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Savannah River Site – Internal Dosimetry Co-Exposure Data	ORAUT-TKBS-0003-7	Rev. 00
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Subject Expert(s): Matthew G. Arno and Nancy Chalmers

Document Owner Approval:	Zachariah C. Tribbett Signature on File for James M. Mahathy, Document Owner	Approval Date:	03/01/2024
Concurrence:	Signature on File John M. Byrne, Objective 1 Manager	Concurrence Date:	03/05/2024
Concurrence:	Signature on File Scott R. Siebert, Objective 3 Manager	Concurrence Date:	03/05/2024
Concurrence:	Vickie S. Short Signature on File for Kate Kimpan, Project Director	Concurrence Date:	03/05/2024
Approval:	Signature on File Timothy D. Taulbee, Associate Director for Science	Approval Date:	03/05/2024

FOR DOCUMENTS MARKED AS A TOTAL REWRITE OR REVISION,
REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

☒ New ☐ Total Rewrite ☐ Revision

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/08/2013	00	New technical information bulletin to provide internal coworker data for the Savannah River Site. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Matthew Arno.
04/01/2013	01	Revision initiated to correct the values provided in Tables 5-6, Type S uranium intake rates for 1968 through 2007, 5-10, changed end date from 2006 to 2007, A-3, plutonium bioassay data for 1955 through 2007, and A-8, neptunium bioassay data for 1991 through 2007. Incorporates formal internal review comments. No changes were made as a result of formal NIOSH review. No sections were deleted. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
12/16/2013	02	Revision initiated to add dose reconstruction guidance for radionuclide assignment in response to an ABRWH request. Text added in Section 5.0 and a new Table 5-1 added. Intake rates for Cm and Cf added for the pre-1995 time period. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
11/22/2016	03	Revision initiated to address the coworker study Implementation Guide requirements for americium, thorium, and tritium. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
03/13/2019	04	Revision initiated to address the coworker study implementation guide requirements for plutonium, uranium, neptunium, cesium, cobalt, and mixed fission products. Adds executive summary. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
09/01/2020	05	Revision initiated to add the intake rates for type SS plutonium, use the ORAUT-RPRT-0096 multiple imputation method for americium bioassay data, update americium and thorium intake rates, and reference ORAUT-RPRT-0070 for thorium intake rates. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
11/19/2021	06-A	Revision initiated to update the americium analysis to incorporate the results of reentering the americium data and recompleting the quality assurance effort. The statistical analysis for americium and the intake modeling for americium and thorium were revised accordingly. Sections 4.1, 5.1, 5.8 and Attachments A, D, E.1, E.4.9, F.1, and F.8 were updated. Initiated by John M. Byrne and authored by Matthew G. Arno.
12/16/2021	06-B	Incorporates formal internal review comments. Initiated by John M. Byrne and authored by Matthew G. Arno.
01/24/2022	06-C	Incorporates formal NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by John M. Byrne and authored by Matthew G. Arno.

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
03/05/2024	Rev 00	New document created to convert ORAUT-OTIB-0081, Rev. 06-C, “Internal Dosimetry Co-Exposure Data for the Savannah River Site,” to ORAUT-TKBS-0003-7, Rev. 00, “Savannah River Site – Internal Dosimetry Co-Exposure Data.” Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by John M. Byrne and authored by Matthew G. Arno.

TRADEMARK INFORMATION

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ACRONYMS AND ABBREVIATIONS

ABRWH Advisory Board on Radiation and Worker Health
ACD Analytical Chemistry Division
AEC U.S. Atomic Energy Commission
AQL acceptance quality level
AWE atomic weapons employer

C&D Construction and Demolition
CATI computer-assisted telephone interview
CPF Californium Processing Facility
cpm counts per minute
CTW construction trade worker
CV coefficient of variation

d day
D&D decontamination and decommissioning
DCAS Division of Compensation Analysis and Support
DDCP dibutyl-*N*,*N*-diethylcarbamylphosphonate
DNA delayed neutron analysis
DOE U.S. Department of Energy
DOL U.S. Department of Labor
dpm disintegrations per minute
DTPA diethylene triamine pentaacetic acid
DU depleted uranium

E&I Electrical and Instrumentation
EEOICPA Energy Employees Occupational Illness Compensation Program Act of 2000
EU enriched uranium

F fast (absorption type)
FP fission product

GM geometric mean
GSD geometric standard deviation

HDEHP bis(2-ethylhexyl) phosphoric acid
HEU highly enriched uranium
HLC high-level cave
HP Health Physics
HPRED Health Protection Radiation Exposure Database
hr hour
HTO tritiated water vapor

IA insufficient amount
ID identification (number)
IDOT Internal Dosimetry Tool
IMBA Integrated Modules for Bioassay Analysis
in. inch
IREP Interactive RadioEpidemiological Program

keV kiloelectron-volt, 1,000 electron-volts
kg kilogram

KPA	kinetic phosphorescence analysis
L	liter
LIP	lost in process
LTPD	lot tolerance percent defective
m	meter
M	moderate (absorption type)
MDA	minimum detectable amount
MFP	mixed fission product
MFPG	mixed fission product-gamma
mL	milliliter
MSM	Master/Slave Manipulator
n	number of datapoints checked in a dataset
N	total number of data points in a dataset
nCi	nanocurie
ng	nanogram
NIOSH	National Institute for Occupational Safety and Health
NMD	Nuclear Materials Division
NOCTS	NIOSH DCAS Claims Tracking System
NP	neptunium analysis
NTA	nuclear track emulsion, type A
NU	natural uranium
OC	Operational Characteristic
ORAU	Oak Ridge Associated Universities
ORAUT	ORAU Team
pCi	picocurie
ppm	parts per million
PRID	payroll ID (number with optional dash separator)
PUREX	plutonium-uranium extraction
QA	quality assurance
REAC/TS	Radiation Emergency Assistance Center/Training Site
ROI	region of interest
RU	recycled uranium
S	slow (absorption type)
SCD	Separation Chemistry Division
SEC	Special Exposure Cohort
SED	Separations Engineering Division
SRDB Ref ID	Site Research Database Reference Identification (number)
SRS	Savannah River Site
SS	super S (absorption type)
SSN	Social Security Number
T&T	Transportation and Traffic Department
TBD	technical basis document
TIB	technical information bulletin
TIOA	triisooctylamine

TRM	target residual material
TWOPOS	time-weighted one person–one statistic
U.S.C.	*United States Code*
WBC	whole body count
yr	year
α	producer's risk (ORAU Team risk)
β	consumer's risk (DCAS risk)
μCi	microcurie
μg	microgram
μm	micrometer
§	section or sections

7.1 INTRODUCTION

Technical basis documents (TBDs) and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular U.S. Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies), such as changing scientific understanding of operations, processes, or procedures involving radioactive materials. These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of individual dose reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA).

In this document the word “facility” is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an “AWE facility” or a “DOE facility.” The term “AWE facility” is defined in EEOICPA to mean “a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling.” 42 *United States Code* (U.S.C.) § 7384l(5). On the other hand, a DOE facility is defined as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located—(A) in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program); and (B) with regard to which the [DOE] has or had—(i) a proprietary interest; or (ii) entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services.” 42 U.S.C. § 7384l(12). The DOE determines whether a site meets the statutory definition of an AWE facility and the U.S. Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Under EEOICPA, a Part B cancer claim for benefits must be based on an energy employee’s eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility’s designated time period and location (i.e., a “covered employee with cancer”). After DOL determines that a claim meets the eligibility requirements under Part B of EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. 42 U.S.C. § 7384l(11). Also under EEOICPA, the types of exposure to be included in dose reconstructions for DOE employees are those radiation exposures incurred in the performance of duty. As such, NIOSH includes all radiation exposures received as a condition of employment at DOE facilities in its dose reconstructions for covered employees, which may include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. This is because NIOSH does not determine the fraction of total measured radiation exposure at a DOE facility that is contributed by the Naval Nuclear Propulsion Program at the DOE facility during a specified period of time for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees [NIOSH 2010]:

- Background radiation, including radiation from naturally occurring radon present in conventional structures, and
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons.

7.1.1 Purpose

Some employees at DOE sites were not monitored for potential intakes of radioactive material, or the records of such monitoring are incomplete or unavailable. In such cases, data from monitored workers with similar exposure potential can be used to assign an internal dose to address potential intakes of radioactive material. The purpose of this TBD is to provide monitored co-exposure information for calculating and assigning occupational internal doses to employees at the Savannah River Site (SRS) for whom no or insufficient monitoring records exist.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 7.6.

7.1.2 Scope

Most of this TBD chapter is organized by radionuclide evaluated. Section 7.3 contains discussion of factors applicable to multiple radionuclides including source data for the co-exposure study and the stratification evaluation. For each radionuclide, subsection 1 addresses data adequacy and information regarding who was monitored, the applicability of that data to unmonitored workers, and bioassay techniques. Subsection 2 discusses source data completeness, representativeness, quality, and interpretation. Subsection 3 presents the statistical analysis, and subsection 4 contains the results of the intake modeling and the derived intake rates to be used for unmonitored workers. Section 7.4 contains the summary guidance for dose reconstructors for all radionuclides on assignment of intakes by facility and time period.

7.1.3 Special Exposure Cohort

January 1, 1953, through September 30, 1972
The Secretary of the U.S. Department of Health and Human Services has added the following class of SRS employees to the SEC [Sebelius 2012, p. 3]:

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953, through September 30, 1972, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.*

The Secretary based this designation on the findings of NIOSH's SEC Evaluation Report, which found it is not feasible to estimate internal exposures with sufficient accuracy for all externally monitored employees from January 1, 1953, through December 31, 1957, whose records have dosimetry codes A, G, CMX, or TNX. Further, NIOSH found that it lacked sufficient internal thorium monitoring data or other data or methods to support bounding internal thorium doses for SRS workers who may have worked with thorium in the 700 Area or the CMX/TNX Area from January 1, 1958 through September 30, 1972, whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z [NIOSH 2011].

October 1, 1972, through December 31, 1990
The Secretary has also added the following class [Becerra 2021, p. 3]:

> *All construction trade employees of Department of Energy subcontractors [excluding employees of the following prime contractors who worked at the Savannah River Site in Aiken, South Carolina, during the specified time periods: E. I. du Pont de Nemours and Company, October 1, 1972, through March 31, 1989; and Westinghouse Savannah*

> *River Company, April 1, 1989, through December 31, 1990], who worked at the Savannah River Site from October 1, 1972, through December 31, 1990, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.*

The Secretary based this designation on the recommendation of the Advisory Board on Radiation and Worker Health (ABRWH) which found that dose reconstruction for unmonitored subcontractor construction trades workers who should have been monitored via the permit-driven job-specific monitoring program is not feasible using the co-exposure models NIOSH developed due to the nature of radiological work assigned to transient subcontractor construction trades workers, the lack of assurance provided their bioassay monitoring, and identified gaps in the permit-driven job-specific monitoring program. The ABRWH concluded that the completeness and representation of subcontractors who were, or should have been, monitored has not been sufficiently established [Anderson 2021].

Although the ABRWH found that it is not possible to completely reconstruct radiation doses for either class, NIOSH intends to use any internal and external monitoring data that might become available for an individual claim and that can be interpreted using existing NIOSH dose reconstruction processes or procedures to conduct partial dose reconstructions for employees who do not qualify for inclusion in the SEC [NIOSH 2011; Anderson 2021].

7.2 GENERAL METHODS

This section provides information on the general selection characteristics of the data and methods of analysis. More detailed, radionuclide-specific information is provided in Section 7.4.

ORAUT-OTIB-0019, *Analysis of Coworker Bioassay Data for Internal Dose Assignment* [ORAUT 2005], describes the general process NIOSH uses to analyze bioassay data for the assignment of doses to individuals based on co-exposure results. ORAUT-PLAN-0014, *Coworker Data Exposure Profile Development* [ORAUT 2004a], describes the approach and processes to develop reasonable exposure profiles based on available dosimetric information for workers at DOE sites. DCAS-IG-006, *Criteria for the Evaluation and Use of Coworker Datasets* provides the criteria to evaluate the adequacy and completeness of co-exposure data [NIOSH 2020a]. In the sections below, the data and evaluations required by the guidance are provided for each evaluated radionuclide.

Bioassay data in the NIOSH DCAS Claims Tracking System (NOCTS) for SRS employees were used to develop a representative database of co-exposure bioassay data using the guidance of ORAUT-OTIB-0075, *Use of Claimant Datasets for Coworker Modeling* [ORAUT 2016a], and NIOSH [2015] except for americium and neptunium, for which analytical laboratory logbooks were used.

A statistical analysis of the data was performed according to ORAUT-OTIB-0019 [ORAUT 2005], ORAUT-RPRT-0053, *Analysis of Stratified Coworker Datasets* [ORAUT 2014a], and ORAUT-RPRT-0096, *Multiple Imputation Applied to Bioassay Coworker Models* [ORAUT 2021]. The results were entered in the Integrated Modules for Bioassay Analysis (IMBA) and Internal Dosimetry Tool (IDOT) computer programs to obtain intake rates for the assignment of dose distributions.

7.2.1 <u>Data Sources</u>

There are two basic data sources for the co-exposure study. The first is NOCTS bioassay data from energy employees who worked at SRS. The second is data from laboratory logbooks for americium and neptunium. For these radionuclides, there is insufficient NOCTS bioassay data available to perform a co-exposure study. The NOCTS sources are discussed in this section and the logbook data sources are discussed in the radionuclide-specific discussions below.

7.2.1.1 Completeness of Claims Tracking System Data

For the period before availability of the Health Protection Radiation Exposure Database (HPRED) data (before 1991), NOCTS data were used as the best available compilation of data in a usable form (i.e., electronic spreadsheet or database). This dataset contained over 260,000 tritium bioassay results and over 100,000 nontritium in vitro bioassay results for samples submitted by more than 1,500 workers between 1954 and 1990. There are also records of almost 15,000 in vivo (whole body or chest) counts. NOCTS data are not complete because not all workers are claimants. However, the NOCTS data are assumed to be a random sampling that can be considered representative of co-exposure bioassay data based on the analysis in ORAUT-OTIB-0075 [ORAUT 2016a]. This analysis demonstrated that, for three evaluated cases, claimant datasets can be considered to be random samples of the complete dataset, and the analysis provides justification for applying this assumption to other sites and datasets. For this effort, bioassay data for claimants with a claim number less than 35,000 with U.S. Department of Labor (DOL)-verified employment at SRS was used. No effort was made to find bioassay data for claimants with employment at SRS that was not DOL-verified or outside of verified employment periods.

Although the individuals in NOCTS are a subset of all workers at SRS, it is still desirable that the data for those particular individuals be complete. Reviews were performed to check that the data entry process from the NOCTS hardcopy records was complete. This review was performed in two steps based on ORAUT-RPRT-0086, *Internal Dosimetry Coworker Data Completeness Test* [ORAUT 2017a]. The first step consisted of verifying that all individuals with at least 1 day of verified employment at SRS during the period of interest who had any bioassay data in their NOCTS records also had some bioassay records in the respective NOCTS in vivo and in vitro bioassay datasets. This was a claim-level check for the existence of any data at all and not a check of each bioassay datum in the records. Any missing records found during this process were corrected with additional data entry and the process repeated until no further missing records were found.

The second step consisted of selecting a sampling of NOCTS claims with bioassay data and verifying that all the data in the hardcopy records was in the applicable dataset. Using this method it was determined that the missing data rate for the NOCTS in vitro bioassay dataset had a point estimate of 0.79% with a 95% confidence interval of 0.03% to 3.99%. The NOCTS in vivo dataset had a point estimate of 0.64% with a 95% confidence interval of 0.25% to 1.35%. Completeness testing was done during the development of ORAUT-RPRT-0086 [ORAUT 2017a]; therefore, the exact method of ORAUT-RPRT-0086 was not used. The details of the results of these evaluations are contained in Attachment A.

7.2.1.2 Accuracy of Claims Tracking System Data

The NOCTS data are split into three types: in vivo bioassay data, nontritium in vitro bioassay data, and tritium in vitro bioassay data. The data quality on each piece was evaluated separately. The tritium bioassay data quality review is discussed in Section 7.3.2.2. For each data source, the data entry process was subjected to quality assurance (QA) checks in accordance with ORAUT-RPRT-0078, *Technical Basis for Sampling Plan* [ORAUT 2016b]. This report describes a sampling plan that computes “transcription” error rates, which quantify the degree to which an electronic dataset agrees with the original hardcopy records. The sampling plan is used to select a random sample of the data and to estimate the transcription error rates. Statistical sampling techniques, in which a comparison of the electronic dataset to the original data is performed after the transcription is complete, are used to confirm that the specified unacceptable error rates have not been exceeded and to generate error rate confidence intervals. Sampling plans for “critical” fields are created with an unacceptable error rate of

1% or higher, while plans for "all" fields have an unacceptable error rate of 5% or higher. Critical fields are those fields containing an analytical result or that are used to identify an individual payroll ID (number with optional dash separator) (PRID).

The data transcription accuracy of the in vitro bioassay data was checked in accordance with ORAUT-RPRT-0078 [ORAUT 2016b]. The nuclide, result, and "<" fields were checked with a maximum 1% allowable error rate. The QA check resulted in a point estimate error rate of 0.25% with a 95% confidence interval of 0.13% to 0.45%. The fields checked above, sample date, and other nonblank data entry fields were evaluated with a maximum 5% allowable error rate. The QA check resulted in a point estimate error rate of 0.46% with a 95% confidence interval of 0.13% to 1.17%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

The data transcription accuracy of the in vivo bioassay data was checked in accordance with ORAUT-RPRT-0078 [ORAUT 2016b]. The nonblank fields relevant to calculating a body burden were checked with a maximum 1% allowable error rate. The QA check resulted in a point estimate error rate of 0.43% with a 95% confidence interval of 0.26% to 0.67% excluding errors associated with PRIDs that do not affect use of the data. The fields checked above, sample date, and other nonblank data entry fields were evaluated with a maximum 5% allowable error rate. The QA check resulted in a point estimate error rate of 2.75% with a 95% confidence interval of 1.77% to 4.06%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

7.2.2 Stratification

For co-exposure models, a priori stratification is based on either (1) differences (or similarities) of the radiological work being conducted (i.e., exposure potential) or (2) known differences (or similarities) in radiological monitoring methodology. At SRS, there are three main groups of radiological workers: Operations (Production), Maintenance (DuPont Construction), and Construction. For the stratification of the co-exposure models, NIOSH chose to stratify based on the type of radiological work being conducted because all three groups have a variety or hybrid of Health Physics (HP) personnel monitoring as discussed in more detail below. The main difference in exposure from different types of radiological work is based on normal operations versus off-normal operations.

In the case of SRS, there are differences in the nature of the exposure potential between construction trade workers (CTWs) (Maintenance and Construction) and operations workers that warrant considering them as two distinct cohorts or strata in relation to co-exposure models.

Operations or Production workers (chemists, physicists, operators, technicians, material handlers, etc.) generally work with larger quantities of radioactive materials, but the materials are well controlled in gloveboxes or fume hoods to prevent or minimize worker exposure. Radiological work conducted by CTWs, on the other hand, typically involves contaminated equipment (i.e., smaller quantities), but the engineered controls (e.g., gloveboxes, cabinets, fume hoods, duct work) that contain the radioactive materials are sometimes intentionally compromised to conduct renovation or repair. As a result, the CTW exposure potential could be (1) less than operations workers, (2) equal to operations workers, or (3) greater than operations workers depending on the work being conducted. Further complicating the total exposure is the duration of the specific job. In some cases, the magnitude of the exposure for CTW could be greater but the duration is shorter (days or weeks). This could result in a similar total intake as experienced by operations but with a different delivery.

In general, the exposure potential for CTWs is viewed as being potentially greater but of a shorter duration. This difference in exposure potential based on the type of work being conducted is the main justification for the stratification. As a result, NIOSH decided to a priori stratify the Operations (nonCTW) and CTW models for SRS.

7.2.2.1 Worker Classification Background

At SRS, CTWs were deployed temporarily but frequently for short periods to perform specific tasks usually pertaining to facility construction and modification, system maintenance, and decontamination. CTWs worked around the site, while production and operation staff normally worked at fixed locations. While workers assigned to Roll 2 were employed directly by DuPont Construction and Bechtel Savannah River, workers in Rolls 4 and 5, or subcontractors, were employed at SRS for periods ranging from a few days to years. One [redacted] worked lengthy periods between [redacted] and [redacted], while another [redacted] worked varying periods from [redacted] through [redacted]. Workers from each of the rolls were assigned to do jobs. Some tasks such as painting were mostly performed by workers in Roll 4 and some in Roll 5, while others such as instrument maintenance were mostly performed by workers in Roll 2. Maintenance and decontamination tasks shared common exposure profiles where workers in some of the jobs could be exposed to higher levels of radiation from surface and airborne contamination.

An important note is that not all construction work involved exposure to radioactive materials. The larger projects (new facilities) tended to be clean construction work, so radiological monitoring was not required. Maintenance work in a radiological facility tended to be mostly radiological in nature, which is believed to be the reason there were semi-dedicated crafts workers as part of the maintenance team at each of the major facilities.

Bingham [1997] stated that the DOE stated in Congressional testimony that it is likely that the greatest risks to workers on its sites involve mainly the construction workers, including those who are involved in decommissioning, dismantling of facilities, and maintenance or repair activities. According to SRS procedures, the HP Department provided the same level of job planning and monitoring to these tasks as it did with operation and production tasks [DuPont 1959–1971, no date a]. HP surveyed and collected air monitoring samples in all areas where release of contamination was possible. NIOSH has collected air monitoring data for areas where known CTW work was performed. Examples of personnel monitoring include monitoring of a job by a CTW on Roll 4, subsequent monitoring of CTW contamination in a job in H Area in 1972 [DuPont 1972], and monitoring of [redacted] on Roll 2 contaminated in a similar job in F Area in [redacted] [DuPont 1974]. [Redacted] were exposed to high concentrations of airborne [redacted] contamination while working in Savannah River Laboratory in [redacted] [DuPont 1974–1984]. In 1979, a Roll 4 [redacted] received an intake of radioactive material while removing a hood at Savannah River Laboratory [DuPont 1974–1984].

Another important note is that while there were differences in biological monitoring, <u>all</u> groups participated in biological monitoring for radiological intakes, especially when workplace conditions required follow up. The differences are the degree to which each group had routine, job-specific, and incident monitoring. Workplace monitoring and radiological protection requirements appear to be based on exposure potential, not on group or craft.

Based on a review of hundreds of job plans and radiological surveys for SRS, it is clear that multiple types of crafts workers participated on the same type of jobs with common exposure potential. For example, maintenance workers (DuPont Construction) were cutting a 4-in. section from the High Level Drain Line as shown in Figure 7-1. The pipe ends were to be plugged and taped. The workers wore two pair of coveralls and respirators and had continuous coverage by HP during the job. In a similar job, subcontractor construction trades workers, pipefitters from B. F. Shaw, were connecting the cell line to the high-level drain line in a laboratory as shown in Figure 7-2. Like the maintenance workers, the pipefitters were required to wear two pair of coveralls and respirators when the line was being connected (i.e., line break). HP also covered this job, continuously monitoring for contamination.

JOB PLAN

Date: 1/[illegible]/83
Time of Operation: 8:00 A.m.
Contact: LSD
Done by: Maint.
Phone: 3401

PROTECTIVE CLOTHING	Rq'd
1. Coveralls One (Two)	✓
2. Respirator	✓
3. Breathing Air	
4. Cap (Hood)	✓
5. Shoe Covers	✓
6. Gloves	✓
7. TLD Badge (BY)	✓
8. Self-reading Dosimeter	✓
9. Safety Belt	
10. Rubber Boots	
11. Lab Coat	
12. RT-1 Pers. Rad. Monitor	
13. Neutron Badge	
14.	

JOB EVALUATION	Rq'd
1. Does job alter ventilation patterns?	
2. Rigging approved?	
3. Building Services?	✓
4. Will operation effect other jobs and/or personnel?	
5. Does job require a special procedure?	
6. Has area been properly cleared for job?	
7. Procedure review for HLC personnel?	
8. Procedure review with Crafts (Maint., E&I, T&T)?	✓
9. Fire Hazard?	
10. Lockout required?	
11. Does job equipment meet safety specs?	
12. Voice Announcement	
13. Preplan required	✓
14.	

MONITORING	Rq'd
1. Self-monitoring permitted	
2. Monitoring at start of job by Radiation Control	
3. Intermittent monitoring by Radiation Control	
4. Continuous monitoring by Radiation Control	✓

SURVEY RESULTS

Surveyed by: [redacted]
3mR/hr gen work area

Operation

Describe operation, safety precautions, and radiation and contamination control precautions.

Title of Job: Remove a 4" section of the 2" HL. Drain line (old abandoned) at a weld next to the end that was cut off. B-005 North East Side Col: J-14 east over filter for B-126.
This sample is for CED test for corrosion.

Maint. to use the bag method to get this sample of pipe. Plug ends of pipe with rubber stoppers & tape.

ESTIMATED EXPOSURE

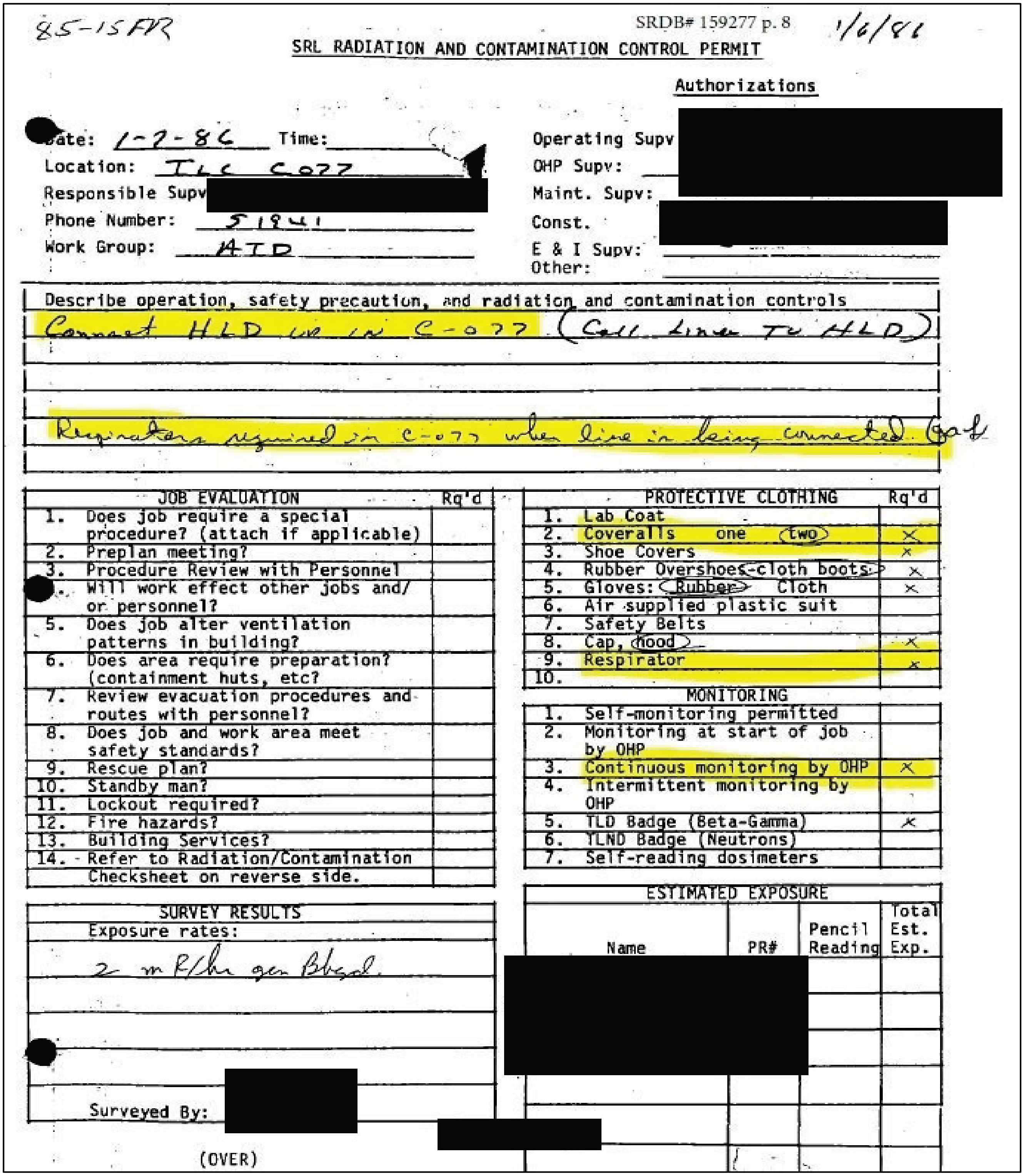
Name	Body Pencil mR	Left Hand mrem	Right Hand mrem
[redacted]	3		
	3		

AUTHORIZATIONS

HLC Supv:
✓Rad. Cont. Supv [redacted]
✓Maint. Supv: [redacted]
T&T Supv:
E&I Supv:
OFF[redacted]

Figure 7-1. Maintenance work on High Level Drain Line [DuPont 1983a].

Repair of the Master/Slave Manipulator (MSM) arms was almost exclusively a maintenance operation as shown in Figure 7-3. There are multiple job plans for this type of work because the repairs appeared to be routine, but a new Job Plan was filled out for each repair. In general, if the maintenance or repair involved the clean side (nonradiologically contaminated or Master components), no Health Physicist coverage was needed. If any part of the slave end (contaminated cell side) was disturbed, a Health Physics Survey was required. Two coveralls and respirators were required when dictated by the Radiation Control Survey. HP coverage was intermittent during this operation depending on the repairs being conducted. In general, very few construction operations



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SRL RADIATION AND CONTAMINATION CONTROL PERMIT

Authorizations

Date: 1-2-86 Time:
Location: ILC C077
Responsible Supv [redacted]
Phone Number: 51841
Work Group: HTD

Operating Supv [redacted]
OHP Supv:
Maint. Supv:
Const. [redacted]
E & I Supv:
Other:

Describe operation, safety precaution, and radiation and contamination controls

Connect HLD line in C-077 (Cell Line to HLD)

Respirators required in C-077 when line is being connected.

JOB EVALUATION	Rq'd
1. Does job require a special procedure? (attach if applicable)	
2. Preplan meeting?	
3. Procedure Review with Personnel	
4. Will work effect other jobs and/or personnel?	
5. Does job alter ventilation patterns in building?	
6. Does area require preparation? (containment huts, etc?	
7. Review evacuation procedures and routes with personnel?	
8. Does job and work area meet safety standards?	
9. Rescue plan?	
10. Standby man?	
11. Lockout required?	
12. Fire hazards?	
13. Building Services?	
14. Refer to Radiation/Contamination Checksheet on reverse side.	

PROTECTIVE CLOTHING	Rq'd
1. Lab Coat	
2. Coveralls one (two)	X
3. Shoe Covers	X
4. Rubber Overshoes-cloth boots	X
5. Gloves: (Rubber) Cloth	X
6. Air supplied plastic suit	
7. Safety Belts	
8. Cap, (hood)	X
9. Respirator	X
10.	

MONITORING	
1. Self-monitoring permitted	
2. Monitoring at start of job by OHP	
3. Continuous monitoring by OHP	X
4. Intermittent monitoring by OHP	
5. TLD Badge (Beta-Gamma)	X
6. TLND Badge (Neutrons)	
7. Self-reading dosimeters	

SURVEY RESULTS

Exposure rates:

2 mR/hr gen Bkgd.

Surveyed By: [redacted]

ESTIMATED EXPOSURE

Name	PR#	Pencil Reading	Total Est. Exp.
[redacted]			

[redacted]

(OVER)

Figure 7-2. Construction work on the High Level Drain Line [DuPont 1986].

mention the MSMs. One job noted removal of the MSM covers, which exposed the workers to the cell as shown in Figure 7-4. This is a similar exposure potential to when Maintenance would be working on the slave end of the manipulator (i.e., an opening into the contaminated cell). In this instance, pipefitters, sheet metal workers, and laborers all participated in the same job. They all wore two coveralls and respirators. In addition, HP provided monitoring throughout the job. Stratification by CTW type in this example is not appropriate because all of the workers had the same exposure

ORIGINAL

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JOB PLAN

Date: 11-11-81
Time of Operation: 8-4
Contact: [redacted]
Done by: Maintenance
Phone: 2008

PROTECTIVE CLOTHING	Rq'd
1. Coveralls One Two	x
2. Assault Mask *	x
3. Breathing Air	
4. Cap Hood	
5. Shoe Covers	x
6. Gloves	x
7. TLD Badge (Fy)	x
8. Self-reading Dosimeter	
9. Safety Belt	
10. Rubber Boots	
11. Lab Coat	
12. HT-1 Pers. Rad. Monitor	
13. Neutron Badge	x
14.	

JOB EVALUATION	Rq'd
1. Does job alter ventilation patterns?	no
2. Rigging approved?	yes
3. Building Services?	no
4. Will operation effect other jobs and/or personnel?	no
5. Does job require a special procedure?	job plan
6. Has area been properly cleared for job?	yes
7. Procedure review for HLC personnel?	yes
8. Procedure review with Crafts (Maint., E&I, T&T)?	yes
9. Fire Hazard?	no
10. Lockout required?	no
11. Does job equipment meet safety specs?	yes
12. Voice Announcement	no
13. Preplan required	yes
14.	

MONITORING	Rq'd
1. Self-monitoring permitted.	
2. Monitoring at start of job by Radiation Control	
3. Intermittent monitoring by Radiation Control	yes
4. Continuous monitoring by Radiation Control	

SURVEY RESULTS
3 mR Thru gen workarea

Surveyed by: [redacted] [redacted]

Operation

Describe operation, safety precautions and radiation and contamination control precautions.

Title of Job: Remove End and Repair MSM repair manipulator CPF per standard MSM Maintenance techniques.

Radiation Control survey required when disturbing any parts on slave end of thru tube.

*Assault mask required when dictated by Radiation Control survey.

ESTIMATED EXPOSURE

Name	Body Pencil mR	Left Hand mrem	Right Hand mrem
[redacted]	6		
	6		

AUTHORIZATIONS

HLC Supv: [redacted]
Rad. Cont. Supv: [redacted]
Maint. Supv: [redacted]
T&T Supv:
[redacted] Supv:

Figure 7-3. Maintenance on MSMs [DuPont 1981, p. 80].

JOB PLAN

Date: 10/31/83
Time of Operation: DAYS
Contact: [redacted]
Done by: CONSTR.
Phone: 3868

PROTECTIVE CLOTHING	Rq'd
1. Coveralls One (Two)	✓
2. Respirator	✓
3. Breathing Air	
4. Cap (Hood)	✓
5. Shoe Covers	✓
6. Gloves	✓
7. TLD Badge (BY)	✓
8. Self-reading Dosimeter	✓
9. Safety Belt	
10. Rubber Boots	
11. Lab Coat	
12. RT-1 Pers. Rad. Monitor	
13. Neutron Badge	
14. Finger Rings	✓

JOB EVALUATION	Rq'd
1. Does job alter ventilation patterns?	NO
2. Rigging approved?	YES
3. Building Services?	N/A
4. Will operation effect other jobs and/or personnel?	NO
5. Does job require a special procedure? JOB PLAN prepared.	YES
6. Has area been properly ~~cleared~~ for job?	YES
7. Procedure review for ~~HLC~~ CRAFT personnel? JOB PLAN	YES
8. Procedure review with Crafts (~~Maint., E&I, T&T~~)? CONST. (VERBAL)	YES
9. Fire Hazard?	NO
10. Lockout required?	NO
11. Does job equipment meet safety specs?	YES
12. Voice Announcement	N/A
13. Preplan required HALO 10/28/83	YES
14.	

MONITORING	Rq'd
1. Self-monitoring permitted	
2. Monitoring at start of job by Radiation Control	
3. Intermittent monitoring by Radiation Control	
4. Continuous monitoring by Radiation Control	✓

SURVEY RESULTS

Surveyed by: [redacted]
30 mR/hr @ 3' top of cell
50 mR/hr @ 1½' top of Cell [redacted]

Operation

Describe operation, safety precautions, and radiation and contamination control precautions.

Title of Job: Remove Piping - Hook-up Liner - Install Pipe - Sheet metal - Laborers.

1. This job plan is for 3 operations
2. Cut piping, cover exposed ends and remove to waste.
3. Install PVC bag for pulling liner up and into.
4. Hook-up liner to facilitate removal.
5. Remove covers on MSM port, with push stick move mat'l on floor to front of liner.
6. Install a temporary line to facilitate putting Halon into cell during subsequent cutting operations.

ESTIMATED EXPOSURE

Name	Body Pencil mR	Left Hand mrem	Right Hand mrem
[redacted]			

AUTHORIZATIONS

TLC ~~HLC~~ Supv: [redacted]
E&I Supv:

Figure 7-4. Construction removing MSM covers [DuPont 1983b, p. 161].

potential. Due to similarity of jobs and exposures, NIOSH believes all crafts should be included in a single co-exposure model. The workplace monitoring at SRS varied depending on the magnitude of the exposure potential and associated risk. HP monitoring and personnel protective equipment changed depending on this exposure potential and is quite similar to radiological monitoring conducted today.

Many, but not all, CTWs as shown in ORAUT-RPRT-0083 [ORAUT 2017b] should have some bioassay just from the routine nature of compliance monitoring or from job monitoring of workers. If a worker participated intermittently on jobs in radiological areas, the combination of routine, job-specific, and incident monitoring of coworkers should identify an upper bound of the worker's radiological dose that is favorable to the claimant.

The discussion provided illustrates that all trades workers had a similar potential for exposure and in some instances the exact same potential for exposure as they worked on the same job. As a result, stratifying by type of CTW (i.e., craft) is not considered appropriate in these instances. The combining of all construction trades workers into a single stratum is considered appropriate for all unmonitored construction trades workers.

As stated, workers in the CTW population would perform frequent tasks of generally short duration that could nevertheless present a potential for external and internal radiation exposure. Bingham [1997] provided the following set of workers for the Oak Ridge study:

- Carpenters,
- Ironworkers,
- Electricians,
- Painters,
- Asbestos Workers or Insulators,
- Pipefitters or Steamfitters,
- Cement Masons,
- Laborers,
- Bricklayers,
- Boilermakers,
- Mechanics or Millwrights,
- Operating Engineers or Heavy Equipment Operators,
- Sheet Metal Workers,
- Roofers, and
- Truck Drivers.

For SRS, the Center to Protect Workers' Rights compiled the list in Table 7-1 taken from Bingham [1997]. It identified the same list, although laborers, roofers, and truck drivers were identified by their unions. Truck drivers met the criteria of a CTW at SRS. They frequently hauled radioactive wastes to the tank farms, to the burial grounds, or to the burning pits. Workers with the job title E&I Mechanic went to areas of the site to perform installation, maintenance, and repair of control and measurement equipment; they had a similar exposure profile to that of electricians and mechanics.

Table 7-1 lists the job titles from SRS that should be included in CTW data population. This list includes all the occupations in the list of construction worker trades in ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers* [ORAUT 2014b]. SRS PRID prefixes and craft code [DuPont 1954] are included.

Table 7-1. Construction trade crafts with roll and craft codes.

Craft	Roll and craft code
Boilermaker	Roll 4, craft code 20
Carpenter	Roll 2, 4, craft code 6
Concrete Worker (or cement worker or mason)	Roll 4, craft code 8
Construction Worker	Roll 4
Driver	Roll 2, 4, craft code 10
E&I Mechanic	Roll 2
Electrician	Roll 2, 4, craft code 25
Heavy Equipment Operator	Roll 2, 4, craft code 14
Insulator	Roll 2, 4, craft code 31
Ironworker	Roll 2, 4, craft code 21
Laborer	Roll 2, 4, craft code 5
Mechanic	Roll 2
Millwright	Roll 2, 4, craft code 18
Painter	Roll 2, 4, craft code 33
Pipefitter (or plumber)	Roll 2, 4, craft code 26
Rigger (or Laborer)	Roll 2, 4, craft code 5
Roofer	Roll 2, 4
Sheet metal Worker	Roll 2, 4, craft code 21

7.2.2.2 Worker Classification Methodology

The determination of whether an individual is a CTW is based on the person's PRID prefix and the occupation. The PRID prefix is the primary designator, but the occupation title is used to exclude or include some occupations when the PRID prefix would otherwise erroneously indicate the person is or is not a CTW. The method consists of using the PRID associated with the bioassay data for which a CTW determination is needed, if available, and an occupation title extrapolated from the datasets for which those occupation titles are available. For this co-exposure study, workers were considered CTWs if they had a Roll 4 or Roll 6 or higher PRID prefix, except if their job title was one of the nonCTW job titles in Table 7-2. If no Roll code is available, the person is assumed to be Roll 2 and the designation is made based on the occupation title. This approach is applicable to the DuPont era at SRS. A different classification methodology will be needed for the Westinghouse era.

There are two applications of this methodology:

1. <u>Self-contained dataset</u>. A dataset internally containing all the data necessary to make the CTW determination. The datasets that meet this description are the americium and neptunium logbook data. In these cases, the worker's occupation title has been directly obtained from the worker history cards on each bioassay date. The datasets also contain the PRID, which is also verified from the worker history cards. CTW determinations are directly made from this information.

2. Dataset without occupation titles and/or PRIDs. The datasets that meet this description are the NOCTS in vivo data, NOCTS in vitro data (other than tritium), and the NOCTS tritium data, which is a separate dataset. The NOCTS in vitro dataset is the source for plutonium, uranium, and strontium plus fission product (FP) bioassay data. The NOCTS in vivo dataset is the source for cesium and part of the neptunium bioassay data. In these cases, the following procedure is followed to make the CTW determination.

   - Create a "master" occupation and PRID lookup table by merging:
     - Americium logbook data,
     - Neptunium logbook data,

Table 7-2. CTW determination job titles.

CTW occupations
Boilermaker
Carpenter
Concrete worker
Construction worker
Driver
E&I Tech
Electrician
Heavy equipment operator
Insulator
Ironworker
Laborer
Maintenance
Mechanic
Painter
Rigger
Sheet metal worker
Welder

nonCTW occupations
Administrative Assistant
Assistant
Cafeteria
Clerical
Crane Process Operator
Engineer
Escort
HP
Human Resources
Instructor
Laundry
Layout
Machinist
Manager
Pilot
QA
Reactor Operator
Security
Specialist
Supervisor

     - NOCTS whole body count (WBC) data, and
     - ORAUT-RPRT-0058 [ORAUT 2012a] in vitro data.

   - Determine individual's name from NOCTS based on the claim number for a given bioassay sample (tritium dataset only).

   - For each bioassay result in the dataset (NOCTS in vitro or tritium data), find the bioassay date preceding or closest to it within 5 years for that person in the master lookup table. Base the lookup on the PRID if available or the person's name otherwise.

   - If a preceding or closest bioassay date within 5 years is found:
     - Assign the occupation title (and PRID if needed) from the bioassay date in the master lookup table to the bioassay result.

   - If no preceding or closest bioassay data within 5 years is found (person not listed in the master lookup table):

   - Manually look up the occupation title and PRID (if needed) on the bioassay date from the worker history cards.

- Make the CTW determination based on the PRID and assigned occupation title.

For this revision, the mixed fission product (MFP) statistical analysis was based on the source NOCTS data rather than the ORAUT-RPRT-0058, *A Comparison of Mixed Fission and Activation Product Coworker Models at the Savannah River Site*, in vitro data created specifically for the MFP stratification report [ORAUT 2012a]. This is due to changes in how MFPs were evaluated. Therefore, the only future use of this dataset is via its inclusion in the master lookup table described above. Similarly, the neptunium data for the neptunium stratification report [ORAUT 2012b] have no future use.

7.2.2.3 Worker Classification Quality Assurance

As discussed above, a Master Occupation Table was compiled from four data sources: americium logbook data, neptunium logbook data, NOCTS WBC data, and ORAUT-RPRT-0058 [ORAUT 2012a] in vitro data. The data entry accuracy for each of these sources was evaluated in accordance with ORAUT-RPRT-0078 [ORAUT 2016b]; the fields containing the PRID and the numerical sample results were evaluated with a maximum 1% allowable error rate. All other fields from the hardcopy records were evaluated with a maximum 5% allowable error rate. Each dataset passed the QA check, the results of which are summarized in Table 7-3. The details of the results of the evaluation are contained in Attachment A.

Table 7-3. Master Occupation Table data source QA check results.[a]

Data source	1% check results (95% confidence interval)	5% check results (95% confidence interval)
Americium logbook data (1963–1989)	0.59% (0.39%–0.86%)	0.69% (0.25%–1.49%)
Neptunium logbook data (1961–1969)	0.67% (0.46%–0.95%)	1.53% (0.83%–2.59%)
NOCTS WBC data (1966–1990)	0.62% (0.41%–0.89%)	2.17% (1.31%–3.37%)
ORAUT-RPRT-0058 MFPG in vitro data (1955–1988)	0.43% (0.27%–0.67%)	0.12% (0.0042%–0.65%)

a. MFPG = mixed fission product-gamma.

In addition, the accuracy of the CTW determinations obtained using the Master Occupation Table were checked for the NOCTS in vivo bioassay dataset, the NOCTS in vitro bioassay dataset, the NOCTS tritium bioassay dataset, the americium logbook dataset, and the neptunium logbook bioassay dataset. The results are summarized in Table 7-4. The details of the results of the evaluation are contained in Attachment A.

Table 7-4. CTW determination QA check results.

Data source	Check results (95% confidence interval)
NOCTS in vivo data (1966–1990)	0.83% (0.34%–1.68%)
NOCTS in vitro data (1953–1990)	1.15% (0.55%–2.09%)
NOCTS tritium data (1954–1990)	0.69% (0.25%–1.49%)
Neptunium logbook data (1961–1969)	0.28% (0.06%–0.94%)
Americium logbook data (1963–1989)	0.47% (0.14%–1.19%)

7.2.3 <u>Evaluation of Missed Dose</u>

For individual dose reconstructions, missed dose is assigned based on results that are less than the minimum detectable amount (MDA) or reporting level of the results and fitted dose is typically separately assigned based on results above this level. For internal dose co-exposure studies, missed and fitted dose are addressed simultaneously by the use of all bioassay data in the statistical analysis regardless of whether an entry is above or below the MDA. The actual uncensored <MDA results are used when available, and the techniques used to fit distributions to censored datasets in ORAUT-RPRT-0096 [ORAUT 2021] are used otherwise. The results of the statistical analysis are used to determine intake rates that include any potential missed dose, applying the general guidelines in Section 3.4.2 of ORAUT-OTIB-0060, *Internal Dose Reconstruction* [ORAUT 2018], and treating all of the statistical analysis results as positive values.

7.3 RADIONUCLIDE ANALYSES

7.3.1 Americium

7.3.1.1 Data Adequacy

7.3.1.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, instructions for requesting and collecting urine samples, and related administrative controls in the *Bioassay Control* procedures. The earliest available version of the procedure is Revision 2 dated January 2, 1968 [DuPont 1968a]. It indicates an americium sample size of 500 mL was used with a “positive result” level of 1 dpm/250 mL and a resample level of 5 dpm/250 mL. The procedure does not specify americium sampling frequencies. The sample request process indicates that 24-hour composite samples required approval by an HP Senior Supervisor or above, indicating that routine samples were probably not 24-hour samples.

In Revision 3 of the *Bioassay Control* procedure [DuPont 1970], the positive level for total activity from trivalent actinides (americium, curium, and californium) was noted as 0.3 dpm/1.5L and the sample positive level was used for the resample level. The sample size was reduced to 250 mL. An intake was considered confirmed if the initial bioassay result was >1 dpm/1.5L and a resample result was >0.3 dpm/1.5L. The sampling frequencies for various personnel are provided in Attachment B. The process for requesting samples was similar to the previous process, but approval of an HP Senior Supervisor or above was no longer required for 24-hour samples. Additional instructions were provided for collecting samples in the event of suspected inhalations, ingestions, injections, skin contaminations, or whenever airborne contamination exceeded control guides. In 1971, additional guidance for Construction Division personnel was added but with no specific guidance for trivalent actinides. “Other nuclides,” which would have included the trivalent actinides, were monitored as specified by area HP in the construction Job Plans [DuPont 1971a].

The periodicity of routine urine sampling changed throughout the 1970s for various work locations and as a result of the introduction of in vivo counting [DuPont 1971a, 1971b, 1976]. The sampling frequencies for various personnel at various times are provided in Attachment B.

The *1990 Internal Dosimetry Technical Basis Manual* monitoring program for trivalent actinides specified quarterly urine bioassay, an annual chest count, semiannual fecal bioassay, and personal air sampling [WSRC 1990]. If monitored by workgroup, the urine bioassay decreased to annually unless a member of the workgroup had a confirmed intake. Trivalent actinide monitoring was required for the F-Area New Special Recovery facility.

7.3.1.1.2 Applicability to Unmonitored Workers

Records of in vitro bioassay for trivalent actinides show urinalysis data back to about 1963. As discussed above in the description of the sample collection process, there was guidance for whom to sample by 1970, which is consistent with a substantial increase in the number of collected samples in

1969. With additional experience and history, the number of collected samples, both by workers in the monitoring program and the frequency of samples, decreased during the 1970s and 1980s as can be seen in Table 7-5. (Additional discussion of other results in Table 7-5 is provided in Section 7.3.1.2.1.) The sampling frequency decreased during this same period as detailed in Tables B-2 through B-8, resulting in some of the decrease in the total number of samples per year. The inference is that the increased sampling during the early 1970s provided the basis for selection of those worker groups, work locations, and job classifications for which trivalent actinide monitoring was needed and for an appropriate sampling frequency. The transition to workgroup monitoring in the 1980s also resulted in a reduction in the number of samples collected.

