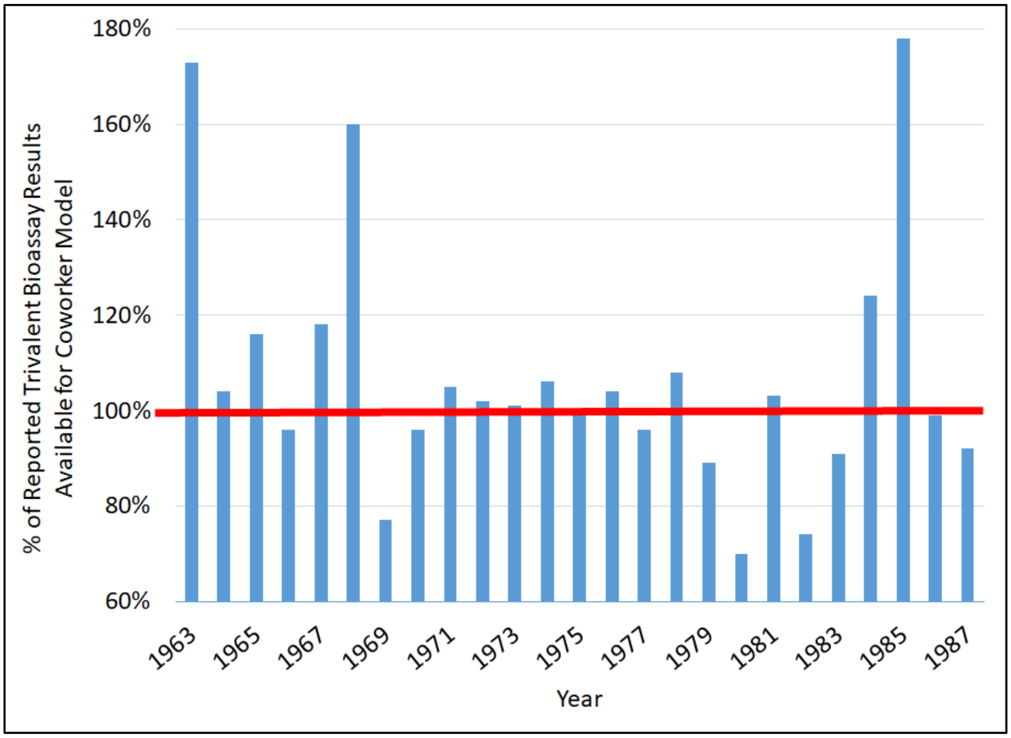
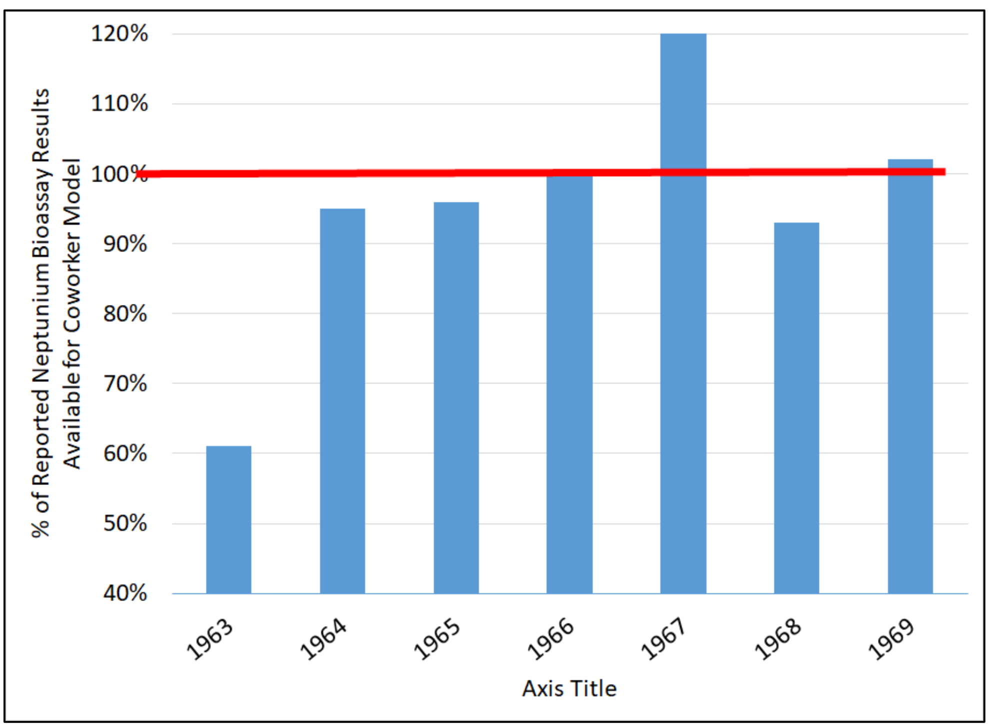


Figure 17. Comparison of available neptunium logbook data versus the reported number of analyzed bioassay samples



For americium, the number of samples available for coworker modeling actually exceeded the number of reported bioassay samples in available health physics reports (the average over all years was 105 percent of the reported samples). Specific to the post-SEC period (after September 1972), the number of available samples closely matched the number of reported samples. The notable exceptions occur in 1980 and 1982, when only 70 percent and 74 percent of the reported samples were identified in the available logbooks, respectively. These years are not specifically addressed in OTIB-0081, revision 04.

Observation 4: Available trivalent logbook data show notable differences with the number of reported samples taken in 1980 and 1982. These years, and any changes in operations, are not discussed specifically in OTIB-0081. However, a future NIOSH report on americium exposure potential at SRS is pending that may address the apparent gaps in the data.

The percentage of available neptunium urinalysis data shown in figure 17 shows that there is a significant completeness issue in 1963, when only 61 percent (544 of 898) of the reported urinalysis results were available. In addition, no comparison could be made for the years 1961 and 1962 because the total neptunium bioassay samples analyzed in these years was not available. However, SC&A would note that this period is also covered by SEC-00103; thus, any deficiencies in completeness would only result in the proposed internal dose methodologies becoming invalid for noncompensable claims. For periods outside the established SEC, OTIB-0081 uses claimant whole body count data available in NOCTS. The completeness of NOCTS data is discussed in section 4.1 of this report.

5 Evaluation of Coworker Stratification

The stratification of coworker models into different subgroups at a specific work site must be carefully evaluated when there is reason to believe that the different subgroups have appreciably different exposure potential. The coworker models developed in OTIB-0081 have elected to stratify the available coworker models into CTWs and nonCTWs. The following two subsections provides SC&A's review and discussion of the stratification of the SRS coworker models. Section 5.1 provides general comments on the decisions and assumptions underlying NIOSH's decision to stratify calculated coworker intakes into the two subgroups. Section 5.2 describes SC&A's evaluation of the ability to effectively identify workers and assign their internal monitoring results with the appropriate stratified dataset.

5.1 General comments on stratification of OTIB-0081

As noted in the introduction, the coworker implementation guide (NIOSH, 2015a) requires that coworker model stratification (i.e., the development of separate coworker distributions) must be evaluated when the following conditions exist:

> 1) accurate job categories and/or descriptions can be obtained for all workers making up the general coworker dataset; 2) there is reason to believe that one of the job categories is more highly exposed; and, 3) there were unmonitored workers in this job category. [NIOSH, 2015a, p. 10]

NIOSH (2015a) also states that once the distributions for each coworker strata have been developed, they must be evaluated to determine if there is an actual significant *statistical* difference between the two (or more) worker populations. For the development of OTIB-0081, NIOSH has elected to use the a priori assumption that CTWs[2] and nonCTWs represent different exposure profiles. The decision to stratify the coworker data into CTW and nonCTW was based primarily on the following two qualitative observations:

- NonCTWs generally perform what is considered operational work, which involves handling large quantities of radioactive material on a routine basis. However, this work is conducted with much more stringent procedural and engineering controls in place to limit internal exposure potential.

- CTWs generally perform what is considered off-normal work, which potentially involves contact with smaller relative quantities of radioactive material and on a less routine basis. However, because of the nature of the work, there is considerably more procedural uncertainty, and established engineering controls might have been purposely breached or otherwise rendered ineffective.

Observation 5: OTIB-0081 does not provide a statistical comparison of the two stratified groups as prescribed in the coworker implementation guide. The various coworker models were stratified based on the a priori assumption that exposure potential between CTWs and nonCTWs was different.

Another important assumption in OTIB-0081 is that subcontractor CTWs do not have a different exposure potential that prime contractor CTWs. This is an important assumption because it allows for both types of CTWs to be subsumed into a single coworker distribution for each contaminant of interest (refer to section 3.2.1 of OTIB-0081 for a discussion). NIOSH bases this assumption largely on a review of a subset of job plans and radiological surveys. Based on this review, NIOSH concluded that:

> it is clear that multiple types of crafts workers participated on the same type of jobs with common exposure potential. [NIOSH, 2019a, p. 28]

OTIB-0081 provides three examples of job plans exhibiting these characteristics, with additional examples in appendix B. SC&A does not find these limited qualitative examples to be compelling evidence that subcontractor workers and prime contract workers were doing the same exact jobs and thus had the same exposure potential.

In the first example, one set of workers is cutting a section of an old abandoned drain line to obtain a sample for analysis, and one set of workers is connecting a drain line. The operations were in two separate areas, and two different general external dose rates were measured (though the differences were admittedly small).

However, assuming the external dose rates listed on the job plan are reflective of the work environment, the differences in the external dose rates associated with the second example involving master slave manipulator (MSM) work are a more than a factor of 10 different

[2] The *construction trade worker* category includes energy employees for both the prime contractor and subcontractors operating at SRS.

(3 milliroentgen per hour (mR/hr) and 30–50 mR/hr). In addition, OTIB-0081 states the following about MSM work:

> Repair of the Master/Slave Manipulator (MSM) arms were almost exclusively a maintenance operation as shown in Figure 3-3. There are multiple job plans for this type of work as the repairs appeared to be routine . . . . In general, very few construction operations mention the MSMs. [NIOSH, 2019a, pp. 29–30]

The implication from this excerpt is that these types of jobs were almost always done by routine maintenance workers (presumably the prime contractors), which is at odds with the assumption that subcontractor and prime contractor CTWs worked side by side on the same jobs.

Finally, the third example provided states the following:

> Portions of three Job Plans for a set of connected work in Building 773-A Rooms C-135/C-139 are shown in Figure 3-5. Work was performed by construction Carpenters, E&I Mechanics, and Maintenance Mechanics, which supports the premise that both DuPont and subcontracted CTWs performed similar work for short periods across SRS. [NIOSH, 2019a, p. 34]

In this case, the job tasks were performed on completely different days and involved different work:

- Job Plan 1: Construction carpenters drilling catch pans and performing line breaks to install hoses.
- Job Plan 2: Electrical and Instrumentation (E&I) Mechanics removing a light fixture in a shielded area. Afterwards, construction carpenters would erect scaffolding to perform a new drill line installation.
- Job Plan 3: Repair a handle on a glove box dust damper (the worker type is not indicated on the job plan).