Table 7-5. Americium logbook data summary and completeness estimate.

Year	Monthly report # of Am samples	Logbook # of Am samples	% of summary samples in logbook
1963	11	19	173
1964	72	72	100
1965	173	213	123
1966	295	284	96
1967	253	303	120
1968	480	771	161
1969	1,194	930	78
1970	2,730	2,687	98
1971	2,016	2,100	104
1972	1,820	1,837	101
1973	1,332	1,368	103
1974	1,274	1,360	107
1975	891	879	99
1976	761	821	108
1977	593	573	97
1978	446	497	111
1979	664	646	97
1980	387	276	71
1981	344	365	106
1982	466	410	88
1983	413	363	88
1984	334	398	119
1985	244	420	172
1986	540	536	99
1987	420	384	91

DuPont workers, which included Roll 2 CTWs, were part of the routine monitoring program in the bioassay control procedures detailed in Section 7.3.1.1.1. The monitoring program was based on work location, and the radionuclides for which monitoring was performed and bioassay frequency was chosen were based on the exposure potential of each facility. Construction Division workers were not necessarily included in this routine monitoring program. The monitoring program for the Construction Division was different in that it was job specific. Area HPs specified the bioassay monitoring for each specific Job Plan. Those nonCTWs in areas with the potential for exposure (a decision made during Job Plan review) were thus included in the monitoring program.

Both of these types of monitoring programs can be considered variations on routine representative sampling. For workers normally present in an area (i.e., nonCTWs and Roll 2 CTWs), the monitoring is specified on an annual basis in the bioassay control procedures. For workers intermittently present in an area (i.e., some CTWs), the monitoring was based on the Job Plan. For the duration of the Job Plan and the duration of the exposure potential, the required monitoring was specified. The key point is that in both instances monitoring was based on exposure potential rather than being driven by incidents. In either case, if an incident did occur, incident-driven sampling would have been performed.

SRS also used workgroup monitoring as a representative sampling method to confirm the lack of intakes. The bioassay frequency of individual workers was reduced while still monitoring the entire group. Effectively, it was assumed that a worker's intake potential could be based on the bioassay data for coworkers, very similar to this co-exposure study. If coworker bioassay data were negative, it was assumed that there was no intake for all the workers in the workgroup. If an intake (positive bioassay result) was confirmed, bioassay frequencies for the entire workgroup increased. Indications are that this practice began in the 1980s, which is consistent with the observed decrease in the number of bioassay records available in NOCTS.

7.3.1.1.3 <u>Bioassay Analysis Techniques</u>

Records showing urinalysis for trivalent actinides date back at least to the mid-1960s, using liquid ion exchange: triisooctylamine (TIOA) followed by bis(2-ethylhexyl) phosphoric acid (HDEHP), deposition on planchets, and alpha counting. A 10% thenoyl trifluoroacetone in toluene extraction was used to remove solids and reduce alpha self-absorption in the samples. Tracer recoveries were greater than 90% [Butler 1964]. The early reporting levels varied from 1 to 3 dpm/1.5 L. In 1964, solid-state surface barrier detectors replaced the previous counting method for using alpha track counting [Butler and Splichal 1965]. Samples were usually analyzed in batches of 20, including spikes and blanks, with one blank and two to four spikes in each batch. Multiple counts of a sample (assumed to be separate aliquots) were not common until 1969, when the logbook records also start to record "dpm/disc" values [DuPont 1963–1970].

In about 1970 an extraction method using the bidentate dibutyl-*N*,*N*-diethylcarbamylphosphonate (DDCP) was developed that allowed sequential separation of plutonium, neptunium, and uranium with TIOA, followed by extraction of thorium, americium, curium, berkelium, californium, and einsteinium with bidentate. (It would also have captured fermium.) The extraction efficiency for americium was 89 ±8% [Butler and Hall 1970]. The sensitivity of that method was reported to be 0.02 ±0.01 dpm/250 mL or 0.12 dpm/1.5 L for a 24-hour count. The article states that alpha spectrometry can be used to identify individual radionuclides, but the sensitivity appeared to be based on a gross alpha count [Butler and Hall 1970, pp. 3, 4]. Samples were analyzed in batches of 20, including spikes and blanks, with one blank and two spikes in each batch [DuPont 1970–1973]. In 1971, the reporting level using gross alpha counting on a solid-state detector was listed as 0.3 dpm/1.5 L [Taylor 2000, p. 4]. The Butler and Hall article was a report on research and reported the limits obtainable under research conditions [Butler and Hall 1970]. The 0.3 dpm/1.5L reporting level provided by Taylor is assumed to be the actual reporting level in practice under production conditions.

In 1990, a change in radiochemical processing (ion exchange resin) resulted in an MDA of 0.15 dpm/L [WSRC 2001, p. 182; Taylor et al. 1995, p.79]. Alpha spectrometry has been used since 1992 for special samples and since 1995 for routine samples with MDAs of 0.064 dpm/L for ^{241}Am and 0.047 dpm/L for ^{244}Cm and ^{252}Cf [WSRC 2001, p. 58]. A review of the recorded data show that the transition from gross alpha to alpha spectrometry was not clean, with a few routine samples having alpha spectrometry in 1993 and 1994. The gross alpha results are listed as "AmCmCf" in the database.

7.3.1.1.4 <u>Paired Measurements Sample Variance</u>

The americium data from the logbooks contain multiple counts for each sample. Commonly making multiple counts began in 1969 and tapered off in the late 1980s. A review of the coefficient of variation of the results was performed to identify results with significant variation in the individual counts. Those with significant variation were investigated further to attempt to determine the reason for this variation. This evaluation is contained in Attachment C. The conclusion of the evaluation is that the occurrence of samples with significant intra-count variation is limited and that there is no systematic issue with the analytical procedure used for americium.

7.3.1.2 Data Validation

7.3.1.2.1 Logbook Data Completeness

For the period before availability of the HPRED data (before 1991), data from analytical laboratory logbooks was used [DuPont 1961–1969, 1963–1970, 1969, 1969–1973, 1970–1973, 1973–1978, 1973–1979, 1978–1983, 1979–1980, 1980–1981a,b, 1981–1986, 1986–1989]. The quantity of data from the logbooks was compared to annual bioassay summaries [DuPont 1965–1968, 1968b, 1969–1981, 1973–1986, 1988] with the number of samples in the logbooks shown as a percentage of the number given in the bioassay summaries. The results of this comparison are shown in Table 7-5. The ability to compare these numbers directly is limited by the fact that the logbooks record the date of sample collection while the summaries indicate the number of analyzed samples and include fecal samples for 1969 and after. On some occasions, samples were not analyzed until months after collection. Before 1969, the number of recorded samples in the logbooks exceeds the number in the summaries. Beginning in 1969, on average, about 90% of the number of samples in the summaries are recorded in the logbooks, and fecal samples can be assumed to account for at least part of the difference.

7.3.1.2.2 Data Quality

The data entry effort was evaluated in accordance with ORAUT-RPRT-0078 [ORAUT 2016b]; the fields with the numerical sample results were evaluated with a maximum 1% allowable error rate. The QA check resulted in a point estimate error rate of 0.52% with a 95% confidence interval of 0.33% to 0.78%. All fields were evaluated with a maximum 5% allowable error rate. The QA check resulted in a point estimate error rate of 0.23% with a 95% confidence interval of 0.03% to 0.82%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

7.3.1.2.3 Data Interpretation

A single americium urine sample was commonly counted multiple times, usually twice, but as many as eight times was noted. The data in the logbooks consisted of one or more count rate results for each urine sample in units of dpm per disc, depending on how many times a sample was counted (this information was not used) and count-specific results in units of net dpm per unit volume or sample (this information was used). Further, a reported value for each sample, also in units of dpm per unit volume or sample, was usually provided. The result in dpm per unit volume or sample for each count of a sample was generally recorded as an uncensored value (i.e., the calculated result was recorded regardless of its value). In contrast, the “reported” values were generally censored (i.e., results less than some level, typically the detection or reporting limit, were reported as a less-than result). Some dpm per unit volume or sample data that were less than zero were reported as zero.

On some occasions, nonstandard sample aliquots were used. Often this was due to a small total sample volume or expected high concentrations. The count-specific results were adjusted to correct for the nonstandard volume. The details of this correction methodology are contained in the statistical analysis instructions in Attachment D.

Not all sample records included all this information, and in some instances, the count-specific results were censored. If count-specific results were available, the valid results were averaged by the Oak Ridge Associated Universities (ORAU) Team to determine the sample result. This value was generally uncensored. If count-specific results were not available, the reported values were used, many of which were censored.

7.3.1.2.4 Data Exclusion

Samples marked as LIP (lost in process), those marked DTPA (diethylene triamine pentaacetic acid) to indicate chelation, and those that lacked sufficient identifying information [e.g., sample date or worker payroll identification (ID) number] were excluded. Individuals with intakes of actinides are sometimes treated by chelation to accelerate the excretion of the radionuclides. Bioassay data influenced by chelation treatment are not suitable for use in an internal dose co-exposure study due to the altered biokinetics during chelation treatment. A listing of individuals who received chelation at SRS was compiled from Site Research Database (SRDB) chelation records from the Radiation Emergency Assistance Center/Training Site (REAC/TS) (see Table B-1). Bioassay data for samples collected within 100 days after receiving chelation treatment were not used.

Examination of the data revealed occasions during which individuals were involved in incidents that resulted in large intakes and excretions. Post-incident results for [redacted] individuals were excluded due to an [redacted]. These incidents and intakes were characterized by an extremely high number of bioassay results, many of which were orders of magnitude higher than the bioassay data for other individuals. They were considered unrepresentative of the potential exposure to an unmonitored worker and were removed. The incidents were:

- [Redacted].
- [Redacted].
- [Redacted].
- [Redacted].

The above discussion is a general summary of the method. The detailed statistical analysis instructions are in Attachment D.

7.3.1.3 Statistical Analysis

Statistical analysis of the americium bioassay data were performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the time-weighted one person–one statistic (TWOPOS) method and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2021]. The data were analyzed on an annual basis except for 1963 to 1964 and 1988 to 1989 for the nonCTW data and for 1966 to 1967, 1983 to 1984, 1985 to 1986, and 1987 to 1989 for the CTW data. These years were merged due to the small number of workers with bioassay data available for them. Table 7-6 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-5 and 7-6. The box and whisker plots are overlaid with the cumulative excretion results predicted by the intake modeling as discussed further below. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990. The top line is the predicted excretion 84th percentile for all intakes. The bottom line is the predicted excretion GM for all intakes.

Table 7-6. Calculated 50th- and 84th-percentile urinary excretion rates of americium based on a lognormal fit to the TWOPOS data, 1963 to 1989 (dpm/d).[a]

Year[b]	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD[c]	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1963 1964	0.299	0.910	3.04	41	Not applicable	Not applicable	Not applicable	Not applicable
1965	0.258	0.946	3.67	123				
1966	0.444	1.297	2.92	144	0.440	1.463	3.32	50
1967	0.394	1.175	2.98	182				
1968	0.220	0.629	2.85	277	0.241	0.671	2.79	86
1969	0.169	0.461	2.72	277	0.185	0.546	2.95	94
1970	0.136	0.290	2.13	447	0.127	0.256	2.01	120
1971	0.134	0.236	1.76	530	0.133	0.241	1.81	100
1972	0.078	0.176	2.25	538	0.074	0.150	2.02	106
1973	0.018	0.076	4.09	520	0.020	0.077	3.80	106
1974	0.035	0.098	2.79	367	0.036	0.099	2.75	84
1975	0.028	0.092	3.31	361	0.028	0.097	3.52	94
1976	0.031	0.093	2.99	359	0.030	0.078	2.65	89
1977	0.032	0.092	2.84	316	0.033	0.082	2.51	68
1978	0.057	0.147	2.57	163	0.054	0.132	2.46	51
1979	0.043	0.111	2.56	248	0.044	0.111	2.55	59
1980	0.041	0.106	2.56	182	0.039	0.095	2.42	41
1981	0.019	0.073	3.80	245	0.029	0.131	4.49	40
1982	0.023	0.158	6.91	323	0.028	0.205	7.27	45
1983	0.125	0.197	1.57	277	0.120	0.222	1.85	63
1984	0.043	0.114	2.65	256				
1985	0.038	0.081	2.11	235	0.053	0.111	2.09	34
1986	0.052	0.139	2.68	243				
1987	0.114	0.151	1.32	283	0.105	0.157	1.50	26
1988 1989	0.108	0.186	1.73	282				

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.
b. Where multiple years are noted for a single line of excretion rates, the data for these years were combined for the statistical analysis.
c. GSD = geometric standard deviation.

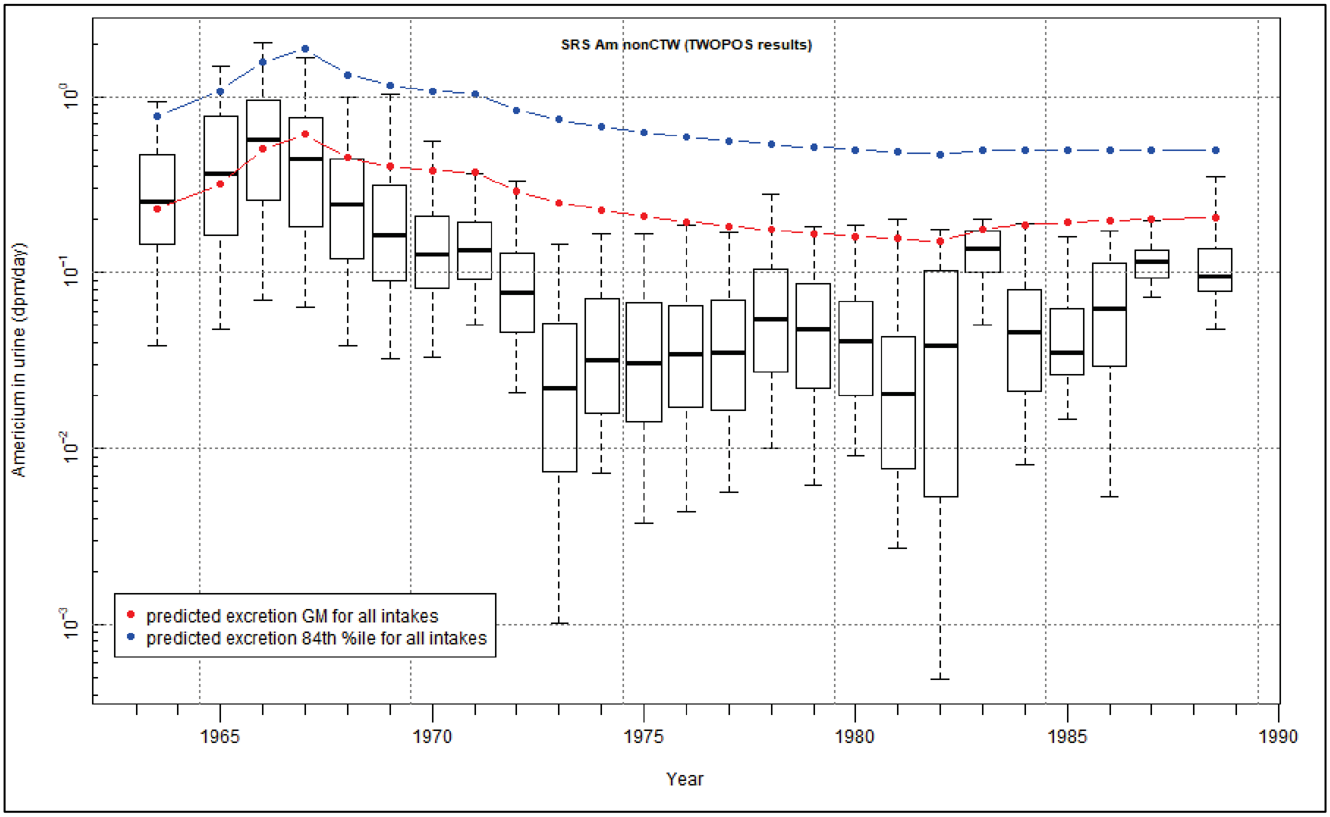

Figure 7-5. Americium nonCTW TWOPOS data box and whisker plot.

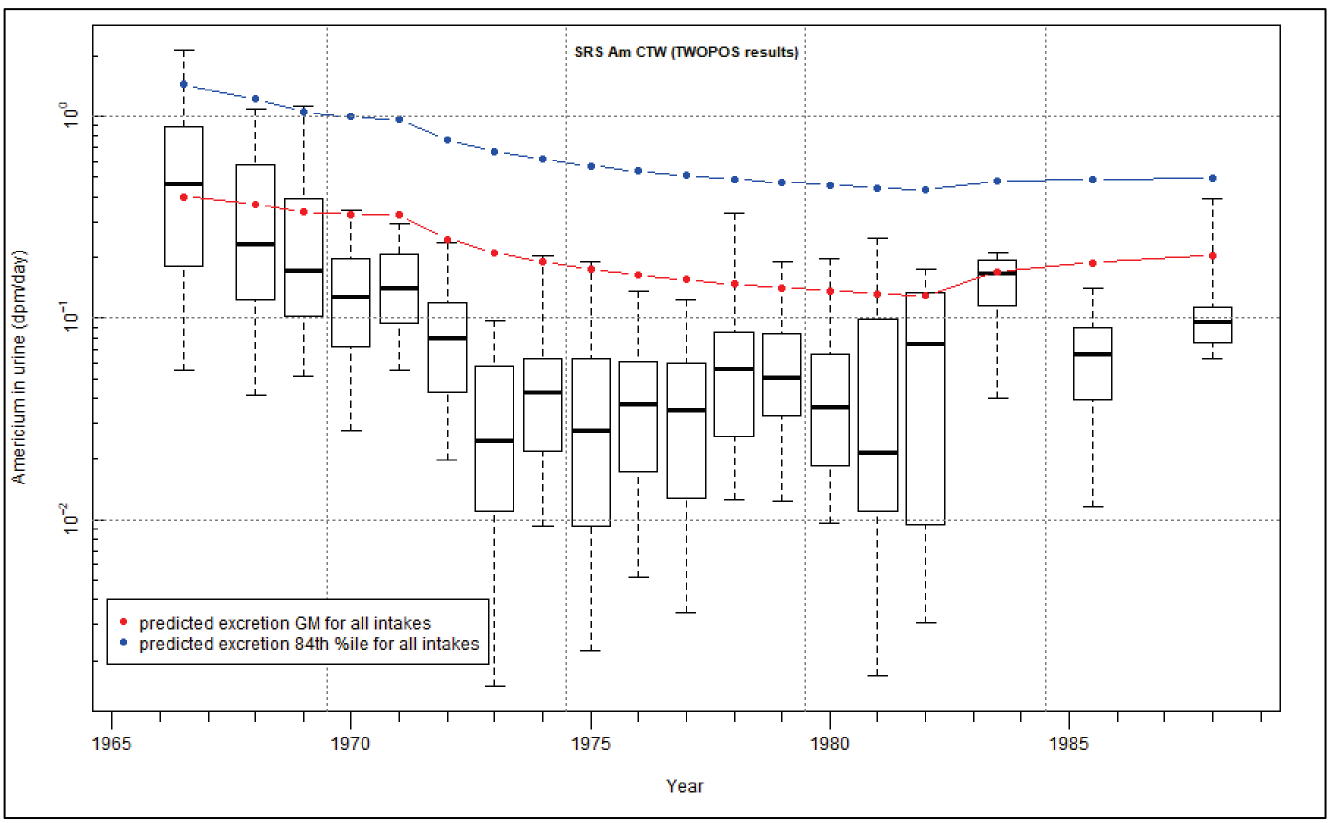

Figure 7-6. Americium CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.1.4 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. The IMBA program requires in vitro bioassay results to be in units of activity per day; therefore, all urinalysis results were normalized as needed to 24-hour samples using 1,500 mL (the volume of urine assumed by SRS to be excreted in a 24-hour period).

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-µm activity median aerodynamic diameter particle size distribution.

IMBA was used to fit the bioassay results to a series of chronic inhalation intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar, applying a rule of thumb that the results be within about a factor of 2. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1963 through 1989 were divided into multiple chronic intake periods.

Because americium has a very long half-life and the material is retained in the body for long periods, urinary excretion results are not independent. For example, an intake in the 1950s could contribute to excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked for relatively short periods, each intake period was fit independently using only the bioassay results from that period. For a particular individual, this fitting method will result in a best estimate of dose if the person worked in only one period and a potential overestimate if an individual worked in multiple periods. Only the results in the intake period were selected for use in the fitting of each period. Excluded results are shown as an "X" in the figures in Attachment E; included results are shown as dots. The results of the statistical analysis that was used to calculate the intakes are provided for americium in Table 7-6.

The solid lines in Figures E-1 to E-18 in Attachment E show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials for nonCTWs and CTWs. Figures E-19 to E-22 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes for nonCTWs and CTWs. Tables E-1 and E-2 list the 50th- and 84th-percentile intake rates with the associated geometric standard deviations (GSDs) from the americium urinalysis for nonCTWs and CTWs, respectively. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Figures 7-5 and 7-6 overlay the cumulative urinary excretion rates (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data. As can be seen, the predicted geometric means (GMs) of the excretion rates are favorable to claimants in comparison with the GMs of the TWOPOS data.

7.3.2 <u>Tritium</u>

7.3.2.1 Data Adequacy

7.3.2.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, instructions for requesting and collecting urine samples, and related administrative controls in the *Bioassay Control* procedures. The earliest available version of the *Bioassay Control* procedure is Revision 2 [DuPont 1968a], which indicates a tritium sample size of one voiding with a “positive level” of 1 µCi/L and a resample level of 5 µCi/L. The procedure does not specify required tritium sampling frequencies. Revision 3 [DuPont 1970] contains the same information. However, tritium sampling frequencies were given in *Radiation & Contamination Control*, DPSOL 100-9707 for 1964, 1965, and 1966. Workers with the highest potential for intakes of ^{3}H, reactor outage process workers, were asked to leave three samples per week. Other workers with a potential for intakes were required to leave one 50-mL urine sample each week [DuPont 1959–1971, pp. 417, 458, 920].

In Revision 5 [DuPont 1971b], there was no positive level and the confirmation level was still 5 µCi/L. Most 221-H and H-Area outside facilities workers submitted bioassay samples for tritium analysis twice a year. Workers in the 100 Areas, 105 Building, 232-H, 234-H, 237-H, 238-H, 241-H, and 244-H submitted bioassay samples as specified in “local procedures.” For the Construction Division, tritium sampling was specified in the Construction Job Plans or in DPSOP 40-1. In Revisions 7 and 8, sampling frequency was still specified in local procedures [DuPont 1959–1971, pp. 458–460 p. 355; 1976; no date b].

Bioassay control remained unchanged from 1978 through 1985 [DuPont 1985b, p. 273], and sampling frequency was still controlled by local procedures and construction Job Plans. The 1990 *Internal Dosimetry Technical Basis Manual* monitoring program for tritium specified monthly urine bioassay [WSRC 1990, p. 235]. In the available tritium dataset, there are over 200,000 bioassay results from individuals who submitted more than one sample for tritium analysis. Almost 30% of these samples were collected either daily or weekly, and over 60% were collected within 7 days. This is illustrated in Figure 7-7.

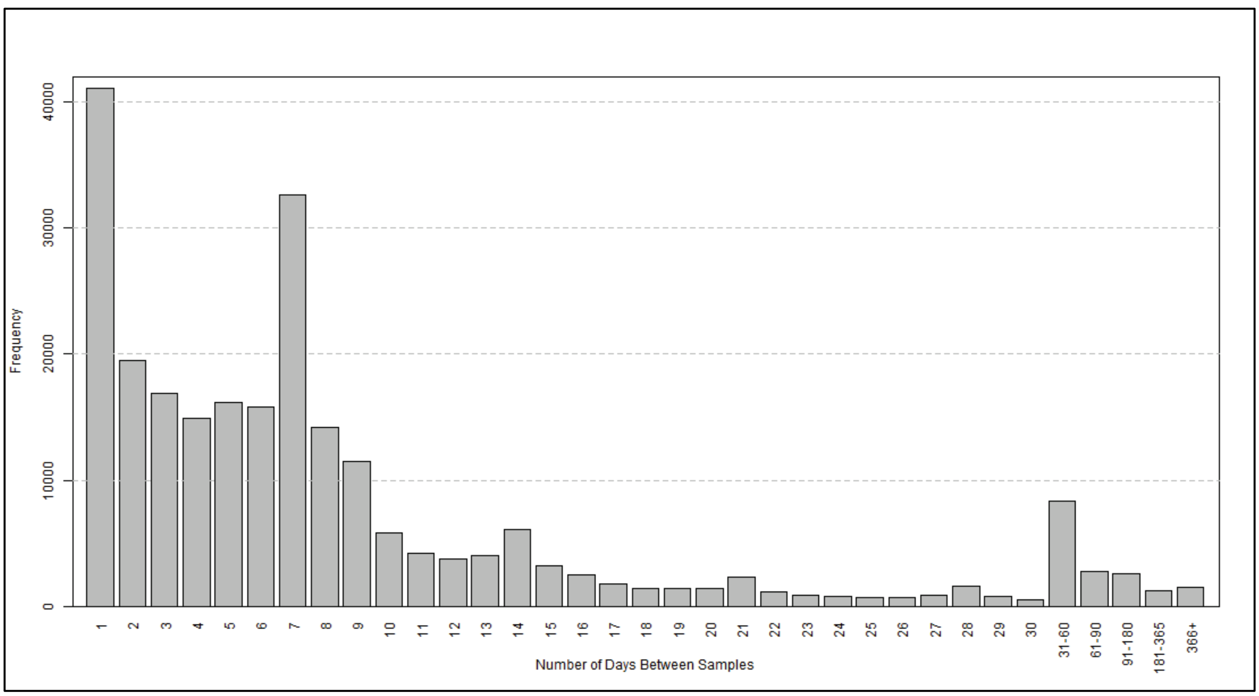

Figure 7-7. Tritium bioassay sample frequency.

7.3.2.1.2 <u>Applicability to Unmonitored Workers</u>

Records of in vitro bioassay for tritium show urinalysis data back to about 1954. As discussed above in the description of the sample collection process, there was guidance for whom to sample by 1968. Tritium was addressed differently from most other radionuclides in that sampling was more frequent and was controlled at the local level rather than in plantwide procedures. By 1976, overall guidance of whom to monitor was in place, but local control still determined precise sampling frequencies. By 1990, facilities with the potential for tritium exposure were using monthly sampling frequencies.

Available NOCTS tritium data on the number of monitored individuals trends the same for CTWs and nonCTWs with a peak in the late 1950s and early 1960s after a gradual decline through 1989 with intermittent increases.

DuPont workers, which included Roll 2 CTWs, were part of the routine monitoring program. The monitoring program was based on work location, and the radionuclides for which monitoring was performed and bioassay frequency were chosen based on the exposure potential in each facility. Construction Division workers were not necessarily included in this routine monitoring program. The monitoring program for the Construction Division was different in that it was job specific. Area HPs specified the bioassay monitoring to be performed for each specific Job Plan. Those nonCTWs in areas with the potential for exposure, a decision made during Job Plan review, were thus included in the monitoring program.

Both of these types of monitoring programs can be considered to be variations in routine representative sampling. For workers normally present in an area (i.e., nonCTWs and Roll 2 CTWs), the monitoring was specified on an annual basis in the bioassay control procedures. For workers intermittently present in an area (i.e., some CTWs), the monitoring was based on the Job Plan. For the duration of the Job Plan and the duration of the exposure potential, the required monitoring was specified. The key point is that in both instances monitoring was based on exposure potential rather than being driven by incidents. In either case, if an incident did occur, incident-driven sampling would have been performed.

SRS also used workgroup monitoring as a representative sampling method to confirm the lack of intakes. The bioassay frequency of individual workers was reduced, but the entire group was still monitored. Effectively, it was assumed that a worker's intake potential could be based on the bioassay data for coworkers, very similar to this co-exposure study. If coworker bioassay data were negative, it was assumed that there was no intake for all the workers in the workgroup. If an intake (positive bioassay result) was confirmed, bioassay frequencies for the entire workgroup increased. Indications are that this practice began in the 1980s, which is consistent with the observed decrease in the number of bioassay records available in NOCTS.

7.3.2.1.3 Bioassay Analysis Techniques

From startup until 1958, tritiated water vapor (HTO) in urine was analyzed by passing hydrogen evolved from the urine sample through an ionization chamber; the reported MDA for this method was 1 μCi/L. In 1958, liquid scintillation counting was initiated and remains in use. The reporting level remained at the value of 1 μCi/L until approximately February 1981 when it was reduced to 0.5 μCi/L. Based on review of bioassay results, the switch was not clean, and some samples dated December 1980 and January 1981 were reported as <0.5 μCi/L, while some samples dated after February 1981 were reported as <1 μCi/L.

The reporting level was reduced again to 0.1 μCi/L in about January 1986. (Again, the date is not certain, and either value was recorded for a few months before and after.) During the 1980s, although the reporting level of 0.5 μCi/L was generally used, some results below 0.5 are listed directly (e.g., 0.4 and 0.3). The true MDA was probably well below the reporting level, and these results below the reporting level should be considered as real. Quality control was ensured by daily, weekly, monthly, and quarterly checks of the bioassay measurement process specified in the DPSOL 47-268 procedure [WSRC 1990].

A *History of Personnel Radiation Dosimetry at the Savannah River Site* [Taylor et al. 1995] reports that the MDA consistently improved to the current level of 20,000 pCi/L (or 0.02 µCi/L). This MDA value was stated in the 1990 technical basis manual, so it was applicable at least that far back [WSRC 1990, p. 396]. It should be noted that for current analyses, tritium results of 0.05 µCi/L or less are reported as "<0.1 µCi L-1," and results between 0.05 µCi/L and 0.1 µCi/L are reported as "0.1 µCi L-1." Results greater than 0.1 µCi/L are reported as measured (to one significant figure) [WSRC 2001, p. 181].

Tritium analyses are listed as "T" on the employee bioassay cards. Tritium might also be listed as "P-10," especially in the 1950s. Tritium results in the 1990s were listed on the same summary form as external dose monitoring results. They are referred to as sample results with dates and analysis results, but the word "tritium" or any other radionuclide identifier is not mentioned directly.

For tritium results, the denominator used for reporting purposes has always been per liter of urine. (The denominator of 1.5 L was never used for tritium as it was for other radionuclides.)

7.3.2.2 Data Validation

Tritium data are from NOCTS bioassay data as discussed in Section 7.2. The data entry effort was evaluated in accordance with ORAUT-RPRT-0078 [ORAUT 2016b]. The numerical sample result fields were evaluated with a maximum 1% allowable error rate. The QA check resulted in a point estimate error rate of 0.32% with a 95% confidence interval of 0.18% to 0.53%. All fields were evaluated with a maximum 5% allowable error rate. The QA check resulted in a point estimate error rate of 0.23% with a 95% confidence interval of 0.03% to 0.82%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

7.3.2.3 Intake Modeling and Statistical Analysis

Tritium was evaluated differently from the other radionuclides in this co-exposure study. For other radionuclides, intake rates were determined. For tritium, individual doses were determined and were statistically evaluated. This is akin to the external dosimetry analysis in external dose co-exposure studies. The protocol in *Technical Information Bulletin: Tritium Calculated and Missed Dose Estimates* [ORAUT 2004b] was used to calculate the dose for each individual with the following rules concerning the elapsed time between consecutive samples:

- If there was a single urine sample in a calendar year and it was a less-than result (less than the MDA or reporting level), that result was excluded from the analysis because it was assumed not to be part of routine monitoring.
- Samples on the same date were ordered from lowest to highest result.
- All dose was assigned as if it occurred on the bioassay date.

The doses for a period were then plotted on a lognormal probability plot and the typical parameters (GM and GSD) were determined from a linear regression. Individuals who received less than 0.001 rem at three significant digits (i.e., less than 0.0005 rem) were excluded from the statistical analysis. Doses for 1954 to 1990 were calculated from the NOCTS dataset, which is considered a random sample of the complete dataset [ORAUT 2016a]. Table 7-7 lists the tritium doses and GSDs to be used for each year of potential tritium exposure for CTWs and nonCTWs. Box and whisker plots of the individual calculated doses are shown in Figures 7-8 and 7-9 for nonCTWs and CTWs, respectively. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990. The top line is the 84th percentile from lognormal fit. The bottom line is the GM from lognormal fit.

Table 7-7. Tritium annual doses (rem) and GSDs.[a]

Year	nonCTW # of individuals	nonCTW 50th percentile	nonCTW GSD	CTW # of individuals	CTW 50th percentile	CTW GSD
1954	89	0.012	1.87	33	0.012	1.93
1955	103	0.013	2.10	57	0.015	2.18
1956	83	0.019	2.67	53	0.016	2.52
1957	166	0.025	2.75	114	0.025	2.57
1958	243	0.035	2.45	157	0.031	2.35
1959	219	0.034	3.02	112	0.038	2.77
1960	231	0.046	3.18	151	0.042	3.06
1961	227	0.050	2.93	142	0.039	3.36
1962	247	0.051	2.81	186	0.041	2.80
1963	239	0.048	2.57	186	0.040	2.73
1964	218	0.060	3.01	158	0.054	2.83
1965	188	0.055	3.37	113	0.043	2.87
1966	182	0.046	2.86	97	0.031	3.12
1967	174	0.049	2.45	79	0.034	2.99
1968	162	0.051	2.75	91	0.030	2.97
1969	160	0.052	2.42	75	0.031	3.24
1970	156	0.042	2.62	68	0.023	3.49
1971	163	0.051	2.29	63	0.028	3.32
1972	214	0.047	2.82	80	0.033	3.33
1973	227	0.045	2.76	83	0.027	3.50
1974	205	0.048	2.64	74	0.031	3.33
1975	188	0.048	2.68	69	0.032	2.97
1976	176	0.047	2.68	69	0.030	3.26
1977	168	0.053	2.39	78	0.026	3.37
1978	170	0.048	2.45	63	0.028	2.97
1979	173	0.047	2.54	59	0.029	2.76
1980	162	0.049	2.20	68	0.024	2.81
1981	166	0.031	2.38	98	0.016	2.74
1982	188	0.027	2.38	99	0.015	2.72
1983	189	0.022	2.40	104	0.016	2.37
1984	183	0.023	2.47	93	0.015	2.75
1985	150	0.025	2.18	63	0.016	2.45
1986	144	0.008	3.32	66	0.006	3.17
1987	132	0.008	3.08	57	0.007	3.12
1988	117	0.008	2.71	47	0.006	3.52
1989	138	0.006	2.79	70	0.004	3.07
1990	136	0.006	2.78	94	0.006	2.57

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

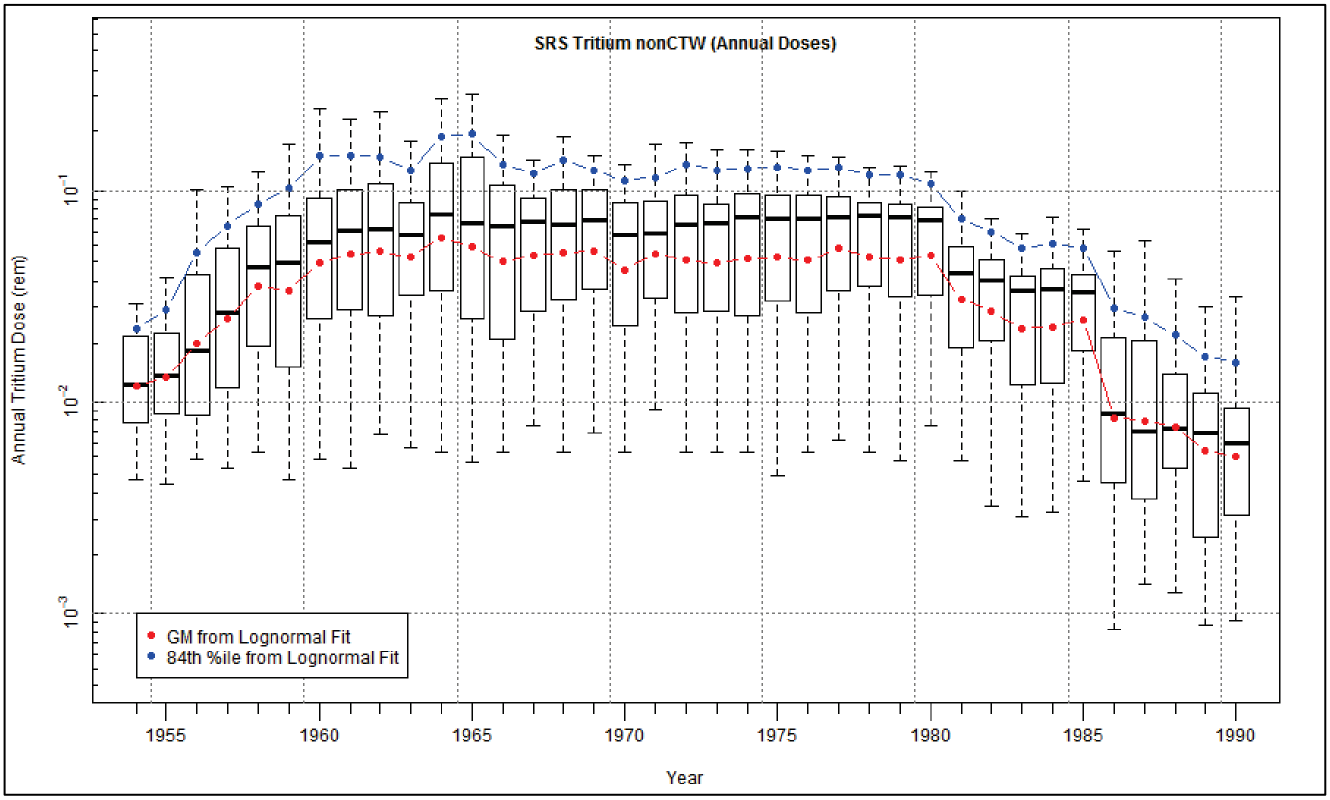

Figure 7-8. Tritium nonCTW individual dose data box and whisker plot.

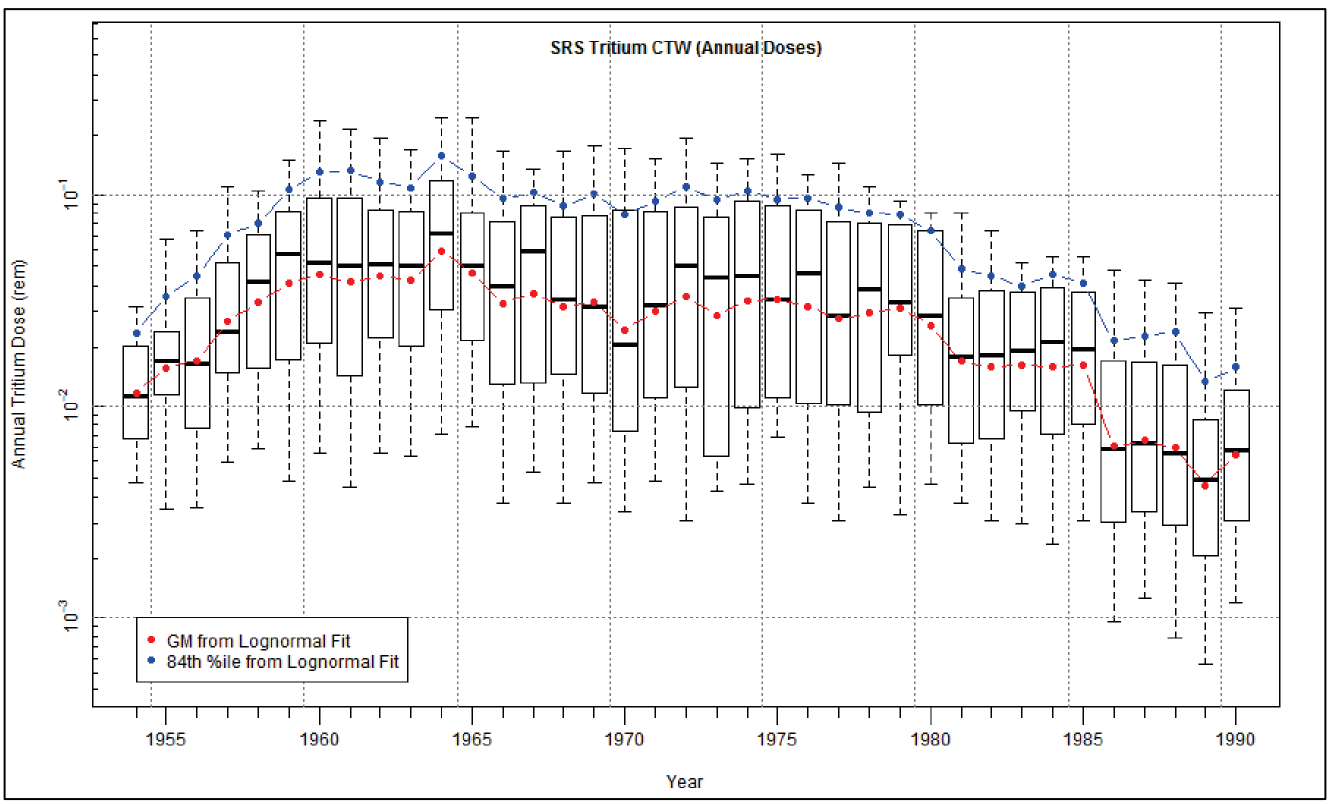

Figure 7-9. Tritium CTW individual dose data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.3 Plutonium

7.3.3.1 Data Adequacy

7.3.3.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, instructions for requesting and collecting urine samples, and related administrative controls in the *Bioassay Control* procedures. The earliest available version of the procedure is Revision 2 dated January 2, 1968 [DuPont 1968a]. It indicates a plutonium sample size of 250 mL was used with a positive result level of 0.1 dpm/1.5L and a resample level of 0.5 dpm/1.5L. The plutonium sampling frequencies are given in Table B-2 for various job categories and work locations. The sample request process indicates that 24-hour composite samples required approval by an HP Senior Supervisor or above, indicating that routine samples were probably not 24-hour samples.

In Revision 3 of the *Bioassay Control* procedure in 1970 [DuPont 1970], the positive level for plutonium was noted as 0.1 dpm/1.5L and the positive level was used for the resample level. An intake was considered confirmed if the initial bioassay result was >0.5 dpm/1.5L and a resample was >0.1 dpm/1.5L. The sampling frequencies for various personnel are provided in Attachment B. The process for requesting samples was similar to the previous process, but HP Senior Supervisor or above approval was no longer required for 24-hour samples. Additional instructions are provided for collecting samples in the event of suspected inhalations, ingestions, injections, skin contaminations, or whenever airborne contamination exceeded control guides. In 1971, additional guidance for Construction Division personnel was added that specified that Construction Division personnel were sampled triennially and at termination.

The frequency of routine urine sampling changed throughout the 1970s for various work locations, and also as a result of the introduction of in vivo counting [DuPont 1971a, 1971b, 1976]. The sampling frequencies for various personnel at various times are provided in Attachment B.

The 1990 *Internal Dosimetry Technical Basis Manual* monitoring program for plutonium specified annual urine bioassay, an annual chest count, annual fecal bioassay, and personal air sampling. If monitored by workgroup, the fecal bioassay and personal air sampling were not performed unless a member of the workgroup had a confirmed intake [WSRC 1990].

7.3.3.1.2 Applicability to Unmonitored Workers

Records of in vitro bioassay for plutonium show urinalysis data back to 1951. As discussed above in the description of the sample collection process, there was guidance for whom to sample by 1970. The amount of available plutonium bioassay data available each year in the NOCTS data are relatively constant from 1955 through 1989, the entire period this dataset is used.

Construction Division workers were not necessarily included in the regular monitoring program, but nonCTWs in all the areas with the potential for exposure were supposed to be part of the monitoring program. By at least 1971, Construction Division personnel submitted a urine sample at least annually that was analyzed for FPs, those radionuclides specified by area HP in the construction Job Plans, and plutonium at least triennially.

7.3.3.1.3 Bioassay Analysis Techniques

From the beginning of the plutonium urinalysis program in 1954 to approximately 1959, urine samples were radiochemically processed using bismuth phosphate and lanthanum fluoride coprecipitation and electroplated, and activities were determined by gross alpha track analysis of exposed nuclear track emulsion, type A (NTA) film. In 1959, nitric acid/hydrogen peroxide dissolution and ion exchange replaced the bismuth phosphate method. This was faster and used less urine but had essentially the same MDA. The reporting level did not change. Results were recorded as Pu or sometimes as ^{238}Pu/^{239}Pu. From around 1964 to 1988, counting for gross alpha activity was performed using a solid-state surface barrier alpha detector. TIOA liquid extraction replaced the ion exchange chemistry in 1966. This method used direct evaporation on planchets instead of electrodeposition. This method also allowed separation of neptunium and uranium from the same sample. Sensitivity was stated at 0.1 dpm/1.5L, which is consistent with the reporting level already in use. In or about 1981, a new coprecipitation technique was introduced for routine samples along with alpha spectrometry. Sample-specific determination of plutonium recovery by use of a ^{242}Pu tracer was also introduced at that time. Results for ^{238}Pu and ^{239}Pu were reported separately. The TIOA method with gross alpha counting continued to be used on special samples until 1988. A database was introduced in 1990 and results were thereafter reported as per liter. Electrodeposition was reinstated in 1994. Separation of plutonium+neptunium, actinides, uranium, and strontium from a single sample using TEVA (Tetra Valent Actinides) and transuranic resins began in 2001. Alpha-emitting plutonium and neptunium isotopes are electrodeposited and counted by alpha spectrometry on a single planchet [Taylor et al. 1995; Taylor 2000].

7.3.3.2 Data Validation

7.3.3.2.1 Data Completeness and Quality

The plutonium bioassay data for the co-exposure study were compiled from NOCTS data. The completeness and quality of this data source are addressed in Section 7.2.1 above.

7.3.3.2.2 Data Interpretation

Most of the plutonium urinalysis data are plutonium gross alpha measurements. During the 1980s, some of the samples were analyzed by alpha spectroscopy, yielding separate results for ^{238}Pu and ^{239}Pu or $^{239/240}$Pu. Because the two analytical techniques overlapped in time, the spectroscopic results were merged with the plutonium gross alpha measurements by using only the ^{239}Pu or $^{239/240}$Pu measurements and assuming a 12% 10-year decay plutonium mixture to convert to an equivalent plutonium gross alpha measurement. This mixture was chosen as favorable to claimants and is most often used during dose reconstructions.

7.3.3.2.3 Data Exclusion

Individuals with intakes of actinides are sometimes treated by chelation to accelerate the excretion of the radionuclides. Bioassay data influenced by chelation treatment are not suitable for use in an internal dose co-exposure study due to the altered biokinetics during chelation treatment. A listing of individuals who received chelation at SRS was compiled from SRDB chelation records from REAC/TS (see Table B-1). Bioassay data for samples collected within 100 days after receiving chelation treatment were not used. In addition, samples marked as LIP, those marked DTPA to indicate chelation, and those that lacked sufficient identifying information (e.g., sample date or payroll ID number) were excluded.

Sample results that were given as per unit mass or with an activity specified in curies rather than dpm were excluded because these are fecal samples.

The above discussion is a general summary of the method. The detailed statistical analysis instructions are in Attachment D.

7.3.3.3 Statistical Analysis

Statistical analysis of the plutonium bioassay data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096, *Multiple Imputation Applied to Bioassay Coworker Models* [ORAUT 2021]. The data were analyzed on an annual basis. Table 7-8 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-10 through 7-21. The box and whisker plots are overlaid with the cumulative excretion results predicted by the intake modeling as discussed further below. Due to the long biological retention period of plutonium, the cumulative excretion curves are split into two regimes: employment beginning in 1955 and employment beginning in 1971. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.3.4 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. The IMBA and IDOT programs require in vitro bioassay results to be in units of activity per day; therefore, all urinalysis results were normalized as needed to 24-hour samples using 1,500 mL (the volume of urine assumed by SRS to be excreted in a 24-hour period).

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-μm activity median aerodynamic diameter particle size distribution.

IMBA and IDOT were used to fit the bioassay results to a series of inhalation intakes. Data were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1955 through 1990 were divided into multiple chronic intake periods.

Because the plutonium isotopes at SRS have very long radiological half-lives, and because the material is retained in the body for long periods, excretion results are not independent. For example, an intake in the 1950s could have contributed to urinary excretion in the 1980s and later. However, because of turnover in the workforce, the workers used to assess intakes in one period might not have been the same as those in a later period. To avoid potential underestimation of intakes in the later periods, each chronic intake was fit independently using only the bioassay results from the single intake period for types M, S, and SS solubility [ORAUT 2020]. This method results in an overestimate of the later TWOPOS results when the cumulative predicted urine sample results from multiple assumed intake periods are plotted. Excluded results are shown as an “X” in the figures in Attachment E; included results are shown as dots. The results of the statistical analysis of the urinalysis bioassay data that was used to calculate the intakes are provided for plutonium in Table 7-8.