The only commonality between the three jobs appears to be the location.

Per prior discussions in November and December 2017 (SRS Work Group, 2017, and ABRWH, 2017, respectively) about subcontractor workers, in particular those monitored by job-specific bioassay, SC&A feels that a more quantitative analysis of job plans is warranted to assure that prime contractor CTWs and subcontractor CTWs worked side by side on the same jobs and thus had the same potential for exposure. This is particularly important when considering the likelihood that prime contractors were on a routine monitoring schedule while many subcontractors may have been on a job-specific monitoring schedule. NIOSH is currently evaluating a significantly larger set of job plans in order to make such quantitative assessments. However, that evaluation was not available at the time of this review; therefore, further discussion of the appropriateness of subsuming all CTWs into a single coworker distribution is not warranted in this report.

Observation 6: SC&A believes a quantitative assessment of available job plans, rather than a qualitative basis, is appropriate to determine that prime contractor and subcontractor CTWs are part of the same exposure strata. Such an assessment has been performed by NIOSH, and a report of their findings has recently been issued (NIOSH, 2019d).

5.2 Evaluation of the identification of workers with the appropriate strata

As described in section 5.1 above, three general criteria are provided in the coworker implementation guide to indicate when stratification must be considered in coworker development. The first criterion requires that accurate job categories and/or descriptions can be obtained for all workers making up the general coworker dataset. This criterion becomes especially important when operating under the premise that the two or more groups identified for stratification evaluation have sufficiently different exposure potential. For example, if it is known (or strongly suspected) that “group A” has a higher exposure potential than “group B,” then any inadvertent inclusion of group B worker monitoring results with the group A strata may incorrectly bias the resulting coworker intakes low for group A (and vice versa for group B).

For SRS coworker models, the chosen strata are delineated as CTWs and nonCTWs. However, in a more a practical sense, the actual chosen strata are the delineation between workers involved in nonroutine work and routine work. Examples of nonroutine work would include (but are not limited to): new construction in contaminated areas, renovation work, maintenance on instrumentation and other equipment, and decontamination and decommissioning work. Examples of routine work are generally described as production work that is performed using existing shielding, glove boxes, and other semipermanent engineering controls that have been specifically designed for the established procedure and radiological process. The coworker model provides a listing of job types that it considers to be CTWs and nonCTWs in table 3-2, which is reproduced here as table 15.

Table 15. CTW and nonCTW job titles as contained in OTIB-0081

CTW occupations	nonCTW occupations
Boilermaker	Administrative Assistant
Carpenter	Assistant
Concrete worker	Cafeteria
Construction worker	Clerical
Driver	Crane Process Operator
E&I Tech	Engineer
Electrician	Escort
Heavy equipment operator	HP [health physicist]
Insulator	Human Resources
Ironworker	Instructor
Laborer	Laundry
Maintenance	Layout
Mechanic	Machinist
Painter	Manager
Rigger	Pilot
Sheetmetal worker	QA
Welder	Reactor Operator
	Security
	Specialist
	Supervisor

Source: NIOSH, 2019a, table 3-2.

It should be noted that "Machinist" is considered a nonCTW in the coworker model; however, it is considered a CTW in OCAS-PER-014 (NIOSH, 2007), which deals with external coworker dose assignment for CTWs. This inconsistency should be discussed and resolved; otherwise, the potential exists for a claimant to receive a CTW coworker assignment for external dose but a nonCTW coworker assignment for internal dose.

Finding 4: Classification of a "Machinist" as a nonCTW in OTIB-0081 is inconsistent with its classification in OCAS-PER-014.

While the above characterization of the chosen strata as shown in table 15 is clear and rather simplistic, the identification of workers within each stratum becomes much more complex when considering workers who have job types that (by default) might involve routine or nonroutine work (or potentially both) during a given time period. Some general examples of ambiguous job designations might include:

- **Supervisor/Foreman:** Such work may be indicative of an energy employee (EE) who is "hands off" and generally only observes the nonroutine work or whose duties mainly include administrative duties related to the nonroutine work. Alternately, a supervisor/foreman (in particular, a first line supervisor) may be performing "hands on" work with a relatively small crew of workers all doing the same task. For this particular job type, the stratification decision may also have a temporal component. Individual evaluations of industrial hygiene exposures in many U.S. Department of Labor (DOL) files indicate the role of supervisors in relation to chemical hazards may have changed in the early 1970s. It is logical that a similar characterization existed for radiological hazards. Figure 18 below shows an example of an industrial hygiene record displaying this boilerplate information.

- **Assistant/Helper:** This category is especially broad, as it could potentially represent an assistant to a number of different CTW-type workers (e.g., welding assistant, carpenter's assistant) in which working conditions would be expected to be sufficiently similar to the CTW category. Alternately, assistant may refer to nonCTW-type work, such as an administrative assistant, laboratory assistant, technical assistant, project assistant, engineering assistant, etc.

- **Operator:** In general, this category would typically be associated with nonCTWs performing production work (such as a "Chemical Operator"). However, SC&A observed evidence that the term "Operator" may also have been used by the site to represent CTW-type jobs, such as Heavy Equipment Operator, Truck Driver, and nonproduction Crane Operator. This appears especially problematic for workers whose specific job title is "General Service Operator." Further confounding the strata designation are EEs whose work is described simply as "operations," which could mean the standard Production Operator category or alternately an E&I Mechanic who performed maintenance activities in operational areas.

For some illustrative examples of these ambiguities identified during SC&A's analysis, please refer to table 17 in the discussion of SC&A's independent evaluation of worker designation later in this section.

Figure 18. Excerpt from an industrial hygiene evaluation included in DOL case files concerning maintenance supervisors

Maintenance Supervisor [redacted]

A typical Maintenance Supervisor coordinated maintenance activities in the facility/area. Until about 1970, Supervisors were more active participants in the tasks performed. After about 1970, it was an infrequent occasion in which a Maintenance Supervisor would have been present during performance of tasks requiring the handling chemicals. During this time, the Supervisor's job would have been observation rather than chemical handling.

Source: Case [redacted], DOL Initial Case, p. 302

In addition to the ambiguous job types described above, care must be taken for workers who transitioned from clear CTW job categories to nonCTW job categories during their career. A typical example observed by SC&A includes a Maintenance Mechanic who transitioned to the job titles of project assistant and then project engineer. In these cases, it becomes important to understand the temporal change in job duties so that the individual's internal monitoring records are correctly divided between the two strata.

The coworker model strata designation is primarily based on a payroll number identification system that is unique to SRS. This methodology is described in section 3.2 of OTIB-0081 and not repeated in this report. In addition to the payroll identifiers, a secondary source of information used to buttress the strata identification in certain cases was the actual occupation listed for the individual. SC&A assumes that this information is extracted directly from the NOCTS listing for the individual EE.

To assess the effectiveness of accurately placing workers in the correct strata, SC&A performed a two-step independent evaluation of worker designation for a subset of “targeted workers” where the risk of inadvertently including a worker in the incorrect stratum is likely the highest (i.e., the somewhat ambiguous job titles and workers with multiple designations as discussed above). It must be stressed that this sampling was a “targeted” evaluation of specific claims that SC&A believes had the greatest potential for misclassification. The targeted sampling does not reflect a representative subset of the claimant population, nor does the resulting evaluation apply to established quality assurance criteria as discussed in section 6 of this report. The first step in the evaluation can be considered more of a qualitative assessment of job duties. For the second step, SC&A extracted the job title information (and by extension the CTW/nonCTW designation) associated with each EE’s in vitro and in vivo result found in the NIOSH databases provided to SC&A[3] for quantitative comparison against alternate sources.

For the first step, SC&A based its evaluation on specific information in the individual claimant’s NOCTS documentation, such as the computer-assisted telephone interview (CATI) and DOL case files. The CATI document often contains specific statements by the EE related to the work they performed and, in some cases, actual dates of different job duties and work locations that provide a more complete picture of which stratum is likely correct for the EE. The DOL case files can contain a number of different references, including (but not limited to) additional statements by the claimant, individual resumes, work performance evaluations, industrial hygiene evaluation summaries, and disability reports. In addition to these, the most useful reference in the DOL case file is the “EEOICPA Occupational History Interview,” which has a listing of job types and an entry for dates in each category (refer to figure 19). In addition, the EEOICPA Occupational History Interview contains an additional section for the EE to add further description, such as building location and a description of duties for each of the entry dates (refer to figure 20).

[3] These databases are titled, “SRS combined in-vitro data 0901818 with CTW.xls” and “SRS combined in-vivo data subset 092518 with CTW.xls.”

Figure 19. Example of an EEOICPA occupational history interview form, showing list of job titles and dates of employment

Section 5 (C): LABOR CATEGORY (While employed at a DOE Facility)

☑ Any that apply

☑	Work Category	Approximate dates of Employment (Example:11//59 – 02//65)
	Crafts	
	Carpenter	
	Electrician	
	Heating, Ventilating, Air-conditioning maintenance	
X	Machinist	[redacted]
	Mason	
	Mechanic, Instrumental	
X	Mechanic, Maintenance	[redacted]
	Mechanic, Vehicle	
	Millwright	
	Painter	
	Plumber and/or Pipefitter	
	Structural and Metal Worker	
	Tool and Die Maker	
	Welder	
	Engineers	
	Chemical Engineer	
	Civil Engineer	
	Construction Engineer	
	Electrical Engineer	
	Industrial Engineer	
	Mechanical Engineer	
	Quality Control Engineer	
	Safety Engineer	
	General Managers, Supervisors, and Project Managers	
	First line supervisor	
	General manager or Executive	
	Project or Program Manager	

Figure 20. Example of an EEOICPA occupational history interview form, showing example entry of building, work activity, years of employment, and frequency

Section 6: WORK AREAS (Building Name and Function)

Please note, the building, work activity, years of employment and frequency in which the employee was performing type of work activity in the identified location. If building name of number is unknown, please mark "unknown" and provide description of activities occurring in building.

Use the following key to fill in the **"Frequency" box:**

5 Daily or most days per week
4 2-3 days per week
3 1-2 days per week
2 Few times per month
1 Once per month or less

Building Number/Name or Description	*Work Activity*	Years of Employment	Frequency Pick 1-3
Example: C200 or Process Bld	***Maintenance***	***1952-58***	***3***

SC&A analyzed claimants who had been characterized as both a CTW and a nonCTW during their monitored employment. Based on a review of the NOCTS documentation, SC&A determined whether there was evidence of both routine and nonroutine work during the EE's employment. SC&A identified 327 claimants who had been classified as both a CTW and a nonCTW during their relevant employment. SC&A found that approximately 65 percent of these targeted claimants displayed evidence of both types of jobs (routine and nonroutine during their employment), while the remaining 35 percent appear to only have performed work relevant to one of the established strata.