The solid lines in Figures E-23 to E-82 in Attachment E show the individual fits to the 50th- and 84th-percentile excretion rates for type M, S, and SS materials for nonCTWs and CTWs. Figures E-83 to E-94 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M, S, and SS intakes for nonCTWs and CTWs. Tables E-3 through E-8 list the 50th- and 84th-percentile intake rates with the associated GSDs from the plutonium urinalysis for solubility types M, S, and SS

Table 7-8. Calculated 50th- and 84th-percentile urinary excretion rates of plutonium based on a lognormal fit to the TWOPOS data, 1955 to 1990 (dpm/d).[a]

Year	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1955	0.01699	0.0537	3.16	245	0.01295	0.0370	2.86	49
1956	0.01859	0.0439	2.36	370	0.01717	0.0428	2.49	91
1957	0.01558	0.0386	2.48	360	0.01343	0.0304	2.27	93
1958	0.01727	0.0462	2.68	328	0.01308	0.0358	2.74	96
1959	0.01862	0.0554	2.98	375	0.01495	0.0519	3.47	100
1960	0.01448	0.0580	4.00	395	0.01255	0.0534	4.25	115
1961	0.00517	0.0196	3.80	402	0.00413	0.0163	3.94	124
1962	0.00220	0.0149	6.77	419	0.00165	0.0123	7.48	165
1963	0.00385	0.0198	5.14	365	0.00315	0.0224	7.12	128
1964	0.00906	0.0387	4.27	339	0.00776	0.0370	4.77	125
1965	0.00868	0.0360	4.14	433	0.00645	0.0332	5.14	167
1966	0.01401	0.0482	3.44	384	0.01284	0.0406	3.16	152
1967	0.00629	0.0387	6.14	358	0.00375	0.0263	7.00	152
1968	0.01186	0.0608	5.13	414	0.00957	0.0530	5.54	146
1969	0.03617	0.1136	3.14	296	0.03434	0.1188	3.46	108
1970	0.02776	0.0894	3.22	290	0.02591	0.0872	3.37	98
1971	0.01480	0.0582	3.94	381	0.01208	0.0564	4.67	110
1972	0.02024	0.0649	3.21	406	0.01819	0.0682	3.75	121
1973	0.00904	0.0435	4.82	402	0.00692	0.0400	5.78	123
1974	0.00828	0.0484	5.85	435	0.00610	0.0427	7.00	120
1975	0.01082	0.0587	5.43	406	0.00697	0.0370	5.30	104
1976	0.00806	0.0478	5.94	441	0.00514	0.0319	6.19	130
1977	0.00992	0.0513	5.17	458	0.00771	0.0377	4.90	118
1978	0.01776	0.0676	3.81	309	0.01556	0.0603	3.88	70
1979	0.01567	0.0638	4.07	406	0.01396	0.0523	3.74	127
1980	0.01153	0.0514	4.46	332	0.00967	0.0461	4.76	156
1981	0.00762	0.0380	4.99	437	0.00642	0.0299	4.65	206
1982	0.00236	0.0244	10.37	457	0.00167	0.0201	12.03	185
1983	0.00296	0.0321	10.83	355	0.00232	0.0292	12.61	125
1984	0.00384	0.0403	10.49	312	0.00317	0.0442	13.94	130
1985	0.00611	0.0483	7.90	277	0.00504	0.0409	8.11	117
1986	0.00672	0.0475	7.07	346	0.00546	0.0414	7.58	141
1987	0.00610	0.0392	6.42	334	0.00517	0.0389	7.53	112
1988	0.00503	0.0258	5.13	341	0.00402	0.0234	5.83	162
1989	0.00371	0.0201	5.42	360	0.00295	0.0173	5.88	157
1990	0.00270	0.0162	6.01	379	0.00251	0.0158	6.31	170

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

and for nonCTWs and CTWs. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Figures 7-10 through 7-21 overlay the urinary excretion rates (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data. Predicted excretion GM from all intakes (Figures 7-10 through 7-15) exceeds the actual TWOPOS median results for years after 1960; the predicted excretion for 1955 to 1960 agrees well with the TWOPOS results. The top line is the predicted excretion 84th percentile from all intakes. The bottom line is the predicted excretion GM from all intakes.

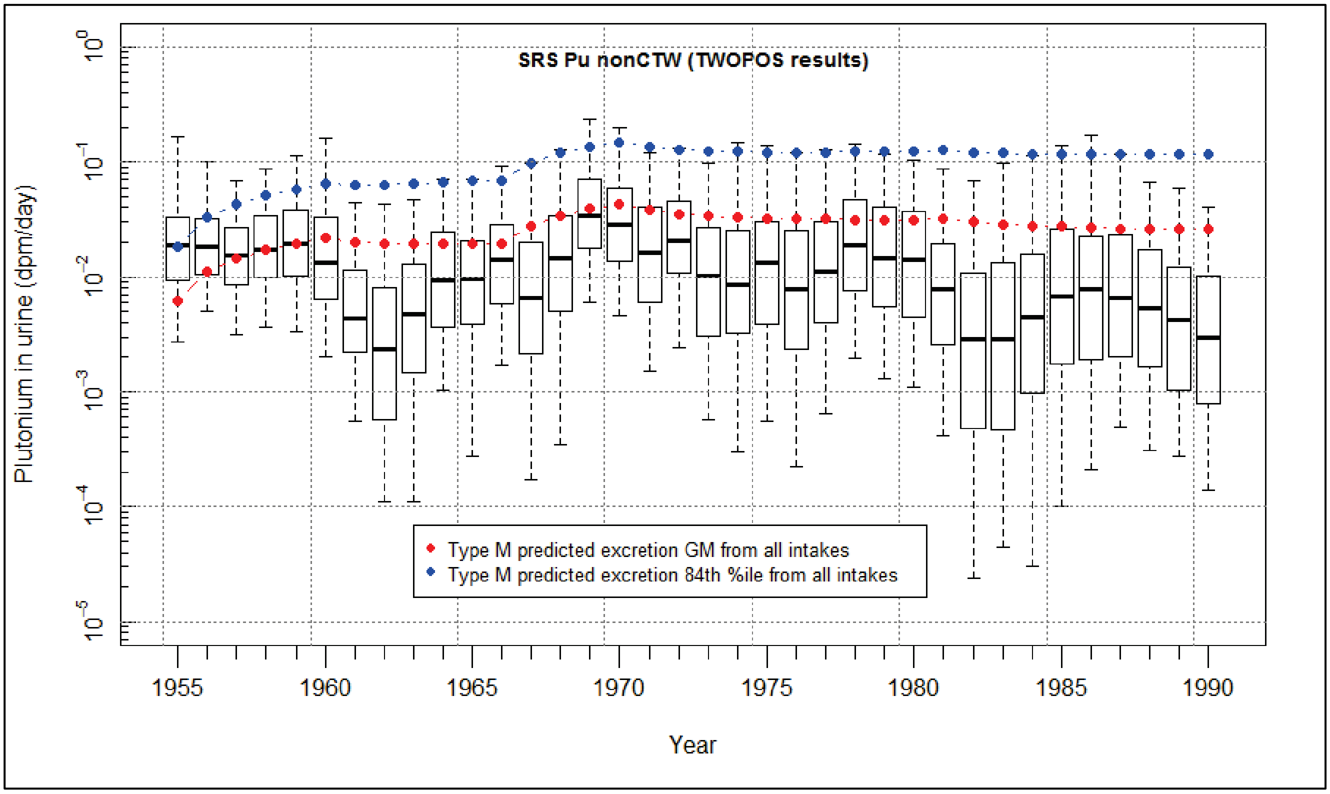

Figure 7-10. Plutonium type M nonCTW TWOPOS data box and whisker plot beginning in 1955.

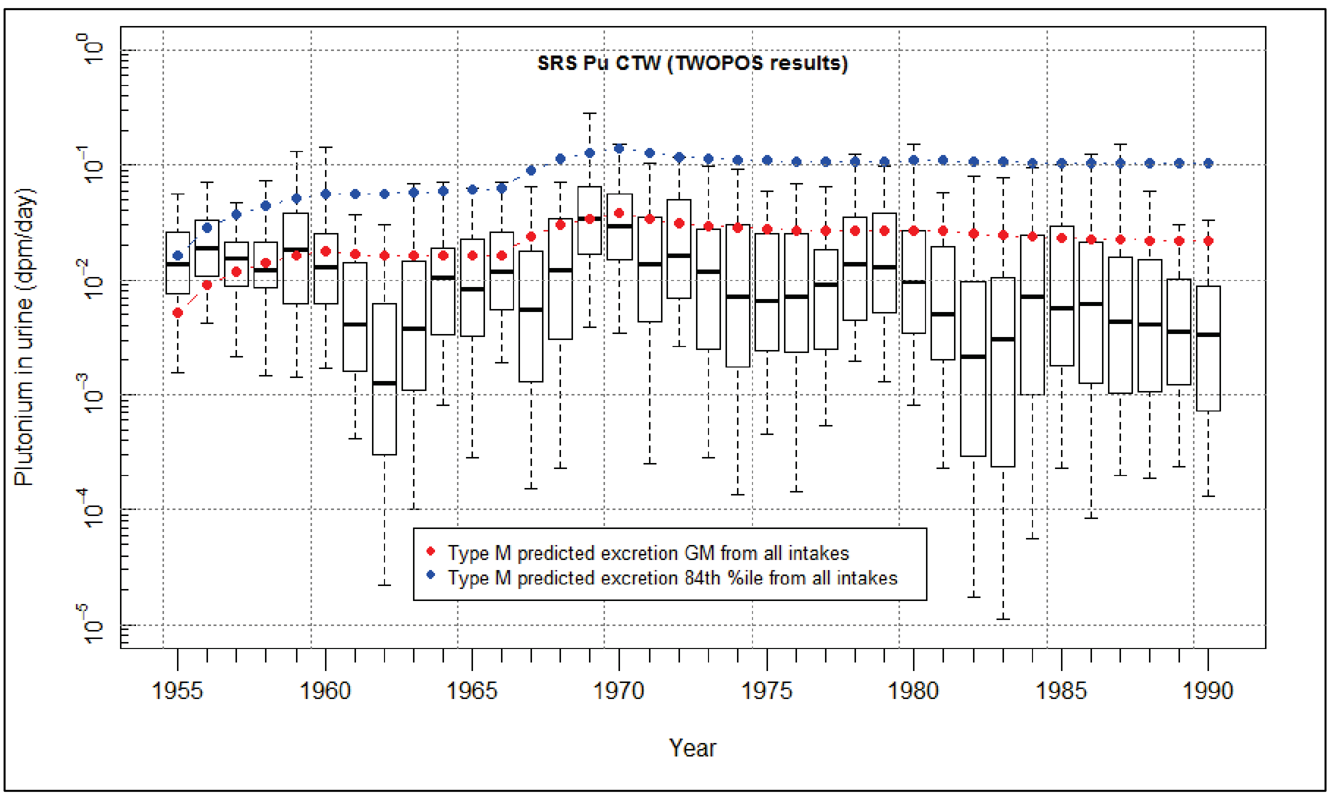

Figure 7-11. Plutonium type M CTW TWOPOS data box and whisker plot beginning in 1955. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

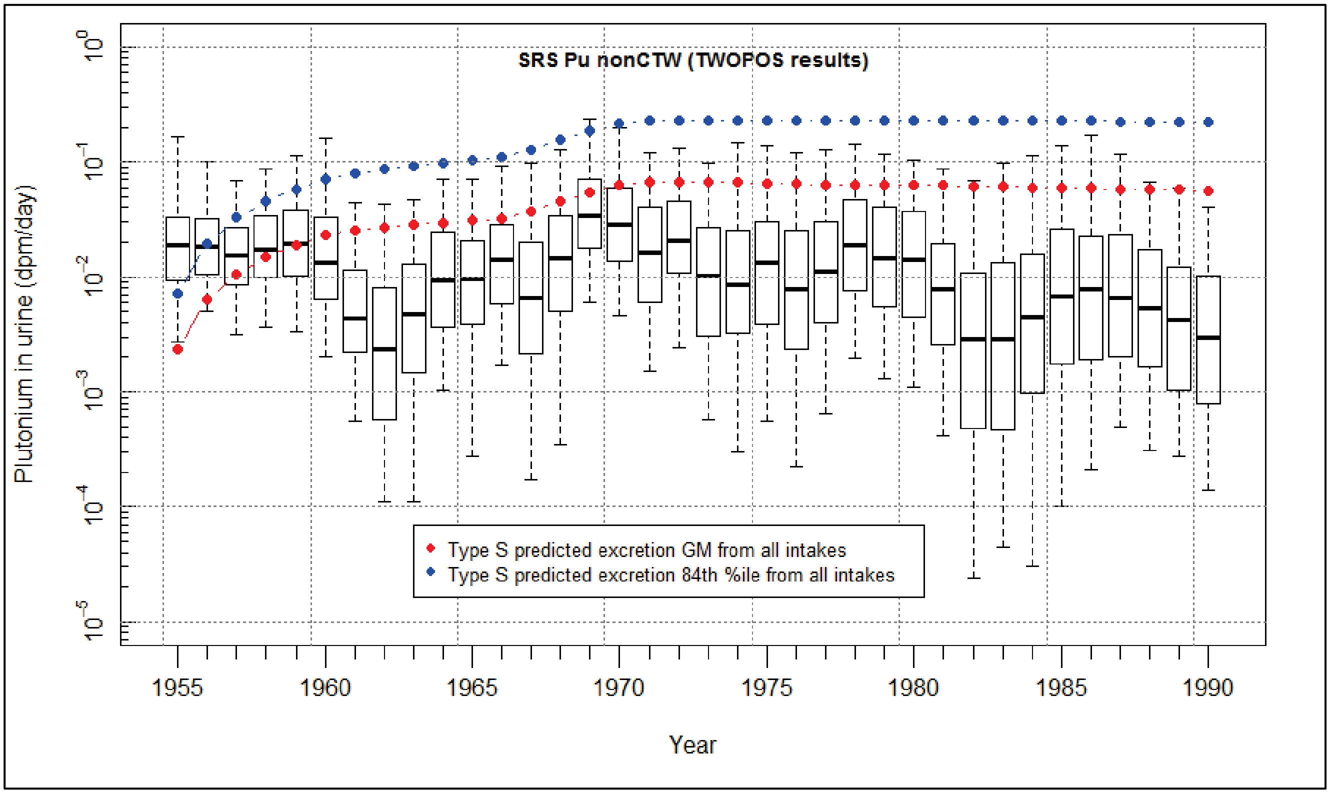

Figure 7-12. Plutonium type S nonCTW TWOPOS data box and whisker plot beginning in 1955.

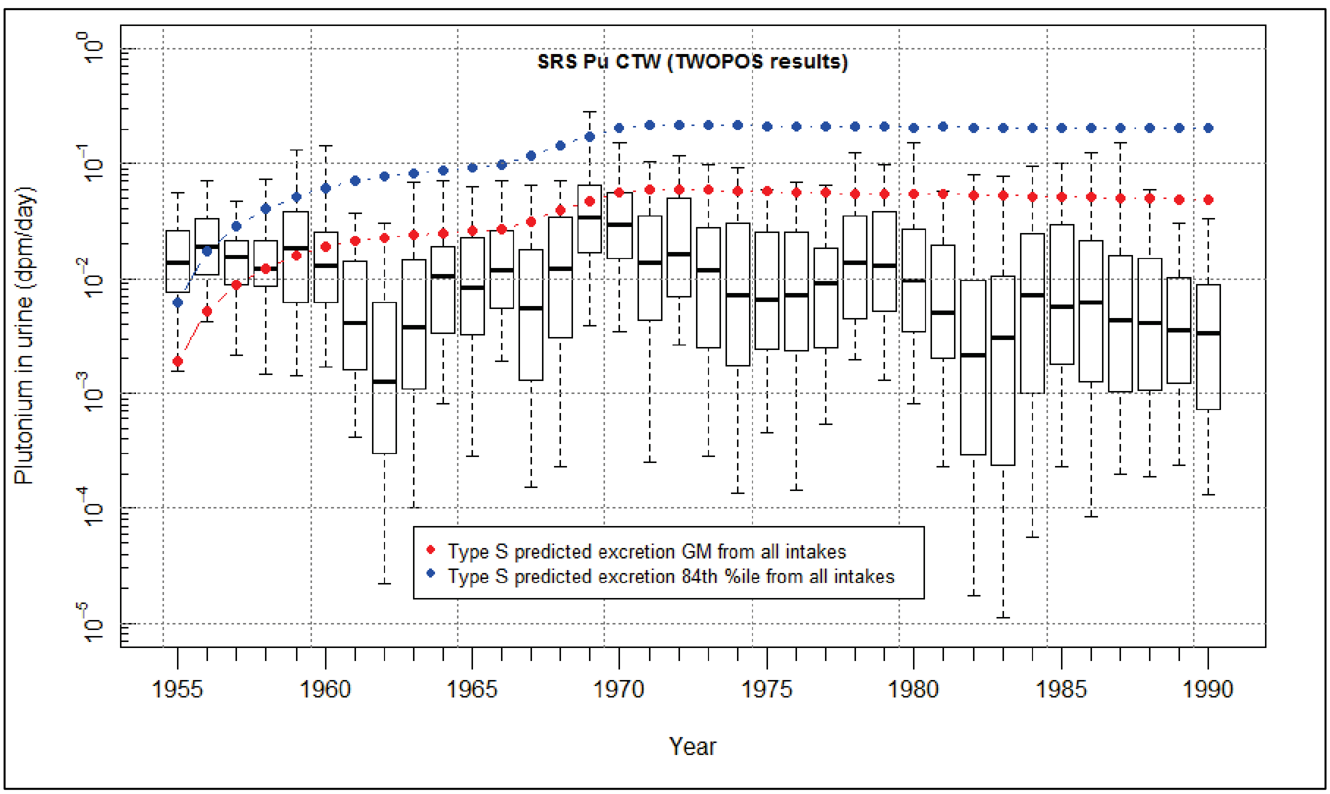

Figure 7-13. Plutonium type S CTW TWOPOS data box and whisker plot beginning in 1955. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

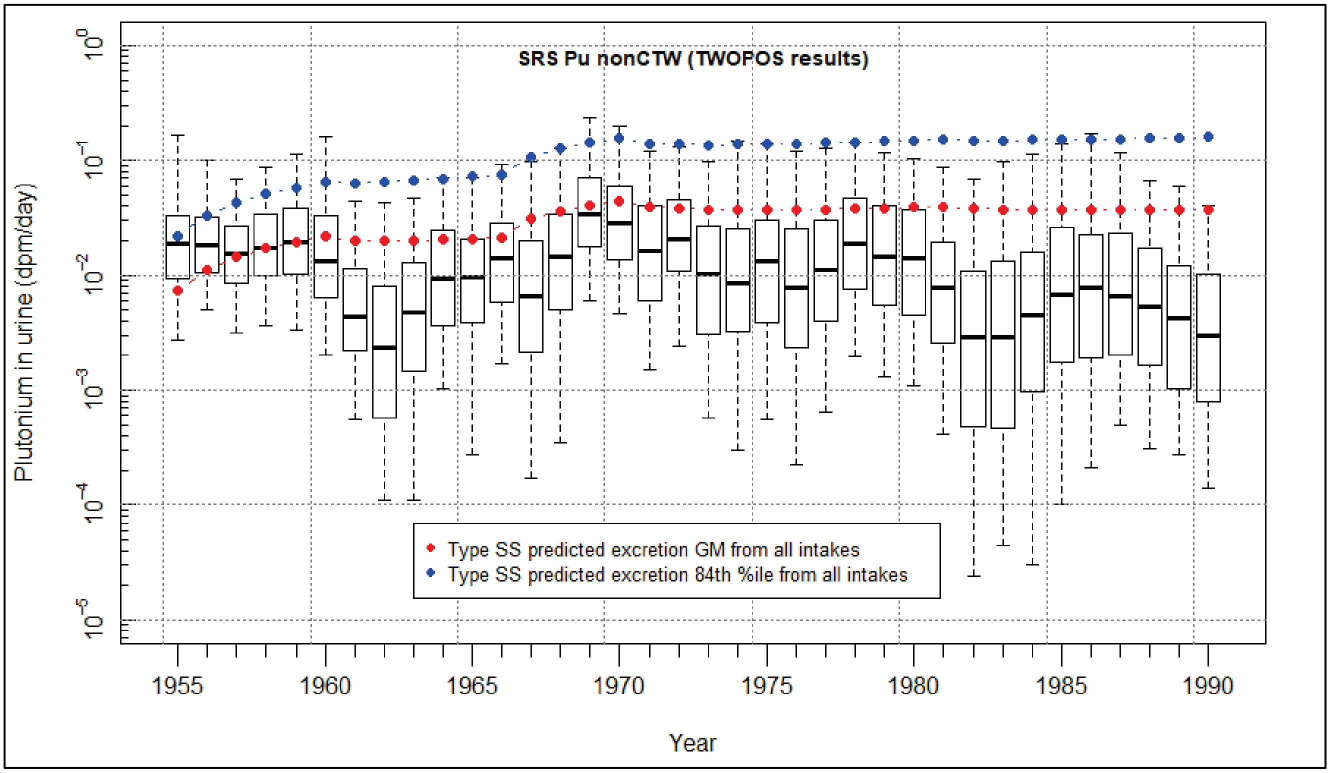

Figure 7-14. Plutonium type SS nonCTW TWOPOS data box and whisker plot beginning in 1955.

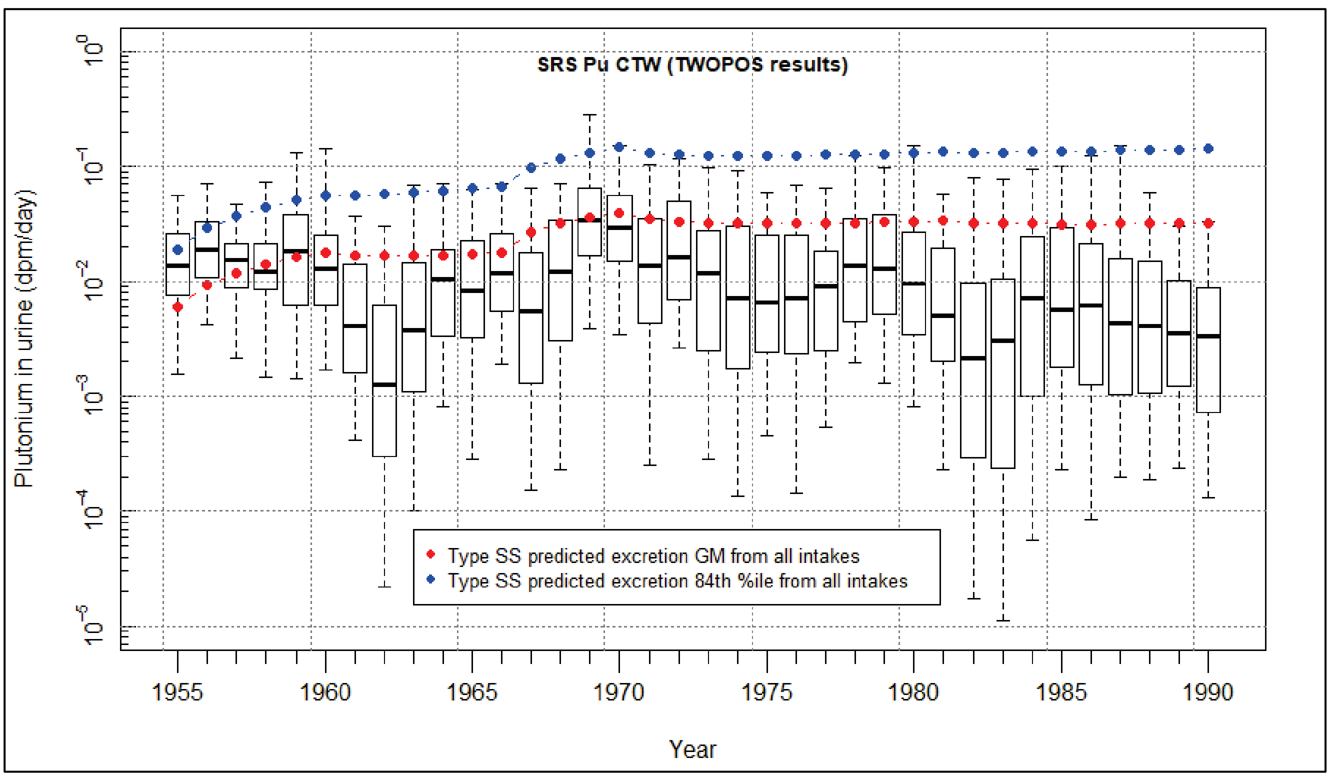

Figure 7-15. Plutonium type SS CTW TWOPOS data box and whisker plot beginning in 1955. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

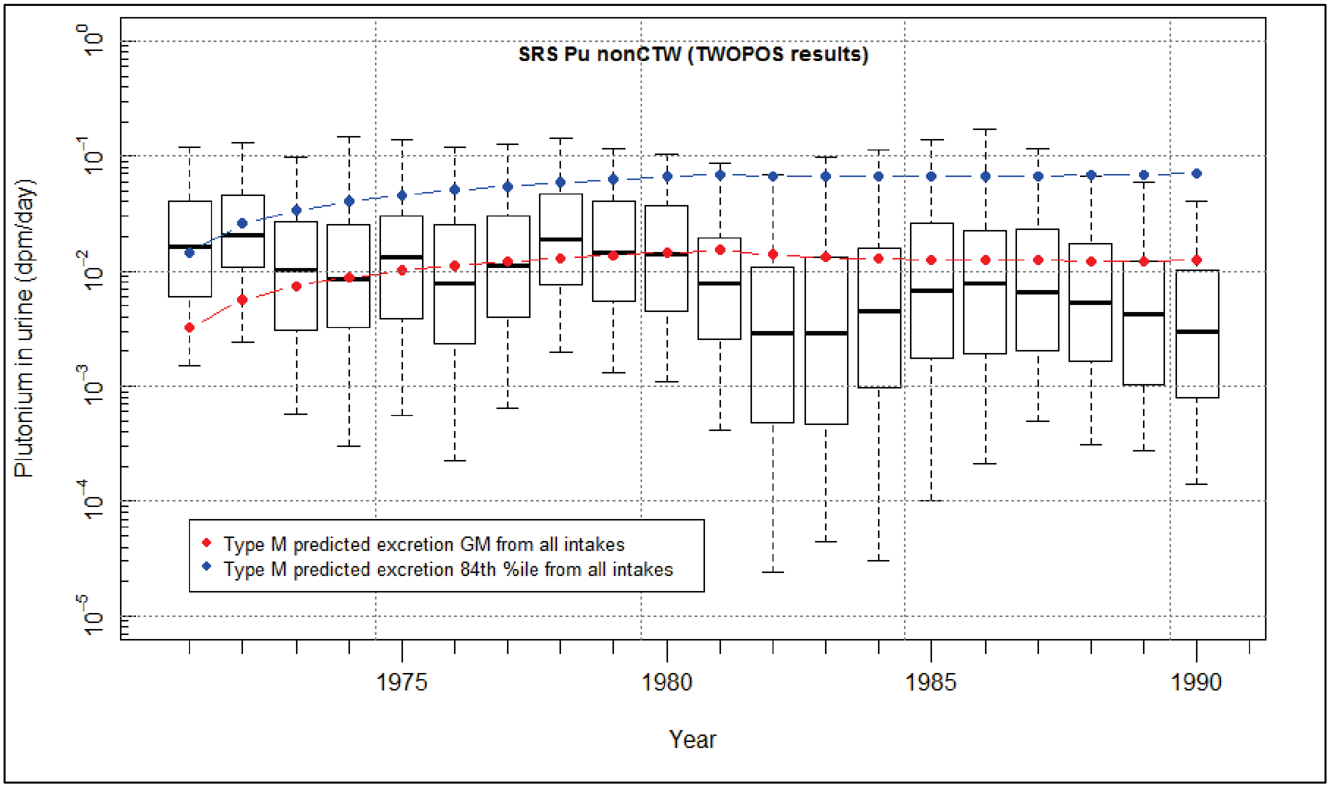

Figure 7-16. Plutonium type M nonCTW TWOPOS data box and whisker plot beginning in 1971.

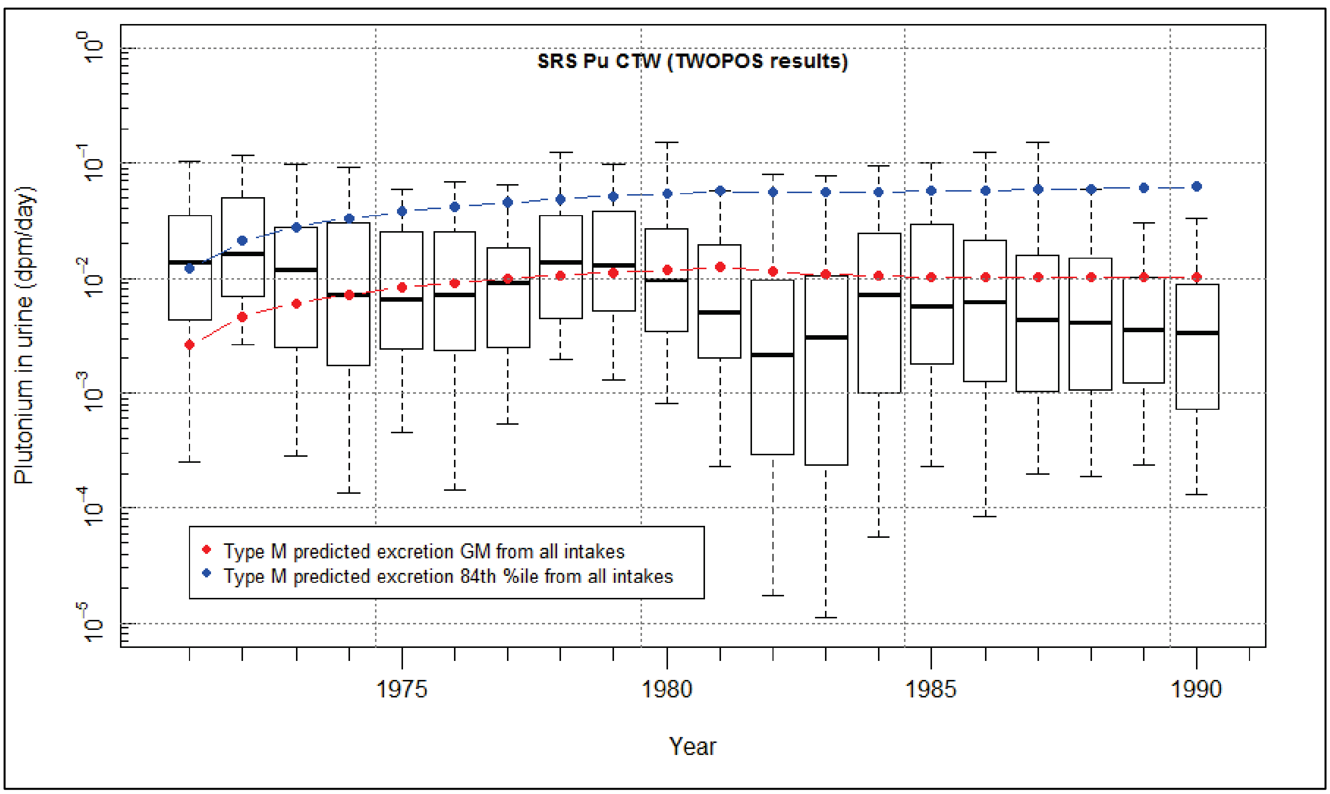

Figure 7-17. Plutonium type M CTW TWOPOS data box and whisker plot beginning in 1971. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

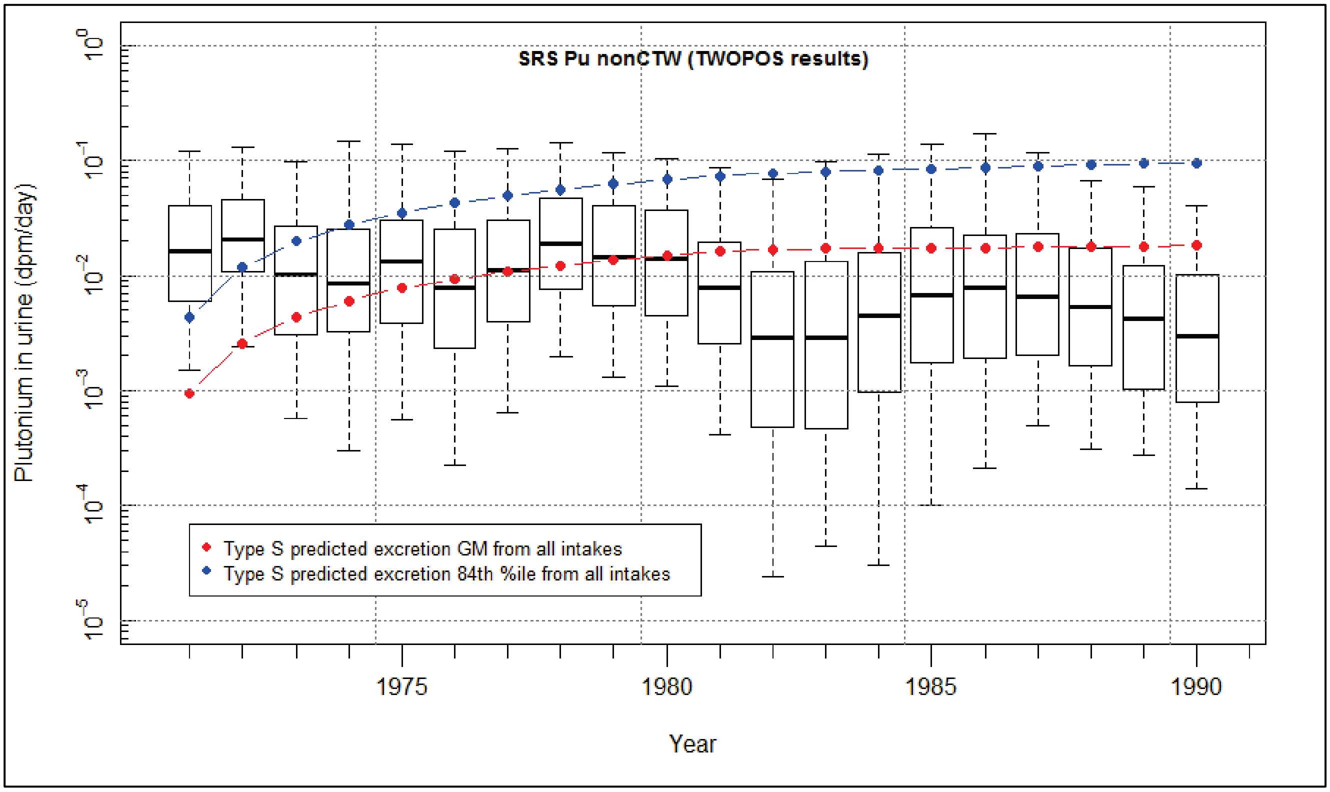

Figure 7-18. Plutonium type S nonCTW TWOPOS data box and whisker plot beginning in 1971.

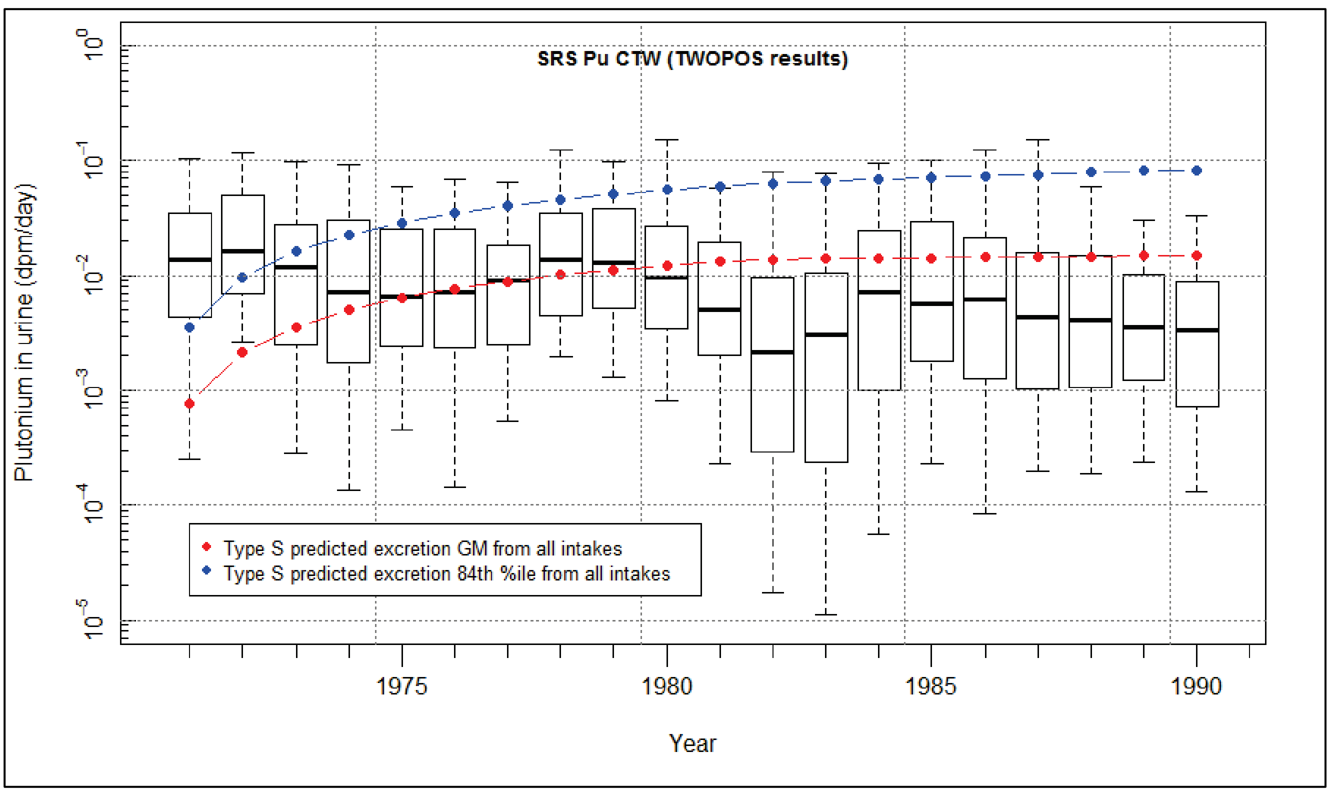

Figure 7-19. Plutonium type S CTW TWOPOS data box and whisker plot beginning in 1971. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

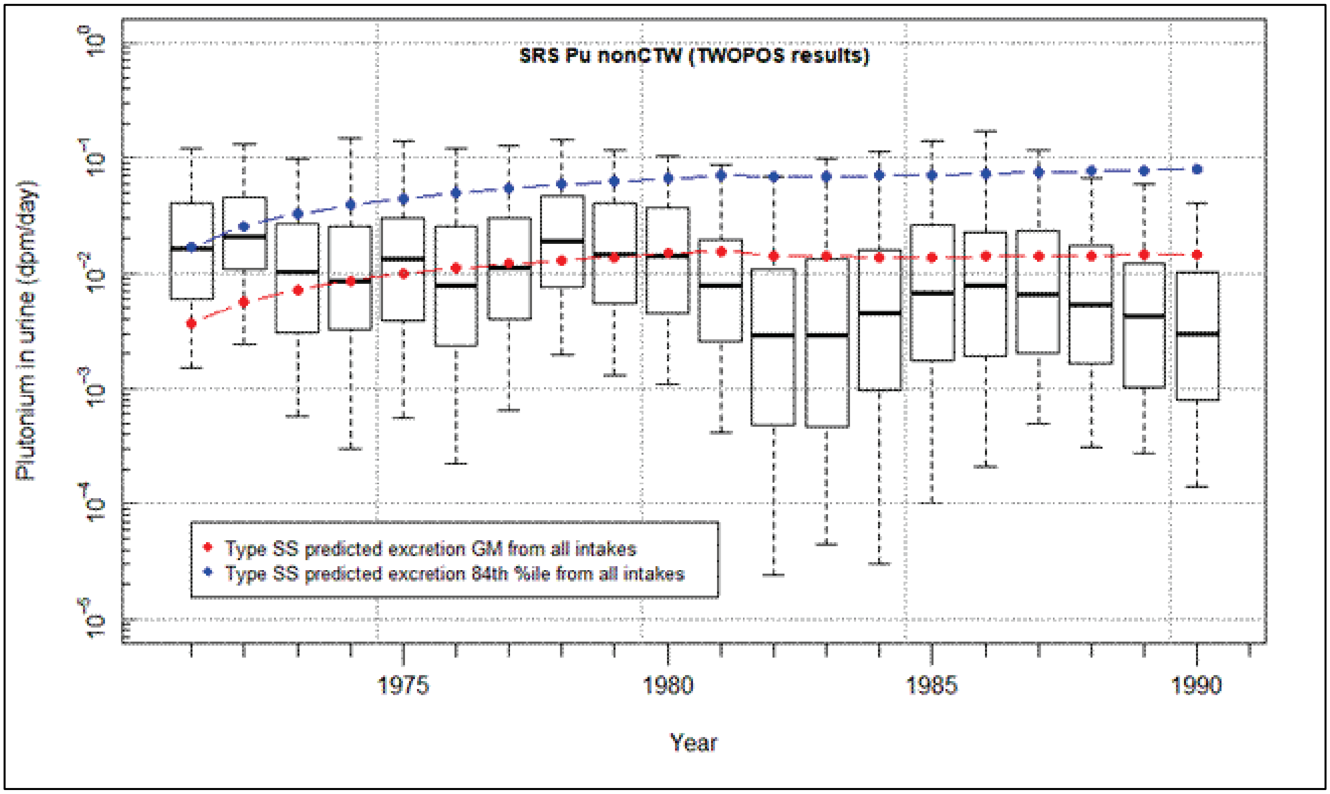

Figure 7-20. Plutonium type SS nonCTW TWOPOS data box and whisker plot beginning in 1971.

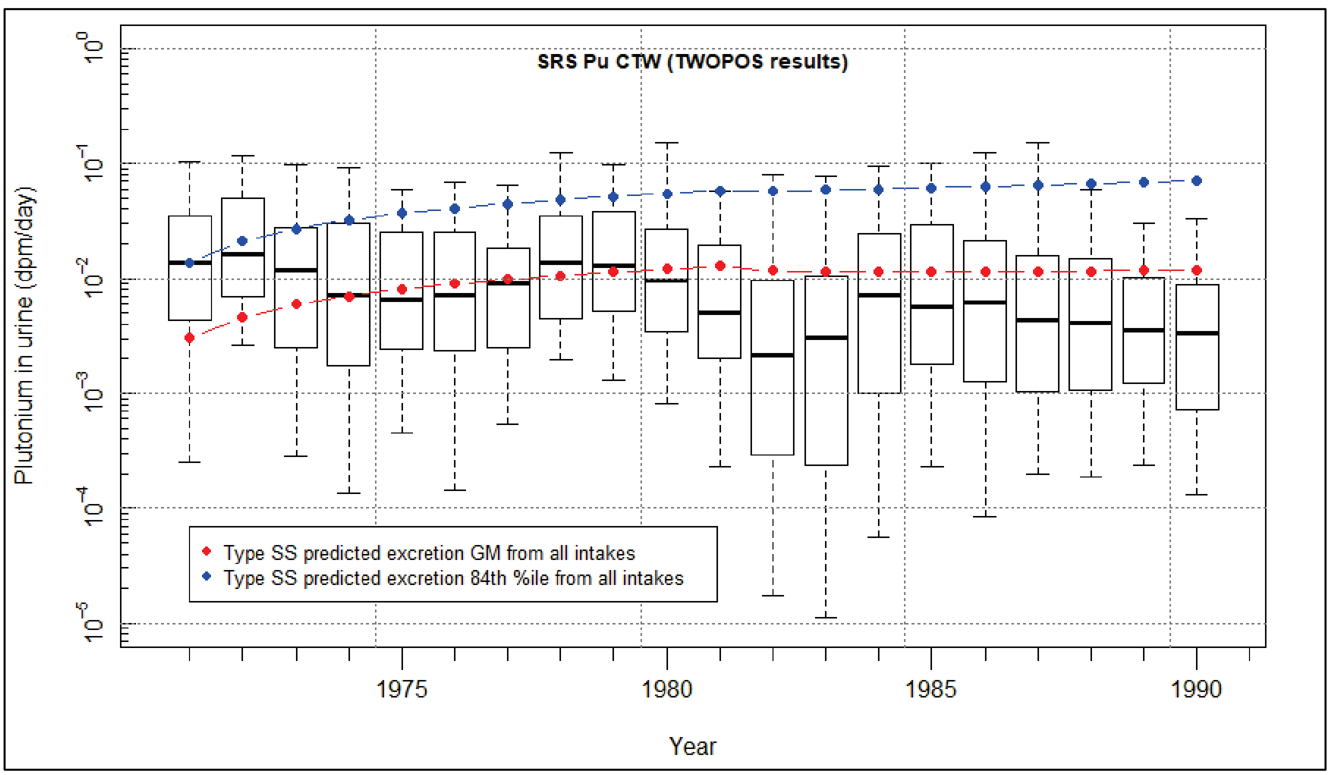

Figure 7-21. Plutonium type SS CTW TWOPOS data box and whisker plot beginning in 1971. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.4 Uranium

7.3.4.1 Data Adequacy

7.3.4.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, instructions for requesting and collecting urine samples, and related administrative controls in the *Bioassay Control* procedures. Both fluorometric (mass) and activity measurements were used. The fluorometric measurements were commonly identified as "U" measurements with the activity measurements identified as "EU" (enriched uranium). The earliest available version of the procedure is Revision 2 dated January 2, 1968 [DuPont 1968a]. It indicates a uranium sample size of 150 mL was used with a positive result level of 5 µg/1.5 L or 1 dpm/1.5 L and a resample level of 15 µg/1.5 L or 15 dpm/1.5 L. The uranium sampling frequencies are given in Table C-2 for various job categories and work locations. The sample request process indicates that 24-hour composite samples required approval by an HP Senior Supervisor or above, indicating that routine samples were probably not 24-hour samples.

The periodicity of routine urine sampling changed throughout the 1970s for various work locations and also as a result of the introduction of in vivo counting [DuPont 1970, 1971a, 1971b, 1976], but the positive levels and resample levels remained the same. The sampling frequencies for various personnel at various times are provided in Attachment B. The process for requesting samples was similar to the previous process, but HP Senior Supervisor or above approval was no longer required for 24-hour samples. Additional instructions were provided for collecting samples in the event of suspected inhalations, ingestions, injections, skin contaminations, or whenever airborne contamination exceeded control guides. In 1971, additional guidance for Construction Division personnel was added but with no specific guidance for uranium. "Other nuclides," which would have included the trivalent nuclides, were monitored as specified by area HP in the construction Job Plans [DuPont 1971a].

The 1990 *Internal Dosimetry Technical Basis Manual* monitoring program for uranium specified semiannual urine bioassay, an annual chest count, annual fecal bioassay, and personal air sampling (Class Y uranium only). If monitored by workgroup, the fecal bioassay and personal air sampling were not performed unless a member of the workgroup had a confirmed intake [WSRC 1990].

7.3.4.1.2 Applicability to Unmonitored Workers

Records of in vitro bioassay for uranium show urinalysis data back to 1953. As discussed above in the description of the sample collection process, there was guidance for whom to sample by 1970. The amount of available uranium bioassay data available in the NOCTS data increases during the mid-1950s, remains relatively constant through the early 1970s, and then gradually diminishes through the 1980s.

Construction Division workers were not necessarily included in the regular monitoring program, but nonCTWs in all the areas with the potential for exposure were supposed to be part of the monitoring program. By at least 1971, Construction Division personnel submitted urine samples no less than annually that were analyzed for FPs and those radionuclides specified by area HP in the construction Job Plans, which could include uranium.

7.3.4.1.3 Bioassay Analysis Techniques

A variety of methods have been used historically to analyze uranium at SRS. These methods and the associated detection capabilities are summarized in Table 7-9.

Table 7-9. Uranium urinalysis.[a]

Period	Uranium mixture and reporting level		Urine analysis method
Startup to mid-1960s	EU	0.15 dpm/1.5 L	Gross alpha for uranium, alpha track counting
Mid-1960s to 1982	EU	1 dpm/1.5 L	Gross alpha for uranium on solid state detector
1954–1982	DU	1-5 µg/L	Fluorophotometric analysis
1982–1986	U-235 NU EU	0.14 ng 1 µg/L 1 dpm/L	DNA DNA analysis for U-235 DNA analysis for U-235
1986–1990	EU	1 dpm/1.5 L	Gross alpha for uranium on solid-state detector.
1986–1994	DU	Not found, use 1 µg/L	KPA
1990–1994[b]	EU	0.4 pCi/L (MDA)	Batch alpha counting
1994–present (EU) (DU)[b]	DU RU HEU U-234 U-235 U-238	Use U-238[c] Use U-238[c] Use U-235[c] 0.032 pCi/L (MDA) 0.036 pCi/L (MDA) 0.032 pCi/L (MDA)	Alpha spectroscopy for specific uranium isotopes

a. DNA = delayed neutron analysis; DU = depleted uranium; EU = enriched uranium; HEU = highly enriched uranium; KPA = kinetic phosphorescence analysis; NU = natural uranium; RU = recycled uranium.
b. Decreasing analytical MDAs generally result in lower calculated co-exposure intake rates and thus extrapolation of the co-exposure intake rates past 1990 is believed to be claimant favorable.
c. Use the applicable isotopic ratios from ORAUT-TKBS-0003-5 [ORAUT 2024b].

SRS technical documentation indicates that for earlier monitoring periods, the designations “enriched” and “depleted” analysis for uranium referred to analysis performed by alpha counting or chemical measurement, respectively, and was not necessarily indicative of the degree of uranium enrichment [ORAUT 2024b]. EU was the code used on employee bioassay cards for the gross alpha count method, and depleted uranium (DU) was used to designate the fluorophotometric method.

Enriched uranium was determined starting in the mid-1950s by alkaline earth phosphate coprecipitation, muffling the sample, and ion exchange separation on Dowex 1-X10 with 8N HCl. The final material was electrodeposited and autoradiographed on Kodak NTA film. This method had a reported sensitivity of 0.15 dpm per 1.5 L of urine. In the mid-1960s, the TIOA/gross alpha counting method was adopted for EU analyses. This method had an MDA of about 1 dpm/1.5 L, which was considered adequate at the time.