SC&A then analyzed claimants categorized as one of the ambiguous job titles discussed above. SCA identified and evaluated 172 claimants designated as a supervisor/foreman (this represents just 17 percent of the total available for review in this job category). Approximately 57 percent of these supervisory positions were associated with CTWs, 30 percent were associated with nonCTWs, and the remaining 13 percent were characterized as indeterminate due to lack of information. Of the supervisory positions associated with CTWs, less than one-third contained information to designate them as "hands on" versus "hands off," which would allow for a more definitive determination of the appropriate strata.

Regarding the job title "Operator," SC&A reviewed 157 total claim files (just 20 percent of the total available for review with that job title). Of the reviewed population, SC&A determined that approximately 45 percent may have been incorrectly associated with nonCTW/routine type work duties. Several examples of this are provided in table 17 at the end of this discussion. Many of these apparent contradictions may be related to the job title "general service operator," as discussed further in this section.

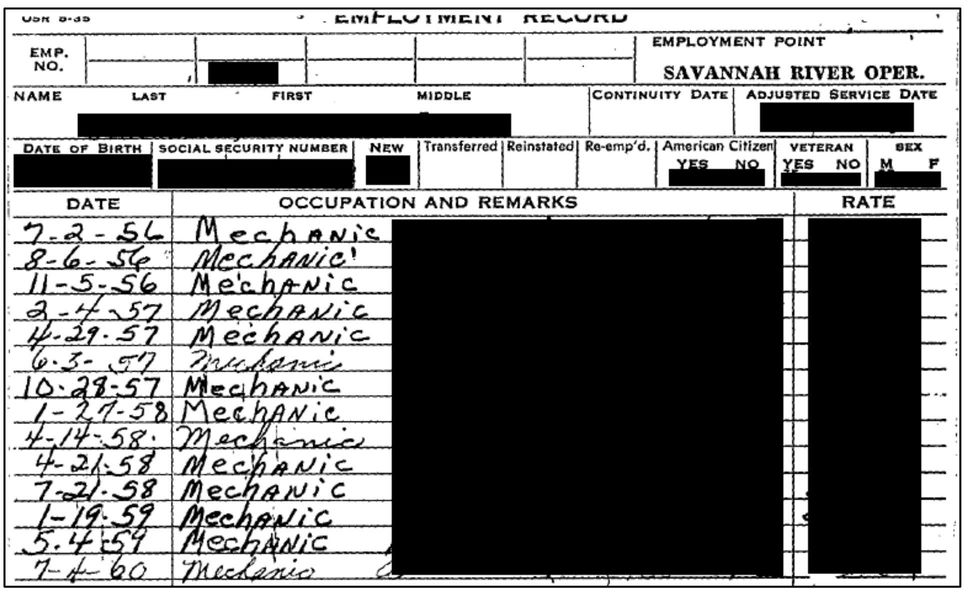
Finally, SC&A reviewed 129 claimant files associated with the "Assistant/Helper" category. Approximately 53 percent of the reviewed claims designated as an "Assistant/Helper" appear to be associated with nonCTW job duties, 22 percent were associated with CTW job duties, and the remaining were judged indeterminate due to lack of additional information.

SC&A acknowledges that the results of the first step of the evaluation are informative but ultimately qualitative for a number of reasons:

- Much of the information is reliant on the EE or their survivor's memory.
- Information provided may be skewed toward those job duties in which the EE recalls a definite exposure potential, while the bioassay monitoring may have included periods when little or no exposure potential was perceived by the EE.
- Temporal information related to the described job duties is not always provided.

Therefore, SC&A performed a more rigorous quantitative analysis that only considered the NOCTS documentation that includes specific temporal information. In addition to the NOCTS documentation, SC&A used a second source that includes specific temporal information: the individual worker's employment history record (an example is shown in figure 21).

Figure 21. Example of an employment history record displaying date and occupation



EMPLOYMENT RECORD

EMP. NO. [redacted]

EMPLOYMENT POINT: SAVANNAH RIVER OPER.

NAME: LAST FIRST MIDDLE [redacted]

CONTINUITY DATE | ADJUSTED SERVICE DATE [redacted]

DATE OF BIRTH [redacted] | SOCIAL SECURITY NUMBER [redacted] | NEW [redacted] | Transferred | Reinstated | Re-emp'd. | American Citizen YES NO [redacted] | VETERAN YES NO [redacted] | SEX M F [redacted]

DATE	OCCUPATION AND REMARKS	RATE
7-2-56	Mechanic [redacted]	[redacted]
8-6-56	Mechanic [redacted]	[redacted]
11-5-56	Mechanic [redacted]	[redacted]
2-4-57	Mechanic [redacted]	[redacted]
4-29-57	Mechanic [redacted]	[redacted]
6-3-57	Mechanic [redacted]	[redacted]
10-28-57	Mechanic [redacted]	[redacted]
1-27-58	Mechanic [redacted]	[redacted]
4-14-58	Mechanic [redacted]	[redacted]
4-21-58	Mechanic [redacted]	[redacted]
7-21-58	Mechanic [redacted]	[redacted]
1-19-59	Mechanic [redacted]	[redacted]
5-4-59	Mechanic [redacted]	[redacted]
7-4-60	Mechanic [redacted]	[redacted]

SC&A analyzed a subset of individual worker strata designations against each of these two sources (when available) to identify any temporal discrepancies in job title assignment. For this comparison, the job titles identified for the CTW and nonCTW categories in OTIB-0081 were used without modification. Furthermore, only the strata designation (and not the actual job title) was used to establish a "match," since the stratification of the coworker model is currently only dependent on correct identification as a CTW versus a nonCTW. The following are some illustrative examples of how this comparison was done:

- Example 1: The NOCTS temporal result indicated the job title of "Project Assistant" (nonCTW), though the available information for that period actually described work consistent with a "Pipefitter." The OTIB-0081 designation for the same date indicated the EE was an assistant. This would be considered a match in the analysis below because a "Project Assistant" and an "Assistant" are both considered nonCTWs per OTIB-0081.

- Example 2: The employment history record indicates the job title of "General Service Operator." The OTIB-0081 designation indicates "Laborer" during the same period. This would *not* be considered a match even if additional evidence (e.g., NOCTS references) indicated the job duties were consistent with a laborer.[4]

- Example 3: The employment history record indicates the job title of supervisor, the NOCTS designation indicates project engineer, and the OTIB-0081 designation is as an operator. This combination would be considered a match, since all three job designations represent nonCTW work categories in OTIB-0081.

The subset of workers for which SC&A performed this analysis included workers with multiple CTW/nonCTW designations but also the subset of 157 operators discussed previously in this section. A total of 15,244 internal monitoring data points used in OTIB-0081 were checked against SC&A's independent compilation of employment history record information and temporal-based NOCTS documentation. The results are shown as an unadjusted total and an adjusted total in table 16. The unadjusted totals indicate situations in which either the employment history record or the NOCTS temporal designation was in apparent conflict with the coworker model designation. The adjusted total accounts for situations in which the coworker model designation is in conflict with one of the SC&A references, but not both (e.g., the OTIB-0081 designation agrees with the NOCTS designation but not the employment history designation). As seen in table 16, the total adjusted percentage of conflicts identified between the targeted sample of OTIB-0081 strata designations and the two temporal-based resources used by SC&A was just over 9 percent. A little less than one-third of the adjusted conflicts reflected situations in which both the temporal NOCTS data and the employment history were in conflict with the NIOSH strata definition.

Table 16. Summary of strata comparison between OTIB-0081 disposition and SC&A analysis

Category of conflict with OTIB-0081 rev. 04 worker stratification designation	Unadjusted total (%)	Adjusted total (%)
Conflict with both NOCTS and employment history	417 (2.74%)	417 (2.83%)
Conflict with employment history only (NOCTS information not available)	594 (3.90%)	454 (3.09%)
Conflict with NOCTS only (employment history information not available)	866 (5.68%)	473 (3.22%)
Total conflicts	1,877 (12.31%)	1,344 (9.14%)
No conflict	13,367 (87.69%)	13,367 (90.86%)

[4] As noted in this section, adjustments were made for situations in which the employment history record and the NOCTS strata designation were conflicting.

Finding 5: A targeted sampling comparing the OTIB-0081 strata designation (CTW or nonCTW) against two alternate sources for identifying worker job classification indicated that just over 9 percent of the entries appear to be in conflict when comparing the NIOSH and SC&A analyses. As this was a targeted subgroup of the monitored claimant population, it does not represent the entirety of the monitored population and, therefore, is not subject to the established quality assurance criteria for evaluating coworker datasets.

During the course of this temporal comparison, SC&A noted several cases that illustrate the difficulties and potential issues with correctly identifying a worker with the appropriate stratum. These cases are discussed in table 17. Each case was assigned an arbitrary alphabetical designation that does not reflect the actual EE in any identifiable way. Claim numbers associated with the arbitrary case designations are provided in attachment C for reference.

Table 17. Illustrative examples of strata conflicts identified by SC&A analysis

Case ID	Summary of strata designations *	Additional comments
A	**OTIB-0081 Designation:** Operator, Technician, Technical Assistant, Laborer **Work History Designation:** General Service Operator, [redacted] **NOCTS Designation:** Laborer, Lab Tech, Lab Analyst	The CATI with the EE indicates laborer work at the burial ground; the DOL files indicate this occurred [redacted] There was no indication of laborer work at the end of the employment/monitored period. It is unclear if the work designations were inadvertently "flipped." Other cases exhibiting this behavior include Case IDs C and D. This is also an example where it appears "General Service Operator" was actually representative of a Laborer at the burial ground. Other cases illustrating potential problems with strata designation involving General Service Operators include Case IDs L–AB.
B	**OTIB-0081 Designation:** Operator, Construction **Work History Designation:** [redacted] General Service Operator [redacted] **NOCTS Designation:** Construction, General Laborer, Production Operator	This case illustrates a situation where the job designation might have been "flipped," with the OTIB-0081 designation changing from operator to construction while the CATI/DOL information indicates that work started in construction before moving to operator. In addition, this case indicated General Service Operator for employment periods that were designated as a General Laborer and a Production Operator per information in the CATI/DOL files.
E	**OTIB-0081 Designation:** First five entries (covering 6 years) indicate Helper, with the remainder of internal dosimetry designated as a Mechanic. **Work History Designation:** Started as a "Mechanic A" then Maintenance Mechanic for entire employment. **NOCTS Designation:** Maintenance Mechanic.	The DOL initial case for this claim indicates the EE [redacted] a Maintenance Mechanic. A description of job duties indicates welding as well as regular maintenance. The "Helper" designation is considered a nonCTW in OTIB-0081. Other examples where the "Helper/Assistant" designation was applied when a CTW job type was likely appropriate include Case IDs F–J.