Analyses for DU were performed with the Oak Ridge fluorophotometric method before 1982. It is unknown when this procedure was adopted at SRS. The delayed neutron analysis (DNA) method was adopted for both EU and DU analyses around 1982. This method involved coprecipitating the uranium with calcium fluoride, activating the sample in a reactor, and counting the delayed neutrons emitted by the ^{235}U. This procedure had an MDA of 0.14 ng of ^{235}U, which provided a 1 µg/L MDA for natural uranium (NU) and a 1 dpm/L MDA for enrichments typically encountered at SRS.

With the shutdown in 1986 of the reactor facility used for DNA of uranium, the TIOA method was again adopted for EU and the Jarrell-Ash method for DU. Kinetic phosphorescence analysis (KPA) was used for DU from 1986 through 1994 [WSRC 2001].

7.3.4.2 Data Validation

7.3.4.2.1 Data Completeness and Quality

The uranium bioassay data for the co-exposure study were compiled from NOCTS data. Completeness and quality of this data source are addressed in Section 7.2.1.1 above.

7.3.4.2.2 Data Interpretation

Uranium urine samples were analyzed using radiometric and/or chemical means as discussed above. Some samples were analyzed in both manners. Based on a review of the data, the mass-based data (micrograms per unit volume) were assumed to be in units of µg/L through July 10, 1961, and in units of µg/1.5L thereafter. It was converted to activity before statistical analysis by assuming NU (1.52 dpm/µg) through 1967 and DU (0.826 dpm/µg) thereafter [McCarty 2000].

The above discussion is a general summary of the method. The detailed statistical analysis instructions are in Attachment D.

7.3.4.2.3 Data Exclusion

Sample results that were given as per unit mass were excluded because these are fecal samples.

7.3.4.3 Statistical Analysis

Statistical analysis of the uranium bioassay data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2021]. The data were analyzed on an annual basis except for CTW data from 1979 through 1990, which were fit with 2-year intervals. These years were merged due to the small amount of CTW workers with data available in those years. Table 7-10 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-22 through 7-27. The box and whisker plots are overlaid with the excretion results predicted by the intake modeling as discussed further below. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.4.4 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. The IMBA program requires in vitro bioassay results to be in units of activity per day, so all urinalysis results were normalized as needed to 24-hour samples using 1,500 mL (the volume of urine assumed by SRS to be excreted in a 24-hour period).

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-µm activity median aerodynamic diameter particle size distribution. IMBA was used to fit the bioassay results to a series of inhalation intakes. Data were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1953 through 1990 were divided into multiple chronic intake periods.

Table 7-10. Calculated 50th- and 84th-percentile urinary excretion rates of uranium based on a lognormal fit to the TWOPOS data, 1953 to 1990 (dpm/d).[a,b]

Year	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1953	9.7345	15.298	1.57	47	Not applicable	Not applicable	Not applicable	Not applicable
1954	3.9499	6.064	1.54	139	Not applicable	Not applicable	Not applicable	Not applicable
1955	2.0791	2.885	1.39	341	2.0076	2.676	1.33	65
1956	1.8835	2.602	1.38	482	1.9108	2.586	1.35	89
1957	0.3510	1.768	5.04	272	0.4336	2.971	6.85	37
1958	0.5403	2.116	3.92	198	0.3495	1.589	4.55	37
1959	0.2431	1.230	5.06	258	0.1489	0.781	5.24	50
1960	0.1843	1.060	5.75	322	0.1167	0.516	4.42	53
1961	0.2222	1.040	4.68	279	0.1632	0.730	4.48	49
1962	0.3918	2.404	6.14	298	0.1787	0.939	5.26	65
1963	0.6816	3.919	5.75	324	0.3573	2.864	8.02	77
1964	0.7244	3.872	5.34	324	0.5762	3.255	5.65	80
1965	0.7557	3.951	5.23	316	0.6137	3.753	6.11	60
1966	0.6810	3.952	5.80	268	0.6399	3.966	6.20	53
1967	0.4961	3.311	6.67	259	0.7457	4.134	5.54	54
1968	0.1009	1.219	12.08	264	0.1032	1.089	10.56	60
1969	0.1414	1.326	9.38	216	0.1549	0.852	5.50	47
1970	0.3704	1.292	3.49	213	0.3043	0.979	3.22	58
1971	0.2438	0.957	3.93	266	0.2166	0.653	3.01	63
1972	0.2180	0.848	3.89	273	0.1982	0.667	3.37	62
1973	0.2022	0.844	4.17	263	0.1695	0.693	4.09	63
1974	0.1902	0.775	4.08	244	0.1797	0.777	4.33	69
1975	0.2156	0.730	3.39	241	0.3129	1.175	3.76	87
1976	0.1376	0.515	3.74	230	0.1285	0.469	3.65	59
1977	0.1269	0.510	4.02	137	0.1029	0.547	5.31	32
1978	0.1103	0.557	5.05	125	0.0770	0.383	4.98	28
1979	0.1657	0.610	3.68	127	0.1405	0.492	3.50	34
1980	0.1246	0.548	4.39	102				
1981	0.1947	0.710	3.65	125	0.2008	0.791	3.94	39
1982	0.4912	1.418	2.89	122				
1983	0.4221	1.448	3.43	120	0.3230	1.265	3.92	34
1984	0.3236	1.494	4.62	98				
1985	0.5015	2.243	4.47	125	0.2708	0.957	3.53	37
1986	0.2009	0.588	2.93	126				
1987	0.1815	0.699	3.85	122	0.1442	0.665	4.61	38
1988	0.2058	0.720	3.50	106				
1989	0.1943	0.553	2.85	153	0.1513	0.584	3.86	29
1990	0.1630	0.509	3.12	134				

a. Where multiple years are noted for a single line of excretion rates, the data for these years were combined for the statistical analysis.
b. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Because the uranium isotopes at SRS have very long radiological half-lives, and because the material is excreted over long periods for type S solubility, excretion results are not independent. For example, an intake in the 1950s could contribute to urinary excretion in the 1980s and later. However, because of turnover in the workforce, the workers used to assess intakes in one period might not have been the same as those in a later period. To avoid potential underestimation of intakes in the later periods, each chronic intake was fit independently using only the bioassay results from the single intake period for type S solubility. This method results in an overestimate of the later TWOPOS results when the cumulative predicted urine sample results from multiple assumed intake periods are plotted.

Excluded results are shown as an “X” in the figures in Attachment E; included results are shown as dots. For types M and F solubility, this approach was not used due to the more rapid excretion of material; all intake periods were fit simultaneously. The results of the statistical analysis that was used to calculate the intakes are provided for uranium in Table 7-10. The solid lines in Figures E-95 to E-102 in Attachment E show the fits to the 50th- and 84th-percentile excretion rates for type F and M materials for nonCTWs and CTWs. The solid lines in Figures E-103 to E-126 in Attachment E show the individual fits to the 50th- and 84th-percentile excretion rates for type S materials for nonCTWs and CTWs. Figures E-127 to E-130 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type S intakes for nonCTWs and CTWs. Tables E-9 to E-14 list the 50th- and 84th-percentile intake rates with the associated GSDs from the uranium urinalysis for solubility types F, M, and S, and nonCTWs and CTWs. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Figures 7-22 through 7-27 overlay the urinary excretion rates (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data. The top line is the predicted excretion 84th percentile from all intakes. The bottom line is the predicted excretion GM from all intakes.

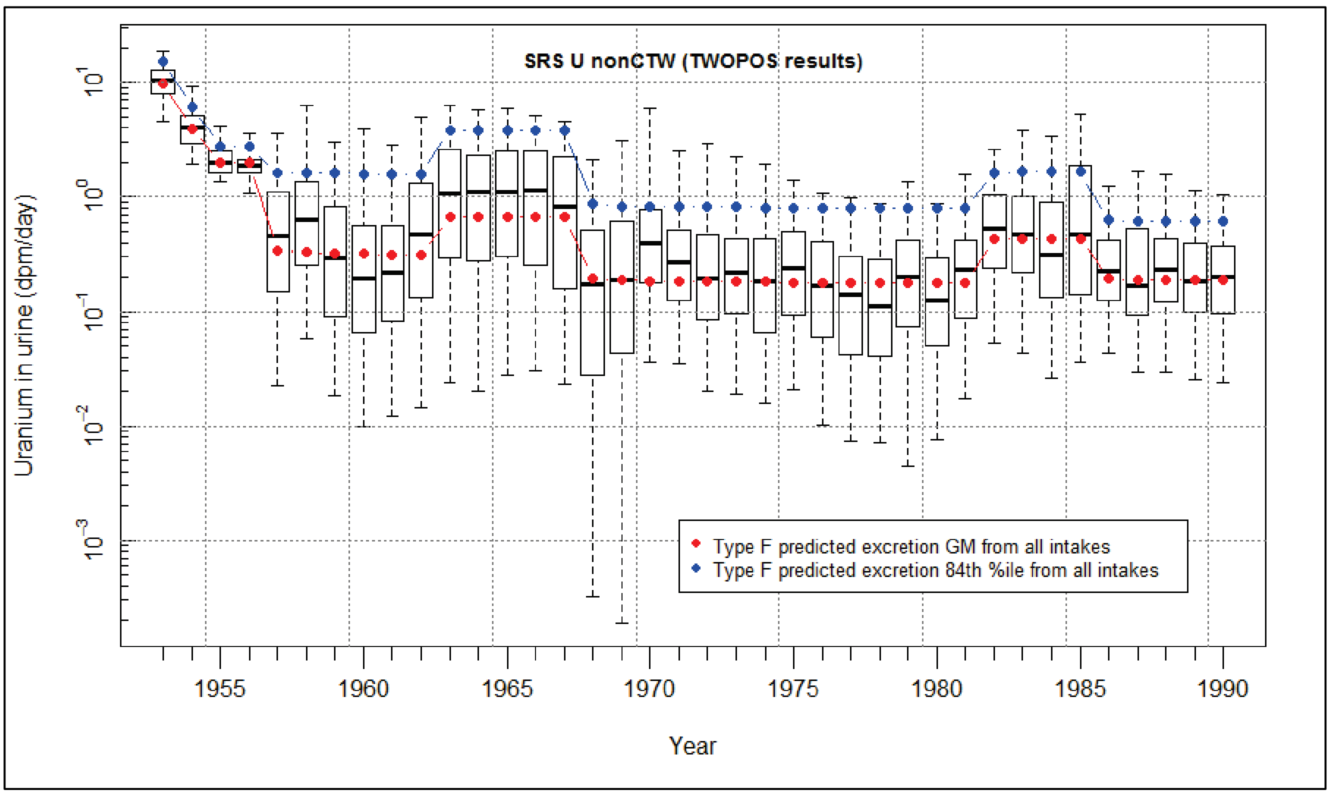

Figure 7-22. Uranium type F nonCTW TWOPOS data box and whisker plot.

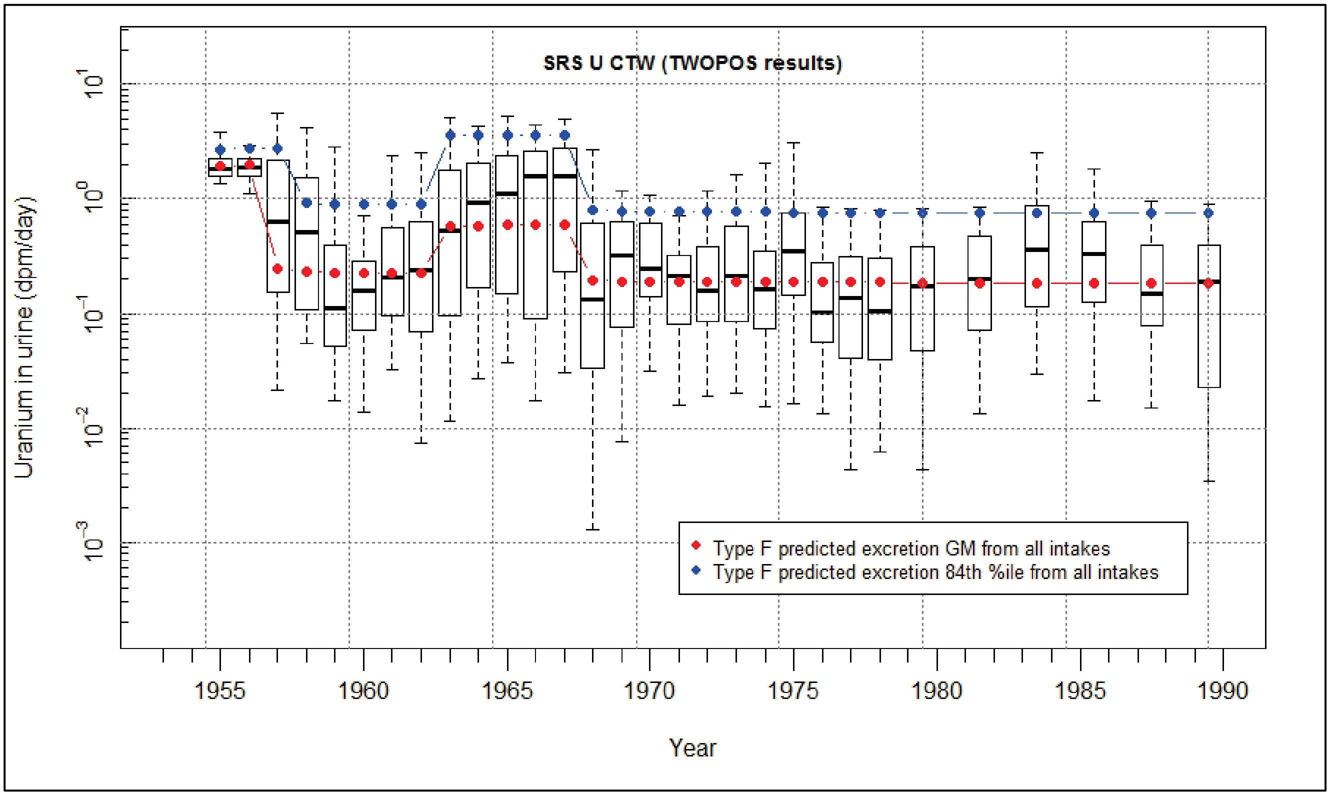

Figure 7-23. Uranium type F CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

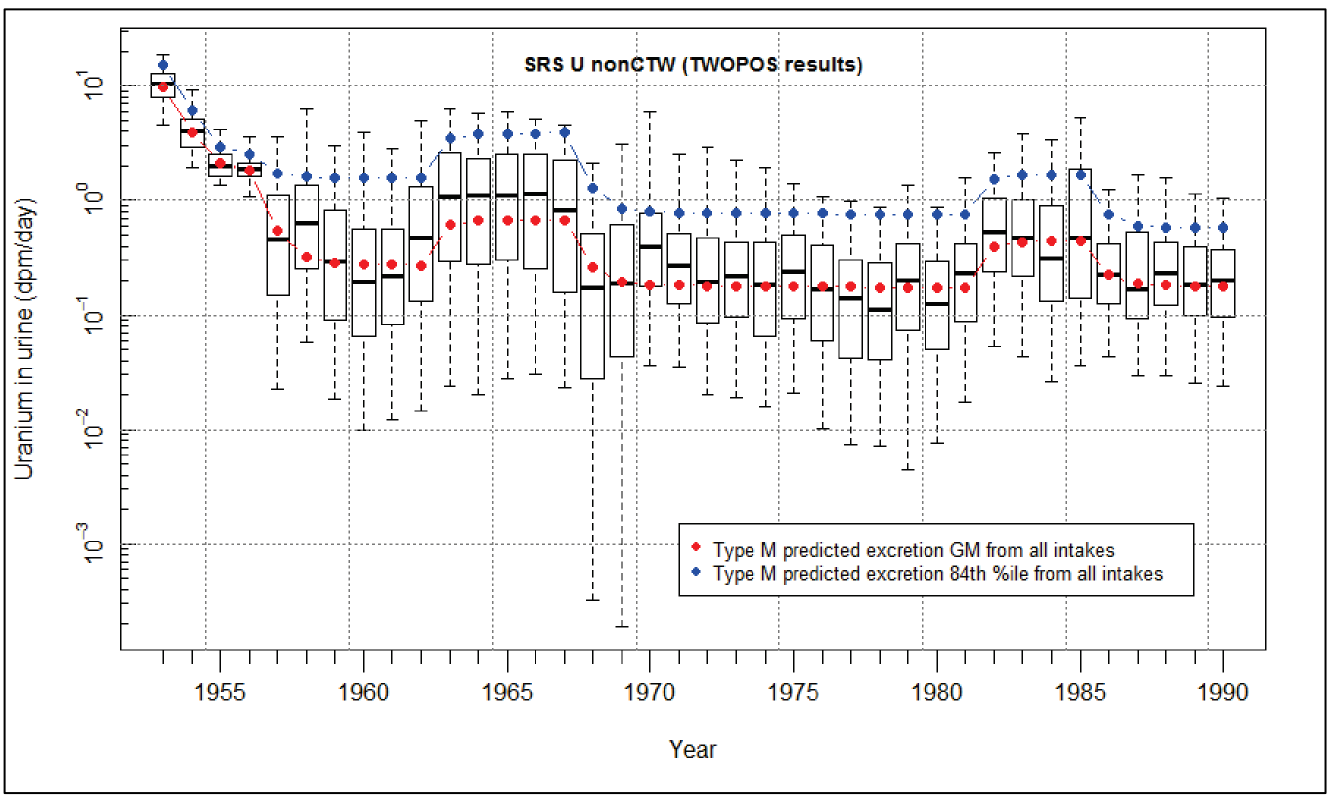

Figure 7-24. Uranium type M nonCTW TWOPOS data box and whisker plot.

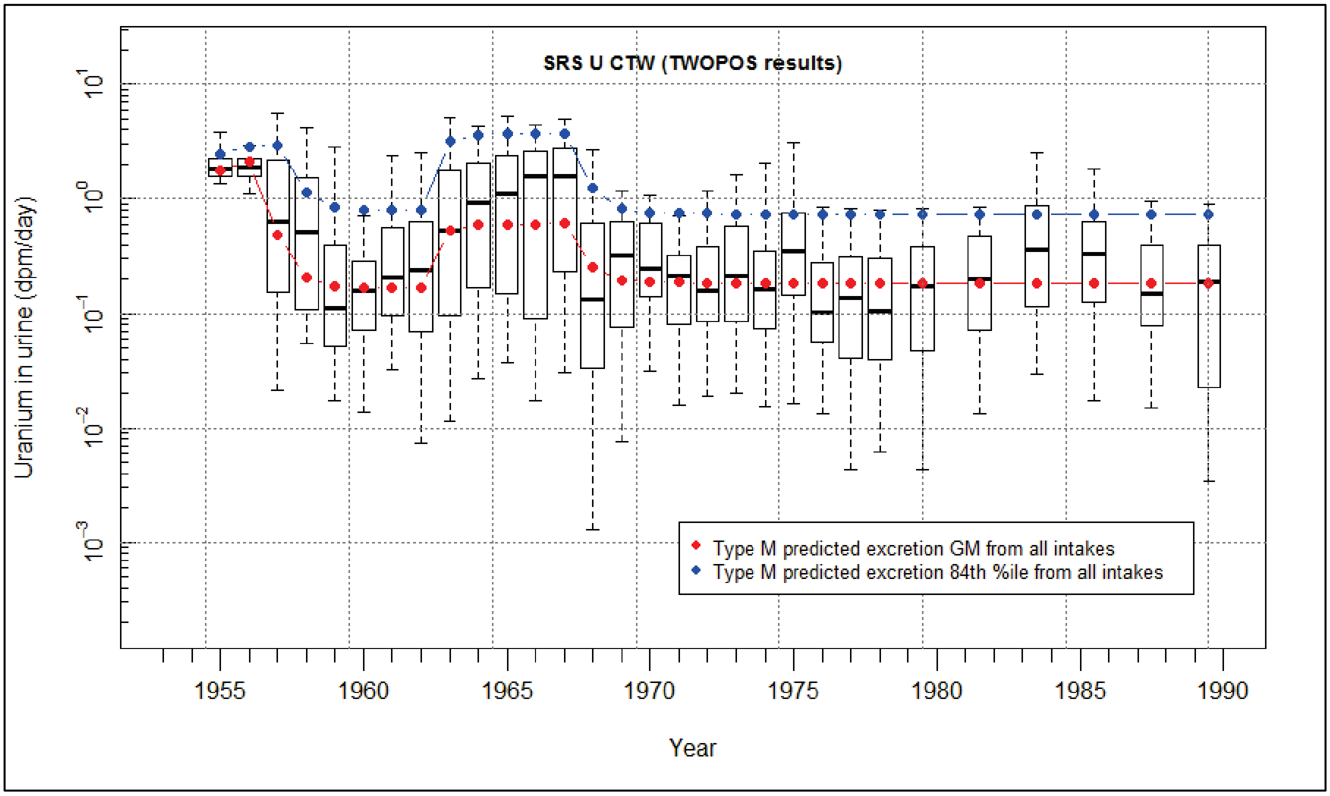

Figure 7-25. Uranium type M CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

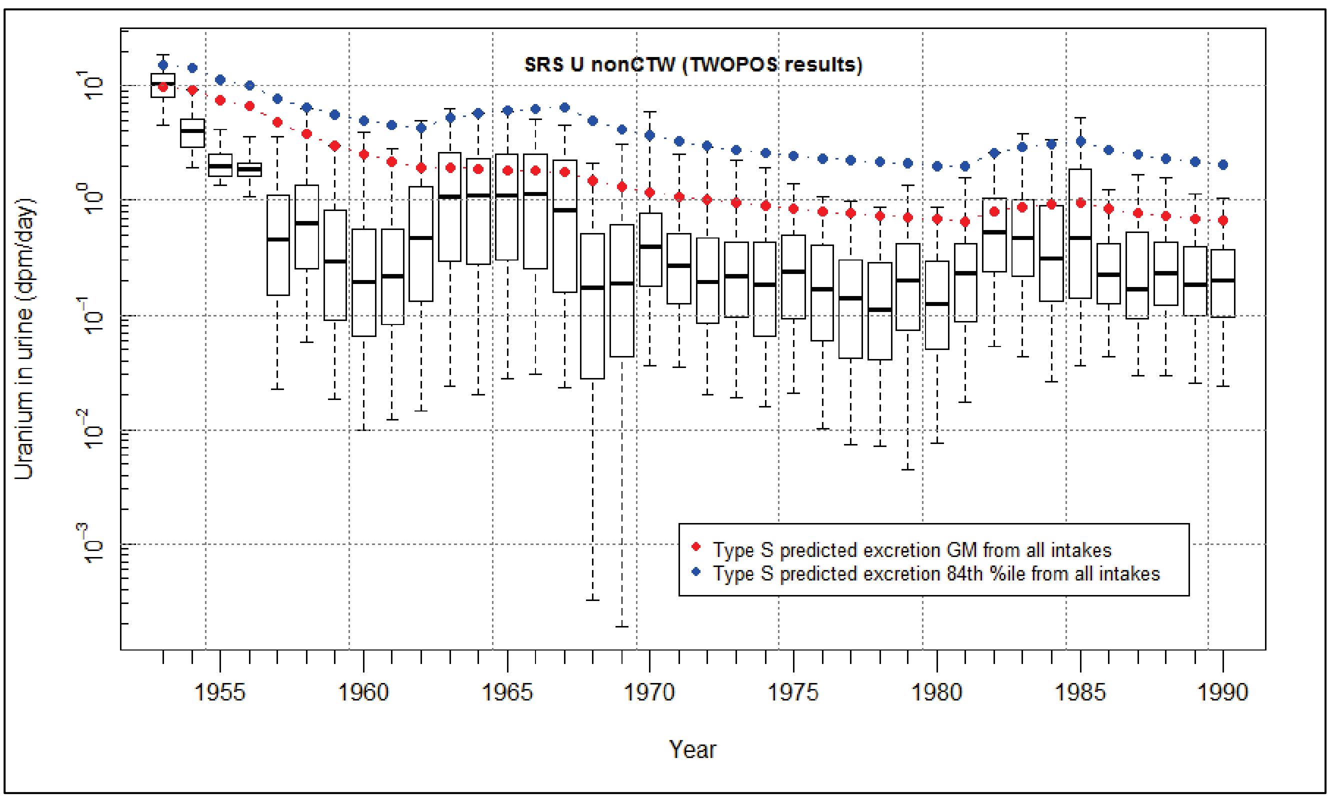

Figure 7-26. Uranium type S nonCTW TWOPOS data box and whisker plot.

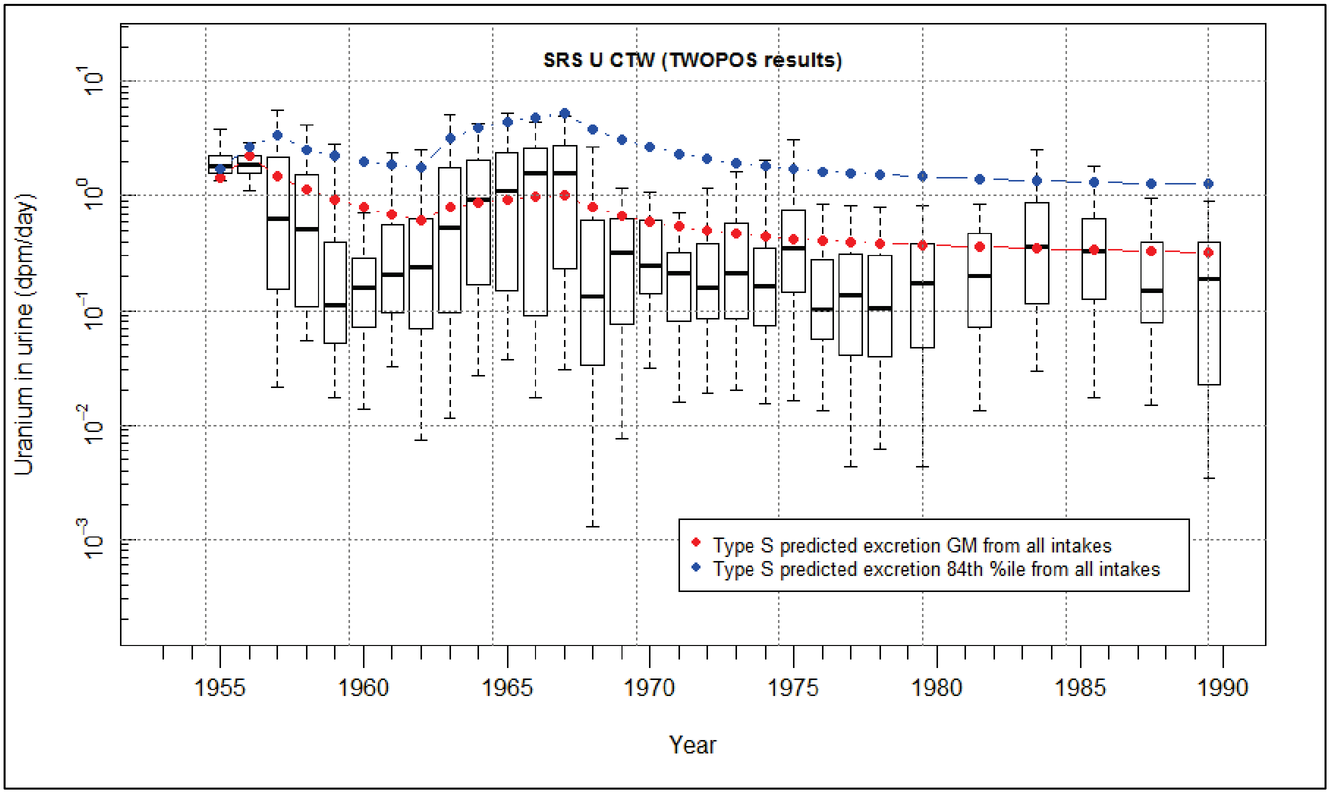

Figure 7-27. Uranium type S CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.5 Fission Products

7.3.5.1 Data Adequacy

7.3.5.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, instructions for requesting and collecting urine samples, and related administrative controls in the *Bioassay Control* procedures. The earliest available version of the procedure is Revision 2 dated January 2, 1968 [DuPont 1968a]. It indicates an FP sample size of 500 mL was used with a positive result level of 100 dpm/1.5L and a resample level of 200 dpm/1.5L. The FP sampling frequencies are given in Table C-2 for various job categories and work locations. The sample request process indicates that 24-hour composite samples required approval by an HP Senior Supervisor or above, indicating that routine samples were probably not 24-hour samples.

7.3.5.1.2 Applicability to Unmonitored Workers

Records of in vitro bioassay for FPs show urinalysis data back to 1951. As discussed above in the description of the sample collection process, there was guidance for whom to sample by 1970. The amount of available FP bioassay data available in the NOCTS data is relatively constant from 1955 through 1989.

Construction Division workers were not necessarily included in the regular monitoring program, but nonCTWs in all the areas with the potential for exposure were supposed to be part of the monitoring program.

7.3.5.1.3 Bioassay Analysis Techniques

From the beginning of the FP bioassay program until 1969, strontium was separated by alkaline earth phosphate coprecipitation followed by beta counting on a GM or proportional counter. Urine samples were acidified with nitric and orthophosphoric acid and a cobalt carrier solution. Ammonium hydroxide was added and the FPs precipitated. The precipitate was fired dry, dissolved with nitric acid, transferred to a planchet, dried again, and counted. This analysis was also called FP analysis. Both ^{89}Sr and ^{90}Sr would have been counted as well as radioisotopes of cerium and promethium, but it is favorable to claimants to assume the result is all ^{90}Sr. Recovery was greater than 90% for strontium, yttrium, and cerium/promethium radioisotopes. The lower limit of sensitivity was 29 dpm/750 mL for ^{90}Sr/Y [Boni 1959]. Bioassay records indicate that reporting levels of 30 dpm/500mL, 60 dpm/1.5L, and 100 dpm/1.5L for beta counting were used.

Taylor [2000] states that from 1969 to 1997 strontium was analyzed by liquid ion exchange that separates the yttrium progeny followed by beta proportional counting. Yttrium-91 would have been included as a possible interference but ^{89}Sr would not. However, beginning with 1966 there are insufficient strontium results to permit statistical analysis, so whole body count records were used for that period. See the ^{137}Cs section for the 1966 through 1990 FP co-exposure model.

7.3.5.2 Data Validation

7.3.5.2.1 Data Completeness and Quality

The FP bioassay data for the co-exposure study were compiled from NOCTS data. The completeness and quality of this data source are addressed in Section 7.2.1.

7.3.5.2.2 Data Interpretation

Most of the FP urinalysis data are from chemically processed gross beta measurements through 1965 (i.e., “major chemical processing,” to use the terminology from ORAUT-OTIB-0054, *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses* [ORAUT 2015].

7.3.5.2.3 Data Exclusion

Samples marked as LIP, IA (insufficient amount), gross gamma results, and those that lacked sufficient identifying information (e.g., sample date or payroll ID number) or result information were excluded. Sample results that were given as per unit mass were excluded because these are fecal samples. The above discussion is a general summary of the method. The detailed statistical analysis instructions are in Attachment D.

7.3.5.3 Statistical Analysis

Statistical analysis of the FP bioassay data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2021]. The data were analyzed on an annual basis. Table 7-11 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-28 and 7-29. The box and whisker plots are overlaid with the excretion results predicted by the intake modeling as discussed further below. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.5.4 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. The IMBA program requires in vitro bioassay results to be in units of activity per day; therefore, all urinalysis results were normalized as needed to 24-hour samples using 1,500 mL (the volume of urine assumed by SRS to be excreted in a 24-hour period).

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-μm activity median aerodynamic diameter particle size distribution.

IMBA was used to fit the bioassay results to a series of inhalation intakes. The FP activity was assumed to be strontium activity for intake modeling. Data were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1955 through 1965 were divided into multiple chronic intake periods. The results of the statistical analysis that was used to calculate the intakes are provided for FPs in Table 7-11.

The solid lines in Figures E-131 to E-134 in Attachment E show the fits to the 50th- and 84th-percentile excretion rates for type F ^{90}Sr for nonCTWs and CTWs, respectively. Tables E-15 and E-16 list the 50th- and 84th-percentile intake rates with the associated GSDs from the FP urinalysis for nonCTWs and CTWs. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Figures 7-28 and 7-29 overlay the urinary excretion rates (lines) from the intake modeling on the box and whisker plots of the TWOPOS data. The top line is the predicted excretion 84th percentile from all intakes. The bottom line is the predicted excretion GM from all intakes.

Table 7-11. Calculated 50th- and 84th-percentile urinary excretion rates of FPs based on a lognormal fit to the TWOPOS data, 1955 to 1965 (dpm/d).[a]

Year	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1955	14.725	32.21	2.19	247	14.983	29.62	1.98	52
1956	17.617	41.96	2.38	333	16.642	37.76	2.27	76
1957	16.238	37.70	2.32	205	16.507	35.50	2.15	78
1958	15.598	36.10	2.31	162	15.510	38.66	2.49	105
1959	8.457	27.92	3.30	224	9.216	29.85	3.24	49
1960	7.146	21.31	2.98	345	7.126	19.43	2.73	109
1961	8.885	23.22	2.61	438	9.433	26.47	2.81	143
1962	17.376	40.43	2.33	556	18.965	45.56	2.40	256
1963	27.747	48.97	1.76	499	28.544	53.54	1.88	253
1964	28.213	50.83	1.80	494	28.956	54.23	1.87	242
1965	18.197	48.56	2.67	492	19.604	54.99	2.80	240

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

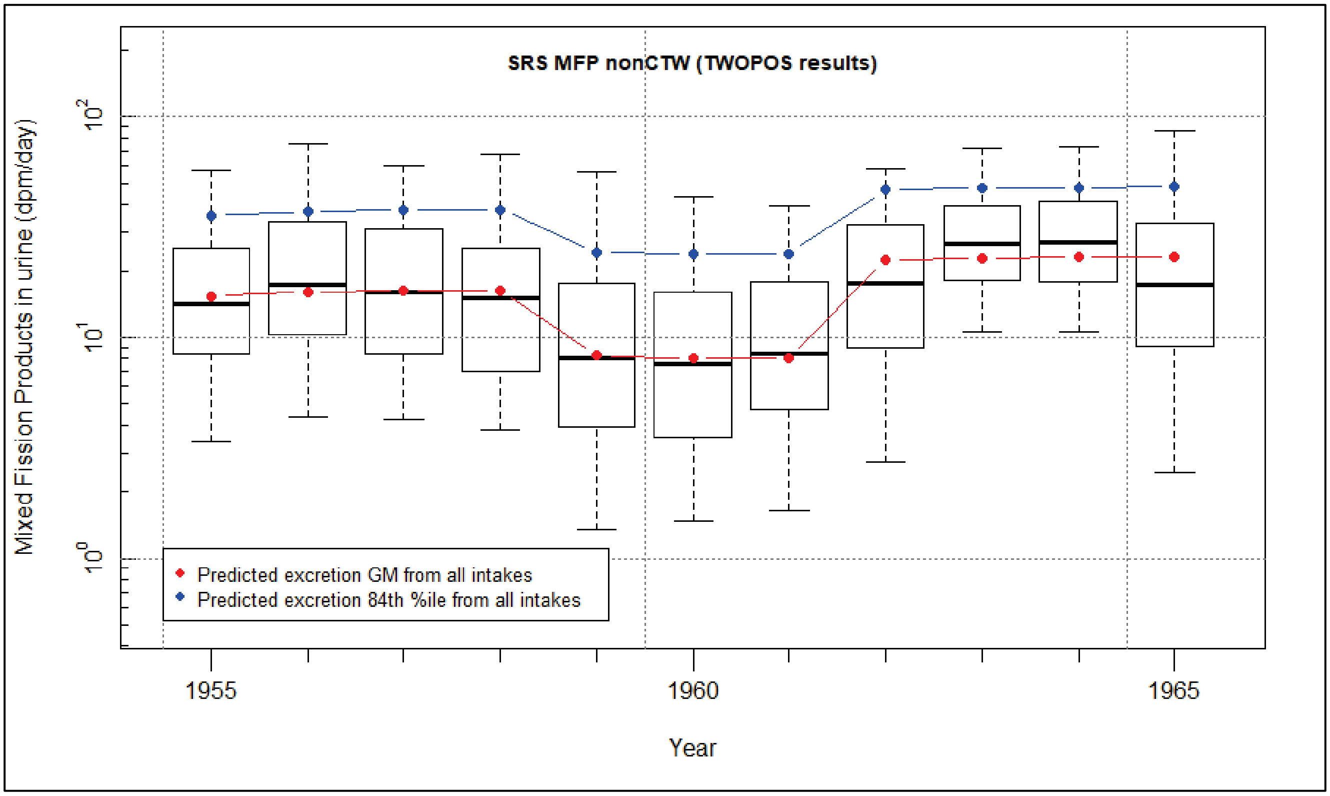

Figure 7-28. FP nonCTW TWOPOS data box and whisker plot.

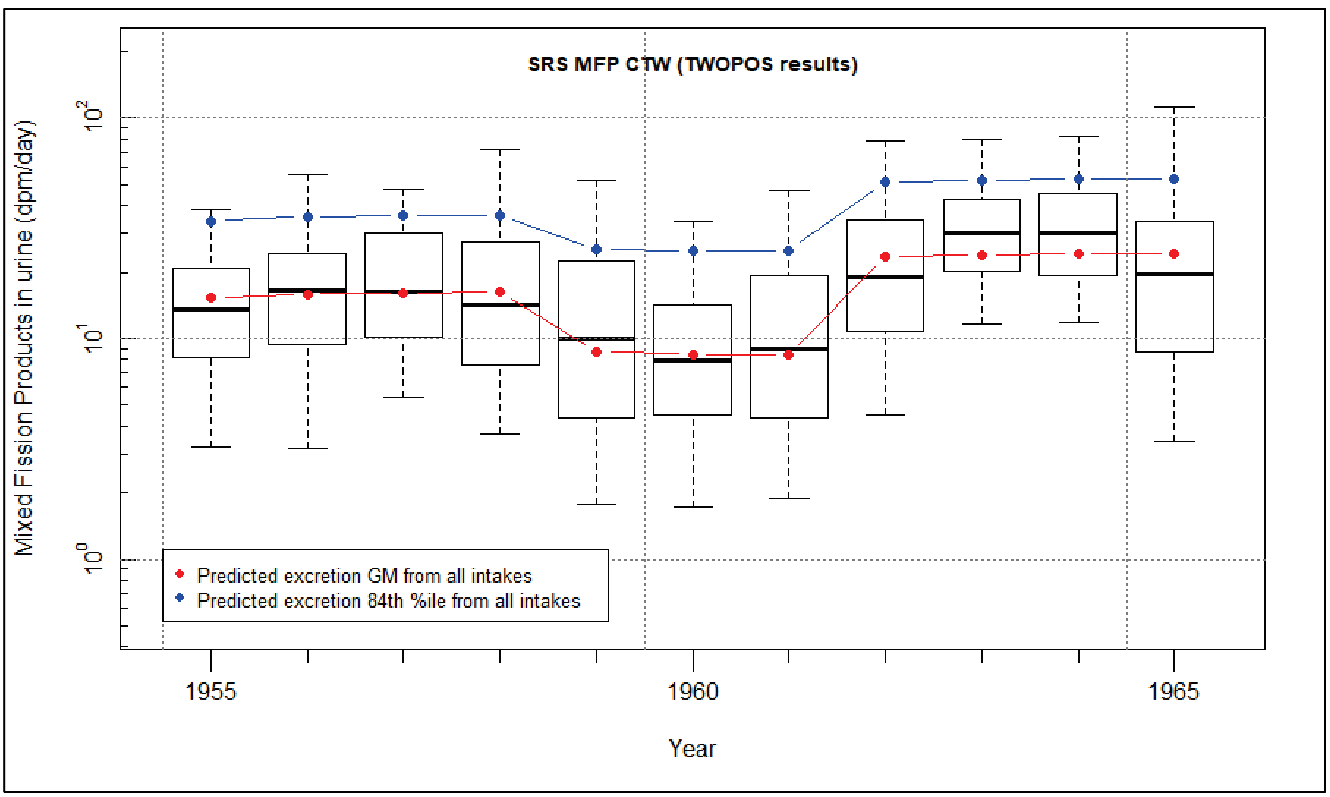

Figure 7-29. FP CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.6 Cobalt-60

Cobalt-60 was evaluated for 1955 through 1970. During this period, some workers handled pure or relatively pure ^{60}Co [Boswell 2000, pp. 116–117].

7.3.6.1 Bioassay Data

The FP bioassay data discussed in Section 7.3.5 was used to model ^{60}Co intakes from 1955 through 1965 based on the beta emissions from ^{60}Co. Boni [1959] indicates the recovery for ^{60}Co for the method used at the time was 85%.

Beginning in 1966, records indicate FP urinalysis was primarily a gross gamma counting method with a reporting level of 1 nCi/1.5L. These data were not used for calculation of MFP co-exposure intakes but are used here for the 1966 to 1970 ^{60}Co analysis. These gross gamma results were divided by 2 to account for the fact that ^{60}Co has two 100% yield gamma rays. The detailed statistical analysis instructions are in Attachment D.

7.3.6.2 Statistical Analysis

Statistical analysis of the FP bioassay data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2021]. The data were analyzed on an annual basis. Table 7-12 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-30 through 7-33. The top line is the predicted excretion 84th percentile from all intakes. The bottom line is the predicted excretion GM from all intakes. The box and whisker plots are overlaid with the urinary excretion predicted by the intake modeling as discussed further below. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-12. Calculated 50th- and 84th-percentile urinary excretion rates of ^{60}Co based on a lognormal fit to the TWOPOS data, 1955 to 1970 (pCi/d).[a]

Year	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1955	6.63	14.51	2.19	247	6.75	13.34	1.98	52
1956	7.94	18.90	2.38	333	7.50	17.01	2.27	76
1957	7.31	16.98	2.32	205	7.44	15.99	2.15	78
1958	7.03	16.26	2.31	162	6.99	17.41	2.49	105
1959	3.81	12.58	3.30	224	4.15	13.45	3.24	49
1960	3.22	9.60	2.98	345	3.21	8.75	2.73	109
1961	4.00	10.46	2.61	438	4.25	11.92	2.81	143
1962	7.83	18.21	2.33	556	8.54	20.52	2.40	256
1963	12.50	22.06	1.76	499	12.86	24.12	1.88	253
1964	12.71	22.90	1.80	494	13.04	24.43	1.87	242
1965	8.20	21.87	2.67	492	8.83	24.77	2.80	240
1966	67.2	214.12	3.19	443	59.9	202.23	3.37	177
1967	91.9	294.15	3.20	467	97.2	314.34	3.24	192
1968	76.3	234.43	3.07	485	80.5	249.70	3.10	240
1969	69.0	215.65	3.13	391	66.7	206.84	3.10	211
1970	60.5	219.60	3.63	467	55.6	203.14	3.66	226

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

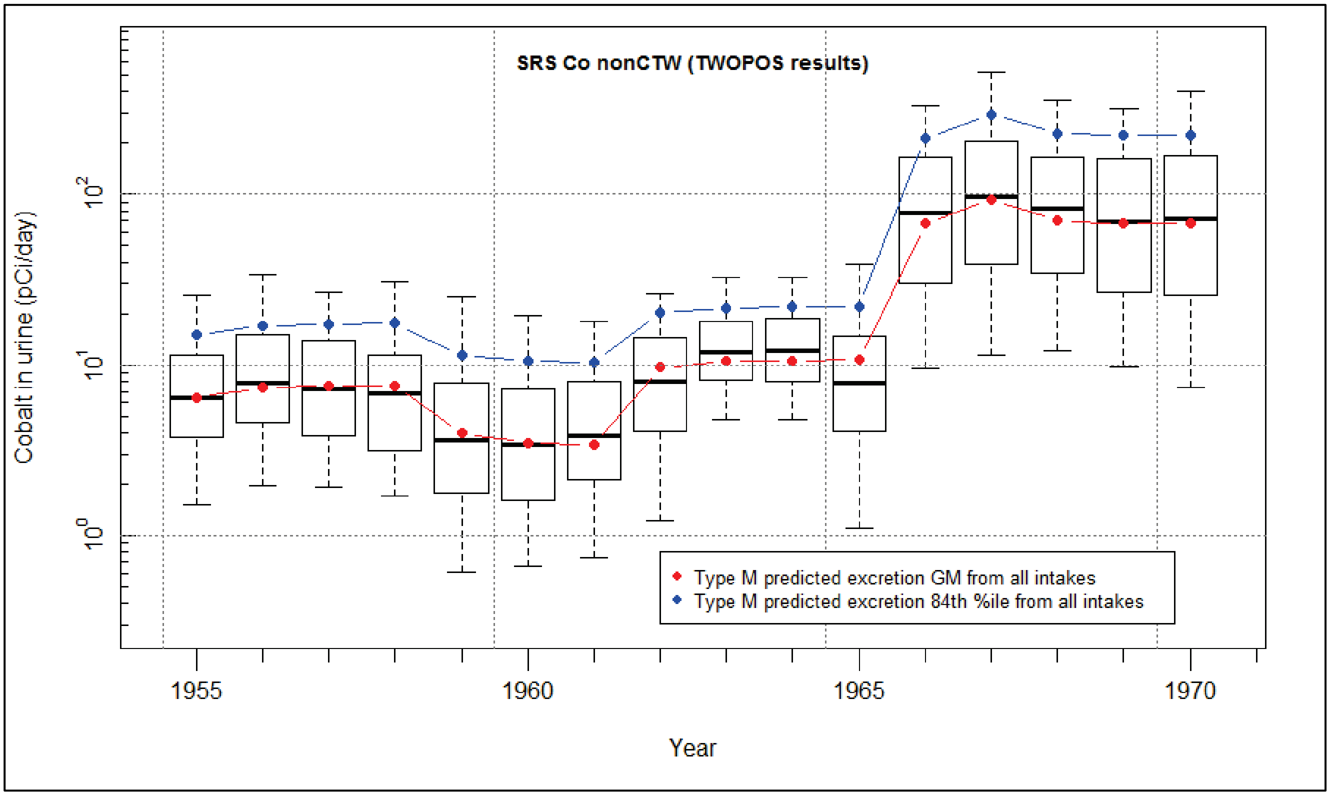

Figure 7-30. Cobalt-60 nonCTW TWOPOS data box and whisker plot, Type M.