Case ID	Summary of strata designations *	Additional comments
K	**OTIB-0081 Designation:** Majority of samples designated as an Operator with last few entries as a Driver. **Work History Designation:** General Service Operator throughout employment. **NOCTS Designation:** Truck Driver	The CATI performed with the EE indicates that this job was to haul whatever was needed, including radioactive waste to the burial grounds. The EE also reported being involved in the cleanup of radioactive spills. [redacted] however, the EE used personal protective equipment such as anti-contamination clothing and respirators. This example illustrates the difficulty with classifying General Service Operators with either the nonCTW or CTW strata category. Other cases that illustrate this difficulty include Case IDs L–AB.
W	**OTIB-0081 Designation:** Operator except for last entry as Laborer. **Work History Designation:** General Service Operator **NOCTS Designation:** Truck Driver	The CATI with the EE's survivor indicates that work during the monitored period was in the transportation department. The DOL case files indicate job duties consistent with a Construction Laborer and a Driver. This example is another case of a General Service Operator likely performing nonroutine duties in relation to internal exposure. Other cases that illustrate this difficulty include Case IDs L–AB.
AE	**OTIB-0081 Designation:** Mostly classified as a Mechanic; however, a roughly 5-year period in the middle of employment is classified as an Operator. **Work History Designation:** Mechanic and Maintenance Mechanic designated throughout employment. **NOCTS Designation:** Maintenance, Machine Repair	The CATI with the survivor describes general machine repair, steam piping repair and insulation, boiler repair, and other routine maintenance. There is no indication in the DOL files of work as an Operator. Other observed examples of potentially erroneous designation as a routine Operator include Case IDs AF–AO.
AP	**OTIB-0081 Designation:** During a 4-year period, the strata assignment alternates between Mechanic and Supervisor, with five changes in designation overall. **Work History Designation:** [redacted] **NOCTS Designation:** Machinist, Maintenance Supervisor, Manager in Training.	This example illustrates the difficulty in determining when a [redacted] has an exposure potential more closely associated with nonCTWs or alternately still CTWs. In this case, the OTIB-0081 method alternated between both designations depending on the sample date and, in some cases, changed during the course of a few weeks.

* Job title designations are listed temporally based on EE's employment (e.g., for Case A per the OTIB-0081 designation, the EE started as an Operator, then became a Technician before transitioning to a Technical Assistant and finally ending the relevant monitored employment as a Laborer).

As seen in the table, Cases A and B indicate a potential issue with strata designation in which the job title assignment may have been temporally flipped. For Case A, the OTIB-0081 designation indicates the start of monitored employment as an Operator before moving to technical positions and ending as a laborer. Conversely, evaluation of the NOCTS documentation indicates work started as a Laborer before moving on to technical positions in the laboratory (a seemingly more logical career path). Similarly, OTIB-0081 indicates Case B started out as an Operator and ended their career in construction, which is the contrary to what the NOCTS documentation indicated.

Case E presents an example in which "Helper" (nonCTW) was assigned for OTIB-0081 analysis; however, the employment history and NOCTS files indicate work as a Mechanic/Maintenance Mechanic. Cases K and W illustrate the issues associated with classifying workers who are designated as a "General Service Operator." In these cases, the correct job title was likely a Truck Driver (CTW) rather than an actual Production Operator (nonCTW). However, SC&A also observed cases where a "General Service Operator" involved other job duties, such as a Janitor or a Mail Clerk (nonCTW designations).

Case AE involved a period designated as an operator that was surrounded by periods as a Mechanic. The employment history and NOCTS documentation indicated that the EE's work was entirely as a Maintenance Mechanic. Case AP showed a roughly 4-year period in which [redacted] were used interchangeably. The employment history indicated the job assignment was entirely as a [redacted] during this period.

The cases referenced and discussed in table 17 illustrate the difficulty of correctly classifying certain workers as either CTW or nonCTW. This is particularly true with job titles that could potentially belong to either group, such as Assistants/Helpers, General Service Operators, and intermediate management positions such as a Foreman. Incorrect characterization of these borderline job titles has the potential to "wash out" the actual exposure potential differences between CTWs and nonCTWs.

One potential test that may provide quantitative information would be to remove the monitoring results associated with borderline job titles and see what effect this has on the resulting CTW and nonCTW distributions. If the effect on the resulting distributions is negligible, then inclusion of the borderline job titles "as is" could be considered sufficient. However, if there is a noticeable difference in the magnitude of the resulting CTW and nonCTW distributions, then a more rigorous evaluation of individual strata classifications may be warranted.

Observation 7: SC&A acknowledges that there are inherent difficulties in correctly associating individual workers with the correct CTW/nonCTW strata. This is particularly true for job titles that could potentially be included in either stratum (e.g., General Service Operators, Assistants/Helpers, Foremen). SC&A suggests a scoping analysis in which such borderline job titles are removed to ascertain the effect on the resulting distributions. Such an analysis would help determine whether current strata designations are sufficient or a more rigorous approach to individual job classification is warranted.

6 Review of Quality Assurance Assessment

Attachment A of OTIB-0081 contains an assessment of the QA tests applied to various facets of the coworker model development per the criteria and guidelines in ORAUT-RPRT-0078 (NIOSH 2016b; "RPRT-0078") and ORAUT-RPRT-0086 (NIOSH, 2017; "RPRT-0086"). This section discusses SC&A's review of the QA test results

6.1 Completeness of SRS claims tracking system data

The NOCTS bioassay samples collected from SRS employees are used as the primary data sources for the coworker study for all radionuclides except americium and neptunium. Laboratory logbooks are used for the latter two radionuclides due to insufficient NOCTS bioassay data. Completeness of the NOCTS database and the logbook data is addressed in the studies reported in attachment A of ORAUT-0081.

Attachment A contains 13 parts, shown in table 18 below.[5] Each part of the attachment reports the results of a QA analysis done in support of one section in the main body of ORAUT-0081, revision 04. Table 18 shows the OTIB-0081 section numbers and titles, along with the attachment A title, completion date, and OTIB-0081 page number reference for the QA analysis. The completeness studies for the NOCTS in vitro and in vivo data are parts 1 and 2 of table 18, respectively. The remaining parts of the table show results for logbook data completeness and CTW determination studies. The logbook data sources are discussed in the radionuclide-specific sections of this review below.

NIOSH conducted three NOCTS studies for the in vitro bioassay data, the in vivo whole body or chest count data, and the tritium data. The first NOCTS study (dated May 5, 2017) addressed completeness of NOCTS in vitro bioassay data. The second (dated August 7, 2017) addressed the in vivo data obtained from whole body or chest counts. These two studies are listed as parts 1 and 2 of table 18, respectively. The NOCTS tritium study (dated May 16, 2016) is found in part 12 of attachment A (p. 128) and is shown in part 12 of table 18, immediately before the other tritium study.

Table 19, parts 1, 2, and 12 summarize the attachment A results for the three NOCTS completeness studies. The table includes a short title for each part of attachment A, the statistical method used in the analysis, the type of fields that were checked, and a summary of the statistical results reported for the study. The following sections discuss the statistical results for the NOCTS studies.

[5] Attachment A of OTIB-0081 does not specifically number individual sections; however, SC&A ascribed section numbers for ease of cross-reference between this review and OTIB-0081.

Table 18. Summary of contents of ORAUT-OTIB-0081, rev. 04, attachment A

Part	OTIB-0081 pages	Attachment A title of QA analysis	Date	OTIB-0081 section	Referencing section of OTIB-0081
1	108–110	Savannah River Site Internal Coworker In Vitro Completeness Check	5/5/2017	3.1.1	Completeness of Claims Tracking System Data
2	111–113	SRS In Vivo Completeness Report	8/7/2017	3.1.1	Completeness of Claims Tracking System Data
3	114–115	Savannah River Site Internal Coworker In Vitro Completeness Check – Neptunium (Np)	3/7/2018	4.8.2.1	Data Completeness and Quality
4	116	SRS NOCTS In Vitro Data QA Summary	5/9/2017	3.1.2	Accuracy of Claims Tracking System Data
5	117	SRS Am QA Summary	6/16/2016	3.2.3	Worker Classification Quality Assurance, table 3-3
6	118–119	SRS Np Logbooks QA Summary	2/26/2018	3.2.3	Worker Classification Quality Assurance, table 3-3
7	120–121	SRS NOCTS WBC QA Summary	6/3/2016	3.1.2	Accuracy of Claims Tracking System Data
8	122–123	SRS Mixed FP Gamma QA Summary	6/6/2016	3.2.3	Worker Classification Quality Assurance, table 3-3
9	124	SRS In Vivo CTW QA Summary	10/5/2017	3.2.3	Worker Classification Quality Assurance, table 3-4
10	125	SRS In Vitro CTW QA Summary	6/1/2017	3.2.3	Worker Classification Quality Assurance, table 3-4
11	126–127	SRS Np Logbook CTW QA Summary	3/6/2018	3.2.3	Worker Classification Quality Assurance, table 3-4
12	128	SRS Tritium QA Summary	5/16/2016	4.2.2	Data Validation
13	129	SRS Tritium CTW QA Summary	7/14/2016	3.2.3	Worker Classification Quality Assurance, table 3-4

Table 19. Summary of ORAUT-0081, rev. 04, attachment A completeness test results

Part	Pages	Short title	Method	Fields checked	LTPD * (%)	Number of claims	Claims sampled	Items checked	Number of misses	Note	Error rate (%)	LCL (%)	UCL (%)
1	108–110	In Vitro Completeness Check	sequential sampling	critical	95% UCL<5	2,875	30	1,762	14	—	0.79	0.03	3.99
2a	111–113	In Vivo Completeness Report: Round 1	sequential sampling	—	95% UCL<5	2,823	101	840	31	—	3.69	0.37	12.89

Part	Pages	Short title	Method	Fields checked	LTPD * (%)	Number of claims	Claims sampled	Items checked	Number of misses	Note	Error rate (%)	LCL (%)	UCL (%)
2b	111–113	Round 2	RPRT-0086	—	5	2,823	410	4,048	26	—	0.64	0.25	1.35
3	114–115	In Vitro Completeness Check – Np	complete census	critical	5	382	100%	1,082	25	—	2.31	N/A	N/A
4a	116	NOCTS In Vitro Data QA Summary	RPRT-0078	critical	1	—	—	4,386	11	—	0.25	0.13	0.45
4b	116	NOCTS In Vitro Data QA Summary	RPRT-0078	all fields	5	—	—	874	4	—	0.46	0.13	1.17
5a	117	Am QA Summary	RPRT-0078	critical	1	—	—	4,242	25	—	0.59	0.39	0.86
5b	117	Am QA Summary	RPRT-0078	all fields	5	—	—	873	6	—	0.69	0.25	1.49
6a	118–119	Np Logbooks QA Summary	RPRT-0078	critical	1	—	—	3,148	27	(a)	0.86	0.61	1.18
6b	118–119	Np Logbooks QA Summary	RPRT-0078	—	—	—	—	—	21	—	0.67	0.45	0.96
6c	118–119	Np Logbooks QA Summary	RPRT-0078	all fields	5	—	—	932	8	—	0.86	0.38	1.67
7a	120–121	NOCTS WBC QA Summary	RPRT-0078	critical	1	—	—	4,375	535	(b)	12.23	11.29	13.22
7b	120–121	NOCTS WBC QA Summary	RPRT-0078	—	—	—	—	—	27	—	0.62	0.41	0.89
7c	120–121	NOCTS WBC QA Summary	RPRT-0078	all fields	5	—	—	874	45	(c)	5.15	3.78	6.83
7d	120–121	NOCTS WBC QA Summary	RPRT-0078	—	—	—	—	—	19	—	2.17	1.31	3.37
8a	122–123	Mixed FP Gamma QA Summary	RPRT-0078	critical	1	—	—	3,282	1,980	(d)	60.33	58.88	61.75
8b	122–123	Mixed FP Gamma QA Summary	RPRT-0078	—	—	—	—	—	14	—	0.43	0.27	0.67