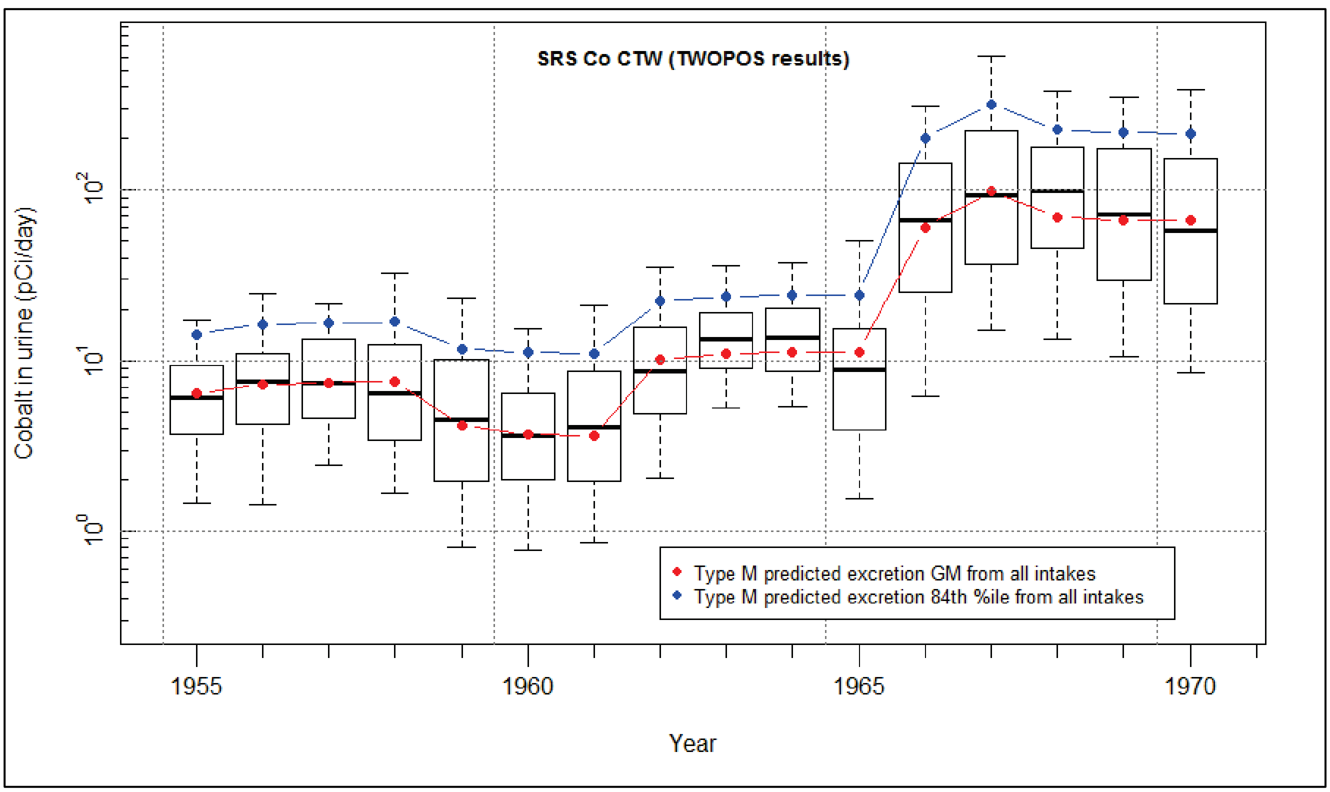

Figure 7-31. Cobalt-60 CTW TWOPOS data box and whisker plot, Type M. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

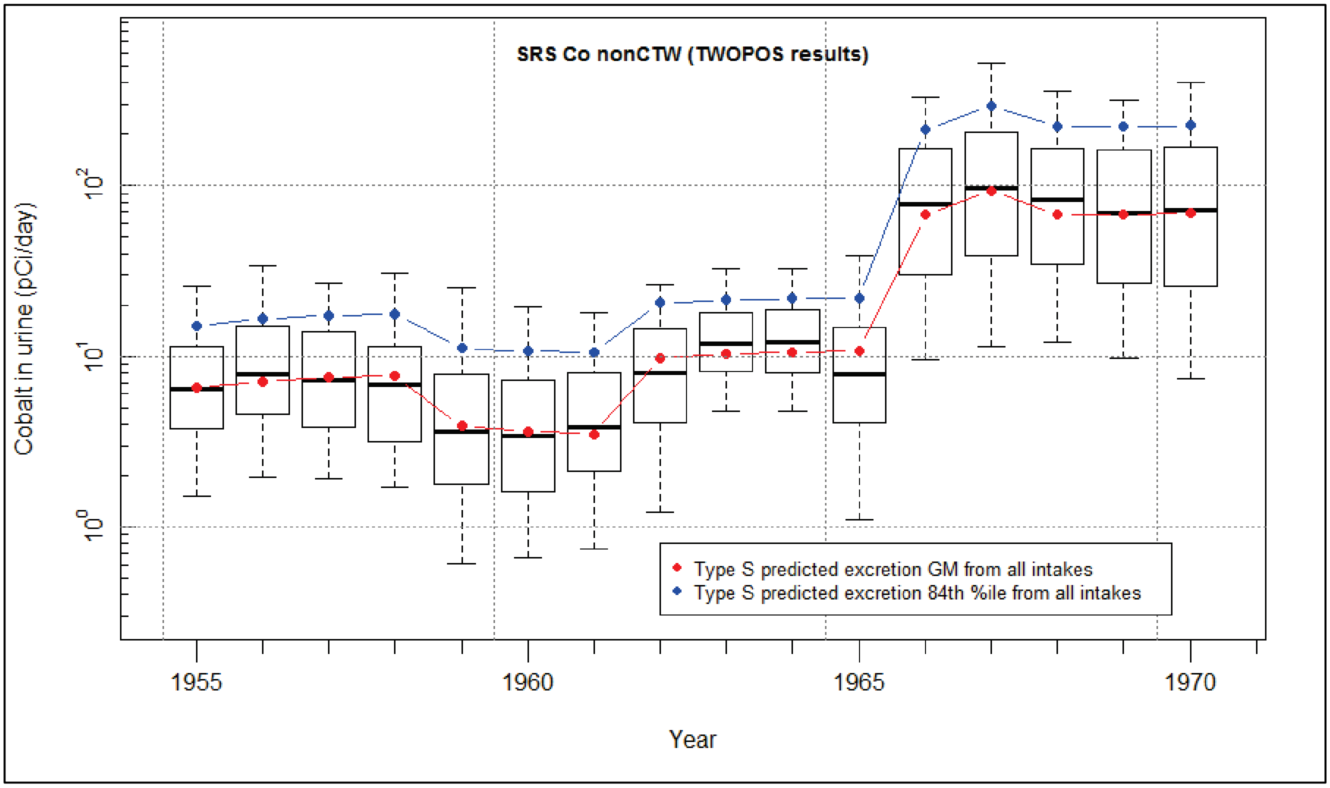

Figure 7-32. Cobalt-60 nonCTW TWOPOS data box and whisker plot, Type S.

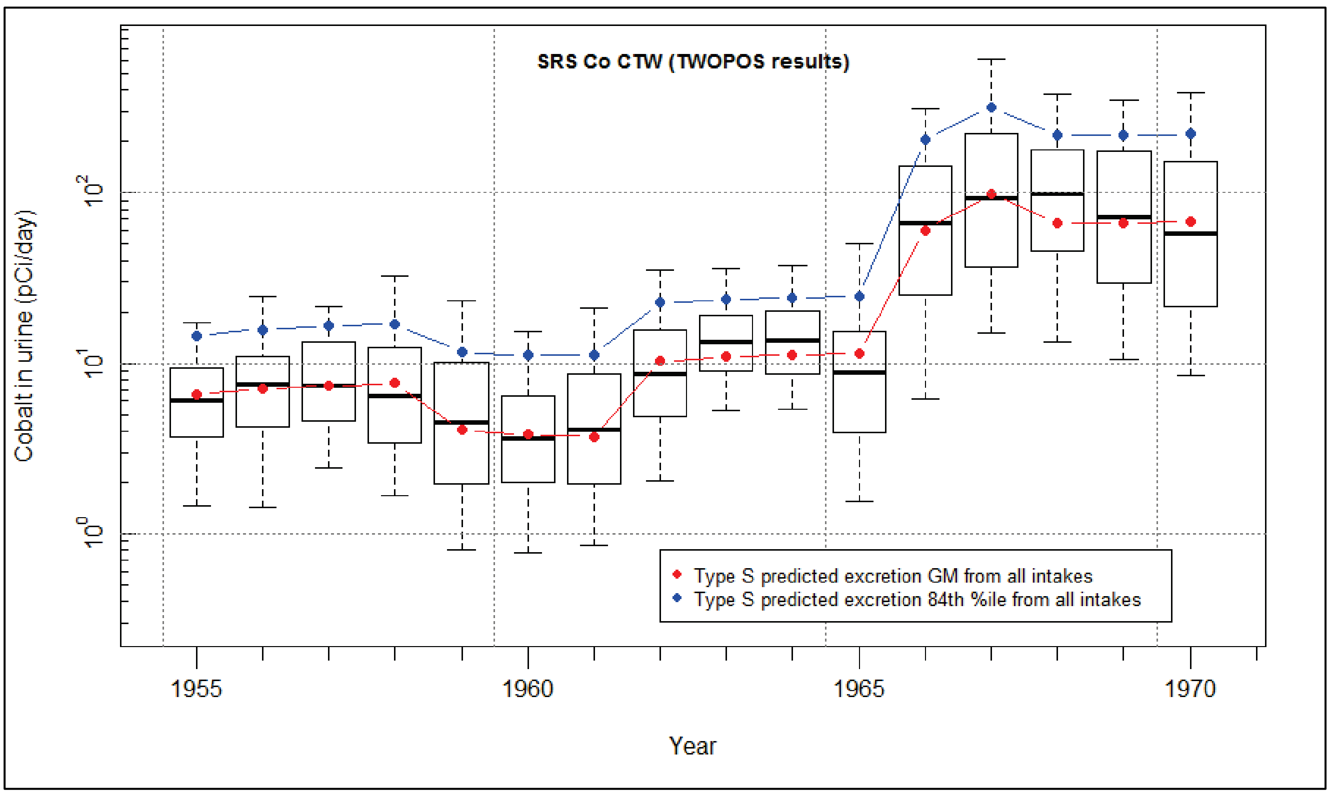

Figure 7-33. Cobalt-60 CTW TWOPOS data box and whisker plot, Type S. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.6.3 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. The IMBA program requires in vitro bioassay results to be in units of activity per day, so all urinalysis results were normalized as needed to 24-hour samples using 1,500 mL (the volume of urine assumed by SRS to be excreted in a 24-hour period).

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-µm activity median aerodynamic diameter particle size distribution.

IMBA was used to fit the bioassay results to a series of inhalation intakes. Data were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1955 through 1970 were divided into multiple chronic intake periods.

The solid lines in Figures E-135 to E-142 in Attachment E show the fits to the 50th- and 84th-percentile excretion rates for types M and S materials for nonCTWs and CTWs. Tables E-17 through E-20 list the 50th- and 84th-percentile intake rates with the associated GSDs from the ^{60}Co urinalysis. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Figures 7-30 through 7-33 overlay the urinary excretion rates (lines) from the intake modeling on the box and whisker plots of the TWOPOS data. The top line is the predicted body content 84th percentile from all intakes. The bottom line is the predicted body content GM from all intakes

7.3.7 Cesium-137

7.3.7.1 Data Adequacy

7.3.7.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, and related administrative controls in the *Bioassay Control* procedure. The earliest version of the procedure that discussed in vivo bioassay is Revision 4 dated March 1971 [DuPont 1971a]. It indicates that routine chest counting was performed for EU, Am/Cm/Cf, and plutonium. For the Construction Division, chest counts and WBCs were required for new employees, employees with confirmed intakes of radionuclides other than tritium, employees who were involved in an incident, and upon termination if the employee had previously had a chest count or WBC. WBCs were also required for elevated nasal or saliva smears.

Although in vivo bioassay is not mentioned in the bioassay control procedure until 1971, in vivo counts were performed much earlier than that, and records of WBCs date back to 1960. The number of WBCs increased beginning in 1971 and it steadily became more common thereafter. By 1976 [DuPont 1976], WBCs had effectively replaced FP urinalysis as the primary means of detecting FP intakes.

The 1990 *Internal Dosimetry Technical Basis Manual* monitoring program for FPs specified semiannual WBCs for gamma emitters regardless of whether there was individual or workgroup monitoring [WSRC 1990].

7.3.7.1.2 Applicability to Unmonitored Workers

Records of in vivo bioassay for FPs show WBC data back to 1960. As discussed above, there was guidance for whom to count by 1971. The amount of available WBC data available in the NOCTS data is relatively limited from 1966 through 1970, rapidly increases during the early 1970s, and is relatively constant from the mid-1970s through 1989.

Construction Division workers were not necessarily included in the regular periodic monitoring program but were scheduled for baseline, termination, and incident-driven WBCs.

NonCTWs in all the areas with the potential for exposure were supposed to be part of the monitoring program. By at least 1976, Construction Division personnel appeared to have been part of the same counting frequency as other employees [DuPont 1976].

7.3.7.1.3 Bioassay Analysis Techniques

The SRS Whole Body Counting Facility was constructed in 1960. During the 1960s, a “40-cm arc” geometry was used where the individual being counted was seated in a chair, which positioned the body from the knees to the chin approximately 40 cm from the detector. A 1-m arc geometry was also used in special counts where higher accuracy was desired. The detector used in this configuration was a cylindrical NaI detector with a diameter of 8 in. and a length of 4 in. The minimum detectable body burden of ^{137}Cs for this detector was 1 nCi [Taylor et al. 1995].

During the early 1970s, the 40-cm arc geometry was replaced with a bed geometry using four 4- by 4-in. NaI detectors positioned in an arc under the bed. Count-specific MDAs are calculated even though a nonzero ^{137}Cs body content was generally reported. In the mid-1980s, mobile whole body counters using large NaI detectors and a shadow shield were purchased to measure high-energy photon emitters, which includes ^{137}Cs [Taylor et al. 1995].

7.3.7.2 Data Validation

7.3.7.2.1 Data Completeness and Quality

The WBC data for the co-exposure study were compiled from NOCTS data. The completeness and quality of this data source are addressed in Section 7.2.1.

7.3.7.2.2 Data Interpretation

In most instances, the WBC data provide results for ^{137}Cs. Results are variously reported as a positive value, an uncensored value, a “<” value, or “<MDA” with a quantified count-specific MDA. Depending on the WBC reporting format, the MDA at the 95% confidence level is also available. During the 1980s, it became more common to report only radionuclides that were detected. In those instances, it can be assumed that a WBC without a reported ^{137}Cs result implies that ^{137}Cs was present at some value less than the detection limit (i.e., a censored result).

7.3.7.2.3 Data Exclusion

Results marked “New,” “New Hire,” or “New Employee” were excluded because these results are not indicative of occupational exposure at SRS. Results that lacked sufficient identifying information (e.g., sample date or payroll ID number) or result information were excluded. No attempt was made to exclude results that could have been influenced by the consumption of wild game. The detailed statistical analysis instructions are in Attachment D.

7.3.7.3 Statistical Analysis

Statistical analysis of the WBC data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2021]. The data were analyzed on an annual basis except for the years indicated in Table 7-13, which were merged due to the small amount of worker data available in those years. No analysis was performed for CTWs for 1960 because there was no CTW worker data in that year for evaluation. Table 7-13 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-34 and 7-35. The box and whisker plots are overlaid with the whole body content predicted by the intake modeling as discussed further below. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder.

7.3.7.4 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-μm activity median aerodynamic diameter particle size distribution.

IMBA was used to fit the bioassay results to a series of inhalation intakes. Data were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1960 through 1990 were divided into multiple chronic intake periods. The results of the statistical analysis that were used to calculate the intakes are provided for ^{137}Cs in Table 7-13. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Excluded results are shown as an “X” in the figures in Attachment E; included results are shown as dots. The solid lines in Figures E-143 through E-150 in Attachment E show the fits individual to the 50th- and 84th-percentile body burdens for type F ^{137}Cs for nonCTWs and CTWs. Figures E-151 to E-154 show the 50th- and 84th-percentile predicted body burdens, respectively, from all type F ^{137}Cs intakes for nonCTWs and CTWs. Tables E-21 and E-22 list the 50th- and 84th-percentile intake rates with the associated GSDs from the ^{137}Cs WBCs. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Figures 7-34 and 7-35 overlay the WBCs from the intake modeling (lines) on the box and whisker plots of the TWOPOS data. The top line is the predicted body content 84th percentile from all intakes. The bottom line is the predicted body content GM from all intakes.

Table 7-13. Calculated 50th- and 84th-percentile ^{137}Cs whole body content based on a lognormal fit to the TWOPOS data, 1960 to 1989 (pCi).[a]

<table>
<tr><th>Year[b]</th><th>nonCTW 50th percentile</th><th>nonCTW 84th percentile</th><th>nonCTW GSD</th><th>nonCTW # of individuals</th><th>CTW 50th percentile</th><th>CTW 84th percentile</th><th>CTW GSD</th><th>CTW # of individuals</th></tr>
<tr><td>1960</td><td rowspan="2">4,954</td><td rowspan="2">6,926</td><td rowspan="2">1.40</td><td rowspan="2">200</td><td>Not applicable</td><td>Not applicable</td><td>Not applicable</td><td>Not applicable</td></tr>
<tr><td>1961</td><td>4,472</td><td>5,884</td><td>1.32</td><td>34</td></tr>
<tr><td>1962</td><td>5,780</td><td>8,696</td><td>1.50</td><td>215</td><td>5,996</td><td>8,067</td><td>1.35</td><td>57</td></tr>
<tr><td>1963</td><td>8,762</td><td>12,464</td><td>1.42</td><td>151</td><td>9,634</td><td>13,846</td><td>1.44</td><td>66</td></tr>
<tr><td>1964</td><td>14,745</td><td>22,345</td><td>1.52</td><td>70</td><td rowspan="3">13,765</td><td rowspan="3">21,442</td><td rowspan="3">1.56</td><td rowspan="3">33</td></tr>
<tr><td>1965</td><td rowspan="2">8,588</td><td rowspan="2">14,187</td><td rowspan="2">1.65</td><td rowspan="2">46</td></tr>
<tr><td>1966</td></tr>
<tr><td>1967</td><td>2,014</td><td>5,667</td><td>2.81</td><td>50</td><td rowspan="2">4,751</td><td rowspan="2">11,273</td><td rowspan="2">2.37</td><td rowspan="2">35</td></tr>
<tr><td>1968</td><td>5,034</td><td>8,422</td><td>1.67</td><td>73</td></tr>
<tr><td>1969</td><td rowspan="2">1,242</td><td rowspan="2">5,052</td><td rowspan="2">4.07</td><td rowspan="2">79</td><td rowspan="3">1,997</td><td rowspan="3">6,309</td><td rowspan="3">3.16</td><td rowspan="3">28</td></tr>
<tr><td>1970</td></tr>
<tr><td>1971</td><td>1,441</td><td>4,165</td><td>2.89</td><td>59</td></tr>
<tr><td>1972</td><td>2,887</td><td>5,702</td><td>1.98</td><td>144</td><td rowspan="2">2,881</td><td rowspan="2">4,951</td><td rowspan="2">1.72</td><td rowspan="2">54</td></tr>
<tr><td>1973</td><td>2,384</td><td>4,581</td><td>1.92</td><td>201</td></tr>
<tr><td>1974</td><td>2,041</td><td>4,384</td><td>2.15</td><td>327</td><td>2,187</td><td>4,379</td><td>2.00</td><td>70</td></tr>
<tr><td>1975</td><td>2,047</td><td>4,769</td><td>2.33</td><td>395</td><td>2,118</td><td>4,323</td><td>2.04</td><td>88</td></tr>
<tr><td>1976</td><td>1,900</td><td>3,704</td><td>1.95</td><td>221</td><td>1,645</td><td>3,272</td><td>1.99</td><td>62</td></tr>
<tr><td>1977</td><td>1,839</td><td>4,073</td><td>2.21</td><td>327</td><td>1,338</td><td>3,137</td><td>2.34</td><td>95</td></tr>
<tr><td>1978</td><td>1,329</td><td>3,668</td><td>2.76</td><td>338</td><td>1,095</td><td>2,660</td><td>2.43</td><td>91</td></tr>
<tr><td>1979</td><td>963</td><td>2,578</td><td>2.68</td><td>308</td><td>736</td><td>2,524</td><td>3.43</td><td>66</td></tr>
<tr><td>1980</td><td>755</td><td>2,230</td><td>2.95</td><td>323</td><td>688</td><td>2,169</td><td>3.15</td><td>81</td></tr>
<tr><td>1981</td><td>654</td><td>2,176</td><td>3.33</td><td>361</td><td>646</td><td>2,003</td><td>3.10</td><td>91</td></tr>
<tr><td>1982</td><td>553</td><td>1,652</td><td>2.99</td><td>348</td><td>458</td><td>1,482</td><td>3.23</td><td>85</td></tr>
<tr><td>1983</td><td>457</td><td>1,487</td><td>3.26</td><td>292</td><td>389</td><td>1,234</td><td>3.17</td><td>92</td></tr>
<tr><td>1984</td><td>364</td><td>1,234</td><td>3.39</td><td>271</td><td>442</td><td>1,273</td><td>2.88</td><td>69</td></tr>
<tr><td>1985</td><td>669</td><td>2,015</td><td>3.01</td><td>219</td><td>545</td><td>1,877</td><td>3.44</td><td>55</td></tr>
<tr><td>1986</td><td>2,017</td><td>4,152</td><td>2.06</td><td>311</td><td>1,336</td><td>3,964</td><td>2.97</td><td>62</td></tr>
<tr><td>1987</td><td>403</td><td>1,622</td><td>4.03</td><td>371</td><td>310</td><td>996</td><td>3.21</td><td>180</td></tr>
<tr><td>1988</td><td>398</td><td>1,313</td><td>3.30</td><td>370</td><td>290</td><td>738</td><td>2.55</td><td>240</td></tr>
<tr><td>1989</td><td>349</td><td>1,044</td><td>2.99</td><td>467</td><td>300</td><td>898</td><td>2.99</td><td>240</td></tr>
<tr><td>1990</td><td>200</td><td>771</td><td>3.86</td><td>653</td><td>202</td><td>767</td><td>3.79</td><td>388</td></tr>
</table>

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

b. Where multiple years are noted for a single line of whole body content data, the data for these years were combined for the statistical analysis.

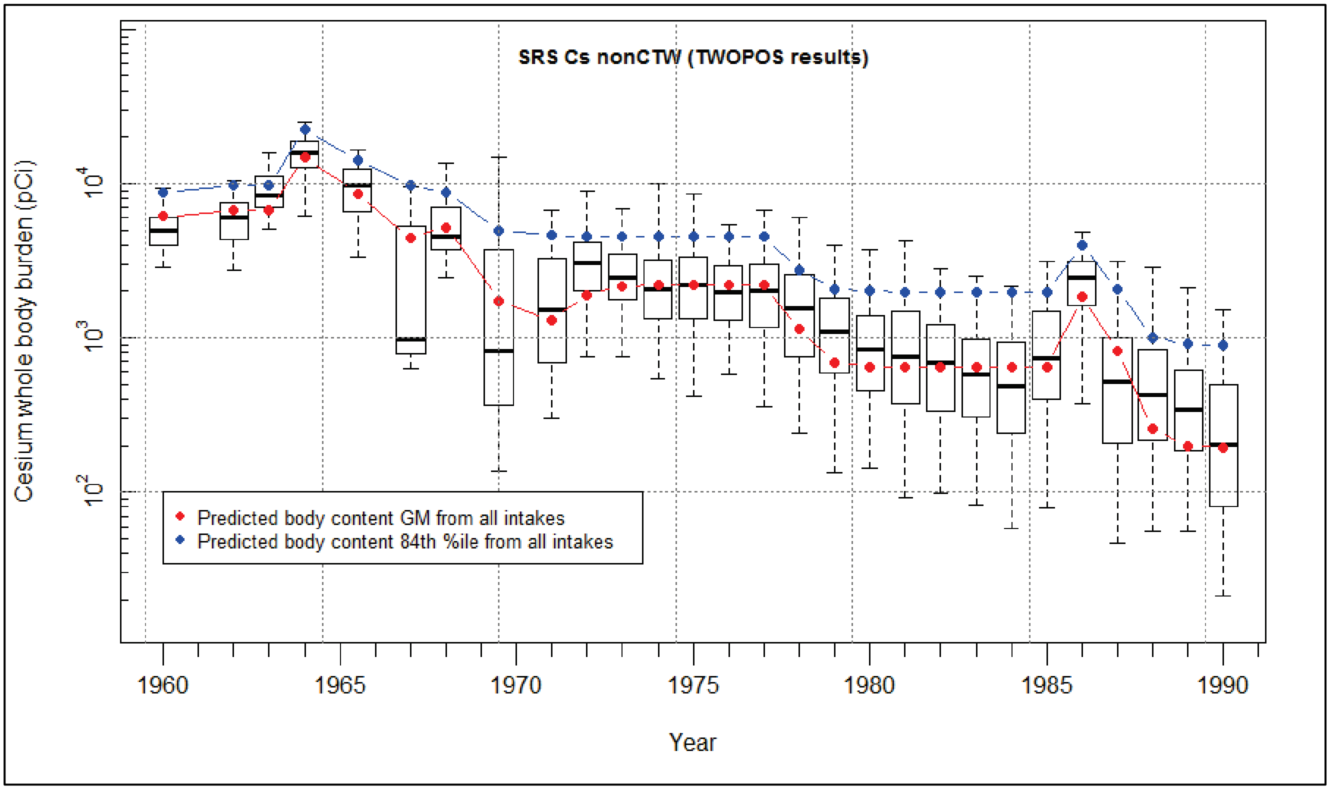

Figure 7-34. Cesium-137 body burden nonCTW TWOPOS data box and whisker plot.

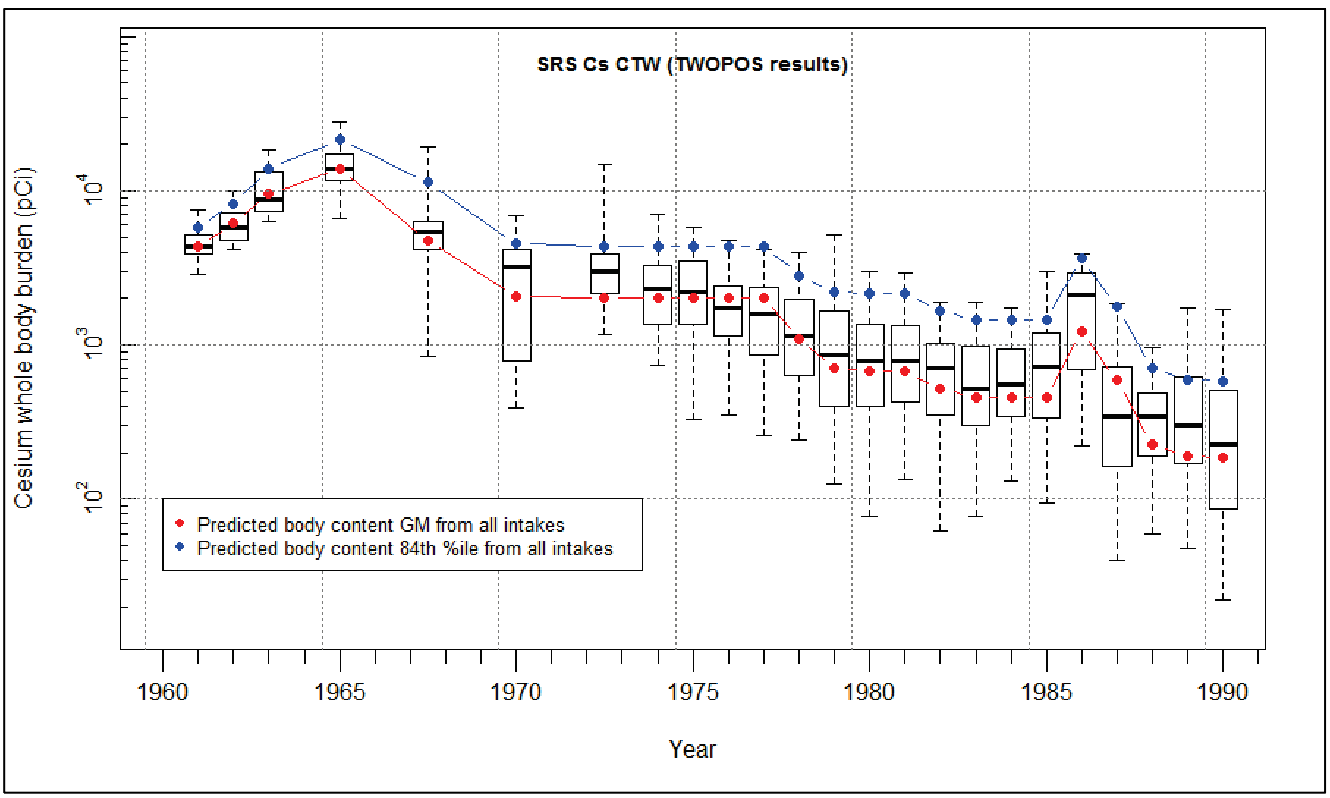

Figure 7-35. Cesium-137 body burden CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.8 Neptunium

7.3.8.1 Data Adequacy

7.3.8.1.1 Personnel Monitoring

DuPont specified bioassay operating guides, sampling frequencies, instructions for requesting and collecting urine samples, and related administrative controls in the *Bioassay Control* procedures. The earliest available version of the procedure is Revision 2 dated January 2, 1968 [DuPont 1968a]. It indicates a neptunium sample size of 250 mL was used with a positive result level of 0.1 dpm/1.5L and a resample level of 0.5 dpm/1.5L, the same as for plutonium. The neptunium sampling frequencies are given in Table C-2 for various job categories and work locations. The sample request process indicates that 24-hour composite samples required approval by an HP Senior Supervisor or above, indicating that routine samples were probably not 24-hour samples.

In Revision 3 of the *Bioassay Control* procedure in 1970 [DuPont 1970], the positive level for neptunium was noted as 0.1 dpm/1.5L and the positive level was used for the resample level, the same as for plutonium. An intake was considered confirmed if the initial bioassay result was >0.5 dpm/1.5L and a resample was >0.1 dpm/1.5L. Neptunium was no longer part of the routine sampling program but was sampled when requested by area HP, and it was stated that "area Health Physics will provide Personnel Monitoring with a list of employees requiring neptunium analysis [NP] if plutonium urinalysis is positive" [DuPont 1970]. The process for requesting samples was similar to the previous process, but HP Senior Supervisor or above approval was no longer required for 24-hour samples. Additional instructions were provided for collecting samples in the event of suspected inhalations, ingestions, injections, skin contaminations, or whenever airborne contamination exceeded control guides.

Throughout the 1970s, the sample collection guidance for neptunium remained the same in that it was only collected from personnel designated by area HP when plutonium urinalysis samples were positive [DuPont 1971a, 1971b, 1976].

The 1990 *Internal Dosimetry Technical Basis Manual* monitoring program for transuranic elements other than plutonium, which includes neptunium, specified a worker monitoring program of quarterly urine bioassay, an annual chest count, semiannual fecal bioassay, and personal air sampling. If monitored by workgroup, annual urine bioassay and an annual chest count were specified [WSRC 1990].

7.3.8.1.2 Applicability to Unmonitored Workers

Records of in vitro bioassay for neptunium show urinalysis data back to 1961. As discussed above in the description of the sample collection process, there was guidance for whom to sample by 1968. The amount of available neptunium bioassay data in the neptunium logbooks is limited and is most common for the 1960s. Review of the available data and the *Bioassay Control* procedures indicates that neptunium urinalysis was largely discontinued unless a worker with the potential for neptunium exposure had a positive plutonium measurement.

Beginning in 1970, the co-exposure evaluation of potential neptunium intakes is based on WBC data due to the reduction in neptunium urinalysis sampling frequency. Although not intended as a primary means of detecting neptunium intakes, the WBC data can be used to estimate intakes. This is due to the nature of WBCs, in which the entire spectrum of data from gamma emitters is typically recorded rather than just specific radionuclides of interest for a particular worker.

7.3.8.1.3 Bioassay Analysis Techniques

Two forms of bioassay analysis were used for neptunium. The first was urinalysis specifically analyzed for neptunium, and the second was WBCs from which neptunium data can be extracted.

The urinalysis method started in 1959. Neptunium was coprecipitated, ion exchanged, electrodeposited, and counted on NTA. In the mid-1960s, the TIOA/gross alpha method was adopted [Butler 1968]. In 1993, anion exchange followed by direct mounting and gross-alpha counting was adopted. Since 1994, extraction chromatography resin has been used to separate neptunium from FPs and other actinides and electrodeposition has been used to mount the sample. There are no suitable isotopes of neptunium available to use as tracers, so this is still a gross alpha counting technique [Taylor et al. 1995].

During the 1970s and 1980s, the primary means of measuring neptunium was via WBCs. Some earlier WBCs identified a region of interest (ROI; gamma-ray energy range) that was associated with neptunium, but the gamma-ray yield in this ROI is relatively low. The gamma ray yield of neptunium and neptunium decay products in other regions of interest is higher. Section 7.3.8.2.2 details how data from the other regions of interest are used to infer potential neptunium whole body contents.

7.3.8.2 Data Validation

7.3.8.2.1 Data Completeness and Quality

For the 1960s, urinalysis data from analytical laboratory logbooks was used [DuPont 1956–1961, 1961–1969, 1968–1972, 1969]. The completeness of the data from the logbooks was evaluated by comparing the annual bioassay summaries [DuPont 1965–1968, 1968b, 1969–1981] with the number of samples in the logbooks shown as a percentage of the number given in the bioassay summaries. The results of this comparison are shown in Table 7-14. The ability to compare these numbers directly is limited by the fact that the logbooks record the date of sample collection while the summaries indicate the number of analyzed samples. On some occasions, samples were not analyzed until months after collection. With the exception of 1963 and 1967, the number of recorded samples in the logbooks is similar to the number of samples noted in the summaries. Some of the samples from 1962 might have been analyzed in 1963, accounting for the discrepancy in that year.

Table 7-14. Logbook data completeness estimate.[a]

Year	Bioassay summary # of Np samples	Logbook # of Np samples	% in logbook
1961	N/A	612	N/A
1962	N/A	1,537	N/A
1963	898	542	60
1964	83	79	95
1965	96	92	96
1966	48	48	100
1967	17	62	365
1968	118	110	93
1969	50	51	102

a. N/A = not applicable.

A completeness test was also performed by determining whether the neptunium logbook dataset had bioassay data for those individuals with neptunium bioassay data in NOCTS. The test was performed in two parts as discussed above for the NOCTS dataset completeness evaluations with the exception that the second part was a 100% check and thus there is no confidence interval on the conclusions. The completeness check determined that the overall completeness was 2.31% missing data with a missing data rate of 1.41% before 1970 and a missing data rate of 12.08% after 1969. Only the pre-1970 data are used for this co-exposure study. The details of the results of these evaluations are contained in Attachment A.

The accuracy of the neptunium logbook data entry effort was evaluated in accordance with ORAUT-RPRT-0078 [ORAUT 2016b]; the fields with the PRID and the numerical sample results were evaluated with a maximum 1% allowable error rate. The QA check resulted in a point estimate error rate of 0.67% with a 95% confidence interval of 0.45% to 0.96%. All fields were evaluated with a maximum 5% allowable error rate. The QA check resulted in a point estimate error rate of 0.86% with a 95% confidence interval of 0.38% to 1.67%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

The neptunium WBC data for the co-exposure study was compiled from NOCTS data. The completeness and quality of this data source are addressed in Section 7.2.1.

7.3.8.2.2 Data Interpretation

The neptunium urinalysis data are gross alpha measurements after chemical separation of neptunium from other radionuclides and are assumed to be 100% ^{237}Np.

WBC data from NOCTS were used for ^{237}Np during the period for which urinalysis data are very limited (i.e., 1970 to 1989). Unlike ^{137}Cs, most WBC reports in NOCTS do not quantify ^{237}Np or report an MDA in units of activity. However, some of the reporting methods provide sufficient information to determine or estimate the ^{237}Np body content. Methods were developed to estimate ^{237}Np for three of the different reporting forms used. These methods use the fact that an ROI used to report activity for radionuclides other than ^{237}Np would also be reporting activity from ^{237}Np or its decay product ^{233}Pa. Protactinium-233 is assumed to be in equilibrium with ^{237}Np for the basis of calculating chronic intakes with a minimum duration of 1 year.

The first form, "Whole Body Counter Data," was in use from approximately 1960 through the mid-1970s and was used with the 40-cm arc geometry [Taylor et al. 1995, p. 64]. Other than ^{137}Cs and ^{40}K, the amounts of radionuclides present are not quantified in units of activity. The results are presented as net cpm. This form reports activities for ^{131}I based on the number of counts in the ROI from 300 to 400 keV. Protactinium-233 has several gammas that fall totally or partially in that energy range: 300 keV (6.6%), 312 keV (38.6%), 340 keV (4.5%), 375 keV (0.6%), and 399 keV (1.27%) [Kocher 1981]. The 300- and 399-keV peaks would fall half in and half out of the ROI, so in effect those abundances are only half of the stated values. Therefore, the total gamma abundance in the 300- to 400-keV ROI for ^{233}Pa is 47.6%. It is possible to use the reported net cpm for ^{131}I to estimate the ^{237}Np body burden by assuming that ^{233}Pa is in equilibrium with ^{237}Np. The conversion factor from net counts in the ^{131}I ROI to nanocuries of ^{237}Np is 0.243 nCi/cpm. This conversion factor was determined by adjusting the ^{137}Cs calibration factor of 0.136 nCi/cpm [Watts 1962–1967, p. 33] for the gamma abundances of ^{137}Cs and ^{233}Pa in their respective ROIs: (0.136)(0.85) ÷ 0.476. To refine the estimate, it is necessary to account for the Compton continuum contribution to the ^{131}I ROI from the ^{40}K body burden. The ^{40}K contribution to the ^{131}I ROI is 0.389 count per ^{40}K ROI net count [Watts 1962–1967, p. 33]. Therefore, the ^{237}Np body burden can be calculated as:

$$nCi\ ^{237}Np = 0.243 \times \left[\left(^{131}I\ net\ cpm \right) - 0.389 \times \left(^{40}K\ net\ cpm \right) \right] \qquad (7\text{-}1)$$

The second reporting form is untitled, and was used in the mid- and late 1970s. It is distinguishable by having the date, time, and name on successive lines on the left margin at the top. This form reports counts in the 300- to 400-keV ROI but does not associate this ROI with a particular radionuclide. For each ROI, gross, background, net, "CALC," and "DIFF" values are reported. The CALC and DIFF values correct the net counts to account for Compton scatter; the CALC value is the Compton scatter contribution and the DIFF value is the net counts minus CALC. Therefore, when using these data, there is no need to apply a ^{40}K Compton scatter as with the “Whole-Body Counter Data” form. When the 40-cm arc geometry was being used, assumed to be in the period before February 1974, the ^{237}Np body burden can be calculated as:

$$nCi\ {}^{237}Np = 0.243 \times \left(DIFF\ counts\ for\ 300\text{-}to\text{-}400\text{-}keV\ ROI\right) \tag{7-2}$$

After January 1974, when the stretcher geometry was in use, the conversion factor changes [Fleming 1973–1979, p. 162] and the ^{237}Np body burden can be calculated as:

$$nCi\ {}^{237}Np = 0.0125 \times \left(DIFF\ counts\ for\ 300\text{-}to\text{-}400\text{-}keV\ ROI\right) \tag{7-3}$$

The third reporting form is the “In-Vivo Count Results” form, which was in use from the late 1970s through the late 1980s. The ROI on this form applicable to determining ^{237}Np is the ^{51}Cr ROI covering the energy range from 290 to 349 keV. This form also reports DIFF values. In addition to the DIFF value, it reports the MDA in units of both nanocuries and counts. Having the MDA reported in both units permits the determination of a count-specific conversion factor from counts to nanocuries. The remaining step is the ratio of the conversion factor for ^{51}Cr to that for ^{233}Pa, which is 0.211 (based on the ratio of gamma abundances in the ^{51}Cr ROI: 0.098 to 0.465). The 0.469 abundance is based on 100% of the 312-keV gamma at 38.6% abundance, 95% of the 340-keV gamma at 4.5% abundance, and 55% of the 300-keV gamma at 6.6% abundance. Percentages are reduced from 100% to account for the fact that a portion of the gamma peak is outside of the ROI. Therefore, the ^{237}Np body burden can be calculated as:

$$nCi\ {}^{237}Np = 0.211 \times \left({}^{51}CR\ DIFF\ counts\right) \times \left({}^{51}Cr\ MDA\ nCi\right) \div \left({}^{51}Cr\ MDA\ counts\right) \tag{7-4}$$

7.3.8.2.3 <u>Data Exclusion</u>

Individuals with intakes of actinides are sometimes treated by chelation to accelerate the excretion of the radionuclides. Bioassay data influenced by chelation treatment are not suitable for use in an internal dose co-exposure study due to the altered biokinetics during chelation treatment. A listing of individuals who received chelation at SRS was compiled from SRDB chelation records from REAC/TS (see Table B-1). Bioassay data for samples collected within 100 days after receiving chelation treatment were not used. In addition, samples marked as LIP, those marked DTPA to indicate chelation, and those that lacked sufficient identifying information (e.g., sample date or payroll ID number) were excluded.

The above discussion is a general summary of the method. The detailed statistical analysis instructions are in Attachment D.

7.3.8.3 Statistical Analysis

Statistical analysis of the neptunium bioassay data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014a] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2021]. The data were analyzed on an annual basis except for the years indicated in Tables 7-15 and 7-16. Tables 7-15 and 7-16 provide the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 7-36 through 7-39. The box and whisker plots are overlaid with the excretion results and whole body burdens predicted by the intake modeling as discussed further below. After 1969, insufficient urinalysis data were available for statistical analysis requiring the use of the WBC data. However, the urinary excretions predicted from the WBC based intakes are presented in Figures 7-40 and 7-41 overlaid with the box and whisker plots of the available urinalysis data. The supporting data for these figures and tables are contained in ORAUT [2022] in the \statistics\ subfolder. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-15. Calculated 50th- and 84th-percentile urinary excretion rates of neptunium based on a lognormal fit to the TWOPOS data, 1961 to 1969 (dpm/d).[a,b]

Year	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1961	0.01002	0.0310	3.10	273	0.00957	0.0308	3.22	39
1962	0.00136	0.0164	12.01	784	0.00112	0.0132	11.85	152
1963	0.00087	0.0150	17.30	401	0.00144	0.0283	19.63	61
1964	0.04227	0.1129	2.67	41	N/A	N/A	N/A	7
1965	0.05684	0.1692	2.98	43	N/A	N/A	N/A	4
1966	0.09036	0.3286	3.64	27	N/A	N/A	N/A	5
1967	0.07637	0.2371	3.11	39	N/A	N/A	N/A	3
1968	0.04617	0.1142	2.47	60	N/A	N/A	N/A	8
1969	0.04560	0.1187	2.60	30	N/A	N/A	N/A	5

a. N/A = not applicable
b. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-16. Calculated 50th- and 84th-percentile whole body burdens of neptunium based on a lognormal fit to the TWOPOS data, 1970 to 1989 (dpm).[a]

<table>
<tr><th>Year[b]</th><th>nonCTW 50th percentile</th><th>nonCTW 84th percentile</th><th>nonCTW GSD</th><th>nonCTW # of individuals</th><th>CTW 50th percentile</th><th>CTW 84th percentile</th><th>CTW GSD</th><th>CTW # of individuals</th></tr>
<tr><td>1970</td><td>14,535</td><td>31,621</td><td>2.18</td><td>29</td><td rowspan="3">8,342</td><td rowspan="3">12,230</td><td rowspan="3">1.47</td><td rowspan="3">33</td></tr>
<tr><td>1971</td><td>9,583</td><td>19,676</td><td>2.05</td><td>42</td></tr>
<tr><td>1972</td><td>7,038</td><td>13,615</td><td>1.93</td><td>131</td></tr>
<tr><td>1973</td><td>5,042</td><td>10,322</td><td>2.05</td><td>171</td><td>4,702</td><td>10,450</td><td>2.22</td><td>30</td></tr>
<tr><td>1974</td><td>2,771</td><td>8,292</td><td>2.99</td><td>299</td><td>3,609</td><td>8,625</td><td>2.39</td><td>59</td></tr>
<tr><td>1975</td><td>1,001</td><td>4,888</td><td>4.88</td><td>379</td><td>1,223</td><td>5,661</td><td>4.63</td><td>84</td></tr>
<tr><td>1976</td><td>1,427</td><td>5,648</td><td>3.96</td><td>63</td><td rowspan="2">2,058</td><td rowspan="2">6,184</td><td rowspan="2">3.00</td><td rowspan="2">67</td></tr>
<tr><td>1977</td><td>1,687</td><td>5,961</td><td>3.53</td><td>216</td></tr>
<tr><td>1978</td><td>2,273</td><td>8,589</td><td>3.78</td><td>330</td><td>1,652</td><td>7,242</td><td>4.38</td><td>88</td></tr>
<tr><td>1979</td><td>969</td><td>4,562</td><td>4.71</td><td>213</td><td>635</td><td>4,446</td><td>7.01</td><td>53</td></tr>
<tr><td>1980</td><td>144</td><td>1,055</td><td>7.35</td><td>315</td><td>77</td><td>692</td><td>9.05</td><td>78</td></tr>
<tr><td>1981</td><td>140</td><td>899</td><td>6.44</td><td>352</td><td>173</td><td>840</td><td>4.86</td><td>88</td></tr>
<tr><td>1982</td><td>169</td><td>813</td><td>4.81</td><td>335</td><td>43</td><td>494</td><td>11.51</td><td>81</td></tr>
<tr><td>1983</td><td>110</td><td>832</td><td>7.54</td><td>276</td><td>94</td><td>753</td><td>7.99</td><td>85</td></tr>
<tr><td>1984</td><td>104</td><td>795</td><td>7.64</td><td>269</td><td>144</td><td>1,068</td><td>7.43</td><td>64</td></tr>
<tr><td>1985</td><td>167</td><td>984</td><td>5.88</td><td>209</td><td>159</td><td>828</td><td>5.21</td><td>53</td></tr>
<tr><td>1986</td><td>287</td><td>1,571</td><td>5.48</td><td>183</td><td>270</td><td>1,477</td><td>5.47</td><td>42</td></tr>
<tr><td>1987</td><td>431</td><td>2,034</td><td>4.72</td><td>216</td><td>650</td><td>3,079</td><td>4.74</td><td>37</td></tr>
<tr><td>1988</td><td>287</td><td>1,315</td><td>4.59</td><td>162</td><td rowspan="2">150</td><td rowspan="2">1,834</td><td rowspan="2">12.22</td><td rowspan="2">45</td></tr>
<tr><td>1989</td><td>381</td><td>1,403</td><td>3.68</td><td>170</td></tr>
</table>

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.
b. Where multiple years are noted for a single line of whole body burdens, the data for these years were combined for the statistical analysis.

In Figures 7-36 and 7-37, the top line is the predicted excretion 84th percentile from all intakes. The bottom line is the predicted excretion GM from all intakes. In Figures 7-38 and 7-39, the top line is the predicted body content 84th percentile from all intakes. The bottom line is the predicted body content GM from all intakes. In Figures 7-40 and 7-41, the top line is the urinary excretion 84th percentile. The bottom line is the urinary excretion GM.

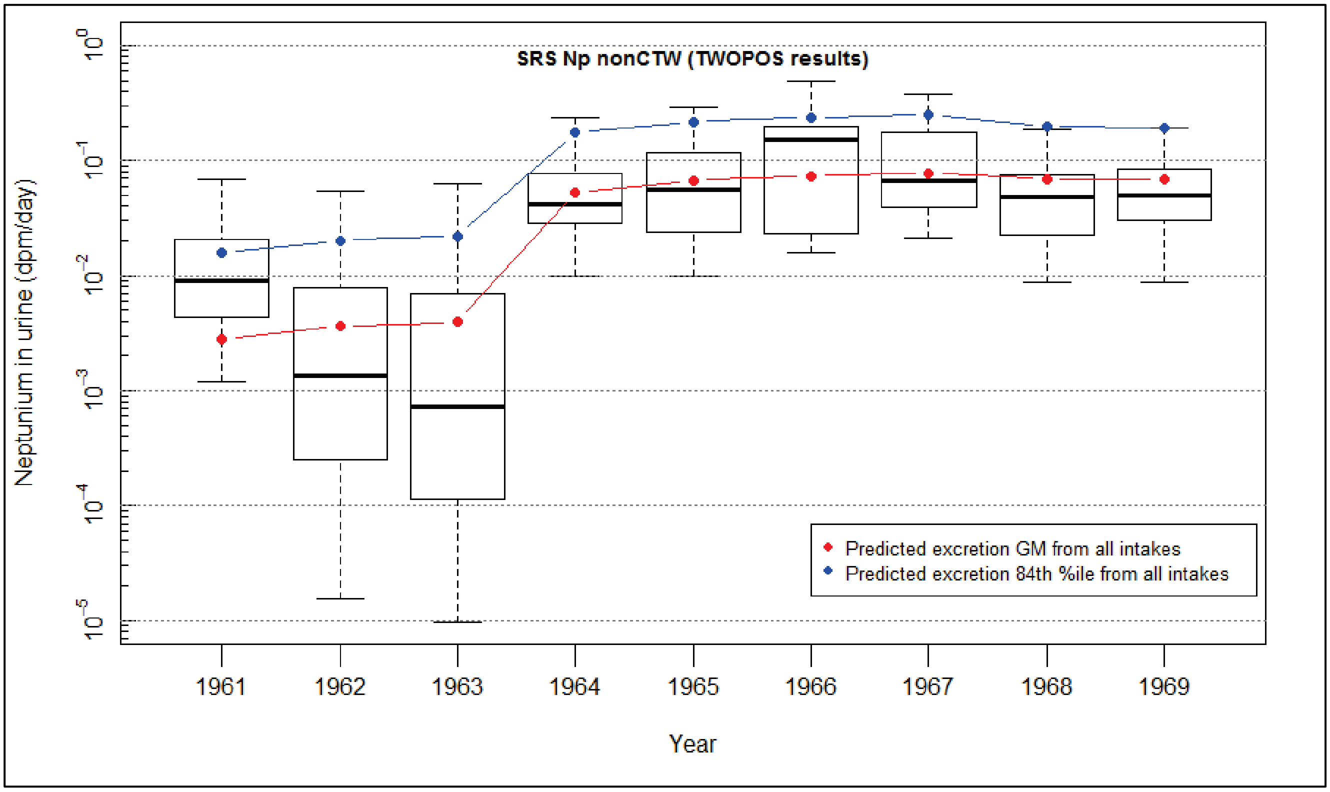

Figure 7-36. Neptunium urinalysis nonCTW TWOPOS data box and whisker plot.

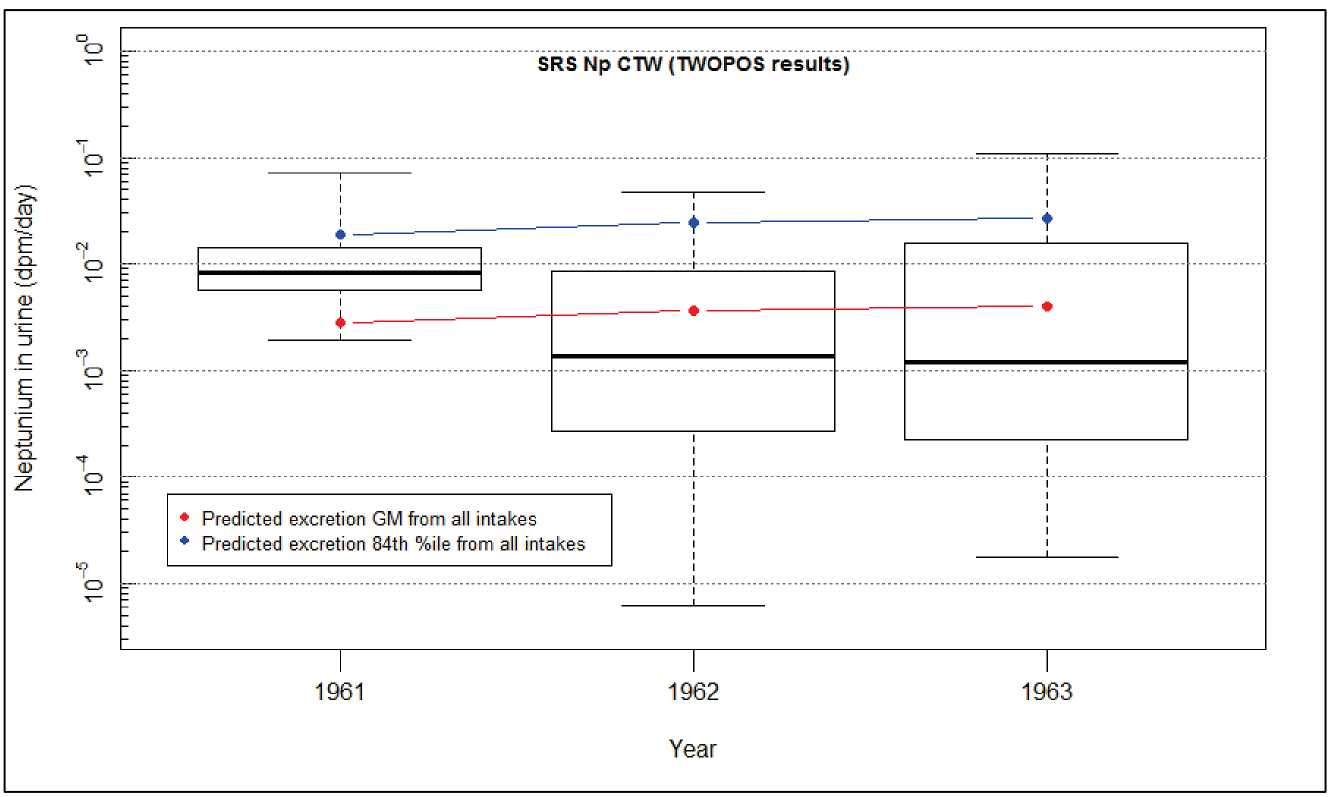

Figure 7-37. Neptunium urinalysis CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

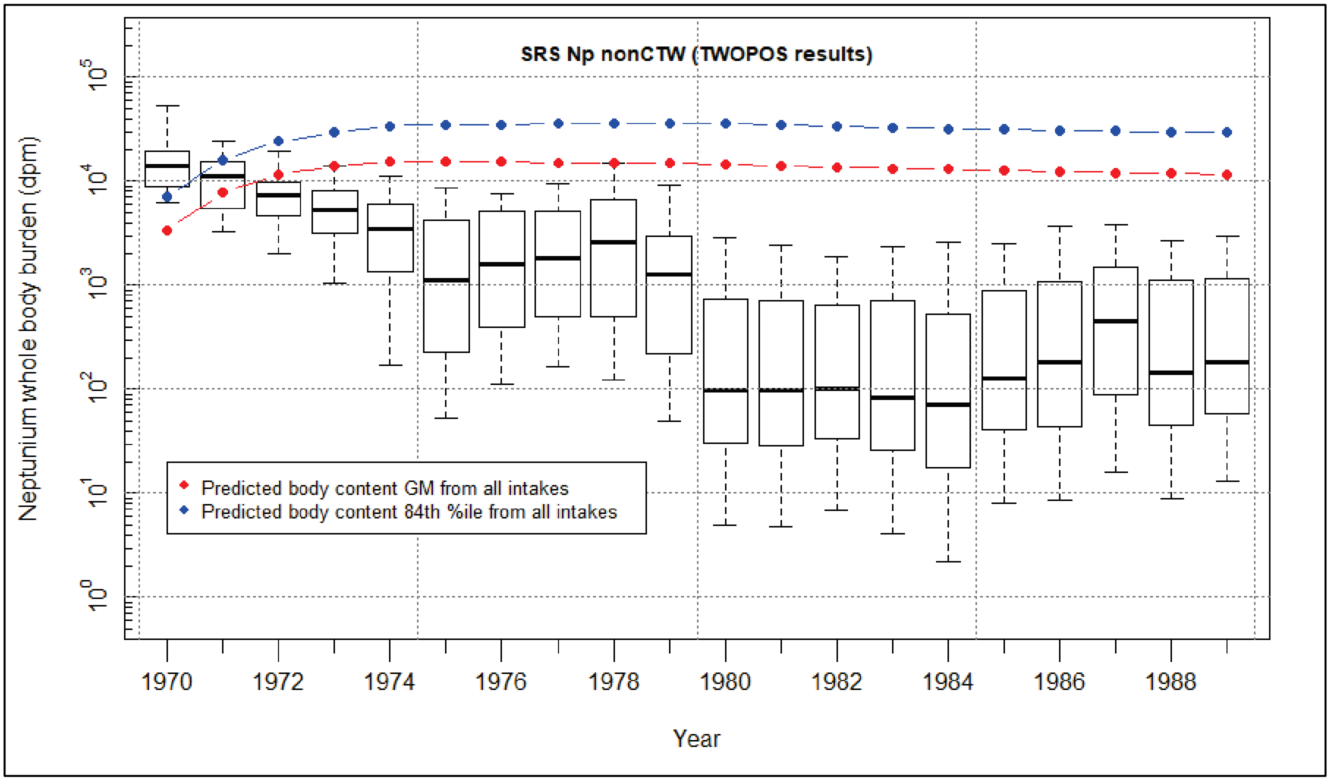

Figure 7-38. Neptunium whole body burden nonCTW TWOPOS data box and whisker plot.

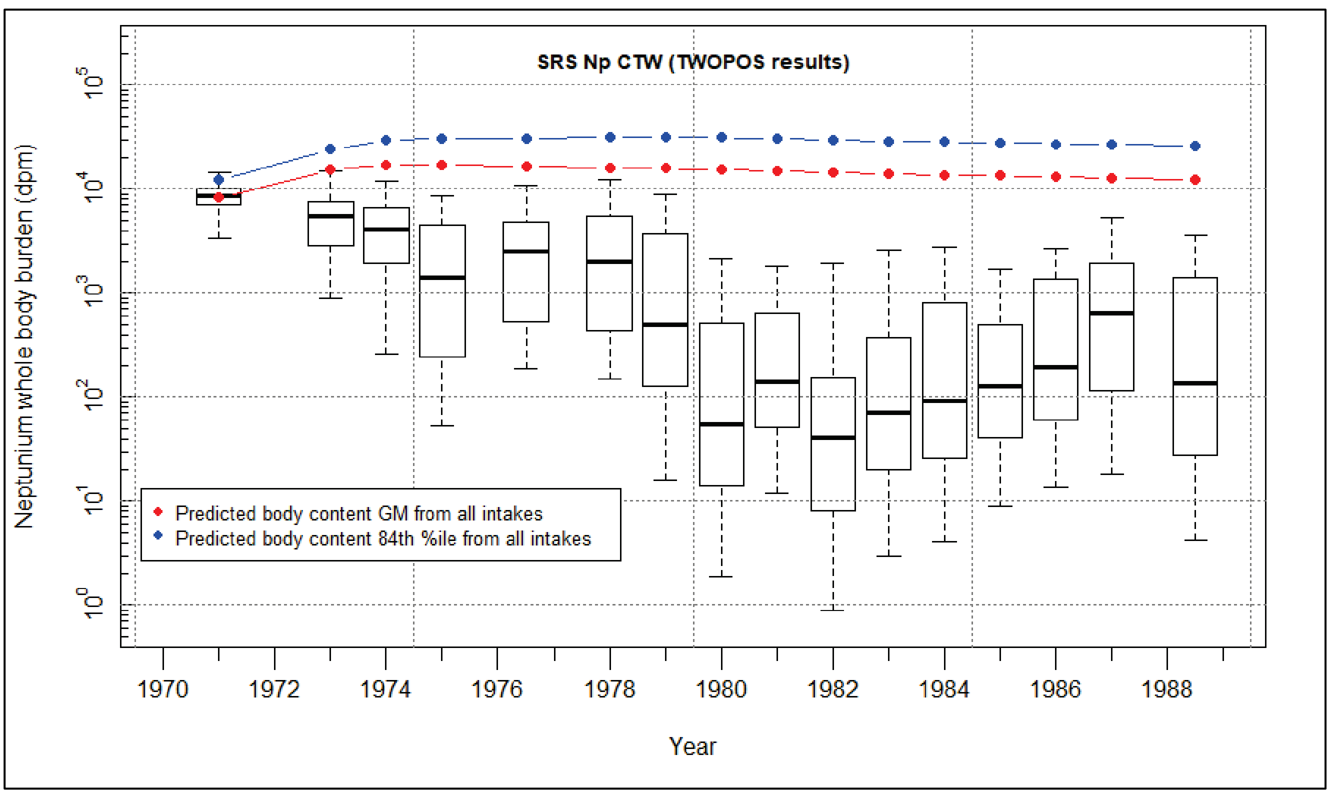

Figure 7-39. Neptunium whole body burden CTW TWOPOS data box and whisker plot. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

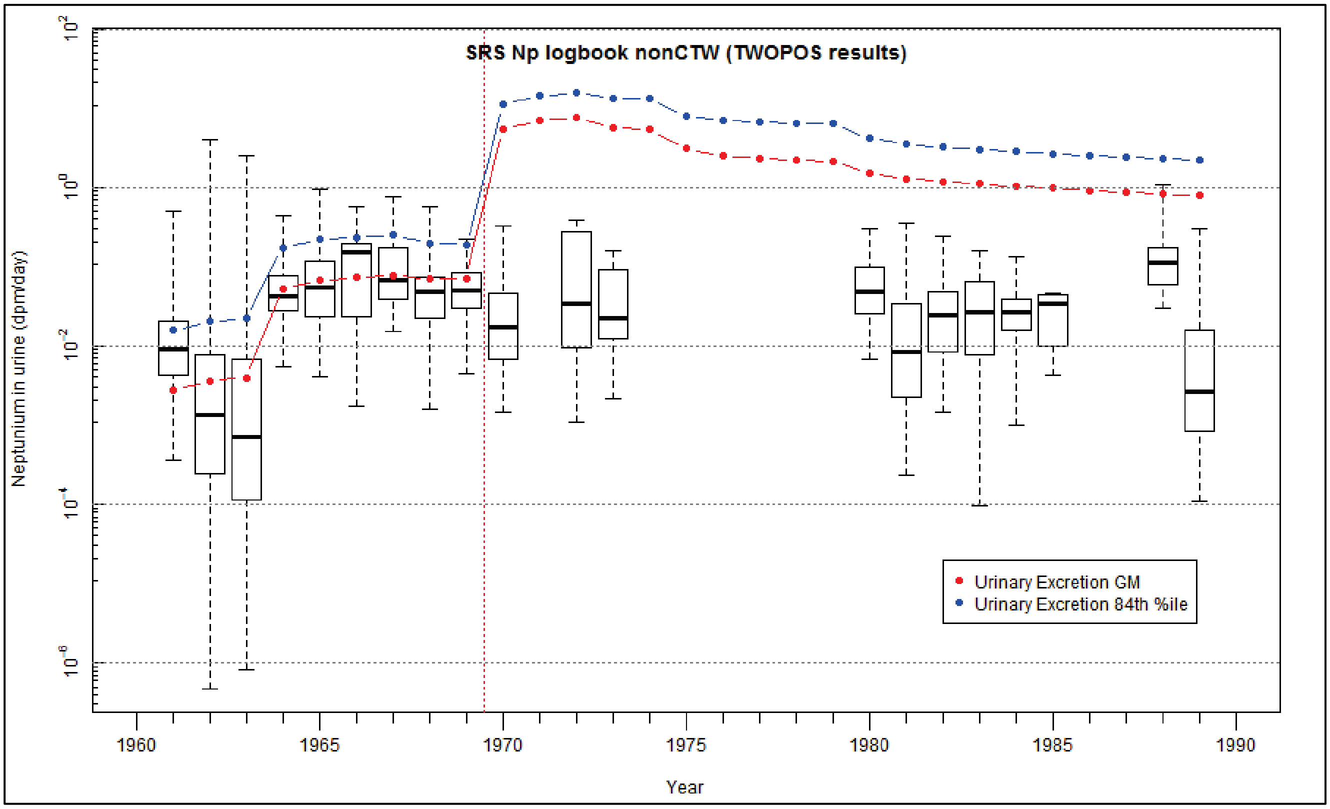

Figure 7-40. Neptunium urinalysis nonCTW TWOPOS data box and whisker plot, 1970 to 1989.

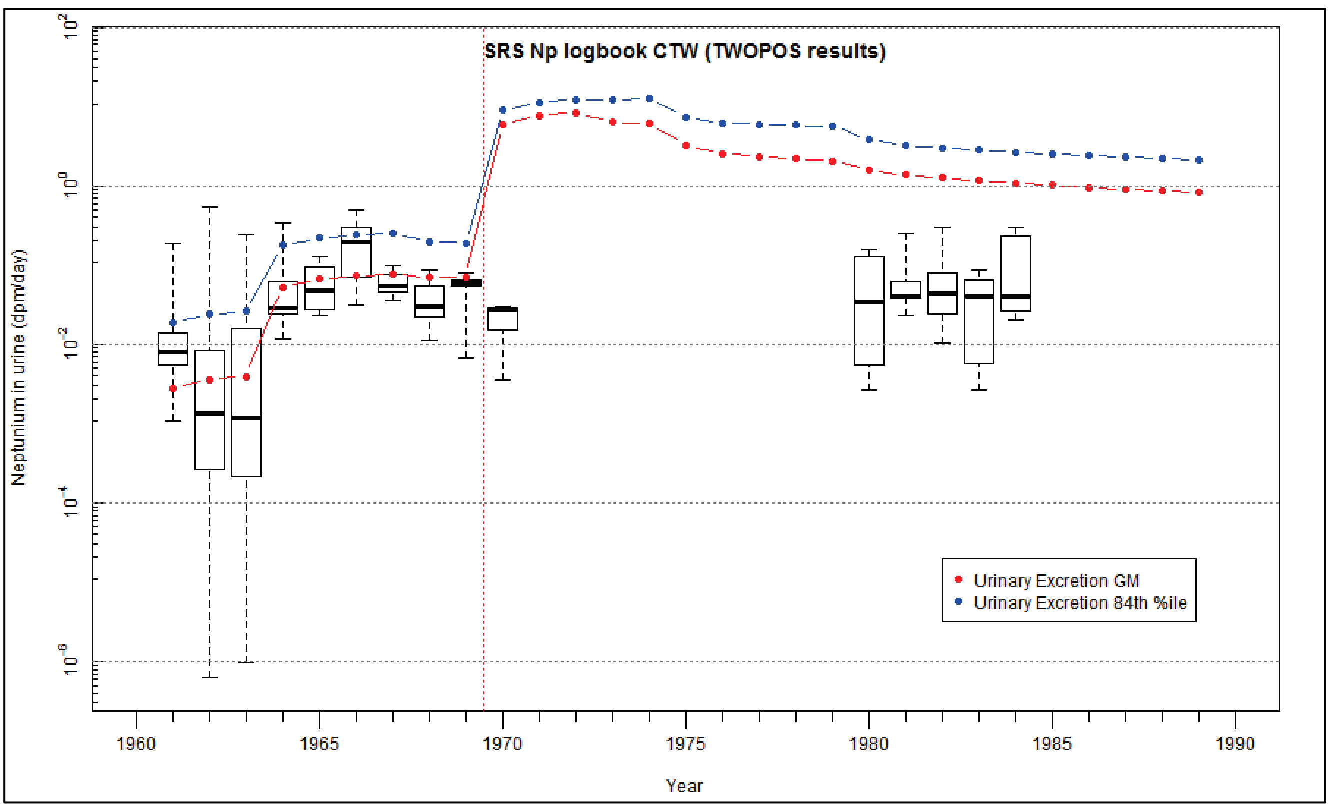

Figure 7-41. Neptunium urinalysis CTW TWOPOS data box and whisker plot, 1970 to 1989. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.8.4 Intake Modeling

Each result that was used in the intake calculations was assumed to have a normal distribution. A uniform absolute error of 1 was applied to all results, thereby assigning the same weight to each result. The IMBA program requires in vitro bioassay results to be in units of activity per day, so all urinalysis results were normalized as needed to 24-hour samples using 1,500 mL (the volume of urine assumed by SRS to be excreted in a 24-hour period).

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-μm activity median aerodynamic diameter particle size distribution.

IMBA was used to fit the bioassay results to a series of inhalation intakes. Data were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1955 through 1989 were divided into multiple chronic intake periods.

Because the neptunium isotopes at SRS have very long radiological half-lives, and because the material is excreted over long periods, excretion results are not independent. For example, an intake in the 1950s could have contributed to urinary excretion in the 1980s and later. However, because of turnover in the workforce, the workers used to assess intakes in one period might not have been the same as those in a later period. To avoid potential underestimation of intakes in the later periods, each chronic intake was fit independently using only the bioassay results from the single intake period. This method resulted in an overestimate of the later TWOPOS results when the cumulative predicted urine sample results from multiple assumed intake periods are plotted. Only the results during the intake period were selected for use in the fitting of each period. Excluded results are shown as an “X” in the figures in Attachment E; included results are shown as dots. The results of the statistical analysis that was used to calculate the intakes are provided for neptunium in Tables 7-15 and 7-16.

Excluded results are shown as an “X” in the figures in Attachment E; included results are shown as dots. The solid lines in Figures E-155 to E-178 in Attachment E show the individual fits to the 50th- and 84th-percentile excretion rates for nonCTWs and CTWs. Figures E-179 to E-186 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all intakes for nonCTWs and CTWs. Tables E-23 and E-24 list the 50th- and 84th-percentile intake rates with the associated GSDs from the neptunium urinalysis for nonCTWs and CTWs.

Figures 7-36 and 7-37 overlay the urinary excretion rates (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data. Figures 7-38 and 7-39 overlay the whole body contents (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data.

There is not enough CTW data from 1964 through 1969 to perform statistical analysis or intake modeling. Therefore, the nonCTW intakes for this period were used as a surrogate due to the similarity of the nonCTW and CTW intake rates before and after this period. Figures 7-40 and 7-41 depict the nonCTW-data based predicted urinary excretion rates in comparison to the limited CTW available. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.3.9 Thorium

By 1990, thorium in urine was quantified by an offsite vendor [WSRC 1990]. However, the analytical techniques SRS used for americium before 1990 also captured thorium [NIOSH 2012; Butler and Hall 1970; Taylor et al. 1995]. Butler [1964] indicates an extraction efficiency of 93% for thorium into 20% HDEHP-toluene. An extraction efficiency of 97% with the TIOA-DDCP technique [Butler and Hall 1970] was reported. DDCP extracts all the alpha-emitting actinides from thorium through einsteinium from the sample. The extraction efficiency for the various actinides is given in Table 7-17. For practical use at SRS, the plutonium, uranium, and neptunium would be stripped first to permit separation of the americium, californium, and curium.

Table 7-17. Extraction efficiencies with DDCP [Butler and Hall 1970].

Element	Principal valence	Extracted %
Ca	2	<1
Cs	1	<1
Fe	3	95
Pm	3	99
Ce	3	99
Th	4	97
U	6	82
Np	5	92
Pu	4	98
Am	3	95
Cm	3	95
Bk	3	98
Cf	3	95
Es	3	97

The TIOA-DDCP method provides a simple, accurate method for quantitative determination of actinides (Figures 7-42 and 7-43). TIOA is used to extract the plutonium, uranium, and neptunium from the sample in an 8N HCl solution. Next, a sequence of nitric acid dissolution steps is performed followed by the use of DDCP to separate the remaining actinides. Toluene is used to return the actinides to the aqueous phase, which is then evaporated to dryness and counted. Separation of the thorium, berkelium, and einsteinium from the americium, curium, and californium was not done because they “are not present in biological samples in sufficient quantities to require separation or routine identification by alpha spectroscopy” [Butler and Hall 1970]. However, if present, they would continue with the americium, curium, and californium. This is shown graphically in Figure 7-42. Thorium was also noted as being included in the americium, curium, and californium determination in 1987 [DuPont 1987, p. 60] as shown in Figure 7-43. Therefore, although not originally intended to measure thorium, the analytical technique for americium measurement would also capture any thorium present in the sample and establish an upper bound on the amount of thorium present.

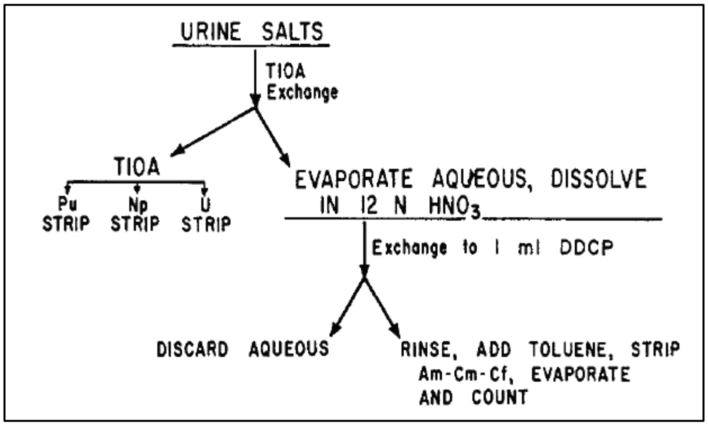

Figure 7-42. TIOA-DDCP sequential stripping process [Butler and Hall 1970].

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AMERICIUM-CURIUM-CALIFORNIUM, PLUTONIUM, NEPTUNIUM, ENRICHED URANIUM SEQUENTIAL DETERMINATIONS

PURPOSE:

To sequentially determine the concentration of americium-curium-californium, plutonium, neptunium, and enriched uranium in urine.

PRINCIPLE, LIMITATION, PRECISION:

This procedure utilizes liquid ion exchange in the determination of the concentration of six actinides. Plutonium, neptunium, and uranium are exchanged to TIOA (tri-isooctylamine) and are removed individually from the organic depending on the strip solution used. Americium, curium, and californium are extracted from the aqueous with bidentate (dibutyl N, N-diethyl carbamylphosphonate).

The urine sample (250 mL) is wet-ashed. The salts are dissolved in 8N hydrochloric acid and then extracted with 10% TIOA-xylene. The organic is washed with 8N hydrochloric and plutonium is stripped with 80°C 8N HCl-0.05M NH_4I; neptunium is stripped with 4N HCl-0.02N HF; enriched uranium is stripped with 0.1N HCl. The residual 8N HCl and rinse of the TIOA are wet ashed. The salts are dissolved in 12N HNO_3 and then extracted with bidentate. Nitric acid (2N) is used to back-extract the remaining actinides from the bidentate. The strip solutions are evaporated, plancheted, and counted in solid state counters.

The procedure has a minimum sensitivity of 0.1 d/m/1.5 liters for plutonium and neptunium and 0.3 d/m/1.5 liters for enriched uranium and americium-curium-californium.

Precision (at the 95% confidence level):
Am-Cm: ±19% at the 6 pCi/1.5 liter level.
Pu: ±49% at the 0.4 pCi/1.5 liter level.
U: ±41% at the 5 pCi/1.5 liter level.

Limitation:
Thorium will be included in the Am-Cm-Cf determination, but it is not normally present in significant quantities.

Figure 7-43. Sample analysis procedure for extracting americium, curium, californium, plutonium, neptunium, and EU [DuPont 1987].

Therefore, the americium bioassay data discussed in Section 7.3.1 were also used to model thorium intakes from November 1, 1972, through May 31, 1980. Separate intake modeling was performed for thorium due to the differing biokinetics of thorium in comparison with americium. The intake rates start on November 1, 1972, because an SEC class covers ^{232}Th exposures before October 1972.

Because of the nature of work at SRS, intakes could have been chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and to occur through inhalation with a default breathing rate of 1.2 m^3/hr and a 5-μm activity median aerodynamic diameter particle size distribution. IMBA was used to fit the bioassay results to an inhalation intake. Only the results during the intake period were selected for use in the fitting.

The solid lines in Figures E-187 to E-194 in Attachment E show the fits to the 50th- and 84th-percentile excretion rates for Type M and S for nonCTWs and CTWs. Tables E-25 and E-26 list the 50th- and 84th-percentile intake rates with the associated GSDs from the neptunium urinalysis for nonCTWs and CTWs. Although included in the source data, the results for CTWs do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Beginning June 1, 1980, thorium intakes are assigned based on the guidance ORAUT-RPRT-0070 [ORAUT 2017c] which assigns intake rates of 4.87 dpm/d from inhalation and 0.1 dpm/d from ingestion.

7.4 GUIDANCE FOR DOSE RECONSTRUCTORS ON ASSIGNMENT OF INTAKES AND DOSES

This section describes the derived intake rates and provides guidance for assigning doses. For the calculation of doses to individuals from bioassay data, a minimum GSD of 3 has been used to account for biological variation and uncertainty in the models. It was considered inappropriate to assign a value less than 3 for the co-exposure data. Therefore, a GSD of at least 3 was assigned for each intake period. The 95th-percentile values were based on the adjusted GSD for the intake period. The original GSDs are provided in the Attachment E tables for each element. For input into the Interactive RadioEpidemiological Program (IREP), the 50th percentile of the calculated intake rates should be assigned as a lognormal distribution with the associated GSDs in the tables in this section to the majority of workers for whom co-exposure intakes are assigned as the default assumption. For cases in which there is justification that the individual could have had intakes larger than the 50th percentile, dose reconstructors should use the 95th-percentile intake rates input into IREP as a constant.

Radiological controls improved in the later years and the detection limits for radionuclides dropped, both of which tend to result in the calculated radionuclide intake rates decreasing. Therefore, the intake rates or dose for the last year listed may be extended to subsequent years as a measure favorable to claimants.

The following sections list the intake rates that should be used for each radionuclide and the period of applicability of each intake rate except for tritium. For tritium, the actual dose that should be used is provided. Co-exposure intakes should be assigned for radionuclides that could have been present at the worker's location and for which the worker was not monitored. Table 7-18 lists the radionuclides potentially present at various SRS facilities or to which a worker who was assigned to a particular facility might have been exposed. Most radionuclides apply to the entire duration of the facility's existence; a few radionuclides apply to limited periods as noted in the table [ORAUT 2013a]. The dosimeter codes applicable to various periods are included to help identify an individual's work location. However, the dosimeter codes are guidance only and claimant-specific information (e.g., telephone interview statements, incident reports, and DOL claim file information) supersedes the guidance provided by the dosimeter codes.

Table 7-18. Radionuclides of concern potentially present at SRS facilities [ORAUT 2023].

Building or facility	Dosimeter codes[a] 1959–1972	Dosimeter codes[a] 1973–08/16/1990	Dosimeter codes[a] 08/17/1990–2003	Dosimeter codes[a] 2004–present	Radionuclides of concern[b,c]
Reactors (R, P, L, K, C)	7A, 8A, 9A, 10A, 11A	1C, 3C, 4C, 6C, 1K, 1P, 1L, 1R	C01, C03 (C04, C06 until 01/29/1992), K01, L01, P01, (R01 until 01/29/1992)	LLL, NMM, SDD[d]	H-3, FP, Pu, DU (1955[e]–1988), EU (1954[e]–1988), NU (12/1953[e]–1967)
F-Area unknown facility	1A	1F 2F	F01, F02	235, CLB, FBL, FCA	Pu, FP, DU (1955[e]–2006)
F-Area A-Line	1A	See 221-F Canyon	See 221-F Canyon	FCA	FP, DU (1955[e]–2006)
221-F B-Line (FB- and JB-Lines)	1A	1F, 2F	F01, F02	FBL	Pu
221-F Canyon	1A	1F, 2F	F01, F02	FBL, FCA	Pu, FP, DU (1955[e]–2006)
MPPF (in 221-F)	1A	1F, 2F	F01, F02	FCA (F-Canyon through 2006)	Pu, Am
F-Area Outside Facilities	1B	9F	F09	FCA	Pu, FP, DU (1955[e]–2006)
$^{238}PuO_2$ Fuel Form Facility and $^{238}PuO_2$ Experimental Facility (235-F)	1A, 1F	1F, 2F, 8F	F01, F02, F08	235	Pu (through 2006), Np (1962–1983), Th (1975–1981)
235-F Vaults	1A	1F, 2F, 8F	F01, F02, F08	235	Pu (through 2006), DU (1955[e]–present), Np (1962–1983), Th (1975–1981)
772-F and 772-1F Laboratories	1A	1A	A01	CLB	Pu, DU (1955[e]–2021), EU (05/1959[f]–2021), U-233[g] (1964–1969), TRM (2017–2020)[h]
F/H Tank Farms	None	5F, 5H (235-F construction, 200-H S Gate construction)	F05, H05 (235-F construction, 200-H South Gate construction)	FTF, HTF	Pu, FP
Effluent Treatment Facility (241-84H), Cooling Water and Retention Basins, 241-102H, 7H/H07	None	3F, 5F, 1H, 3H, 5H (200-F, 200-H South Gate construction)	F03, F05, H01, H03, H05	EPT	Pu, FP
H-Area unknown facility	2A	1H through 4H, 7H	H01 through H04, H07	299, HBL, HCA, EPT, HTF	Pu, Np, DU (1955[d]–present)

Building or facility	Dosimeter codes[a] 1959–1972	Dosimeter codes[a] 1973–08/16/1990	Dosimeter codes[a] 08/17/1990–2003	Dosimeter codes[a] 2004–present	Radionuclides of concern[b,c]
Old HB-Line Facility (221-H) (through 1983)	2A	1H, 2H	H01, H02	HBL	Pu (1963–1983 for Pu-238 insoluble), Np (1962–1983), DU (1955[e]–present), EU (05/1959[f]–present), U-233[g] (1964–1969), TRM (2017–2020)[h]
New HB-Line Facility (1985–2011)	None	1H, 2H (1985–08/16/1990)	H01, H02	HBL	Pu (1985–2011 for Pu-238 insoluble), Np (1985–2011), EU (05/1959[f]–present)
H-Canyon and A-Line	2A	1H, 2H	H01, H02	HCA	Pu, FP, Np, EU (05/1959[f]–present), U-233 (1964–1969), TRM (2017–2020)[h]
221-H Area Outside Facilities	2A	1H, 2H	H01, H02	HCA	Pu, FP, Np EU (05/1959[f]–present),
232-H, 234-H, H Area New Manufacturing Facility, H Area Old Manufacturing Facility, Tritium complex	2A (200-H)	2H, 4H	H02, H04	TEF, TRI	H-3, Zn-65
320-M, 321 M-Area, M Area unknown facility	3A	3M	M03	No active codes, SDD[dc]	DU (1955[e]–1988), EU (05/1959[f]–present), NU (12/1953[b]–1967), Th (10/01/1972), Pu (1963–1965, 1968–1970, 1975, and 1979–1980 only), Np (1961–1998 only)
704-U, 704-B	None	None	None	No active codes	FP
723-A, 773-A	6N, 5A	7L, 5A	A27, A15	SRE, SRT	Pu, Am, Cm, Cf, FP, H-3, Th (after 10/01/1972), Np (1957–present), DU (1955[e]–present), EU (5/1959[f]–present), U-233[g] (1964–1969), TRM (2017–2020)[g]

Building or facility	Dosimeter codes[a] 1959–1972	Dosimeter codes[a] 1973–08/16/1990	Dosimeter codes[a] 08/17/1990–2003	Dosimeter codes[a] 2004–present	Radionuclides of concern[b,c]
735-A and 735-11A	6F	5D	A16	SRT (apply 773-A intakes)	Pu, Am, Cm, Cf, FP, H-3, Th (after 10/01/1972), Np (1957–present), DU (1955[e]–present), EU (05/1959[f]–present), TRM (2017–2020)[g]
776-A[j] Used 773-A Codes	5A (773-A)	5A (773-A)	A15 (773-A)	SRT (apply 773-A intakes)	Pu, Am, Cm, Cf, FP, H-3, Th (after 10/01/1972), Np (1957–present), DU (1955[e]–present), EU (05/1959[f]–present), U-233[g] (1964–1969), TRM (2017–2020)[g]
777-M (Standard Pile, Nuclear Test Gauge)[i]	5B	5B	A33	SRT	FP, Th (1954–1984), Np (1955, 1965–1968), DU (1955[e]–1988), EU (1968–1988), NU (12/1953[b]–1967)
CMX (679-T) 09/01/1951–1983) and TNX (12/10/1951–09/2004) (Semi-works facilities)[j]	5C	5C	T01	No active codes	DU (1955[e]–1988 TNX only)[k], EU (1968–1988)
D-Area	4A	4D	D04	SDD	H-3 (through 1999), FP (through 1999)
E-Area Solid Waste Disposal Facility (643-G Burial Grounds), 618-G Class, Yard)	12A	12B, 4F, 3G, 8G	B12, G03, F04, G08	SWM	H-3, Pu, Cm, FP
Receiving Basin for Off-Site Fuel and Resin Regeneration Facility	See H-Area unknown facility	See H-Area unknown facility	See H-Area unknown facility	RBO	Pu, FP
S-Area Defense Waste Processing Facility (start 1996	None	2W (cannot find in code list)	S02 (cannot find in code list)	SSS	Pu, FP
Waste Certification Facility (724-8E and WCF Building) (start 12/1986)	None	None (643-G Burial Grounds)	None (643-G Burial Grounds)	SSS	H-3, Pu, Cm, FP

Building or facility	Dosimeter codes[a] 1959–1972	Dosimeter codes[a] 1973–08/16/1990	Dosimeter codes[a] 08/17/1990–2003	Dosimeter codes[a] 2004–present	Radionuclides of concern[b,c]
Z-Area (start 1990)	None	2Z	Z02	ZZZ	FP, Pu
Not identifiable or unknown[l]	None	None	None	Blank, any code not already listed	Pu, FP, H-3, Am, Cm, Cf, Np, Th (after 10/01/1972), DU (1955[e]–present), EU (05/1959[f]–present), U-233 (1964-1969), NU (12/1953[b]–1967), TRM (2017–2020)[h]
Central Shops and Maintenance, Pittsburgh Testing Laboratory, includes CTW-specific HPA Area codes[m]	1Z, 6C, 6H, 6I, 6M, 6N, 6R, 12D, 12E, 12I, 12Z	1A, 5F, 5H, 5J, 5W, 6B, 6H, 6W, 7A, 7B, 7G, 7I, 7J, 7K, 7L, 7M, 7N, 7R, 7T, 7Q, 7W, 7Y, 8A through 8C, 8H through 8M, 8P, 8S, 8T, 1N	A18, A12, A24, A25, A26, A27, A29, A34, F05, H05, H06, J01 through J08, J10, J12 through 41, Y01	No active codes	Pu, FP, H-3, Am, Cm, Np, Th (after 10/01/1972), DU (1955[e]–present), EU (05/1959[f]–present), NU (12/1953[b]–1967), U-233 (1964–1969)

a. Source: ORAUT [2014c]. Any code with an "X" should not be included. These indicate offsite assignment.
b. DU/EU indicate which recycled components to use, either DU for depleted uranium components or EU for enriched uranium components (per Table 5-30). See ORAUT-TKBS-0003-2 [ORAUT 2024a] and ORAUT-TKBS-0003-5 [ORAUT 2024b] for radionuclides of concern; periods of applicability in parenthesis.
c. Source: ORAUT [2024a].
d. Code SDD is used both for the reactors and for 300-M Area. If no other information about work location is available, the applicable radionuclides for both locations should be assigned.
e. Received EU, DU, and NU from Y-12 Plant and Feed Materials Production Center. NU shipments began in 1953, DU shipments from SRS began in 1955, and EU shipments began in 1954 [McCarty 2000, pp. 73, 75, 84–85]; manufactured uranium into fuel elements and into target elements [WSRC 2006, p. 42].
f. Separated plutonium from EU after May 1959 using HM process [Reed et al. 2013, p. 195],
g. U-232/233 should only be assigned for 772-F, Old HB-Line, 773-A, 723-A, 735-A, 735-11A, and 776-A for January 1, 1964, through December 31, 1969. Thorium oxide irradiation to produce 130 kg of U-233 began in 1964 [DuPont 1984a, p. 94]. The Thorex IIB campaign in the plant was completed in 1969 with the recovery of 181 kg of U-233 [DuPont 1984b, p. 193]. 772-F and 772-1F ended operations in 2021 [ORAUT 2024a, Table 2-21].
h. TRM = target residual material; a term for uranium remaining from extractions of Mo-99 irradiated targets from a non-SRS facility between 2017 and 2020 (NNSA 2021, p. 3).
i. Contained the Physics Laboratory with three test reactors: the Process Development Pile, the Standard Pile, and the Subcritical Experiment test reactors that were used to test the fuel and targets manufactured in the 300 Area [WSRC 2006, pp. 37, 48, 113]. The reactors in 777-M were effectively shut down in the 1980s after most of their functions had been assumed by computer modeling [Strack 2002, p. 413].
j. Process pilot plants that tested fuel and target elements. TNX construction began in May 1951, and was completed by the following fall. The first uranium had been introduced and pilot runs began December 10, 1951 [Strack 2002, p. 417]. TNX has continued to serve as a pilot plant for operations in the F and H Areas [Strack 2002, p. 418]. CMX construction began in April 1951, and the facility was turned over to operations in September of the same year [Strack 2002, p. 413]. After 1983, the testing of new fuel and target elements was moved from CMX to Savannah River Laboratory [WSRC 2006, p. 48].
k. Irradiated DU targets to make plutonium [Reed et al. 2013, p. 185].
l. Unknown facility radionuclides should only be assigned if no information is available from any source about the worker's work location.
m. CTW might have worked anywhere on site. Ford Building at Central Shops used to repair contaminated reactor heat exchangers since at least 1961 and the mid-1980s [DuPont 1961, p. 282].

If the work location is unknown, the radionuclides listed for “not identifiable or unknown” (the last line in Table 7-18) should be assigned. This might especially apply to Maintenance Department workers sent from the Central Shops area to a variety of work locations and any other workers who worked in multiple facilities.

The CTW intake rates listed in this section cannot be applied to subcontractor CTWs (i.e., CTWs excluding employees of the following prime contractors who worked at the Savannah River Site in Aiken, South Carolina, during the specified time periods: E. I. du Pont de Nemours and Company, October 1, 1972, through March 31, 1989; and Westinghouse Savannah River Company, April 1, 1989, through December 31, 1990, between October 1, 1972, and December 31, 1990). Outside of this time period, the CTW intake rates may be applied to any CTW, whether employed by the prime contractor or a subcontractor.

7.4.1 Americium

Tables 7-19 and 7-20 list the ^{241}Am intakes and associated GSDs to be used for each year of potential americium exposure for nonCTWs and CTWs respectively. The ^{241}Am bioassay also detected ^{244}Cm and ^{252}Cf. When intakes of more than one of ^{241}Am, ^{244}Cm, and ^{252}Cf are possible for the facility that the person worked at as shown in Table 7-18, each applicable radionuclide should be evaluated using the ^{241}Am intake rates below and the radionuclide with the highest dose used. The intake rates ending on 12/31/1989 in these tables may be extended to later years including for best estimates.

Table 7-19. nonCTW type M ^{241}Am intake rates (dpm/d).

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile
01/01/1963	12/31/1965	31.32	3.38	232
01/01/1966	12/31/1967	57.61	3.00	351
01/01/1968	12/31/1971	16.86	3.00	102.7
01/01/1972	12/31/1982	2.61	3.13	17.0
01/01/1983	12/31/1989	7.359	3.00	44.8

Table 7-20. CTW type M ^{241}Am intake rates (dpm/d).[a]

Start	End	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1966	12/31/1967	61.38	3.32	442
01/01/1968	12/31/1971	17.33	3.00	106
01/01/1972	12/31/1982	2.697	3.22	18.5
01/01/1983	12/31/1989	8.248	3.00	50.3

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.2 Tritium

Table 7-21 lists the tritium doses and GSDs to be used for each year of potential tritium exposure. The doses for 1990 in this table may be assigned to later years including for best estimates.

Table 7-21. Tritium annual doses (rem) and GSDs.[a]

Year	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
1954	0.012	3.00	0.073	0.012	3.00	0.071
1955	0.013	3.00	0.080	0.015	3.00	0.093
1956	0.019	3.00	0.116	0.016	3.00	0.100
1957	0.025	3.00	0.151	0.025	3.00	0.154
1958	0.035	3.00	0.215	0.031	3.00	0.190
1959	0.034	3.02	0.208	0.038	3.00	0.232
1960	0.046	3.18	0.306	0.042	3.06	0.264
1961	0.050	3.00	0.304	0.039	3.36	0.284
1962	0.051	3.00	0.313	0.041	3.00	0.251
1963	0.048	3.00	0.295	0.040	3.00	0.242
1964	0.060	3.01	0.368	0.054	3.00	0.329
1965	0.055	3.37	0.403	0.043	3.00	0.261
1966	0.046	3.00	0.281	0.031	3.12	0.200
1967	0.049	3.00	0.301	0.034	3.00	0.208
1968	0.051	3.00	0.310	0.030	3.00	0.182
1969	0.052	3.00	0.315	0.031	3.24	0.215
1970	0.042	3.00	0.258	0.023	3.49	0.180
1971	0.051	3.00	0.308	0.028	3.32	0.204
1972	0.047	3.00	0.286	0.033	3.33	0.238
1973	0.045	3.00	0.276	0.027	3.50	0.212
1974	0.048	3.00	0.293	0.031	3.33	0.227
1975	0.048	3.00	0.294	0.032	3.00	0.196
1976	0.047	3.00	0.285	0.030	3.26	0.207
1977	0.053	3.00	0.326	0.026	3.37	0.192
1978	0.048	3.00	0.295	0.028	3.00	0.168
1979	0.047	3.00	0.286	0.029	3.00	0.179
1980	0.049	3.00	0.300	0.024	3.00	0.147
1981	0.031	3.00	0.188	0.016	3.00	0.100
1982	0.027	3.00	0.164	0.015	3.00	0.093
1983	0.022	3.00	0.135	0.016	3.00	0.095
1984	0.023	3.00	0.138	0.015	3.00	0.093
1985	0.025	3.00	0.150	0.016	3.00	0.095
1986	0.008	3.32	0.061	0.006	3.17	0.043
1987	0.008	3.08	0.052	0.007	3.12	0.045
1988	0.008	3.00	0.047	0.006	3.52	0.050
1989	0.006	3.00	0.036	0.004	3.07	0.027
1990	0.006	3.00	0.034	0.006	3.00	0.036

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.3 Plutonium

Tables 7-22 through 7-24 list the plutonium gross alpha intakes and associated GSDs to be used for each year of potential plutonium exposure for nonCTWs and CTWs. Use the isotopic composition from Table 5-4 of ORAUT-TKBS-0003-5, *Savannah River Site – Occupational Internal Dose* [ORAUT 2024b]. The intake rates ending on 12/31/1990 in these tables may be extended to later years including for best estimates.

Table 7-22. Type M plutonium gross alpha intake rates (dpm/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1960	3.265	3.00	19.90	2.706	3.14	17.74
01/01/1961	12/31/1966	1.606	4.02	15.83	1.356	4.34	15.19
01/01/1967	12/31/1970	5.778	3.49	45.17	5.279	3.70	45.49
01/01/1971	12/31/1981	1.692	4.54	20.37	1.379	4.59	16.91
01/01/1982	12/31/1990	0.7238	6.94	17.5	0.5974	7.78	17.5

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-23. Type S plutonium gross alpha intake rates (dpm/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1960	66.17	3.07	417.98	54.76	3.27	383.92
01/01/1961	12/31/1966	36	3.94	343.71	30.63	4.21	325.69
01/01/1967	12/31/1970	154.5	3.39	1,152.33	142.5	3.61	1,177.28
01/01/1971	12/31/1981	27.02	4.56	328.24	22.13	4.55	267.15
01/01/1982	12/31/1990	12.56	6.64	283.0	10.41	7.41	280.7

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-24. Type SS plutonium gross alpha intake rates (dpm/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1960	454	3.00	2,766	377	3.13	2,463
01/01/1961	12/31/1966	222	4.02	2,192	188	4.33	2,095
01/01/1967	12/31/1970	787	3.52	6,237	719	3.71	6,223
01/01/1971	12/31/1981	230	4.52	2,752	188	4.58	2,297
01/01/1982	12/31/1990	99	6.94	2,397	81.6	7.79	2,391

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.4 Uranium

Tables 7-25 to 7-30 list the total uranium intakes, assigned as ^{234}U intakes and associated GSDs to be used for each year of potential uranium exposure for nonCTWs and CTWs. Recycled uranium contaminants should be assigned with uranium starting in 1961 and forward. The intake rates ending on 12/31/1990 in these tables may be extended to later years including for best estimates.

In Building 773-A from January 1, 1961, through September 30, 1972, and in Building 772-F and the HB-Line from January 1, 1964, through September 30, 1972, ^{233}U production resulted in potential exposure to ^{233}U containing 8 ppm ^{232}U. For workers in those areas and periods, use the intakes in Tables 7-31 through 7-36 [2].

Table 7-25. nonCTW type F ^{234}U intake rates (dpm/d).

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile
01/01/1953	12/31/1953	36.19	3.00	220.5
01/01/1954	12/31/1954	14.27	3.00	86.95
01/01/1955	12/31/1956	7.095	3.00	43.23
01/01/1957	12/31/1962	1.035	5.47	16.92
01/01/1963	12/31/1967	2.366	5.82	42.89
01/01/1968	12/31/1981	0.6054	4.59	7.42
01/01/1982	12/31/1985	1.556	3.81	14.05
01/01/1986	12/31/1990	0.646	3.23	4.45

Table 7-26. nonCTW type M ^{234}U intake rates (dpm/d).

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile
01/01/1953	12/31/1953	175.1	3.00	1,067
01/01/1954	12/31/1954	40.67	3.00	247.8
01/01/1955	12/31/1956	26.46	3.00	161.2
01/01/1957	12/31/1962	3.651	6.26	74.63
01/01/1963	12/31/1967	9.768	5.86	179
01/01/1968	12/31/1981	2.426	4.44	28.12
01/01/1982	12/31/1985	6.469	3.84	59.20
01/01/1986	12/31/1990	2.513	3.19	16.94

Table 7-27. nonCTW type S ^{234}U intake rates (dpm/d).

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile
01/01/1953	12/31/1953	5,477	3.00	33,373
01/01/1954	12/31/1954	2,222	3.00	13,539
01/01/1955	12/31/1956	826.2	3.00	5,034
01/01/1957	12/31/1962	81.69	5.12	1,199
01/01/1963	12/31/1967	185.7	5.75	3,300
01/01/1968	12/31/1981	36.33	4.20	385.1
01/01/1982	12/31/1985	133.8	4.00	1,307
01/01/1986	12/31/1990	53.03	3.24	366.0

Table 7-28. CTW type F ^{234}U intake rates (dpm/d).[a]

Start	End	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1956	7.243	3.00	44.13
01/01/1957	12/31/1957	0.7962	12.71	52.16
01/01/1958	12/31/1962	0.7962	4.06	7.98
01/01/1963	12/31/1967	2.124	6.18	42.46
01/01/1968	12/31/1990	0.6529	4.08	6.59

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-29. CTW type M ^{234}U intake rates (dpm/d).[a]

Start	End	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1956	32.09	3.00	195.5
01/01/1957	12/31/1957	2.349	18.77	292.3
01/01/1958	12/31/1962	2.349	4.98	32.96
01/01/1963	12/31/1967	8.923	6.19	179.0
01/01/1968	12/31/1990	2.625	3.98	25.43

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-30. CTW type S ^{234}U intake rates (dpm/d).[a]

Start	End	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1956	821.4	3.00	5,005
01/01/1957	12/31/1957	53.65	18.19	6,338
01/01/1958	12/31/1962	53.65	4.46	626.9
01/01/1963	12/31/1967	176.2	6.00	3,356
01/01/1968	12/31/1990	35.68	3.97	344.5

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-31. Type F ^{233}U nonCTW intake rates (dpm/d).

Start	End	U-232 50th percentile	U-233 50th percentile	GSD	U-232 95th percentile	U-233 95th percentile
01/01/1961	12/31/1962	0.0176	1.017	5.47	0.288	16.64
01/01/1963	12/31/1967	0.0402	2.326	5.82	0.729	42.16
01/01/1968	12/31/1969	0.0103	0.595	4.59	0.126	7.30

Table 7-32. Type M ^{233}U nonCTW intake rates (dpm/d).

Start	End	U-232 50th percentile	U-233 50th percentile	GSD	U-232 95th percentile	U-233 95th percentile
01/01/1961	12/31/1962	0.062	3.59	6.26	1.27	73.36
01/01/1963	12/31/1967	0.166	9.60	5.86	3.043	175.96
01/01/1968	12/31/1969	0.041	2.385	4.44	0.48	27.65

Table 7-33. Type S ^{233}U nonCTW intake rates (dpm/d).

Start	End	U-232 50th percentile	U-233 50th percentile	GSD	U-232 95th percentile	U-233 95th percentile
01/01/1961	12/31/1962	1.39	80.3	5.12	20.4	1,179
01/01/1963	12/31/1967	3.157	182.5	5.75	56.113	3,245
01/01/1968	12/31/1969	0.62	35.71	4.20	6.55	378.6

Table 7-34. Type F ^{233}U CTW intake rates (dpm/d).[a]

Start	End	U-232 50th percentile	U-233 50th percentile	GSD	U-232 95th percentile	U-233 95th percentile
01/01/1961	12/31/1962	0.0135	0.783	4.06	0.14	7.84
01/01/1963	12/31/1967	0.0361	2.09	6.18	0.722	41.74
01/01/1968	12/31/1969	0.011	0.642	4.08	0.11	6.47

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-35. Type M ^{233}U CTW intake rates (dpm/d).[a]

Start	End	U-232 50th percentile	U-233 50th percentile	GSD	U-232 95th percentile	U-233 95th percentile
01/01/1961	12/31/1962	0.040	2.31	4.98	0.560	32.40
01/01/1963	12/31/1967	0.152	8.771	6.19	3.044	175.99
01/01/1968	12/31/1969	0.045	2.58	3.98	0.43	25.0

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-36. Type S ^{233}U CTW intake rates (dpm/d).[a]

Start	End	U-232 50th percentile	U-233 50th percentile	GSD	U-232 95th percentile	U-233 95th percentile
01/01/1961	12/31/1962	0.912	52.7	4.46	10.66	616
01/01/1963	12/31/1967	3.00	173.2	6.00	57.1	3,300
01/01/1968	12/31/1969	0.607	35.1	3.97	5.86	339

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.5 Fission Products

Table 7-37 lists the FP (^{90}Sr) intakes and associated GSDs to be used for each year, through 1965, of potential FP exposure for nonCTWs and CTWs. The listed intakes are gross beta intakes and should be adjusted for strontium urinary activity fraction. Before 1966, FP intakes are based on ^{90}Sr intakes rather than ^{137}Cs because the ^{90}Sr values are more limiting. Starting in 1966, there is no ^{90}Sr (gross beta) data available and therefore the ^{137}Cs data are used. Tables 7-38 and 7-39 list the ^{137}Cs intakes and associated GSDs to be used for each year of potential ^{137}Cs exposure for nonCTWs and CTWs, respectively. Additional fission and activation product radionuclides should be assigned based on the ^{90}Sr or ^{137}Cs intakes as described in ORAUT-RPRT-0047 [ORAUT 2013b]. The ^{137}Cs intake rates ending on 12/31/1990 in these tables may be extended to later years including for best estimates.