Part	Pages	Short title	Method	Fields checked	LTPD * (%)	Number of claims	Claims sampled	Items checked	Number of misses	Note	Error rate (%)	LCL (%)	UCL (%)
8c	122–123	Mixed FP Gamma QA Summary	RPRT-0078	all fields	5	—	—	849	89	(e)	10.48	8.52	12.73
8d	122–123	Mixed FP Gamma QA Summary	RPRT-0078	—	—	—	—	—	1	—	0.12	0.004	0.65
9	124	In Vivo CTW QA Summary	RPRT-0078	all fields	5	—	—	847	25	—	2.95	1.93	4.30
10	125	In Vitro CTW QA Summary	RPRT-0078	all fields	5	—	—	873	16	—	1.83	1.05	2.95
11	126–127	Np Logbook CTW QA Summary	RPRT-0078	all fields	5	—	—	709	8	—	1.13	0.55	2.10
12a	128	Tritium QA Summary	RPRT00-78	critical	1	—	—	4,383	14	—	0.32	0.18	0.53
12b	128	Tritium QA Summary	RPRT-0078	all fields	5	—	—	874	2	—	0.23	0.03	0.82
13	129	Tritium CTW QA Summary	RPRT-0078	all fields	5	—	—	874	6	—	0.69	0.25	1.49
Total	—	—	—	—	—	—	—	40,127	303	(f)	0.76	0.60	0.94

* Lot tolerance percent defective (LTPD) for RPRT-0078 tests or confidence interval requirement for sequential sampling.
(a) Count includes as errors 6 payroll prefix and other payroll ID issues that would have no impact on data use.
(b) Count includes as errors 508 payroll prefix and other payroll ID issues that would have no impact on data use.
(c) Count includes as errors 26 payroll prefix and other payroll ID issues that would have no impact on data use.
(d) Count includes as errors 1,966 payroll prefix and other payroll ID issues that would not affect use of the data for CTW determination or for proper identification of the person.
(e) Count includes as errors 88 payroll prefix and other payroll ID issues that would not affect use of the data for CTW determination or for proper identification of the person.
(f) Items noted by a, b, c, d, and e are not included in error count total. A 95 percent confidence interval is obtained by simulation (refer to text).

6.1.1 NOCTS in vitro completeness check

The NOCTS data contain over 260,000 tritium bioassay results and over 100,000 non-tritium in vitro bioassay results for samples submitted by more than 1,500 workers between 1954 and 1990. The completeness review was performed on the data entry process that was used to build the NOCTS electronic database from the hardcopy records. The completeness review was performed in two steps. This review was conducted by selecting a random sample of the NOCTS claims with bioassay data and verifying that all the data in the hardcopy records were included in the electronic dataset.

Due to the random sampling of claims, each claim has the same probability of selection. However, each claim contains a variable number of bioassay data. Thus, the individual data elements do not have the same probability of selection. This type of sampling (called cluster sampling) requires a statistical analysis to determine the proper weight to assign to each data element when interpreting the results of the matching to hardcopy data. NIOSH has addressed this type of sampling in RPRT-0086 (NIOSH, 2017). Much of the work on ORAUT-0081 was completed prior to the publication of RPRT-0086, and the methods recommended for cluster sampling were not used in the work for part 1 of attachment A. This issue also affects the analysis of the part 2 in vivo body count data discussed below.

A detailed page-by-page review of the selected claims was conducted to ensure all pertinent data were entered correctly. The counting technique focused on three critical fields: sample date, radionuclide, and the numerical result. If any of these three fields were missing, that entire line of data was counted as not matching the electronic database. A list of 30 claims was selected randomly from the original set of 2,875. The 30 claim files were checked, and a line was called missing if any of the three critical fields were missing. Out of the 1,762 lines of data that were checked, 14 lines were missing from the electronic dataset.

The results of the analysis are shown at the right in the first row of table 19. The error rate in matching the lines of data was very low at 0.79 percent. The 95 percent upper confidence limit (UCL) for the error rate is reported to be about 4 percent. No details are provided for the calculation of the confidence interval in the report. However, NIOSH has indicated that the procedures in RPRT-0086 were used to compute the confidence interval, but not the sample size. A Wald plot is shown, which interprets the results in terms of a sequential sampling approach. Due to the lack of equal probability of selection, this interpretation is not correct.

Despite the problems of unequal weighting, the very low estimated error rate (less than 1 percent) for the in vitro completeness test makes it unlikely that the 95 percent UCL would exceed the 5 percent success criterion.

6.1.2 NOCTS in vivo bioassay data

The NOCTS data contain records of almost 15,000 in vivo whole body counts or chest counts. Two separate completeness reviews were conducted for the in vivo data, referred to as part 2 round 1 and round 2 in table 19. The first round of analysis used a procedure identical to that used in part 1 for the NOCTS in vitro data analysis. The review was conducted by selecting a random sample of the NOCTS claims with counting data and matching lines of data in these claims to the electronic dataset.

The review of the selected claims focused on four critical fields: sample date, nuclide, numerical result, and MDA data. If any of these four fields were missing, that entire line of data was counted as not matching the electronic database. A list of 101 claims was selected randomly from the original set of 2,823 claims with count data. The 101 claim files were checked, and a line was called missing if any of the four critical fields were missing.

Due to the random sampling of claims, each claim has the same probability of selection. However, each claim contains a variable number of lines of data. As with the in vitro data analysis, the sampled lines of data do not have the same probability of selection. The first round completeness review in part 2 was completed prior to the publication of RPRT-0086, and the methods recommended there for cluster sampling were not used in round 1 on the in vivo analysis.

Out of the 840 lines of data that were checked in round 1, there were 31 lines with errors. Of these errors, 30 were due to 2 claims of the 101 sampled claims. The estimated error rate for the round 1 review was 3.56 percent, and the 95 percent UCL was 12.89 percent. Since the UCL was well above the 5 percent success criteria, an additional test was warranted. Corrections were made to the 31 errors found during round 1, and the cluster sampling procedure recommended in RPRT-0086 was applied in the second round of the in vivo completeness test. In the cluster sampling procedure, the unequal probabilities of selection are accounted for by using weights inversely proportional to the probability of selection.

In the round 2 of the in vivo completeness test, a new list of 410 claims were randomly chosen from the set of 2,823 claims. The claim files for these 410 claims were checked, and a row was counted missing if any of the four pieces of necessary information were missing. Of the 4,048 lines of data checked for missing data, 26 errors were noted. The results of the round 2 analysis are shown in table 19. The error rate in matching the lines of data was very low at 0.64 percent. The 95 percent UCL for the error rate is 1.35 percent, well below the 5 percent success criterion.

6.1.3 NOCTS in vitro data QA summary

Part 4 of attachment A and tables 18 and 19 include a data transcription test for the NOCTS in vitro dataset. The data transcription accuracy of the in vitro bioassay data was checked in accordance with RPRT-0078 (NIOSH, 2016b). The nuclide, numerical result, and "<" fields were checked with a maximum 1 percent allowable error rate. The QA check resulted in an estimated error rate of 0.25 percent with a 95 percent UCL of 0.45 percent. The error rate is well below the acceptance criterion for critical fields of 1 percent.

A second data transcription test was conducted for all fields with a maximum 5 percent allowable error rate. This test resulted in an estimated error rate of 0.46 percent with a 95 percent UCL of 1.17 percent. The error rate is well below the acceptance criterion for all fields of 5 percent.

6.1.4 NOCTS tritium data QA summary

Part 12 of attachment A and tables 18 and 19 describe results of the data transcription test for the NOCTS tritium dataset. The data transcription accuracy of the tritium bioassay data was checked in accordance with the lot acceptance procedures described in RPRT-0078. The numerical sample result fields were evaluated with a maximum 1 percent allowable error rate. The QA check resulted in an estimated error rate of 0.32 percent with a 95 percent UCL of 0.53 percent, as shown in in part 12a of table 19. The completeness test result is well within the acceptance criterion for critical fields of 1 percent. The study authors note that 4 of the 14 critical field errors are results from the same claim entered as <0.05 that should be <0.5.

All fields were evaluated for tritium with a maximum 5 percent allowable error rate. The QA check estimate error rate was 0.23 percent with a 95 percent UCL of 0.82 percent, as shown in part 12b of table 19. The completeness test result is well within the acceptance criterion for all fields of 5 percent.

6.2 Completeness of SRS logbook data

Attachment A includes several parts that address radionuclide-specific completeness tests for SRS logbook data for neptunium, americium, and MFPs. These completeness tests were performed in accordance with the lot acceptance procedure described in RPRT-0078. Two acceptance criteria were used for data transcription, one for critical fields and another for all checked fields. Typical critical fields were the reported result, nuclide, and payroll identification number (PRID). The acceptance criterion for all checked fields was a 5 percent maximum allowable error rate, while a stricter 1 percent maximum allowable error rate was applied for critical fields.

6.2.1 Completeness of SRS neptunium logbook data

Urinalysis was the primary method of checking for neptunium intakes at SRS during the 1960s. These results were generally recorded in separate, stand-alone neptunium logbooks. Around 1970, neptunium started to be measured using whole body counts, and neptunium urinalysis was no longer routinely performed at the site. A list of SRS NOCTS Claim IDs with at least 1 day of employment before 1991 was developed and reviewed for the presence of at least 1 neptunium result. This review revealed 382 claims containing neptunium results in both the transcribed logbook database and NOCTS claim data. These 382 claims were used for the neptunium completeness test. Although only the post-1969 neptunium urinalysis data will be used in the coworker study, NIOSH checked all 382 claims in the neptunium in vitro datasets. Since a census of all the claims was done, no sampling was required for this part of attachment A.

Results of the neptunium logbook completeness analysis are shown in part 3 of table 19. A total of 1,082 lines of data were checked, and 25 lines had missing data for an error rate of 2.31 percent. There is no sampling error because this was a complete census of the population.

6.3 SRS construction worker classification QA summaries

The classification of workers as CTWs or nonCTWs workers was compiled from four data sources: americium logbook data, neptunium logbook data, NOCTS whole body count data, and ORAUT-RPRT-0058 (NIOSH, 2012) in vitro data. The data entry accuracy for each of these sources was evaluated in accordance with lot acceptance procedures presented in RPRT-0078. Critical fields were defined as the fields containing the PRID and the numerical sample result. Critical fields were evaluated with a maximum 1 percent allowable error rate. All other fields were evaluated with a maximum 5 percent allowable error rate.

The results of these four analyses are shown in parts 5 through 8 of tables 18 and 19. The americium in part 5 passed the QA check with estimated error rates and the 95 percent UCL below 1 percent for critical and well below 5 percent for all-fields analyses.

The neptunium QA check in part 6 shows two sets of entries for the critical-fields analysis. Part 6a is marked with note (a). As explained in the note, the count of 27 errors includes six payroll prefix and other payroll ID issues that would have no impact on data use in the coworker model. When these errors are included, the 95 percent UCL is 1.18 percent, which exceeds the 1 percent acceptance criterion for critical fields.

Examples of these payroll ID errors are described and dismissed as follows:

> Examples of prefix issues that have no impact on the data use are using "0-," "1-," "T-," or no prefix interchangeably; presence of a prefix when there was not a prefix on the source data and vice versa (although present in other locations and accurate); and substitution of craft codes for a Roll code of 4-, 5-, or 6- or vice versa. Because these errors have no effect on the usability of the data, they were excluded from the calculation of the error rate. [NIOSH, 2019a, p. 119]

When these payroll ID issues are excluded from the error count, the 95 percent UCL is reduced to 0.96 percent, which now meets the 1 percent acceptance criterion for critical fields.

The NOCTS whole body count and MFP tests shown in parts 7 and 8 of tables 18 and 19 also show two sets of results for both critical fields and all fields. The initial results for each analysis (notes (b), (c), (d), and (e) show very high error rates, with estimates ranging from 5 percent to over 60 percent. These estimates exceed the acceptance criteria by a wide margin. As discussed for the neptunium data above, these high error rates were found to be due to large numbers of payroll prefix and other payroll ID issues that would have no impact on data use in the coworker model. After removing these payroll ID errors, the estimated error rates and the 95 percent UCLs all meet the respective acceptance criteria.

6.4 Construction worker determination QA summaries

The accuracy of the CTW determinations obtained from the Master Occupation Table were checked against the NOCTS in vivo bioassay dataset, the NOCTS in vitro bioassay dataset, the NOCTS tritium bioassay dataset, and the neptunium logbook bioassay dataset. The results are summarized in parts 9, 10, 11, and 13 of tables 18 and 19. CTW determinations based on the Master Occupation Table and the CTW Designation Instructions were checked against the worker history cards, or CATI or personnel dosimetry quarterly reports using the lot acceptance procedures described in RPRT-0078. These all-fields analyses were evaluated with a maximum 5 percent allowable error rate as the acceptance criterion.

The results of these four analyses are shown in parts 9, 10, 11, and 13 of table 19. Each analysis passed the QA check with estimated error rates and the 95 percent UCL below 5 percent. The study authors note that most classification errors observed were due to individuals changing occupations from CTW to nonCTW, or vice versa, during their career.

6.5 Summary and conclusions

NIOSH has used a variety of procedures to conduct the series of completeness tests reported in ORAUT-0081, attachment A. Table 19 summarizes the results of these tests. The estimated percentage error rates shown in the table are within the stated goals for each test, except for round 1 of the part 2a in vivo completeness test and the table 19 rows noted by (a), (b), (c), (d), and (e). In part 2a, round 1, a small sample size resulted in a 95 percent UCL that did not meet the stated goal of less than a 5 percent error rate. A follow-up test in round 2 (table 19, part 2b) was conducted using the cluster sampling methodology recommended in RPRT-0086. This test resulted in an almost 5-fold increase in the sample size and a test result that meets the stated goal.

In the table 19 rows noted by (a), (b), (c), (d), and (e) the estimated error rates exceed the goal for the test. This is due to a large number of payroll prefix-matching errors and other PRID issues. The test results obtained, after these errors are corrected, are within the stated goal in each case.

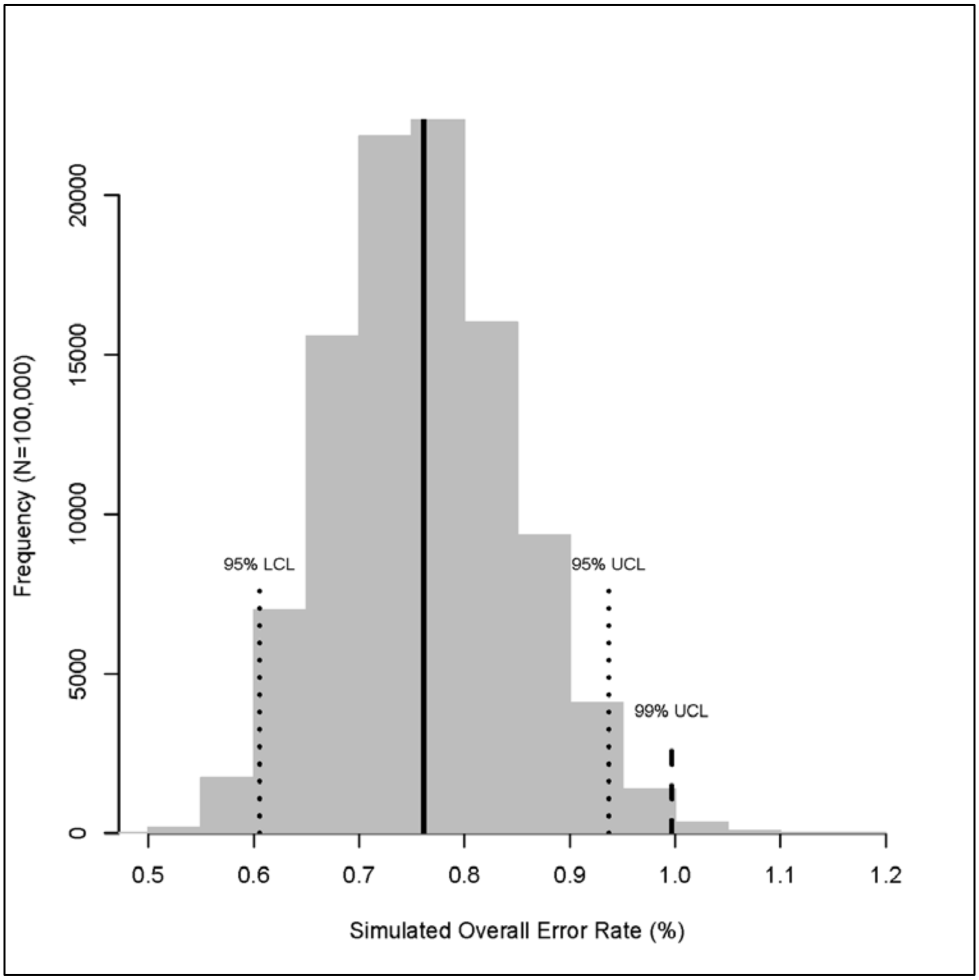
The last row of table 19 shows the total number of items checked without including the rows noted by (a), (b), (c), (d), and (e). The total combines test results for the critical field tests and the all-fields tests. Out of 40,127 items checked, a total of 303 errors were found (refer to note (f)). The estimated overall error rate is 0.76 percent. It is difficult to calculate the 95 percent UCL for the overall test result using a formula, but the information in table 19 (less the rows indicated by notes (a), (b), (c), (d), and (e)) is sufficient to estimate the 95 percent confidence interval for the overall error rate of attachment A using Monte Carlo simulation.

The estimated error rate in each row is assigned a triangular distribution with endpoints at the upper and lower 96 percent confidence limits and a mode at the estimated error rate. In the simulation for each row, an error rate p_i is drawn from the triangular distribution. The number of errors for that row is assigned a binomial distribution with parameters p_i and n_i, where n_i is the number of items checked in table 19. The procedure was iterated 100,000 times, and the results are shown in figure 22 and in the totals row of table 19. The 95 percent LCL for the overall test result is 0.60 percent, and the 95 percent UCL for the overall test result is 0.94 percent. The simulated 99 percent UCL for the overall test result is also shown in figure 22. The estimate is 0.994 percent, slightly less than the 1 percent overall error rate used as a goal for critical field matching in many of the attachment A tests.

In conclusion, the results shown in attachment A of OTIB-0081 demonstrate a high degree of confidence that the acceptable error rates are within the goals established for each test. This conclusion is based on the presumption that the large number of payroll prefix-matching errors and other PRID issues encountered in the noted rows of table 19 would not affect the outcome of coworker modeling or the CTW/nonCTW classification of workers. Were this presumption not true, the favorable conclusion reached here would be reversed.

Observation 8: The results shown in attachment A of OTIB-0081 demonstrate a high degree of confidence that the acceptable error rates are within the goals established for each test. However, this conclusion is dependent on the assumption that payroll ID issues identified would not affect the resulting coworker distributions.

Figure 22. Histogram of simulated overall error rate for attachment A tests with 95% confidence interval and 99% UCL



7 References

Advisory Board on Radiation and Worker Health (ABRWH). (2017). *Advisory Board on Radiation and Worker Health 120th meeting Wednesday, December 13, 2017* [Transcript]. Albuquerque, NM. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2017/tr121317-508.pdf

European Commission. (2018). *Technical recommendations for monitoring individuals for occupational intakes of radionuclides* (Radiation Protection No. 188, ISSN 2315-2826). Retrieved from https://ec.europa.eu/energy/sites/ener/files/rp_188.pdf

International Commission on Radiological Protection (ICRP). (1968). *Report of Committee IV on evaluation of radiation doses to body tissues from internal contamination due to occupational exposure* (Publication 10). Oxford: Pergamon Press.

International Commission on Radiological Protection (ICRP). (1989). Individual monitoring for intakes of radionuclides by workers (Publication 54). *Ann. ICPR, 19*(1-3).

International Commission on Radiological Protection (ICRP). (1997). *Individual monitoring for internal exposure of workers* (Publication 78). *Ann. ICRP*, *27*(3-4).

National Institute for Occupational Safety and Health (NIOSH). (2005). *Savannah River Site* (ORAUT-TKBS-0003, rev. 03). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/tbd/srs3.pdf

National Institute for Occupational Safety and Health (NIOSH). (2007). *Construction trades workers* (OCAS-PER-014, rev. 00). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/pers/oc-per14-r0.pdf

National Institute for Occupational Safety and Health (NIOSH). (2009). *Use of claimant datasets for coworker modeling* (ORAUT-OTIB-0075, rev. 00). Retrieved from SRDB Ref. ID 67223

National Institute for Occupational Safety and Health (NIOSH). (2012). *A comparison of mixed fission and activation product coworker models at the Savannah River Site* (ORAUT-RPRT-0058, rev. 00). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-58-r0.pdf

National Institute for Occupational Safety and Health (NIOSH). (2013). *Los Alamos National Laboratory – occupational internal dose* (ORAUT-TKBS-0010-5, rev. 02). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/tbd/lanl5-r2.pdf

National Institute for Occupational Safety and Health (NIOSH). (2014a). *Rocky Flats Plant – occupational internal dose* (ORAUT-TKBS-0011-5, rev. 03). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/tbd/rocky5-r3.pdf

National Institute for Occupational Safety and Health (NIOSH). (2014b). *Analysis of stratified coworker datasets* (ORAUT-RPRT-0053, rev. 02). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-53-r2.pdf

National Institute for Occupational Safety and Health (NIOSH). (2015a). *Draft criteria for the evaluation and use of coworker datasets* (rev. 4.1). Cincinnati, OH: Division of Compensation Analysis and Support, NIOSH.