Table 7-37. Type F FP (^{90}Sr) intake rates (dpm/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1958	70.05	3.00	427	69.46	3.00	423
01/01/1959	12/31/1961	32.43	3.03	201	34.33	3.01	211
01/01/1962	12/31/1965	97.41	3.00	594	102.2	3.00	623

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-38. Type F ^{137}Cs nonCTW intake rates (pCi/d).

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile
01/01/1966	12/31/1966	111.3	3.00	678.2
01/01/1967	12/31/1967	42.98	3.00	261.9
01/01/1968	12/31/1968	87.45	3.00	532.9
01/01/1969	12/31/1971	18.86	3.53	149.9
01/01/1972	12/31/1977	31.86	3.00	194.1
01/01/1978	12/31/1985	9.396	3.07	59.55
01/01/1986	12/31/1986	34.84	3.00	212.3
01/01/1987	12/31/1990	2.819	4.63	35.02

Table 7-39. Type F ^{137}Cs CTW intake rates (pCi/d).[a]

Start	End	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1966	12/31/1966	201.2	3.00	1,226
01/01/1967	12/31/1968	76.32	3.00	465
01/01/1969	12/31/1977	29.21	3.00	178
01/01/1978	12/31/1981	9.72	3.21	66.04
01/01/1982	12/31/1985	6.556	3.19	44.15
01/01/1986	12/31/1986	22.95	3.00	139.9
01/01/1987	12/31/1990	2.697	3.14	17.74

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.6 Cobalt-60

Tables 7-40 and 7-41 list the ^{60}Co intakes and associated GSDs to be used for each year of potential ^{60}Co exposure for nonCTWs and CTWs and for solubility types M and S, respectively. Cobalt-60 intakes should only be assigned for workers believed to have handled purified ^{60}Co.

Table 7-40. Type M ^{60}Co intake rates (pCi/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1958	91.56	3.00	558	90.85	3.00	554
01/01/1959	12/31/1961	39.72	3.08	252	42.34	3.05	266
01/01/1962	12/31/1965	128.6	3.00	784	135	3.00	823
01/01/1966	12/31/1966	930	3.21	6,347	825.7	3.41	6,213
01/01/1967	12/31/1967	1,185	3.18	7,963	1,282	3.21	8,713
01/01/1968	12/31/1970	804.8	3.28	5,666	785.4	3.27	5,510

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-41. Type S ^{60}Co intake rates (pCi/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1955	12/31/1958	365	3.00	2,224	362.3	3.00	2,208
01/01/1959	12/31/1961	146.6	3.12	953	157.3	3.10	1,014
01/01/1962	12/31/1965	503.2	3.00	3,066	529.7	3.00	3,228
01/01/1966	12/31/1966	3,654	3.21	24,889	3,248	3.41	24,414
01/01/1967	12/31/1967	4,760	3.20	32,316	5,106	3.23	35,090
01/01/1968	12/31/1970	3,137	3.28	22,175	3,068	3.27	21,569

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.7 Neptunium

Table 7-42 lists the neptunium intakes and associated GSDs to be used for each year of potential neptunium exposure for nonCTWs and CTWs. The intake rates ending on 12/31/1989 in these tables may be extended to later years including for best estimates.

Table 7-42. Neptunium intake rates (dpm/d).[a]

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
01/01/1961	12/31/1963	0.1541	5.62	2.638	0.1545	6.71	3.535
01/01/1964	12/31/1967	2.844	3.22	19.43	2.844	3.22	19.43
01/01/1968	12/31/1969	2.16	3.00	13.16	2.16	3.00	13.16
01/01/1970	12/31/1972	297.7	3.00	1,814	328.2	3.00	2,000
01/01/1973	12/31/1974	163.6	3.00	996.9	186.8	3.00	1,138
01/01/1975	12/31/1979	32.76	3.98	318.3	26.36	4.47	309
01/01/1980	12/31/1989	3.183	4.88	43.21	3.119	6.24	63.44

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.4.8 Thorium

Tables 7-43 and 7-44 list the ^{232}Th intakes and associated GSDs to be used for each year of potential ^{232}Th exposure for nonCTWs and CTWs for solubility types M and S, respectively. No ^{232}Th intakes should be assigned for periods before November 1, 1972, because this period is covered under an SEC. The intake rates ending on 12/31/1989 in these tables may be extended to later years including for best estimates.

Table 7-43. Type M ^{232}Th intake rates (dpm/d).

nonCTW

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	4.91	3.00	29.9
06/01/1980	12/31/1989	Inhalation	4.87	Constant	Not applicable
06/01/1980	12/31/1989	Ingestion	0.1	Constant	Not applicable

CTW[a]

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	4.91	3.00	29.9
06/01/1980	12/31/1989	Inhalation	4.87	Constant	Not applicable
06/01/1980	12/31/1989	Ingestion	0.1	Constant	Not applicable

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

Table 7-44. Type S ^{232}Th intake rates (dpm/d).

nonCTW

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	92.5	3.00	564
06/01/1980	12/31/1989	Inhalation	4.87	Constant	Not applicable
06/01/1980	12/31/1989	Ingestion	0.1	Constant	Not applicable

CTW[a]

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	92.1	3.00	561
06/01/1980	12/31/1989	Inhalation	4.87	Constant	Not applicable
06/01/1980	12/31/1989	Ingestion	0.1	Constant	Not applicable

a. These values do not apply to subcontractor CTWs between October 1, 1972, and December 31, 1990.

7.5 CONCLUSIONS

The NIOSH guidance for evaluation and use of co-exposure datasets requires that data adequacy, completeness, and applicability be determined [NIOSH 2020a]. This requires confirmation that the bioassay techniques SRS used were valid, collected data were reliable, and the data can be interpreted. The bioassay analytical techniques discussed above and review of the results provide evidence that the techniques were valid, reliable, and can be interpreted.

The guidance requires that all or a representative sample of the potentially exposed worker population submit samples. The bioassay sample schedules indicate that SRS had a process in place to identify and collect samples from potentially exposed workers with a graded approach commensurate with the exposure potential and that unmonitored workers could be adequately represented by monitored workers.

The stratified statistical analyses established two populations of workers (CTWs and nonCTWs), evaluated the bioassay data from each, and determined intake rates or doses applicable to each for the evaluated range of years. The intake rates or doses in Section 7.4 may be assigned to unmonitored workers to evaluate potential unmonitored internal dose, except these intake rates may not be applied to subcontractor CTWs for October 1, 1972, through December 31, 1990.

7.6 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional References, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database (SRDB).

Tom LaBone served as the initial Subject Expert for this document. Dr. LaBone was previously employed at SRS and his work involved management, direction or implementation of radiation protection and/or HP program policies, procedures or practices related to atomic weapons activities at the site. Preparation of this document has been overseen by a Document Owner who is fully responsible for the content, including all findings and conclusions. In all cases where such information or prior studies or writings are included or relied upon by Dr. LaBone, those materials are fully attributed to the source. Dr. LaBone's Disclosure Statement is available at www.oraucoc.org.

[1] Arno, Matthew G. ORAU Team. Principal Health Physicist. January 2009.
This is based on communications with Tom LaBone indicating "<" values were recorded as negative results in the HPRED.

[2] Mahathy, James M. ORAU Team. Health Physicist. October 2013.
Uranium-233 was produced containing varying amounts of ^{232}U, most of which were in the 5 to 7 ppm range [DuPont 1959–1971, pp. 458–460, 355, 1965a, 1965b, 1984a, 1984b]. Use of 8 ppm is a conservative estimate of ^{232}U content.

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GLOSSARY

absorption type

Categories for materials according to their rates of absorption from the respiratory tract to the blood, which replaced the earlier inhalation clearance classes. Defined by the International Commission on Radiological Protection, the absorption types are F: deposited materials that are readily absorbed into blood from the respiratory tract (fast solubilization), M: deposited materials that have intermediate rates of absorption into blood from the respiratory tract (moderate rate of solubilization), and S: deposited materials that are relatively insoluble in the respiratory tract (slow solubilization).

activity

Amount of radioactivity. The International System unit of activity is the becquerel (1 disintegration per second); the traditional unit is the curie [37 billion (3.7×10^{10}) becquerels].

activity fraction

Proportion of the total activity due to a particular radionuclide.

activity median aerodynamic diameter (AMAD)

Diameter of a unit density sphere with the same terminal settling velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol.

alpha radiation

Positively charged particle emitted from the nuclei of some radioactive elements. An alpha particle consists of two neutrons and two protons (a helium nucleus) and has an electrostatic charge of +2.

bioassay

Measurement of amount or concentration of radionuclide material in the body (in vivo measurement) or in biological material excreted or removed from the body (in vitro measurement) and analyzed for purposes of estimating the quantity of radioactive material in the body. Also called radiobioassay.

body burden

Amount of radioactive material in an individual’s body at a particular point in time.

co-exposure dose

Previously referred to as “coworker" on the Project, co-exposure dose is a representative dose typically assigned because (1) an Energy Employee was not monitored (unmonitored) but should have been or (2) the worker was monitored but the results are unavailable or unreliable.

confidence interval

Interval about an estimate of a stated quantity within which the value of the quantity is expected to be within a specified probability (confidence level) of $1 - \alpha$. Note that $1 - \alpha$ is the probability that the random interval contains the fixed quantity, not the probability that the quantity is in the interval. See *accuracy* and *uncertainty*.

decay products

See *progeny*.

depleted uranium (DU)

Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium. As examples, spent (used) fuel elements, byproduct tails, residues from uranium isotope separation, and some weapons materials contain DU. DU can be blended with highly enriched uranium to make reactor fuel or used as a raw material to produce plutonium. DU was used for ^{239}Pu production at SRS, and the listed isotopic activity fractions were:

Isotope	Activity fraction
^{234}U	0.0840
^{235}U	0.0145
^{238}U	0.9015

dose

In general, the specific amount of energy from ionizing radiation that is absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of rad, rep, or grays.

dosimeter

Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual.

error

Difference between the correct, true, or conventionally accepted value and the measured or estimated value. Error is a qualitative term unless the true value is known. Sometimes used to mean estimated uncertainty. See *accuracy* and *uncertainty*.

enriched uranium analysis

Urinalysis method using alpha activity counting. The analyte is not necessarily enriched uranium.

exposure

(1) In general, the act of being exposed to ionizing radiation; see *acute exposure* and *chronic exposure*. (2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

external dose

Dose received from radiation (e.g., photons, electrons, and neutrons) that originates outside the body including that from medical screening examinations.

fission product (FP)

(1) Radionuclides produced by fission or by the subsequent radioactive decay of radionuclides. (2) Fragments other than neutrons that result from the splitting of an atomic nucleus.

gamma radiation

Electromagnetic radiation (photons) that originates in atomic nuclei and accompanies many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Gamma photons are identical to X-ray photons; the difference is that X-rays do not originate in the nucleus.

half-life (T, T1/2, T½)

Time in which half of a given quantity of a particular radionuclide disintegrates (decays) into another nuclear form. During one half-life, the number of atoms of a particular radionuclide decreases by one half. Each radionuclide has a unique half-life ranging from millionths of a second to billions of years. See *biological half-life* and *effective half-life*.

highly enriched uranium (HEU)

Uranium enriched to at least 20% ^{235}U for use as fissile material in nuclear weapons components and some reactor fuels. Also called high-enriched uranium. SRS lists the isotopic activity fractions as:

Isotope	Activity fraction
^{234}U	0.9806
^{235}U	0.0194
^{238}U	0.0000

intake

Radioactive material taken into the body by inhalation, absorption through the skin, injection, ingestion, or through wounds.

internal dose

Dose received from radioactive material in the body (e.g., plutonium or uranium) that was inhaled, ingested, absorbed, or injected through a wound.

isotope

One of two or more atoms of a particular element that have the same number of protons (atomic number) but different numbers of neutrons in their nuclei (e.g., ^{234}U, ^{235}U, and ^{238}U). Isotopes have very nearly the same chemical properties.

monitoring

Periodic or continuous determination of the presence or amount of ionizing radiation or radioactive contamination in air, surface water, groundwater, soil, sediment, equipment surfaces, or personnel (for example, bioassay or alpha scans). In relation to personnel, monitoring includes internal and external dosimetry including interpretation of the measurements.

natural uranium (NU)

Uranium as found in nature, approximately 99.27% ^{238}U, 0.72% ^{235}U, and 0.0054% ^{234}U by mass. The specific activity of this mixture is 2.6×10^7 becquerel per kilogram (0.7 microcuries per gram).

nuclide

Stable or unstable isotope of any element. Nuclide relates to the atomic mass, which is the sum of the number of protons and neutrons in the nucleus of an atom. A radionuclide is an unstable nuclide.

progeny

Nuclides that result from decay of other nuclides. Also called decay products and formerly called daughter products.

radiation source

(1) Any object or substance that emits radiation. (2) Package of radioactive material constructed to have specific radiation properties used, for example, for medical purposes or to calibrate dosimeters.

radionuclide

Radioactive nuclide. See *nuclide*.

recycled uranium (RU)

Uranium first irradiated in a reactor, then recovered through chemical separation and purification. RU contains minor amounts of transuranic material (e.g., plutonium and neptunium) and fission products (e.g., technetium) or uranium products (e.g., ^{236}U) after purification. SRS lists the isotopic activity fractions as:

Isotope	Activity fraction
^{234}U	0.8489
^{235}U	0.0120
^{236}U	0.1388
^{238}U	0.0003

ATTACHMENT A
QUALITY ASSURANCE SUMMARY[1]

LIST OF FIGURES

[1] This attachment uses the following acronyms: AQL = acceptance quality level; CATI = computer-assisted telephone interview; LTPD = lot tolerance percent defective; N = total number of data points in a dataset; n = number of datapoints checked in a dataset; α = producer's risk or ORAUT risk; β = consumer's risk or DCAS risk.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Savannah River Site Internal Co-Exposure In Vitro Completeness Check

May 4, 2017

Introduction

The purpose of this report is to document activities that have occurred relating to the Dataset Completeness check of in vitro bioassay for the Savannah River Site Internal Coworker Study (ORAUT-OTIB-0081).

The Dataset Completeness process contains two efforts. Part 1 is a claim level check that will test whether an individual who had at least one result in the period of interest is in fact included in the electronic dataset. Part 2, a result level check, will then be performed to ensure that all sample results for a given individual are included in the dataset. This report outlines the findings of the Part 1 and Part 2 completeness tests.

The NOCTS database was queried to obtain a list of SRS claims with at least 1 day of verified employment before 01/01/1991. This was used as the Master List of claims that will be used to develop a list of claims for both Part 1 and Part 2 completeness checks. A total of 3,988 unique NOCTS claims were part of the Master List. The Master List was compared to the list of claims in the transcribed in vitro database compiled for SRS. The transcribed dataset included 2,874 unique NOCTS claims. Therefore, 1,114 claims from the Master List were not in the transcribed dataset. These claims were the initial basis of the Part 1 (Claim Level) completeness test (i.e., no in vitro data exists). The Part 1 testing plan involves a 100% review of all NOCTS data for 1,114 claims to determine if in vitro data before 01/01/1991 exists.

Part 1 (Claim Level) Review

The initial Part 1 review of NOCTS data for the 1,114 claims was completed on 04/10/2017. The final review and comparison against the Master List verified that 1,114 claims from the Master List had no data to be entered into the combined dataset. These 1,114 unique claim IDs will be excluded from the Part 2 completeness review.

In addition, a list of Claim IDs was created with data entered in the combined file but do NOT appear in the Master List (again the Master List is based on verified SRS employment). There were a total of 36 claims to review in this listing. The following is a summary:

- 32 Claim IDs have verified employment outside the timeframe of interest. After reviewing the combined in vitro dataset:
  - 15 of 32 have only one entry with no data recorded. As part of the original data entry effort, claims with no data were added to the dataset as verification the claim information was reviewed.
  - 16 of 32 claims in the dataset have only post-1990 data entered in the combined file. This post-1990 data will not be used in the intake modeling for OTIB-0081 Rev. 04.
  - [Redacted].
- 4 Claim IDs in the electronic dataset were transcribed incorrectly. The appropriate Claim IDs were corrected and all 4 claims had existing lines in the data set.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

After accounting for all issues above, a total of 2,875 NOCTS claims will be used for the Part 2 completeness check.

Part 2 (Result Level) Review

Part 2 of the completeness review involves detailed page-by-page review of a group of Claim IDs to ensure all pertinent data were entered. Based on the outcome of a working demonstration of the process in March 2017, it was determined that a line tally counting technique would be used, with a focus on three critical fields. Sample date, nuclide, and result are the key fields for the completeness check. If any of these three fields were missing from the electronic dataset, the entire line of data is considered unusable.

This completeness test was done during the earliest stages of development of ORAUT-RPRT-0086 [ORAUT 2017a], so published methods are not used here. Limiting the Part 2 claim pool to those with in vitro data, a list of 30 claim IDs were chosen randomly from the original set of 2,875. The claim files for these 30 claims were checked, and a row was called missing if any of the three pieces of necessary information (i.e., sample date, nuclide, or result) were missing. There were 1,762 opportunities for missing lines of data and 14 were actually missing from the dataset. Figure A-1 below summarizes this information. This developmental test is a sequential sampling method, which continues until the values plotted in Figure A-1 extend below the lower diagonal line (passes the test) or above the upper diagonal line (fails the test). The plotted values crossed the lower diagonal line at the vertical red line, but this happened while checking the first claim. The test continued until a minimum of 30 claims were checked.

Figure A-1. Wald plot for 30 individuals. The color of the dots is alternated from red to black going from one person to the next.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Results
14 missing / 1,762 opportunities = 0.79%
We are 95% confident that the missing data rate is between 0.03% and 3.99%.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS In Vivo Completeness Report
August 7, 2017

The NOCTS database was queried to obtain a list of SRS claims with at least 1 day of verified employment before 01/01/1991. This was used as the Master List of claims that will be used to develop a list of claims for both Part 1 and Part 2 completeness checks. A total of 3,988 unique NOCTS claims were part of the Master List. The Master List was compared to the list of claims in the original transcribed in vivo database compiled for SRS. The transcribed dataset included 2,810 unique NOCTS claims, therefore 1,178 claims from the Master List were not in the transcribed dataset. These claims were the initial basis of the Part 1 (Claim Level) completeness test (i.e., no in vivo data exists). The Part 1 testing plan involves a 100% review of all 1,178 claims to determine if in vivo data before 01/01/1991 exists.

Part 1 (Claim Level) Review
The initial Part 1 review of 1,178 claims was complete on 05/17/2017. The final review of the 1,178 claims confirmed that no data were reported in the period of interest. These 1,178 claims were excluded from the Part 2 completeness check.

During the Part 1 completeness testing, a list of Claim IDs was created with data entered in the transcribed dataset but do NOT appear in the Master List (this list is based on verified SRS employment). There were a total of 13 claims to review in this listing. Each claim contained relevant in vivo data before 01/01/1991 and therefore this information was assessed as part of the Part 2 completeness testing. In summary, a total of 2,823 SRS claim files will be subject to the Part 2 completeness.

Part 2 (Result Level) Review
This completeness test was done during the development of ORAUT-RPRT-0086 [ORAUT 2017a], so published methods are not used here. Limiting the Part 2 claim pool to those claim IDs with in vivo data, a list of 101 claims were chosen randomly from the original set of 2,823. The NOCTS claim files for these 101 claims were checked, and a row was called an error if any of the pieces of necessary information (sample date, nuclide, result, or MDA data) were found to be missing. The initial Part 2 review was complete on July 5. A total of 840 lines of data were evaluated for completeness, with 31 errors noted. Of the 31 errors found, 30 were attributed to 2 of the 101 claim IDs. The point estimate for this review was 3.56% and the 95% confidence interval was 0.37% to 12.89%. Considering the upper limit was above the 5% success criteria, an additional test was warranted. The appropriate corrections were made to the 31 errors found and RPRT-0086 was finalized for Part 2 completeness.

Based on analysis of this original dataset and the techniques outlined in RPRT-0086, it was determined that the sample size would be increased to 410 claims for the secondary Part 2 completeness test. A new list of 410 claims was randomly chosen from the original set of 2,823 claims. The claim files for these 410 claims were checked, and a row was called missing if any of the pieces of necessary information were missing. There were 4,048 opportunities for missing records, with 26 errors noted. The point estimate for this review was 0.64% and the 95% confidence interval was between 0.25% and 1.35%. A summary of the effort is included below. Figures A-2 through A-4 summarize this information.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

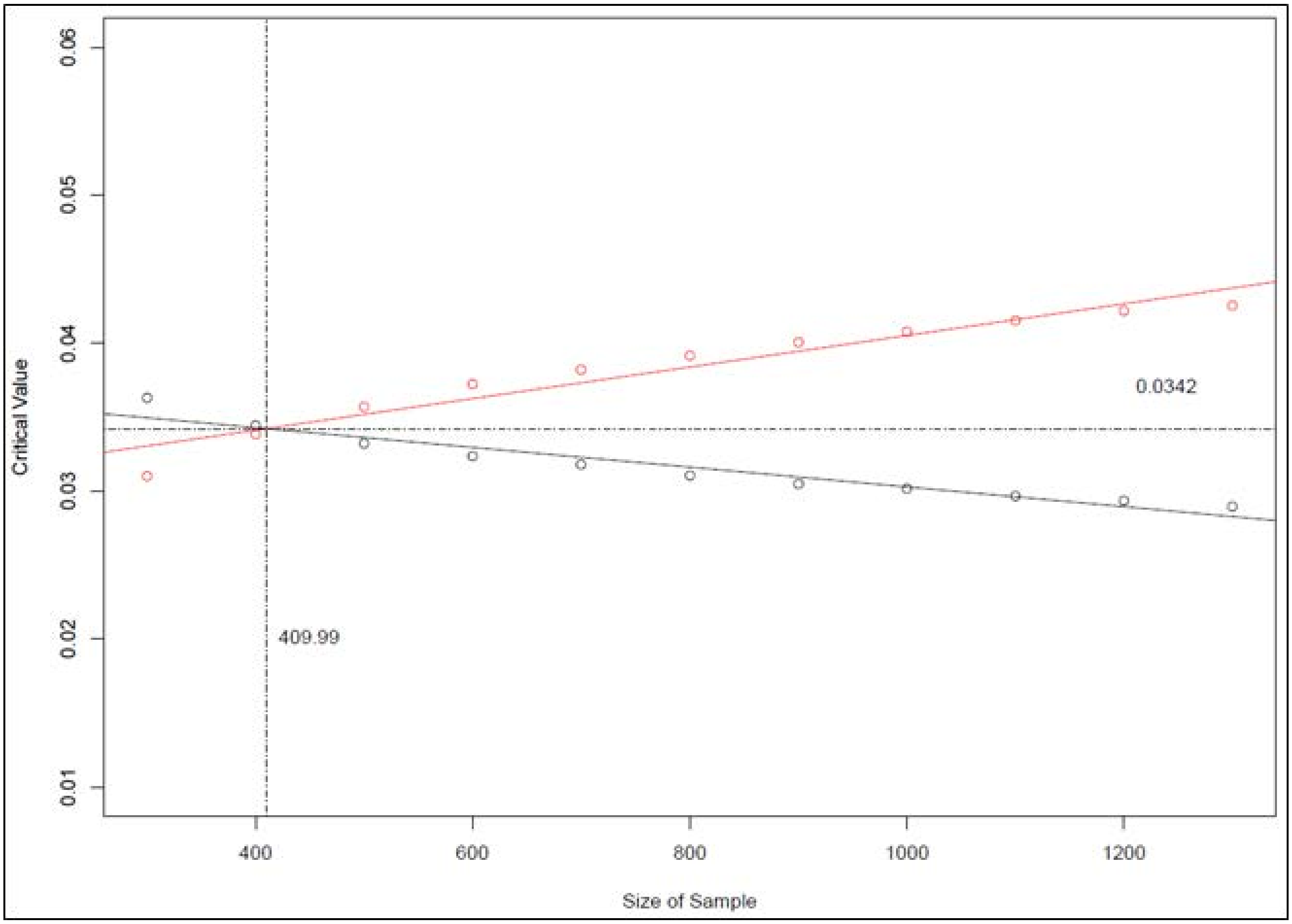


Figure A-2. Plot to determine the minimum number of claims to be sampled.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

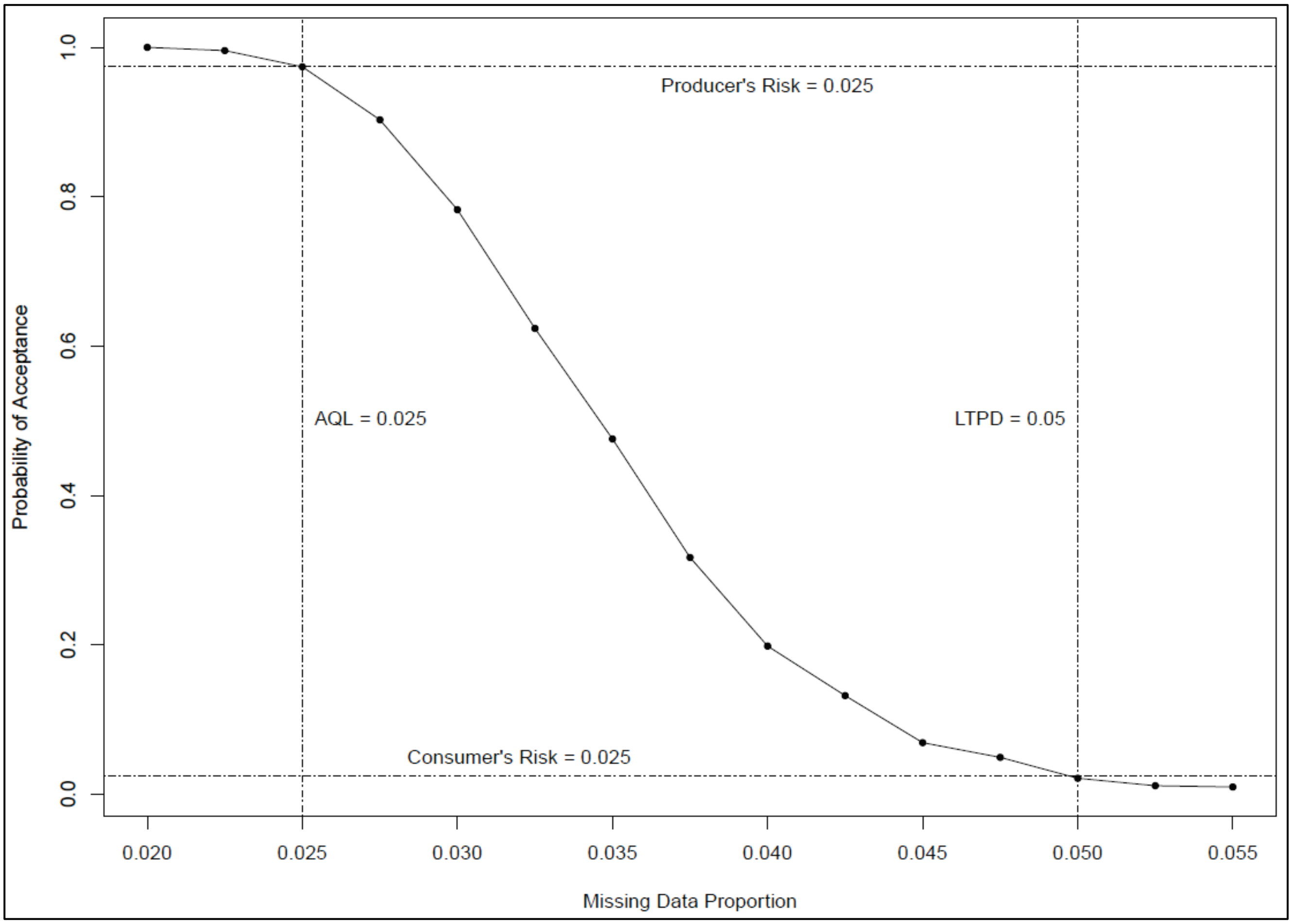


Figure A-3. Operational Characteristic (OC) curve for 410 individuals.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

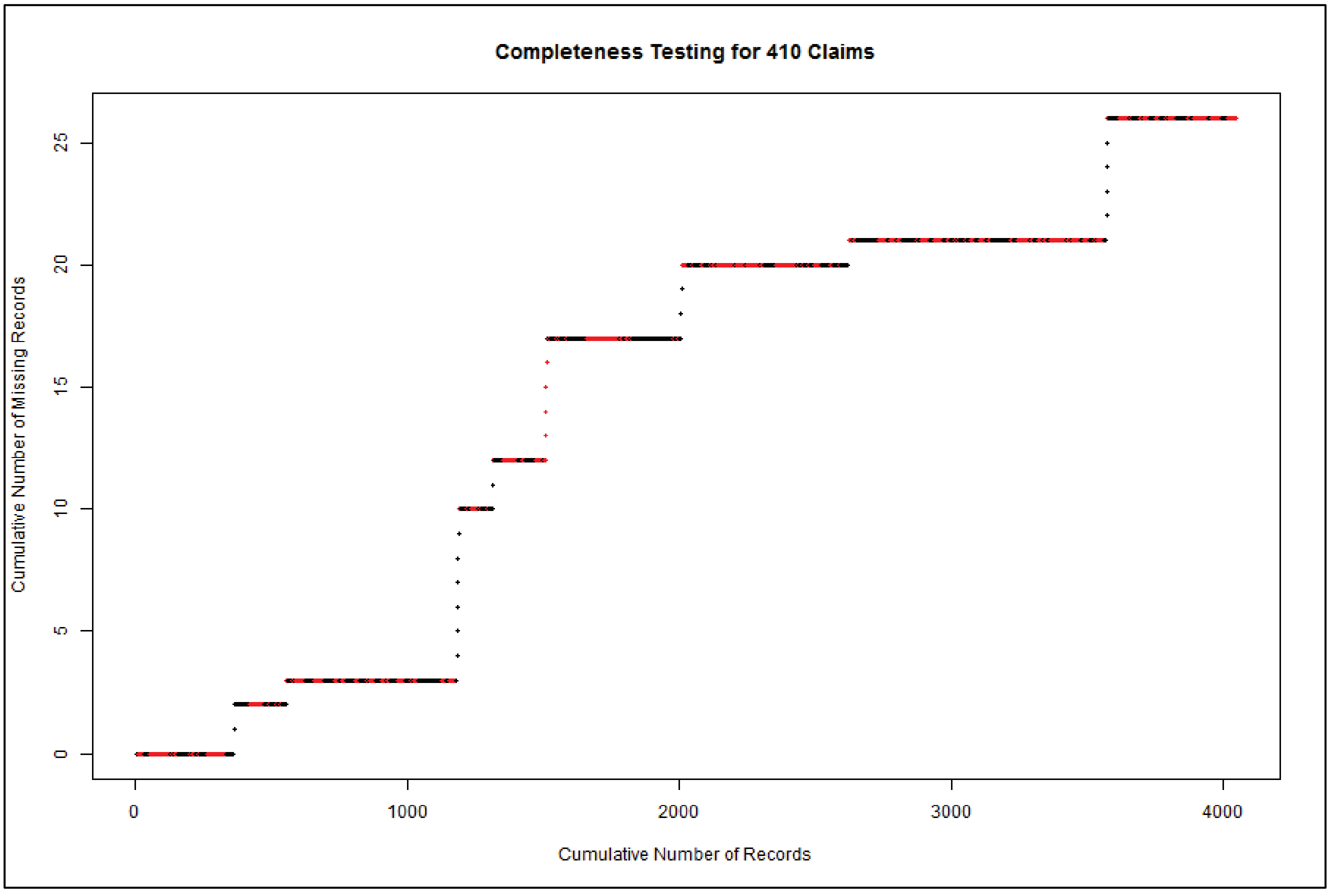


Figure A-4. Sequential plot of missing records plot for 410 individuals. The color of the dots is alternated from red to black going from one person to the next.

Results
26 missing / 4,048 opportunities = 0.64%
We are 95% confident that the missing record rate is between 0.25% and 1.35%.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Savannah River Site Internal Co-Exposure In Vitro Completeness Check – Neptunium (Np)

March 7, 2018

Introduction

The purpose of this report is to document activities related to a Completeness Test of the Np in vitro logbook dataset for the Savannah River Site Internal Co-Exposure Study (ORAUT-OTIB-0081) Revision 04. The original dataset was transcribed before the development and approval of ORAUT-RPRT-0086, *Internal Dosimetry Coworker Data Completeness Test.* Considering that the intake modeling for Np will be performed under Revision 04 of the co-exposure study document, it was decided that a formal Completeness Test was necessary for the Np in vitro dataset.

The Database Completeness process contains two efforts. Part 1 is a claim level check that will test whether an individual who had at least one result in the period of interest is in fact included in the electronic dataset. Part 2, a result level check, will be performed to ensure that all sample results for a given individual are included in the dataset. This report outlines the findings of the Part 1 and Part 2 Completeness Tests for Np in vitro data.

Part 1 (Claim Level) Completeness Check Results

The Np in vitro database used for OTIB-0081 was compiled separately from other SRS nuclides. The Np dataset was transcribed from original logbooks obtained during data capture activities at SRS. The data were not a result of NOCTS Claim mining used for most of the other in vitro datasets. Therefore, the completeness testing protocol involved creating a logbook based employee list for comparison to NOCTS claim information. This logbook mapping process was largely completed outside of the completeness effort. Employee mapping involved recording variations on Last Name, First Name, Middle Initial, and PRID from logbooks and NOCTS documents. A Master 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 one Np result. As a result of this review 382 claims were noted as containing Np results in both the transcribed logbook database and NOCTS claim data. These 382 claims are subject to Part 2 completeness testing.

Part 2 (Result Level) Completeness Check Results

Limiting the Part 2 claim pool to 382 claimants from the Claim Level test, the ORAUT developed a testing plan for this unique dataset. The Np in vitro data are comprised of two different entry efforts with slightly different reporting formats. At SRS, urinalysis was the primary method of checking for Np intakes during the 1960s. These results were generally recorded in separate, stand-alone Np logbooks. Around 1970, Np started to be “measured” by WBCs. Np urinalysis was no longer being routinely performed at the site. The main rationale for Np urinalysis involved a positive Pu urine result. The assumption was that if an Np intake occurred at a level detectable in urine, an associated positive Pu result would be recorded as well. From a reporting standpoint in this era, Np urinalysis results were not recorded in standalone logbooks. Np urinalysis results were included in logbooks for Pu, Am, EU, etc. During the initial evaluation of Np in OTIB-0081 Revision 02, only 1961–1969 Np urinalysis data were considered for intake modeling. The ORAUT plans to use a similar approach in Revision 04. Post-1969 Np modeling will use WBC results in the intake modeling approach.

Although the post-1969 Np urinalysis data will be used in this co-exposure study, the ORAUT decided to do a census, checking all 382 claims, of the Np in vitro datasets. This will allow the exact missing data rate of the complete set to be calculated and eliminate the need for confidence intervals. This will also allow for splitting the data by era and calculating an exact missing data rate. As with previous completeness testing efforts, only fields critical to the co-exposure TWOPOS analysis were considered critical items. This was limited to ‘Date’ and ‘Result’ fields for the Np dataset.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

After evaluating each dataset, the final Part 2 completeness results for Np in vitro dataset are:

- 1,082 lines checked overall
  - 25 missing (2.31%)
- 991 lines checked before 1970
  - 14 missing (1.41%)
- 91 lines checked post 1969
  - 11 missing (12.08%)

The Part 2 completeness test is considered a success (less than 5% overall error). Figure A-5 shows the error checking for the 382 claims in question.

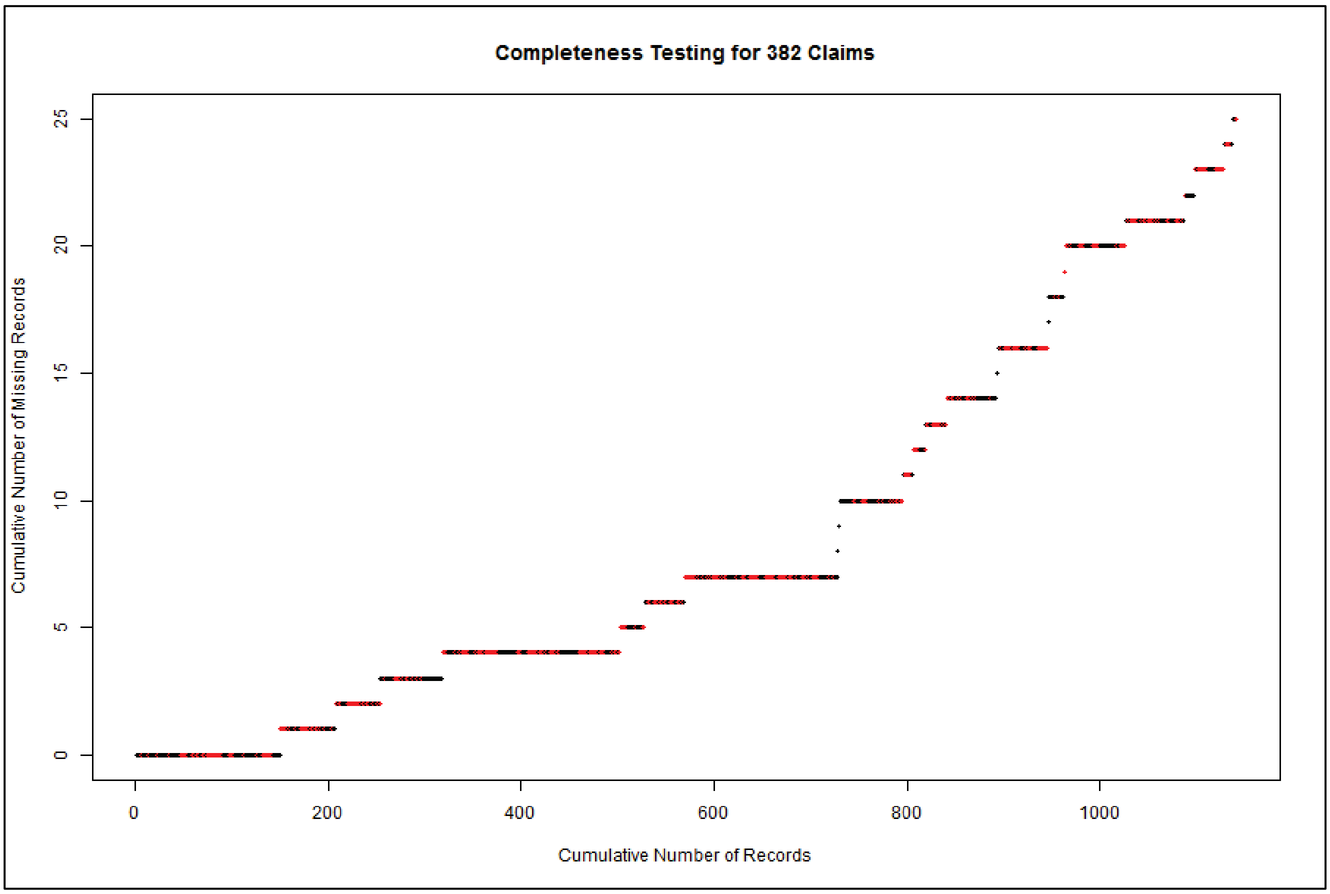


Figure A-5. Sequential plot of missing records plot for 382 individuals. The color of the dots alternates from red to black going from one person to the next.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Savannah River Site Internal Co-Exposure In Vitro Completeness Check – Americium (Am)
June 21, 2021

Introduction
The purpose of this report is to document activities related to a completeness test of the americium in vitro logbook dataset for this revision of this document. The americium dataset was reentered to correctly handle associated samples for Revision 06 of this document, so it was decided that a formal completeness test was necessary for the americium in vitro dataset.

The database completeness process contains two efforts. Part 1 is a claim-level check that tests whether an individual who had at least one result in the period of interest is in fact included in the dataset. Part 2, a result-level check, is performed to ensure that all sample results for a sample of individuals are included in the dataset. This report outlines the findings of these completeness tests for americium in vitro data.

Part 1 (Claim-Level) Completeness Check Results
The americium in vitro database used for this document was compiled separately from other SRS nuclides. The americium dataset was transcribed from original logbooks obtained during data capture activities at SRS. The data were not a result of extracting data from NOCTS as is used for most of the other in vitro datasets. Therefore, the completeness testing protocol involved creating a logbook-based employee list for comparison to NOCTS claim information. This logbook mapping process was largely completed outside of the completeness effort. Employee mapping involved recording variations on Last Name, First Name, Middle Initial, and PRID from logbooks and NOCTS documents.

A Master 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 americium result. As a result of this review, 489 claims were noted as containing americium results in both the transcribed logbook dataset and NOCTS claim data. These 489 claims are subject to Part 2 completeness testing.

Part 2 (Result-Level) Completeness Check Results
Limiting the Part 2 claim pool to 489 claimants from the claim-level test, the ORAU Team developed a testing plan for this dataset. The test requires that a minimum number of claims (102 from Figure A-6) and a minimum number of records (1,132 from Figure A-7) be sampled. By sampling 102 claims, the 1,132 record threshold was not yet met. Six additional claims were sampled to reach the 1,132 record threshold. A list of 108 claims was randomly chosen from the original set of 489 claims. The claim files for these 108 claims were checked. Figures A-6 through A-9 summarize this information.

Note that 3 of the 108 sampled claims did not have relevant results, so the results are reported for 105 claims. Also note that the final number of opportunities does not exceed the 1,132 threshold. This was due to using the number of rows in the logbook to estimate the number of NOCTS rows. Failing to meet these thresholds with the final results causes the confidence interval to be slightly wider than if the thresholds were met, but the final confidence interval here (even though it is wider than the ideal case) is still below 5%, so there are no issues with completeness.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

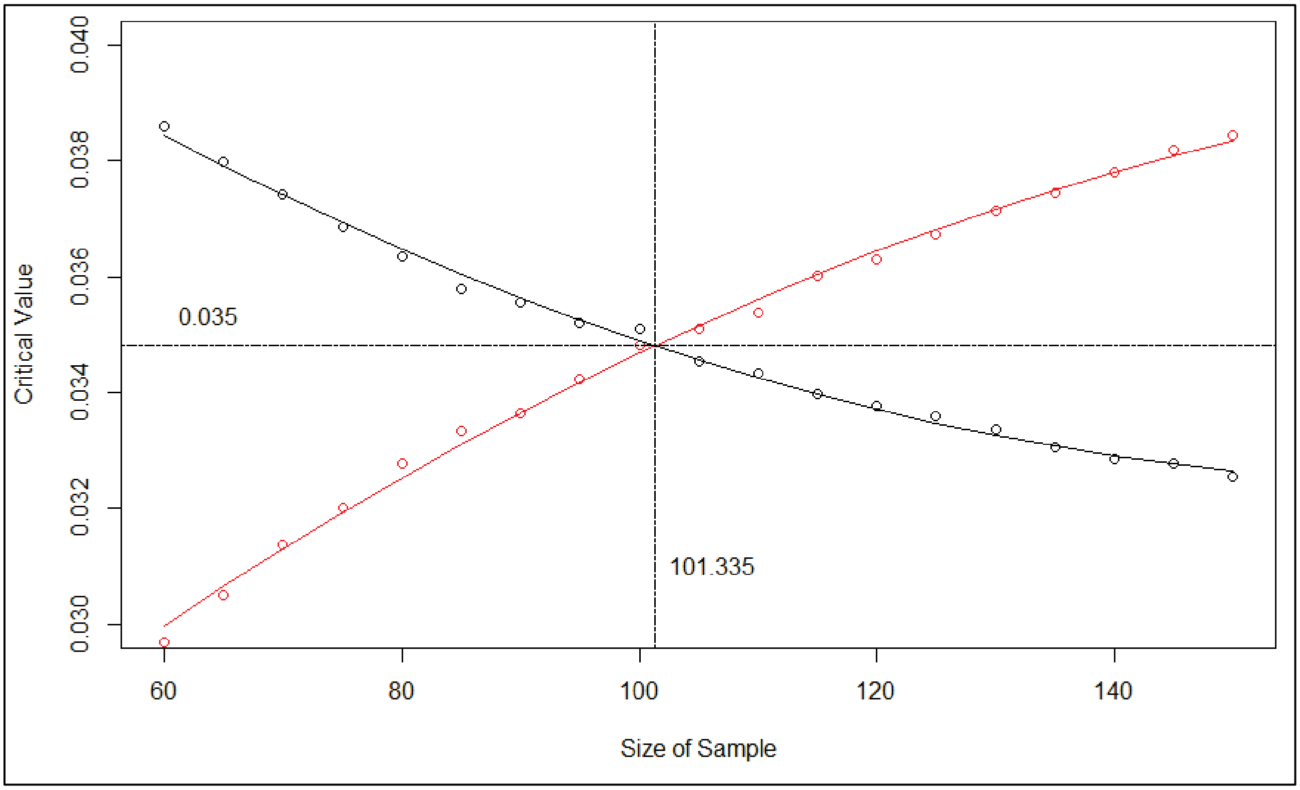


Figure A-6. Plot to determine the minimum number of claims to be sampled.

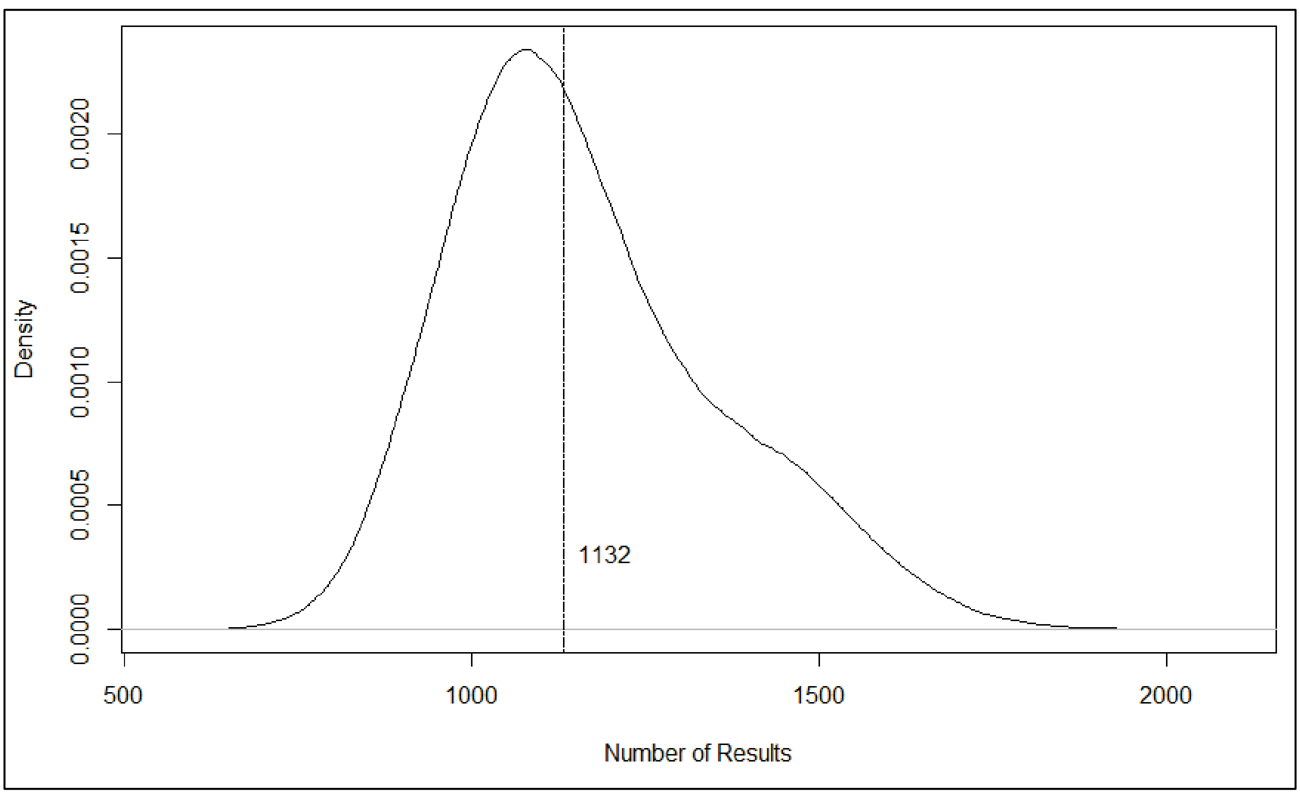


Figure A-7. Plot to determine the minimum number of records to be sampled.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

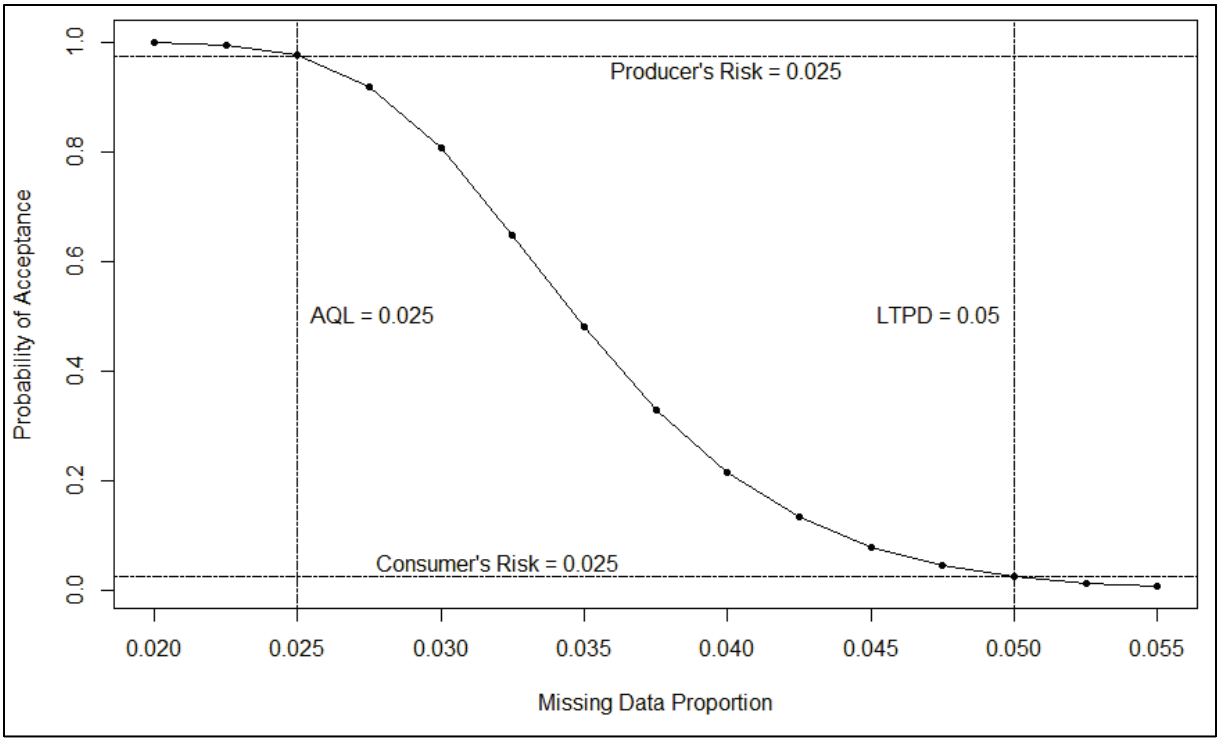


Figure A-8. OC curve for 108 individuals.