National Institute for Occupational Safety and Health (NIOSH). (2015b). *External dose coworker methodology* (ORAUT-RPRT-0071, rev. 00). Retrieved from SRDB Ref. ID 145135

National Institute for Occupational Safety and Health (NIOSH). (2016a). *Internal coworker dosimetry data for the Savannah River Site* (ORAUT-OTIB-0081, rev. 03). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/tibs/or-t81-r3.pdf

National Institute for Occupational Safety and Health (NIOSH). (2016b). *Technical basis for sampling plan* (ORAUT-RPRT-0078, rev. 00). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-78-r0-508.pdf

National Institute for Occupational Safety and Health (NIOSH). (2017). *Internal dosimetry coworker data completeness test* (ORAUT-RPRT-0086, rev. 00). Retrieved from SRDB Ref. ID 167778

National Institute for Occupational Safety and Health (NIOSH). (2018). *Internal dose reconstruction* (ORAUT-OTIB-0060, rev. 02). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/tibs/or-t60-r2-508.pdf

National Institute for Occupational Safety and Health (NIOSH). (2019a). *Internal coworker dosimetry data for the Savannah River Site* (ORAUT-OTIB-0081, rev. 04). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/tibs/or-t81-r4-508.pdf

National Institute for Occupational Safety and Health (NIOSH). (2019b). *Multiple imputation applied to bioassay coworker models* (ORAUT-RPRT-0096, rev. 00). Retrieved from SRDB Ref. ID 175396

National Institute for Occupational Safety and Health (NIOSH). (2019c). *Evaluation of bioassay data for subcontracted construction trade workers at the Savannah River Site* (ORAUT-RPRT-0092, rev. 00). Retrieved from SRDB Ref. ID 176739

National Institute for Occupational Safety and Health (NIOSH). (2019d). *Evaluation of Savannah River Site americium-241 source terms between 1971 and 1999 using bioassay frequency tables* (ORAUT-RPRT-0091, rev. 00). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-91-r0-508.pdf

SC&A, Inc. (2010). *Review of ORAUT-OTIB-0075: Use of claimant datasets for coworker modeling for construction workers at Savannah River Site*. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-ortib75-r0.pdf

SC&A, Inc. (2014, February 24). *Discussion items and clarifications for February 26th work group meeting* [Memorandum]. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-srswg-022414.pdf

SC&A, Inc. (2017a). *Focused review on the concurrence of ORAUT-OTIB-0081, revision 03, and the draft coworker implementation criteria* (SCA-TR-2017-SEC005, rev. 0). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-tib81r3dcic-r0.pdf

SC&A, Inc. (2017b). *SC&A's evaluation of ORAUT-OTIB-0075, revision 01, "Use of claimant datasets for coworker modeling"* (SCA-TR-2017-PR011, rev. 0). Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-ortib75r1-r0.pdf

SEC Issues Work Group. (2015). *U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Advisory Board on Radiation and Worker Health, SEC Issues Work Group, Tuesday, March 10, 2015*. [Transcript of teleconference meeting]. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2015/wgtr031015.pdf

SRS Work Group. (2014a). *U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Advisory Board on Radiation and Worker Health, Savannah River Site (SRS) Work Group, Wednesday, February 5, 2014* [Transcript]. Hebron, KY. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2014/wgtr020514.pdf

Savannah River Site (SRS) Work Group. (2014b). *U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Advisory Board on Radiation and Worker Health, Savannah River Site Work Group, Wednesday, February 26, 2014* [Transcript of teleconference meeting]. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2014/wgtr022614.pdf

Savannah River Site (SRS) Work Group. (2017). *U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Advisory Board on Radiation and Worker Health, Work Group on Savannah River Site, Tuesday, November 14, 2017* [Transcript], Hebron, KY. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2017/wgtr111417-508.pdf

Savannah River Site (SRS) Work Group & Special Exposure Cohort (SEC) Issues Work Group. (2017). *U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Advisory Board on Radiation and Worker Health, Savannah River Site (SRS) Work Group and the Special Exposure Cohort (SEC) Issues Work Group, Wednesday, August 16, 2017* [Transcript of teleconference meeting]. Retrieved from https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2017/wgtr081617-508.pdf

Westinghouse Savannah River Corporation (WSRC). (1990). *Internal dosimetry technical basis manual* (WSRC-IM-90-139). Retrieved from SRDB Ref. ID 11266

Attachment A: Disposition of SC&A's OTIB-0081, Rev. 03 (SC&A, 2017a) Findings and Observations

Findings

SC&A (2017a) Finding 1

> The analysis of the completeness of trivalent logbook records provided in [OTIB-0081, revision 03] ends in 1981, though the proposed coworker analysis of trivalent bioassay extends through 1989. It would be beneficial to extend the completeness analysis to all years in which trivalent urinalysis data is being proposed for coworker evaluation. This is particularly important because the current completeness analysis suggests that the available logbook data totals are less than those reported in monthly and annual health physics summaries beginning in 1969.

SC&A recommended disposition

Internal monitoring data for trivalent radionuclides are provided up through 1987, with intake estimates provided up through 1989 in section 5.0 of OTIB-0081, revision 04. In addition, it was noted that many of the totals associated with available logbook data had been inadvertently reported low due to the original tallies not including samples that had been excluded from the coworker model for valid reasons, such as samples "lost in process." Additional discussion of the completeness of Am/Cm/Cf logbook results can be found in section 4.2 of this report. SC&A finds that this issue has been addressed in the context of the OTIB-0081, rev. 03 review and recommends **closure.**

SC&A (2017a) Finding 2

> SC&A does not find the discrepancies between reported bioassay totals of Am/Cm/Cf and available logbook results to be credibly explained by the inclusion of fecal results beginning in 1969. Evidence suggests that fecal results were tabulated separately, as shown in a Works Technical Report from January 1972.

SC&A recommended disposition

No additional information concerning this issue is provided other than previous statements hypothesizing that inclusion of fecal results, among other uncertainties, caused the discrepancy between reported bioassay totals and available logbook results. Am/Cm/Cf bioassay data completeness is discussed in section 4.2 of this report. SC&A considers this finding to remain **open** pending further work group discussion.

SC&A (2017a) Finding 3

> The combination of multiple years of trivalent actinide bioassay data during the 1980s was not sufficiently justified with a corresponding discussion of site activities and/or associated exposure potential at SRS as mandated in [NIOSH, 2015a]. Group or cohort monitoring may justify the appropriate combination of annual data; however, this practice was not sufficiently established in [OTIB-0081, revision 03].

SC&A recommended disposition

No further justification based on site activities and/or associated exposure potential at SRS was presented in revision 04 to justify the combination of multiple years for TWOPOS analysis. Therefore, SC&A believes this finding should remain **open.** However, SC&A notes that a new NIOSH report concerning americium exposures is imminent, which is expected to address this issue.

SC&A (2017a) Finding 4

> The SRS bioassay procedures for routinely monitored workers during the early periods (1954–1970 for tritium and 1964–1967 for exotic trivalent actinides) are not addressed in [OTIB-0081, revision 03]. SC&A's review of the Bioassay Control Reports referenced for this period did not find any sampling schedules or bioassay procedures listed. Therefore, it would be advantageous to have additional information about the bioassay requirements for the early periods.

SC&A recommended disposition

OTIB-0081, revision 04, page 46 added two paragraphs concerning tritium bioassay frequency with Site Research Database (SRDB) references added for 1964–1966 and 1959–1971; SC&A agrees that this addressed the tritium issue. However, OTIB-0081, revision 04 did not provide any additional information about the bioassay requirement for the exotic trivalent actinides for the early period of 1964–1967; therefore, this part of the finding is still **open.** However, SC&A notes that a new NIOSH report concerning americium exposures is imminent, which is expected to address this issue.

SC&A (2017a) Finding 5

> While evaluating monitoring practices related directly to thorium is not possible because SRS did not directly monitor for thorium, a discussion of the relationship between trivalent actinide monitoring practices and thorium exposure potential is warranted to establish that Am/Cm/Cf urinalysis data are an appropriate surrogate for thorium exposures. It does not appear that a verification demonstrating that a sufficient percentage of known thorium workers were included in the Am/Cm/Cf coworker dataset was performed, as was requested at the February 5, 2014, meeting of the SRS Work Group [SRS Work Group, 2014a].

SC&A recommended disposition

No additional information concerning thorium exposure was included in revision 04 of OTIB-0081. However, NIOSH has provided additional information in the Board Review System (BRS) for work group discussion. Therefore, this finding can be considered **in progress.**

SC&A (2017a) Finding 6

> Derived coworker intakes were stratified into construction and non-construction workers for each of the three revised coworker models. However, [OTIB-0081, revision 03] does not present the statistical basis used to determine that stratification is necessary for each radionuclide of interest and for each time period as detailed in ORAUT-RPRT-0053, Revision 02, *Analysis of Stratified*

> *Coworker Datasets* [NIOSH, 2014b], as well as in the implementation guide [NIOSH, 2015a].

SC&A recommended disposition

OTIB-0081, revision 04, pages 26–27 provided additional information concerning stratification of CTWs versus nonCTWs. While some of the coworker data in section 5.0 of OTIB-0081, revision 04 indicate similar intake values for CTWs as for nonCTWs, the additional radionuclides addressed in revision 04 of OTIB-0081 illustrate that there were noticeable differences in intake for CTWs versus nonCTWs for some other radionuclides. The basis for stratification is subsumed by the discussion in section 5 of this report; therefore, SC&A recommends that finding 6 be considered **closed** in the context of OTIB-0081, revision 03.

Observations

Observation 1

> SC&A requests clarification and/or documentation of the analytical chemistry phenomenon in which chelation treatment causes heterogeneity of contaminants for aliquots of a single bioassay voiding.

SC&A recommended disposition

SC&A could find no significantly new information concerning this issue in revision 04 of OTIB-0081; NIOSH uses approximately the same wording on pages 21, 43, 54, 83, 139, 140, 151, 152, 153, and 156 as in revision 03 of OTIB-0081. Section 3.1 of this report provides additional discussion in a statistical context of the issue of measurement variability among aliquots of the same sample. Therefore, this observation is considered **in progress** but can likely be subsumed under finding 1 of this report.

Observation 2

> Derived coworker tritium doses appear to increase substantially beginning in 1958, which coincides with the change in bioassay analysis for tritium. The cause for the apparent change in exposure potential should be discussed to determine if the prior method to detect tritium intakes was insufficient or if actual exposures markedly increased during this time, which would explain the increase in coworker doses.

SC&A recommended disposition

SC&A could find no significantly new information concerning this issue in revision 04 of OTIB-0081. However, the issue had been discussed and **closed** during work group discussions in August 2017 (SRS Work Group & SEC Issues Work Group, 2017).

Observation 3

> It is unclear based on [OTIB-0081, revision 03] how NIOSH intends to reconstruct intakes of exotic trivalent actinides and thorium post-1989 (e.g., extension of 1989 derived coworker intake rates, use of electronic Health Physics Radiological Exposure Database [HPRED] data, or application of some fraction of the derived air concentration).

SC&A recommended disposition

SC&A could find no significantly new information concerning this issue in revision 04 of OTIB-0081. Approximately the same wording ("may be extended") is used on page 90 of revision 04 as on page 31 of revision 03 of OTIB-0081. However, it is SC&A's understanding that this issue will be addressed in the future on an as-needed basis and pending acceptance of current dose reconstruction methods. SC&A considers this observation **in abeyance.**

Observation 4

> Discrepancies between the number of available exotic trivalent logbook entries and health physics summary reports prior to 1969 are not discussed in [OTIB-0081, revision 03]. Documentation of the internal monitoring in 1967 may indicate that health physics summary reports did not include Construction Trade Workers (CTWs).

SC&A recommended disposition

SC&A could find no significantly new information concerning this issue in revision 04 of OTIB-0081 as compared to revision 03. NIOSH's position, as stated on the BRS, is that the agreement between the number of logbook entries and reported results shows "quite good agreement." Furthermore, the comparison is only qualitative due to uncertainty in the interpretation of such reports. However, work group deliberations on the observation have not been finalized. Therefore, this observation can be considered **in progress.**

Observation 5

> It is not clear to SC&A why the date of the bioassay sample is not considered a "critical field" for the purposes of performing quality assurance (QA) tests on the transcribed dataset for trivalent actinides as well as tritium. The date of the sample is a crucial component to correctly performing the time-weighted one person-one sample (TWOPOS) calculation for Am/Cm/Cf and thorium as well as the annual dose for tritium.

SC&A recommended disposition

OTIB-0081, page 109 of revision 04 includes three items in the critical field (date of bioassay, radionuclide, and results). This item was discussed during the SRS Work Group meeting on August 16, 2017, and it was decided that the date of the sample does not qualify as a "critical field." The work group **closed** the observation at that time (SRS Work Group & SEC Issues Work Group, 2017).

Observation 6

> SC&A requests clarification on what aspects of the tritium coworker model analysis were subject to the QA criteria described in Section 2.0 of [NIOSH, 2015a] and proceduralized in ORAUT-RPRT-0078, *Technical Basis for Sampling Plan* [NIOSH, 2016b]. Based on SC&A's interpretation of the analysis in [NIOSH, 2016b], it appears that only the delineation between construction and non-construction workers was tested for quality assurance.

SC&A recommended disposition

OTIB-0081, page 48, section 4.2.2 added information concerning this issue, and pages 108–116 in attachment A of revision 04 contains a transcription of the complete QA test results that were not in revision 03. Therefore, SC&A considers this observation sufficiently addressed and recommends **closure.**

Observation 7

> The available CTW bioassay data for subcontractors has yet to be validated and verified; i.e., it has yet to be demonstrated that the majority of the subcontractor CTW bioassay data has been located and has correctly been transcribed to the databases used to create the coworker model intakes. This validation and verification activity is currently being undertaken at the direction of the SRS Work Group.

SC&A recommended disposition

This additional evaluation by NIOSH and the SRS work group is still ongoing; therefore, this issue can be considered **in progress.**

Observation 8

> [OTIB-0081, revision 03] appears to contradict itself on whether prime CTWs represent a similar monitoring protocol as subcontractor CTWs. Prime construction workers are described as being exposed “temporarily but frequently for short periods” but also on an annual bioassay schedule specified by the bioassay control procedures. Subcontractor workers were monitored on a case-by-case basis depending on the localized requirements of the job.

SC&A recommended disposition

There is additional information in section 3.2, pages 26–33, of revision 04 related to this issue. Additionally, current evaluations in progress by SC&A and NIOSH concerning subcontractor CTW bioassays compared to primary contractor CTW bioassays are intended to address this issue further. Therefore, SC&A recommends **closure** of this observation in relation to its review OTIB-0081, revision 03.

Attachment B: Disposition of SC&A's ORAUT-OTIB-0075 Review Findings

SC&A had 13 findings (SC&A, 2010) concerning ORAUT-OTIB-0075, "Use of Claimant Datasets for Coworker Modeling," revision 00 (NIOSH, 2009; "OTIB-0075"). In 2017, SC&A revisited the 13 findings subsequent to the issuance of revision 01 of OTIB-0075 for relevance to SEC-00103 and found that findings 1, 6, and 7 were applicable to the National Security Complex (Y-12), findings 2 and 8 were applicable to Mound Laboratory, and findings 3, 4, 5, 9, 10, 11, 12, and 13 were applicable to SRS (SC&A 2017b). This attachment presents an updated review of the SRS findings to determine if the recently released revision 04 of OTIB-0081 contains new or additional information that may resolve any of the original SC&A findings for SRS from the original review of OTIB-0075.

SC&A (2010) Finding 3

> At SRS, the complete (all-worker) and claimant datasets for annual tritium doses from 1991 to 2001 show no significant difference at the annual level of aggregation, but the sample size is very small and the regression results were dominated by a single year with high exposure, 1991. If this year is omitted, the complete and claimant datasets for annual tritium doses period from 1992 through 2001 again show no significant difference at the annual level of aggregation.

SC&A 2019 comment

This was a statement that SC&A concurred with NIOSH's results but cautioned that they cannot be extrapolated to other radionuclides and time periods. Therefore, this presently would be considered an observation instead of a finding. However, issues associated with the representativeness of claimant datasets to the sitewide worker population is beyond the scope of this report and will be addressed separately.

SC&A (2010) Finding 4

> At SRS, OTIB-0075 includes data only for tritium from 1991 to 2001 in comparing the claimant population to that of all workers. No analysis of uranium or plutonium exposures at SRS was possible, because the available hardcopy data have not been reduced to electronic form. Similarly, no analysis of uranium or fission product exposures regarding the validity of the central hypothesis of OTIB-0075 for SRS could be done for any period. No analysis of tritium exposures before 1991 was done for the same reason. Furthermore, the tritium conclusion cannot be back-extrapolated in time, since the production and work conditions relating to tritium were different in earlier periods.

SC&A 2019 comment

OTIB-0081 provides coworker intake values for uranium and fission products as well as annual tritium doses. However, these intakes/doses were developed under the assumption that claimant datasets are representative of the full monitored workforce. Issues associated with the representativeness of claimant datasets to the sitewide worker population is beyond the scope of this report and thus should be addressed separately.

SC&A (2010) Finding 5

> Data for the entire SRS were aggregated by year for the NIOSH analysis, with no detail by work area or by job type. The proposed NIOSH coworker model for SRS construction workers includes no analysis of these details.

SC&A 2019 comment

OTIB-0081, revision 04, has stratified the SRS workers into the two categories of nonCTW and CTW, and further work is currently in process concerning the exposure potential and monitoring practices for prime CTW and subcontract CTW. Additional discussion on this issue is presented in section 5.2 of this report concerning individual strata designation. However, this does not fully address the issue of differences in exposure potential among different work areas and specific job types rather than general classification. SC&A recognizes that further stratification according to work areas of the already stratified nonCTW and CTW coworker data and radionuclides could potentially result in large uncertainties and/or the lack of sufficient data points due to the diminishing number of bioassay results available for each subcategory. However, if a unique situation is identified in a given area in which a specific radionuclide may have presented a much larger than normal intake than sitewide monitoring would indicate, then that exposure potential would have to be addressed on an individual basis. Such area- and job-specific analysis indicating the potential for further stratification is beyond the scope of this report and will be addressed separately.

SC&A (2010) Finding 9

> At SRS, the 84th percentile of exposures to tritium, plutonium, uranium, and other radionuclides for non-construction workers in specific work areas show considerable differences from the 84th percentile of exposures to non-construction workers site-wide. Similar results are observed for the corresponding ratio of the GSDs.

SC&A 2019 comment

Same as for the SC&A (2010) finding 5 recommendation.

SC&A (2010) Finding 10

> At SRS, the 84th percentile of exposures to tritium, plutonium, and other radionuclides for construction workers in specific work areas show considerable differences from the 84th percentile of exposures to all [non] construction workers site-wide. Similar results are observed for the corresponding ratio of the GSDs.

SC&A 2019 comment

Same as for the SC&A (2010) finding 5 recommendation.

SC&A (2010) Finding 11

> At SRS, the 84th percentile of exposures to tritium and plutonium for construction workers in specific work areas show large differences from the 84th percentile of site-wide exposures to construction workers. Similar results are observed for the

> corresponding ratio of the GSDs. In many cases, there are insufficient data for construction workers to make a comparison for uranium, enriched uranium, and fission products.

SC&A 2019 comment

Same as for the SC&A (2010) finding 5 recommendation.

SC&A (2010) Finding 12

> At SRS, the 84th percentile of exposures to tritium for construction workers in specific crafts shows large differences from the 84th percentile of exposures to all construction workers. Similar results are observed for the corresponding ratio of the GSDs.

SC&A 2019 comment

Same as for the SC&A (2010) finding 5 recommendation.

SC&A (2010) Finding 13

> At SRS, the 84th percentile of exposures to tritium for construction workers in specific crafts shows large differences from the 84th percentile of site-wide exposures for non-construction workers. Similar results are observed for the corresponding ratio of the GSDs.

SC&A 2019 comment

Same as for the SC&A (2010) finding 5 recommendation.

Attachment C: NOCTS Claim Numbers Associated with Arbitrary Case IDs Used in Section 5.2

Arbitrary case ID	NOCTS claim #
A	[redacted]
B	[redacted]
C	[redacted]
D	[redacted]
E	[redacted]
F	[redacted]
G	[redacted]
H	[redacted]
I	[redacted]
J	[redacted]
K	[redacted]
L	[redacted]
M	[redacted]
N	[redacted]
O	[redacted]
P	[redacted]
Q	[redacted]
R	[redacted]
S	[redacted]
T	[redacted]
U	[redacted]
V	[redacted]
W	[redacted]
X	[redacted]
Y	[redacted]
Z	[redacted]
AA	[redacted]
AB	[redacted]
C	[redacted]
AD	[redacted]
AE	[redacted]
AF	[redacted]
AG	[redacted]
AH	[redacted]
AI	[redacted]
AJ	[redacted]
AK	[redacted]
AL	[redacted]
AM	[redacted]

Arbitrary case ID	NOCTS claim #
AN	[redacted]
AO	[redacted]
AP	[redacted]
AQ	[redacted]