Figure A-9. Sequential plot of missing records for 105 individuals. The color of the dots is alternated from black to red going from one person to the next.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Results
9 missing / 1,037 opportunities = 0.87%
We are 95% confident that the missing record rate is between 0.39% and 1.66%.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS NOCTS In Vitro Data QA Summary
May 9, 2017

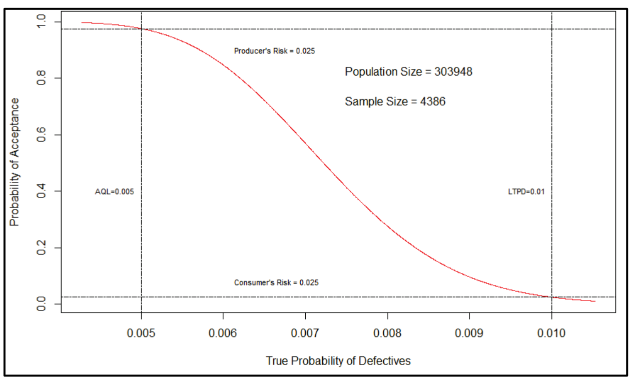
Critical Fields Plan

Fields

Isotope
<
Result

Sampling Plan

N = 303,948
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer’s risk or ORAUT risk)
β = 0.025 (consumer’s risk or DCAS risk)
n = 4,386



Results

11 errors / 4,386 checked = 0.25%

We are at least 95% confident that the critical fields transcription error rate is between 0.13% and 0.45%.

Evaluation

The critical fields 95% confidence interval is entirely below 1%. There is no issue with the critical field transcription error rate in this SRS in vitro dataset.

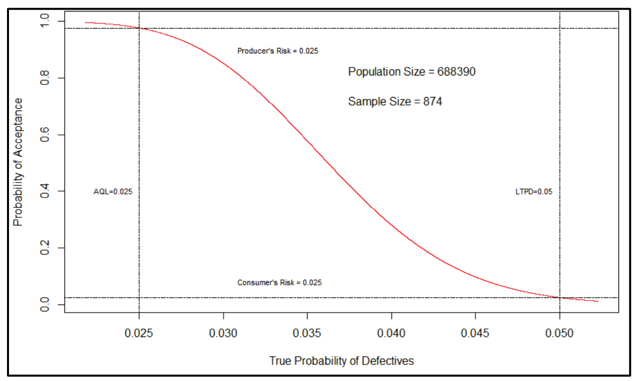
All Fields Plan

Fields

Critical Fields
Last Name (nonblank
First Name (nonblank)
Middle Name (nonblank)
PR (nonblank)
Date
Units (nonblank)
Area (nonblank)

Sampling Plan

N = 688,390
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer’s risk or ORAUT risk)
β = 0.025 (consumer’s risk or DCAS risk)
n = 874



Results

4 errors / 874 checked = 0.46%

We are at least 95% confident that the all fields transcription error rate is between 0.13% and 1.17%.

Evaluation

The all fields 95% confidence interval is entirely below 5%. There is no issue with the all field transcription error rate in this SRS in vitro dataset.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Combined In Vivo QA Report
August 28, 2017

Combined (old and new entries) In-Vivo Data – subset for use in OTIB-0081 Rev 4 (Spreadsheet called "SRS in-vivo subset 080717.csv")

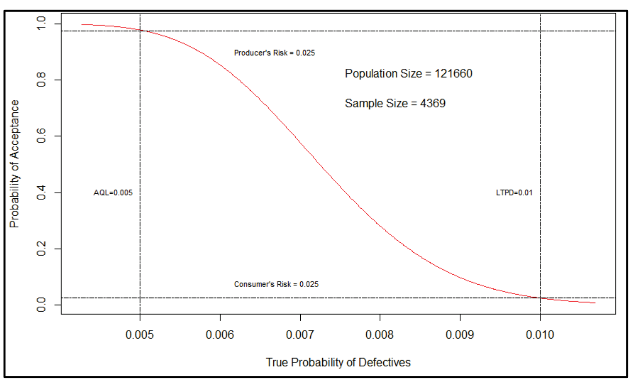
Critical Fields Plan

Fields

- Form Type (non-blank)
- Nuclide
- gross counts (non-blank)
- bkg counts (non-blank)
- net counts (non-blank)
- NET c/m (non-blank)
- DIFF counts (non-blank)
- Result (nci) (non-blank)
- MDA @95%CL (counts) (non-blank)
- MDA @95%CL (nCi) (non-blank)
- Lung Burden (nCi) (non-blank)

Sampling Plan

- N = 121,660
- AQL = 0.5%
- LTPD = 1%
- α = 0.025 (producer's risk or ORAUT risk)
- β = 0.025 (consumer's risk or DCAS risk)
- n = 4,369



Results

19 errors / 4,374 checked = 0.43%

We are at least 95% confident that the critical field transcription error rate is between 0.26% and 0.67%.

Five more critical fields were checked than what was prescribed by the sampling plan. This only improves the critical field transcription error rate interval.

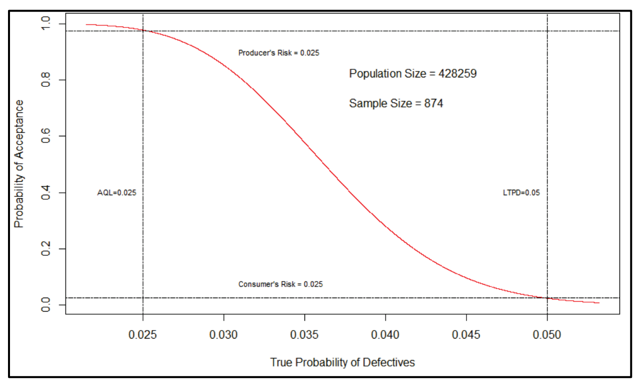
All Fields Plan

Fields

- Critical Fields
- Last name
- First Name
- Middle Name
- PR
- Occupation Title (non-blank)
- Position Title (non-blank)
- Date
- Dept
- location
- Type (WBC or CC)
- Reason
- Detector
- Comments (non-blank)

Sampling Plan

- N = 428,259
- AQL = 2.5%
- LTPD = 5%
- α = 0.025 (producer's risk or ORAUT risk)
- β = 0.025 (consumer's risk or DCAS risk)
- n = 874



Results

24 errors / 874 checked = 2.75%

We are at least 95% confident that the all field transcription error rate is between 1.77% and 4.06%.

Not counting payroll prefix issues as errors:

10 errors / 874 checked = 1.14%

We are at least 95% confident that the all field transcription error rate (not counting payroll prefix issues as errors) is between 0.55% and 2.09%

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Evaluation

The critical fields interval is entirely below 1%, and the all fields interval is entirely below 5%. There is no issue with the transcription error rates for the SRS in-vivo dataset.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Np Logbooks QA Summary
February 26, 2018

Critical Fields Plan

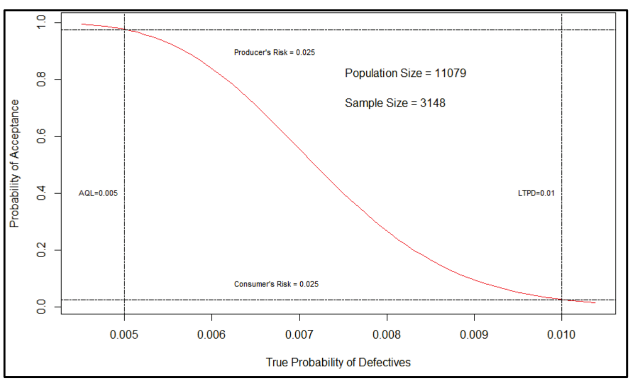
Fields

Data 1
Payroll ID #
Pu results (nonblank)
Pu units (nonblank)
Np results (nonblank)
Np units (nonblank)

Data 2
Payroll ID #
dpm/1.5L (10 columns)
(nonblank)
Report (nonblank)

Sampling Plan

N = 11,079
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 3,148



Results

27 errors / 3,148 checked = 0.86%

We are at least 95% confident that the critical fields transcription error rate is between 0.61% and 1.18%.

Excluding payroll prefix issues:

21 errors / 3,148 checked = 0.67%

We are at least 95% confident that the critical fields transcription error rate (*excluding payroll prefix issues*) is between 0.45% and 0.96%.

All Fields Plan

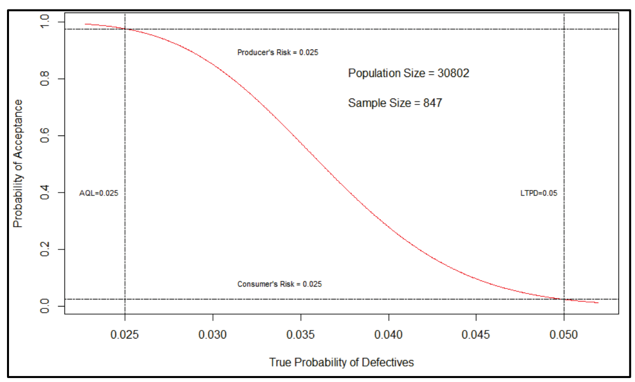
Fields

Data 1
Critical fields
Area
Employee Last Name
Employee First Initial
Employee Middle Initial
Bottle Date (nonblank)
Rec'd Date (nonblank)
Comment (nonblank)

Data 2
Critical fields
Employee Last Name
Employee First Initial
Employee Middle Initial
Volume
Area
Bottle Date
Type
Remarks (nonblank)

Sampling Plan

N = 30,802
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 847



Results

8 errors / 932* checked = 0.86%

We are at least 95% confident that the all fields transcription error rate is between 0.38% and 1.67%.

* The sampling plan requires 847 fields to be checked. The other 85 fields were checked because of a coding error in the sampling plan. The additional 85 fields help to narrow the confidence interval.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Critical Fields Plan	All Fields Plan
Critical Fields Evaluation 6 of the errors were PRID prefix issues that have no impact on the usability of the data for an error rate point estimate of 0.47%. 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. The critical fields 95% confidence interval (*excluding payroll prefix issues*) is entirely below 1%.	All Fields Evaluation The all fields 95% confidence interval is entirely below 5%. There are no issues with the transcription error rates in these SRS Np logbook datasets.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Am QA Summary
July 21, 2021

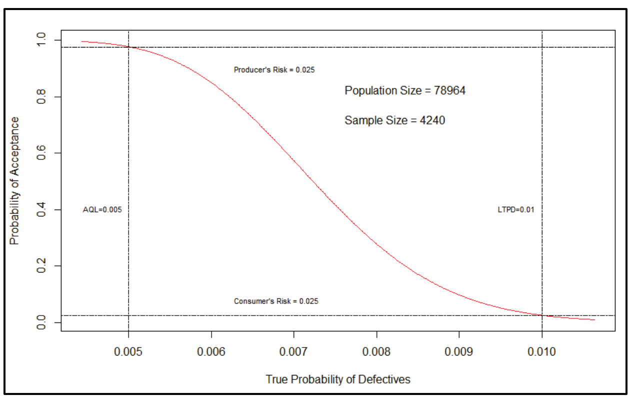
Critical Fields Plan

Fields

Volume (non-blank)
discResult (1 through 10) (combination of IsLip, IsIllegible, LessThan, and numeric result) (*non-blank*)
Am_discResultUnits (*non-blank*)
report (combination of IsLip, IsIllegible, LessThan, and numeric report) (*non-blank*)
Am_reportUnits (*non-blank*)
a_h_ (*non-blank*)

Sampling Plan

N = 78,964
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAU Team risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 4,240



Results

22 errors / 4,240 checked = 0.52%

We are at least 95% confident that the critical fields transcription error rate is between 0.33% and 0.78%.

Evaluation

The critical fields 95% confidence interval is entirely below 1%. There is no issue with the critical field transcription error rate in this SRS americium dataset.

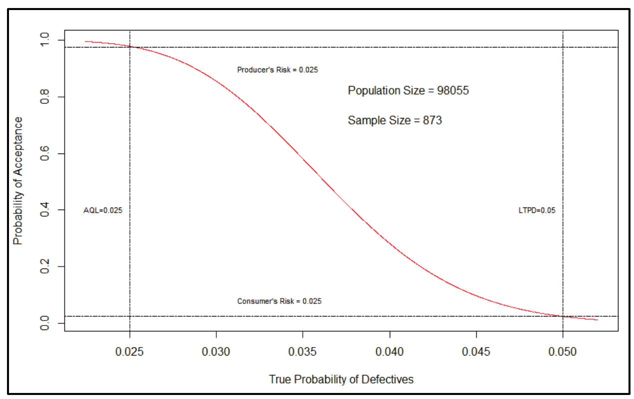
All Fields Plan

Fields

Critical Fields
date (combination of bottleDate and dateIllegibleType)

Sampling Plan

N = 98,055
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAU Team risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 873



Results

2 errors / 873 checked = 0.23%

We are at least 95% confident that the all fields transcription error rate is between 0.03% and 0.82%.

Evaluation

The all fields 95% confidence interval is entirely below 5%. There is no issue with the all field transcription error rate in this SRS americium dataset.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Tritium QA Summary
May 20, 2016

Tritium Data (Access database titled "SRS NOCTS Triitum_052710_postQA.mdb" using the table titled "QC copy of SRS NOCTS Tritium_052710") located at (O:\Coworker Data\Working Files\SRS\Coworker Study)

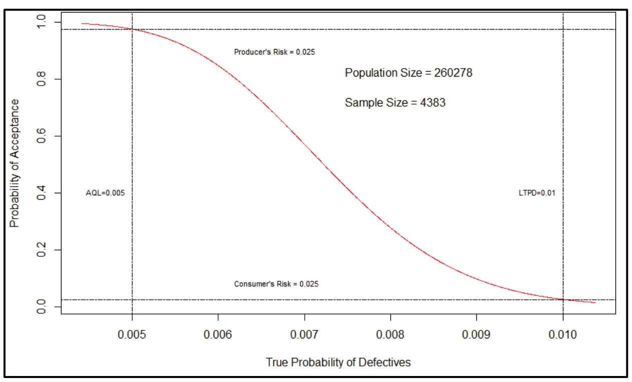
Critical Fields Plan

Fields

Result

Sampling Plan

N = 260,278
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 4,383



Results

14 errors / 4,383 checked = 0.32%

We are at least 95% confident that the critical field transcription error rate is between 0.18% and 0.53%.

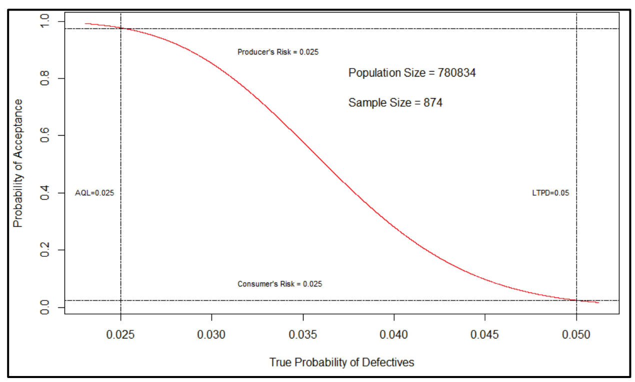
All Fields Plan

Fields

Result
Date
Area

Sampling Plan

N = 780,834
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 874



Results

2 errors / 874 checked = 0.23%

We are at least 95% confident that the all field transcription error rate is between 0.03% and 0.82%.

Evaluation

The critical field interval is entirely below 1%. The all field interval is entirely below 5%.

There are no issues with the transcription error rates in this SRS tritium dataset.

Note: 4 of the 14 critical field errors are results from the same claim entered as <0.05 that should be <0.5.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS In Vitro CTW QA Summary
September 17, 2018

QA of SRS in vitro data CTW determination. The 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).

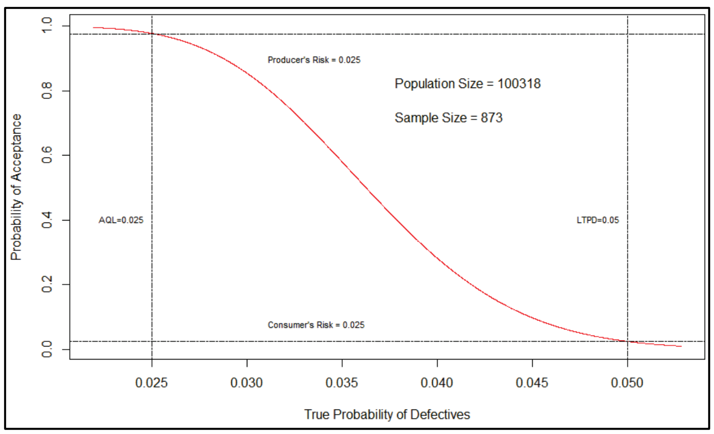
All Fields Plan

Fields

Rev4CTW

Sampling Plan

N = 100,318
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 873



Results
10 errors / 873 checked = 1.15%

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 0.55% and 2.09%.

Evaluation
The CTW determination and worker history cards classification error rate interval is entirely below 5%. There is no issue with the classification error rate.

Note: Most of the errors were due to individuals changing occupations from CTW to non-CTW, or vice versa, during their career.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS In Vivo CTW QA Summary
September 25, 2018

QA of SRS in vivo data CTW determination. The CTW determinations based on the Master Occupation Table and the CTW Designation Instructions were checked against the worker history cards (or claimant interviews or personnel dosimetry quarterly reports).

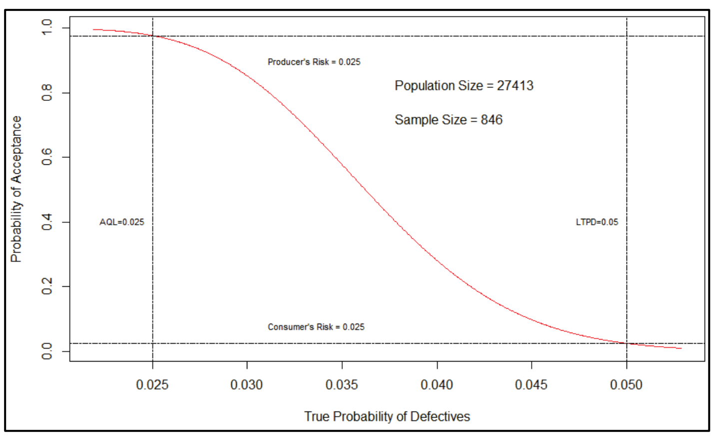
All Fields Plan

Fields

Rev4CTW

Sampling Plan

N = 27,413
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 846



Results

7 errors / 846 checked = 0.83%

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 0.34% and 1.68%.

Evaluation

The CTW determination and worker history cards classification error rate interval is entirely below 5%. There is no issue with the classification error rate.

Note: Most of the errors were due to individuals changing occupations from CTW to nonCTW, or vice versa, during their career.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Np Logbook CTW QA Summary
October 2, 2018

QA of SRS Np logbook data CTW determination. The 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).

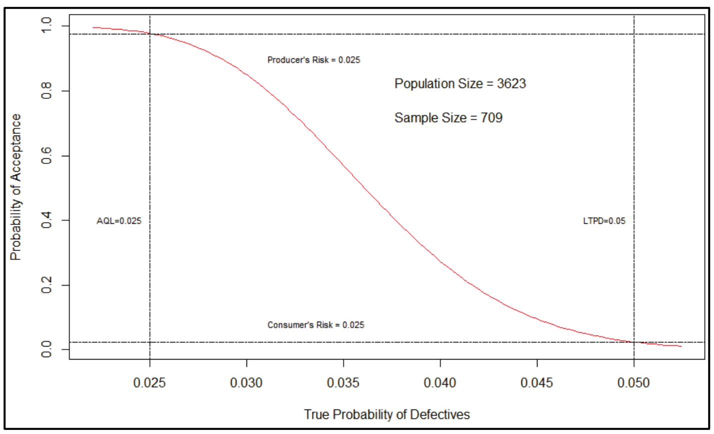
All Fields Plan

Fields

Rev4CTW

Sampling Plan

N = 3,623
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 709



Results
2 errors / 709 checked = 0.28%

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 0.06% and 0.94%.

Evaluation
The CTW determination and worker history cards classification error rate interval is entirely below 5%. There is no issue with the classification error rate.

Note: Most of the errors were due to individuals changing occupations from CTW to nonCTW, or vice versa, during their career.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Am Logbook CTW QA Report
August 6, 2021

QA of SRS Am logbook data CTW determination. The CTW determinations based on the Master Occupation Table and the CTW Designation Instructions were checked against the worker history cards (or claimant interviews or personnel dosimetry quarterly reports).

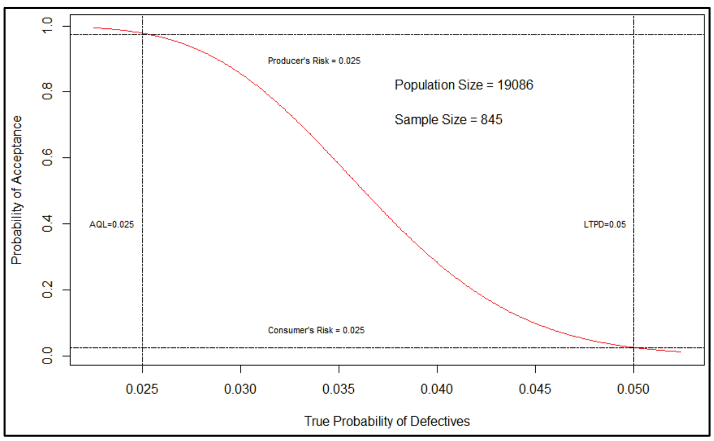
All Fields Plan

Fields

Rev6CTW

Sampling Plan

N = 19,086
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 845



Results

4 errors / 845 checked = 0.47%

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 0.14% and 1.19%.

Evaluation

The CTW determination and worker history cards classification error rate interval is entirely below 5%. There is no issue with the classification error rate.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Tritium CTW QA Summary
July 14, 2016

QA of tritium data CTW determination. The CTW determinations based on the Master Occupation Table and the CTW Designation Instructions were checked against the worker history cards (or claimant interviews or personnel dosimetry quarterly reports).

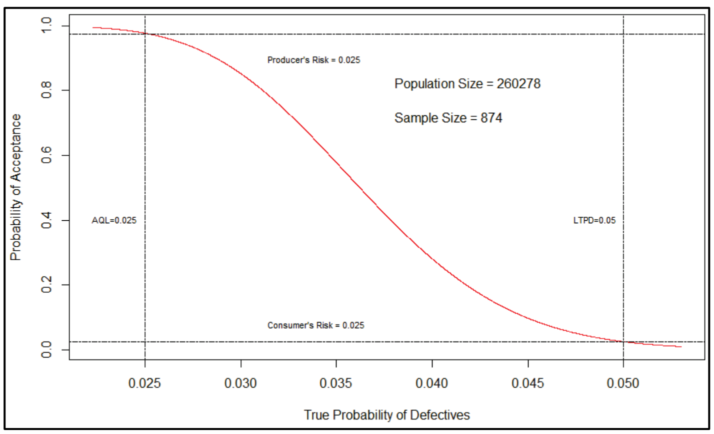
All Fields Plan

Fields

Rev3CTW

Sampling Plan

N = 260,278
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 874



Results

6 errors / 874 checked = 0.69%

Evaluation

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 0.25% and 1.49%.

The CTW determination and worker history cards classification error rate interval is entirely below 5%. There is no issue with the classification error rate.

Note: Five of the errors were the CTW determination algorithm calling the person a CTW when the worker history cards said they were not; one was the algorithm calling the person a nonCTW when they were.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Np Logbooks QA Report
May 20, 2016

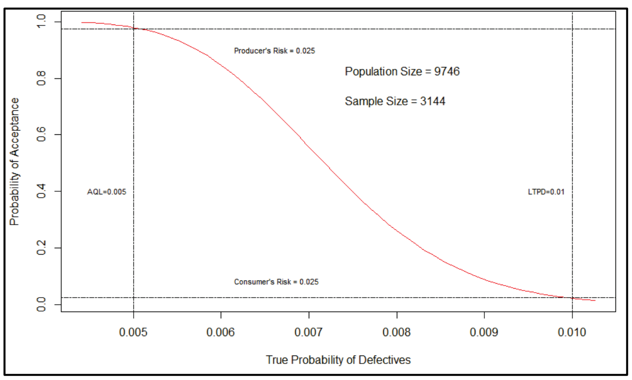
Np Logbooks (Spreadsheet called 'Compiled_SRS Np Logbook_WHC_07202011r0 Mike.xlsx')

Critical Fields Plan

Fields
- Payroll ID #
- Pu results (non-blank)
- Pu units (non-blank)
- Np results (non-blank)
- Np units (non-blank)

Sampling Plan

N = 9,746
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 3,144



Results

21 errors / 3,144 checked = 0.67%

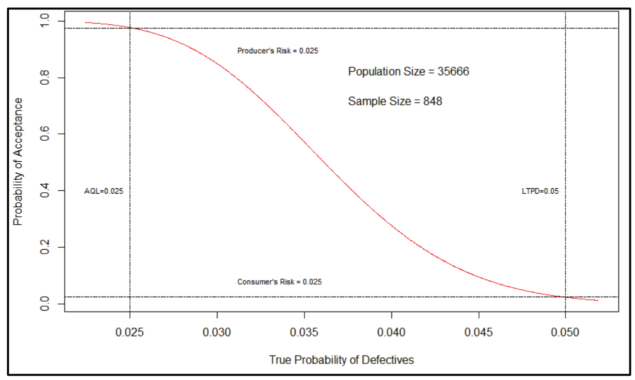
We are at least 95% confident that the critical field transcription error rate is between 0.46% and 0.95%.

All Fields Plan

Fields
- Critical fields
- Area
- Employee Last Name
- Employee First Initial
- Employee Middle Initial
- Occupation Title
- Bottle Date
- Received Date
- Comment (non-blank)

Sampling Plan

N = 35,666
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 848



Results

13 errors / 848 checked = 1.53%

We are at least 95% confident that the all field transcription error rate is between 0.83% and 2.59%.

Evaluation

The critical field interval is entirely below 1%. The all field interval is entirely below 5%.

There are no issues with the transcription error rates in this SRS tritium dataset.

Note: Of the 21 critical errors, 10 were payroll ID prefix issues. Six of the payroll ID prefix issues had to do with the presence or absence of a "0-" prefix.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS NOCTS WBC QA Summary
June 3, 2016

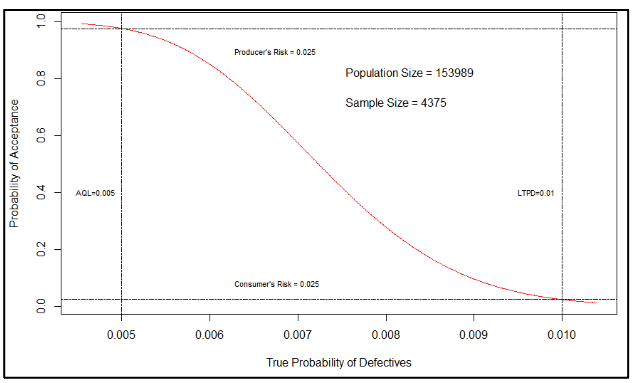
Critical Fields Plan

Fields

PR
Form Type (nonblank)
Nuclide
gross counts (nonblank)
bkg counts (nonblank)
net counts (nonblank)
NET c/m (nonblank)
DIFF counts (nonblank)
Result (nCi) (nonblank)
MDA @95%CL (counts) (nonblank)
MDA @95%CL (nCi) (nonblank)
Lung Burden (nCi) (nonblank)

Sampling Plan

N = 153,989
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAU Team risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 4,375



Results

535 errors / 4,375 checked = 12.23%

We are at least 95% confident that the critical fields transcription error rate is between 11.29% and 13.22%.

Not counting payroll prefix issues as errors:

pt. est. = 1.37%

95% confidence interval: (1.05%, 1.76%)

Counting errors in columns other than PRID and PRID errors that impact CTW determination:

pt. est. = 0.62%

95% confidence interval: (0.41%, 0.89%)

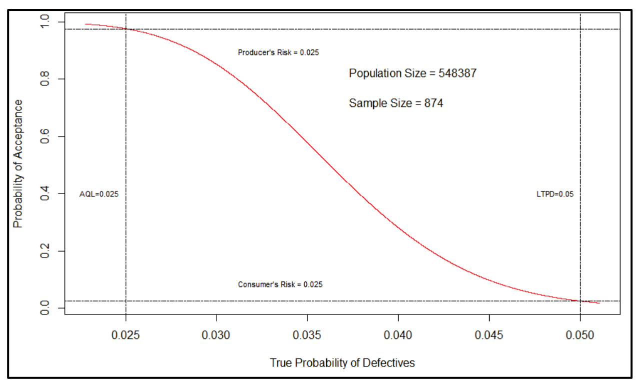
All Fields Plan

Fields

Critical Fields
Last Name
First Name
Middle Name
Occupation Title
Position Title
Date
Dept
Location
Type (WBC or CC)
Reason
Detector
Comments (nonblank)

Sampling Plan

N = 548,387
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAU Team risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 874



Results

45 errors / 874 checked = 5.15%

We are at least 95% confident that the all fields transcription error rate is between 3.78% and 6.83%.

Not counting payroll prefix issues as errors:

pt. est. = 2.17%

95% confidence interval: (1.31%, 3.37%)

Critical Fields Plan

Critical Fields Evaluation

PRID issues comprise the majority of the transcription errors, 523 of the 535 errors identified, although PRID fields were less than 25% of the total number of critical fields sampled. There were 12 non-PRID errors out of 3,373 non-PRID critical fields sampled for a non-PRID error rate point estimate of 0.4%.

There were 523 PRID errors out of 1,002 PRID critical fields sampled for an error rate point estimate of 52%. 475 of the 523 were PRID prefix issues that have no impact on the data use for an error rate point estimate of 47%. 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.

Of the 48 remaining (523-475) PRID errors, only 15 of the errors affected use of the data for CTW determination or for proper identification of the person. Most of the errors were either simple transposition errors already caught in subsequent data cleanup or instances where a worker was promoted from operator, laboratory technician, or similar job to a salaried position with no change in CTW status. However, there is still sufficient information to properly identify the person by claim number, name, or corrected PRID. These types of errors, while errors, do not affect the subsequent use of the data. CTW status is unchanged, and the use of the data for calculation of bioassay statistics is not affected.

Therefore, the set of all errors can be refined to the subset of errors that affect data use. There are 27 such errors, the 12 non-PRID errors and the 15 PRID errors that affect CTW determination or proper identification of the person. The error rate for this subset of errors is 0.62% with a 95% confidence interval of 0.41% to 0.89%, below the desired 1% error rate acceptance criteria.

All Fields Plan

All Fields Evaluation

As with the critical fields, PRID prefix issues that have no impact on the data use comprised the majority of the all fields errors, 26 of 45 errors. Although the overall error rate is above the desired acceptance rate of 5%, excluding these PRID prefix errors reduces the error rate to 2.17% with a 95% confidence interval of 1.31% to 3.37%, below the desired 5% error rate acceptance criteria. Since this error rate is below the desired acceptance criteria, no further evaluation of the significance of the non-PRID prefix errors was performed.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Mixed FP Gamma QA Summary
June 6, 2016

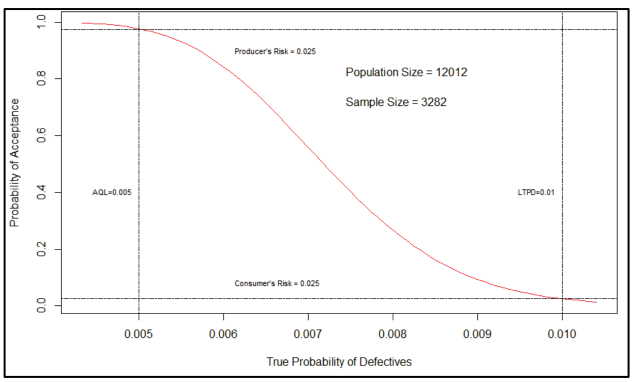
Critical Fields Plan

Fields

PR

Sampling Plan

N = 12,012
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAU Team risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 3,282



Results

1,980 errors / 3,282 checked = 60.33%

We are at least 95% confident that the critical fields transcription error rate is between 58.88% and 61.75%.

Not counting payroll prefix issues as errors:

pt. est. = 1.34%

95% confidence interval: (1.03%, 1.72%)

Counting errors in columns other than PRID and PRID errors that affect CTW determination and person identification:

pt. est. = 0.43%

95% confidence interval: (0.27%, 0.67%)

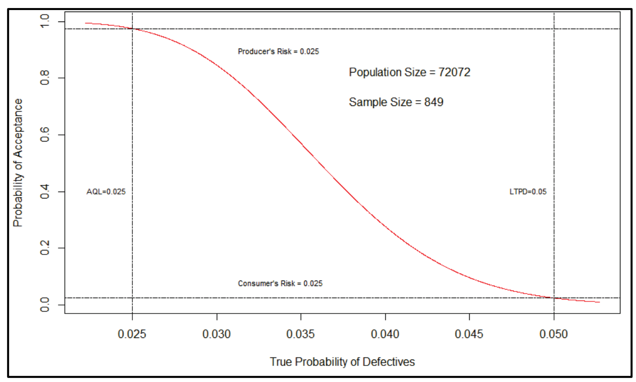
All Fields Plan

Fields

PR
Date
Last Name
First Name
Middle Name
Occupation Title

Sampling Plan

N = 72,072
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAU Team risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 849



Results

89 errors / 849 checked = 10.48%

We are at least 95% confident that the all fields transcription error rate is between 8.52% and 12.73%.

Not counting payroll prefix issues as errors:

pt. est. = 0.12%

95% confidence interval: (0.0042%, 0.65%)

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Critical Fields Plan

Critical Fields Evaluation

PRID prefix issues comprise the majority of the transcription errors, 1,936 of the 1,980 errors identified.

The 1,936 PRID prefix errors have no impact on the data use and have an error rate point estimate of 59%. 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.

Of the 44 remaining (1980 to 1936) PRID errors, only 14 of the errors affected use of the data for CTW determination or for proper identification of the person. Most of the errors were either simple transposition errors already caught in subsequent data cleanup or were instances where a worker was promoted from operator, laboratory technician, or similar job to a salaried position with no change in CTW status. However, there is still sufficient information to properly identify the person by claim number, name, or corrected PRID. These types of errors, while errors, do not affect the subsequent use of the data. CTW status is unchanged, and the use of the data for calculation of bioassay statistics is not affected.

Therefore, the set of all errors can be refined to the subset of errors that affect data use. There are 14 such errors. The error rate for this subset of errors is 0.43% with a 95% confidence interval of 0.27% to 0.67%, below the desired 1% error rate acceptance criteria.

All Fields Plan

All Fields Evaluation

As with the critical fields, PRID prefix issues that have no impact on the data use comprised the majority of the all fields errors, 88 of 89 errors. Although the overall error rate is above the desired acceptance rate of 5%, excluding these PRID prefix errors leaves only a single error and reduces the error rate to 0.12% with a 95% confidence interval of 0.0042% to 0.65%, below the desired 5% error rate acceptance criteria.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS Am QA Report
June 16, 2016

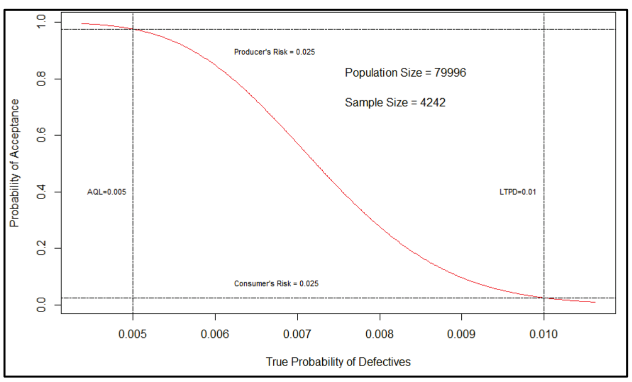
RPRT-0055 Data (Spreadsheet called "REVIEWED_Am Final Compiled_SRS WHC_06302011r2_Ready Updated rev 3_051616.xlsx")

Critical Fields Plan

Fields
- Payroll ID#
- Pu dpm/1.5L (12 columns) (non-blank)
- Pu Report (non-blank)
- EU dpm/1.5L (10 columns) (non-blank)
- EU Report (non-blank)
- Am dpm/1.5L (10 columns) (non-blank)
- Am Report (non-blank)
- Np dpm/1.5L (10 columns) (non-blank)
- Np Report (non-blank)

Sampling Plan

N = 79,996
AQL = 0.5%
LTPD = 1%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 4,242



Results

25 errors / 4,242 checked = 0.59%

We are at least 95% confident that the critical field transcription error rate is between 0.39% and 0.86%.

Evaluation

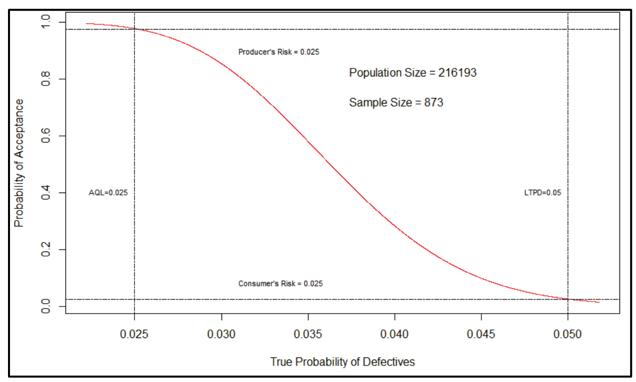
The critical field interval is entirely below 1%. There is no issue with the critical field transcription error rate in this SRS americium dataset.

All Fields Plan

Fields
- Critical Fields
- Employee Last Name
- Employee First Initial
- Employee Middle Initial
- Volume
- Area
- Occupation Title
- Bottle Date
- Remarks (non-blank)

Sampling Plan

N = 216,193
AQL = 2.5%
LTPD = 5%
α = 0.025 (producer's risk or ORAUT risk)
β = 0.025 (consumer's risk or DCAS risk)
n = 873



Results

6 errors / 873 checked = 0.69%

We are at least 95% confident that the all field transcription error rate is between 0.25% and 1.49%.

Evaluation

The all field interval is entirely below 5%. There is no issue with the all field transcription error rate in this SRS americium dataset.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES

LIST OF TABLES

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-1. SRDB Ref IDs for REAC/TS chelation data.

Ref ID	Ref ID	Ref ID	Ref ID	Ref ID	Ref ID	Ref ID	Ref ID	Ref ID
71929	72155	72147	72211	72256	72333	72418	72842	73044
71930	72157	72148	72212	72259	72334	72421	72844	73047
71933	71977	72158	72213	72260	72335	72428	72848	73049
71934	71978	72159	72214	72262	72336	72430	72851	73050
71936	71979	72161	72216	72263	72340	72431	72852	73051
71939	71980	72163	72217	72264	72341	72434	72857	73060
71940	71981	72166	72218	72265	72342	72451	72858	73064
71941	71982	72167	72219	72266	72344	72452	72860	73069
71943	71983	72169	72220	72267	72345	72455	72861	73071
71945	71984	72171	72221	72269	72346	72456	72862	73072
71946	71985	72173	72222	72270	72347	72460	72863	73075
71952	71986	72174	72223	72274	72348	72461	72865	73077
71953	71987	72175	72224	72275	72350	72462	72866	73080
71954	71988	72178	72226	72276	72351	72464	72867	73082
71955	71989	72179	72228	72301	72352	72466	72868	73083
71956	71990	72181	72229	72303	72361	72467	72873	73088
71957	71991	72183	72230	72306	72363	72470	72875	73091
71959	71995	72186	72231	72308	72364	72477	72879	73092
71960	71998	72188	72233	72310	72365	72478	72881	73095
71961	72001	72190	72234	72311	72366	72479	72883	73099
71963	72004	72192	72241	72313	72369	72647	72885	73108
71964	72007	72193	72242	72314	72372	72650	72889	73112
71965	72010	72194	72243	72316	72377	72651	72890	73121
71967	72013	72195	72244	72318	72382	72652	72891	73125
71969	72019	72196	72245	72321	72386	72654	72935	73128
71970	72116	72197	72246	72323	72388	72821	72936	75412
71971	72128	72199	72247	72324	72391	72824	73026	72656[a]
71972	72131	72200	72248	72325	72394	72828	73031	72813[a]
71973	72134	72202	72249	72328	72406	72831	73035	165427[a]
71974	72137	72205	72252	72330	72408	72833	73036	None
71975	72138	72206	72253	72331	72413	72838	73039	None
71976	72144	72209	72255	72332	72417	72839	73041	None

a. Used for americium only.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-2. 1968 bioassay frequencies (samples per year by analysis type) [DuPont 1968a].[a]

Category	Description	Pu	FP	EU	U	NP
A	**Minimum potential (except HTO).** Personnel assigned to 232-H, 234-H, 284-F & -H, 704-F & -H, 706-F & -H, 717-F, and 235-F nonprocess sections; patrolmen.	1 ea. 3 yr	1 ea. 3 yr	1 ea. 3 yr	1 ea. 3 yr	1 ea. 3 yr
B	**221-H fourth level.** Separations senior supervisors and above; all separations technology personnel, control room operators, and secretaries.	1	1	1	N/A	N/A
C	**221-H regulated areas and H-Area outside facilities.** All personnel assigned to H-Area outside facilities; all utility operators, janitors, power operators, and selected E&I and maintenance mechanics assigned to 221-H regulated areas.	1	2	2[b]	N/A	N/A
D	**221-H maximum potential (canyons).** All auxiliary operators, crane process operators, HP personnel, and selected E&I and maintenance mechanics.	2	2	2[b]	N/A	N/A
E	**B-Line, H Area.** All assigned personnel.	4	1	N/A	N/A	2
F	**235-F.** All personnel assigned to process section of building.	4	1	N/A	N/A	N/A
G	**221-F fourth level.** Separations senior supervisors and above; all separations technology personnel, control room operators, and secretaries.	1	1	N/A	N/A	N/A
H	**221-F regulated areas, 723-F, 643-G and 717-A.** All personnel assigned to 723-F and 634-G; all janitors, power operators, and selected E&I and maintenance mechanics assigned to 221-F regulated areas; all 717-A field crews assigned.	1	2	N/A	N/A	N/A
I	**221-F maximum potential (canyons).** All auxiliary operators, utility operators, crane process operators, HP personnel, and selected E&I and maintenance mechanics.	2	2	N/A	N/A	N/A
J	**JB-Line and B-Line, F Area.** All assigned personnel.	4	1	N/A	N/A	N/A
K	**Outside facilities, F Area.** All assigned personnel.	1	2	N/A	4	N/A
L	**772-F, UO_3 section.** All assigned personnel.	1	1	1	4	N/A
M	**772-F (excluding UO_3 section).** All assigned personnel.	4	2	2[b]	1	N/A
N	**313 and 320-M.**	N/A	N/A	N/A	1	N/A
O	**322-M.** All assigned personnel.	N/A	N/A	1	1	N/A
P	**322-M.** Personnel processing samples from field.	N/A	1	1	1	N/A
Q	**321-M.** Machine casting.	N/A	N/A	4	N/A	N/A
R	**321-M.** Service groups.	N/A	N/A	2	N/A	N/A
S	**321-M.** All assigned personnel.	N/A	N/A	1	N/A	N/A
T	**100 Areas, 105 Buildings**. Reactor department personnel from C&D crews, purification, and pump room observation; control room and monitor operators; all 100-Area HP, maintenance, and T&T personnel; all E&I, laboratory, and HP personnel assigned to 105 buildings; T&T personnel in central shops; reactor tech personnel as designated by supervision.	(c)	(c)	(c)	(c)	(c)
U	**773-A.** Radiation control and maintenance.	1	1	N/A	1	N/A
V	**773-A.** Area maintenance mechanics.	1	1	1	1	N/A
W	**773-A.** Special group.	(d)	(d)	(d)	(d)	(d)
X	**700 Area.** Shop personnel provide samples as considered advisable by 3/700-Area survey.	(e)	(e)	(e)	(e)	(e)

a. N/A = not applicable; C&D = Construction and Demolition; T&T = Transportation and Traffic.
b. Personnel are sampled for applicable isotope at frequency shown during operation of plutonium-uranium extraction (PUREX) and (HM).
c. IA and FP.
d. IA.
e. As considered advisable by 3/700-Area survey.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-3. 1970 bioassay frequencies (samples per year by analysis type) [DuPont 1970].[a,b]

Category	Description	Pu	FP	EU	U	NP
A	**Minimum potential (except HTO).** Personnel assigned to 232-H, 234-H, 284-F & -H, 704-F & -H, 706-F & -H, 717-F, and 235-F nonprocess sections; patrolmen.	1 ea. 3 yr	1 ea. 3 yr	1 ea. 3 yr	1 ea. 3 yr	1 ea. 3 yr
B	**221-H fourth level.** Separations senior supervisors and above; all separations technology personnel, control room operators, and secretaries.	1	1	1	N/A	N/A
C	**221-H regulated areas and H-Area outside facilities.** All personnel assigned to H-Area outside facilities; all utility operators, janitors, power operators, and selected E&I and Maintenance Mechanics assigned to 221-H regulated areas.	1	2	2	N/A	N/A
D	**221-H maximum potential (canyons).** All auxiliary operators, crane process operators, HP personnel, and selected E&I and Maintenance Mechanics.	2	2	2	N/A	N/A
E	**B-Line, H Area.** All assigned personnel.	4	1	N/A	N/A	2
F	**235-F.** All personnel assigned to process section of building.	4	1	N/A	N/A	N/A
G	**221-F fourth level.** Separations senior supervisors and above; all separations technology personnel, control room operators, and secretaries.	1	1	N/A	N/A	N/A
H	**221-F regulated areas, 723-F, 643-G and 717-A.** All personnel assigned to 723-F and 634-G; all janitors, power operators, and selected E&I and Maintenance Mechanics assigned to 221-F regulated areas; all 717-A field crews assigned.	1	2	N/A	N/A	N/A
I	**221-F maximum potential (canyons).** All auxiliary operators, utility operators, crane process operators, HP personnel, and selected E&I and Maintenance Mechanics.	2	2	N/A	N/A	N/A
J	**JB-Line and B-Line, F Area.** All assigned personnel.	4	1	N/A	N/A	N/A
K	**Outside facilities, F Area.** All assigned personnel.	1	2	N/A	4	N/A
L	**772-F, UO_3 section.** All assigned personnel.	1	1	1	4	N/A
M	**772-F (excluding UO_3 section).** All assigned personnel.	4	2	2	1	N/A
N	**313 and 320-M.**	N/A	N/A	N/A	1	N/A
O	**322-M.** All assigned personnel.	N/A	N/A	1	1	N/A
P	**322-M.** Personnel processing samples from field.	N/A	1	1	1	N/A
Q	**321-M.** Machine casting.	N/A	N/A	4	N/A	N/A
R	**321-M.** Service groups.	N/A	N/A	2	N/A	N/A
S	**321-M.** All assigned personnel.	N/A	N/A	1	N/A	N/A
T	**100 Areas, 105 Buildings**. Reactor department personnel from C&D crews, purification, and pump room observation; control room and monitor operators; all 100-Area HP, Maintenance, and T&T personnel; all E&I, laboratory, and HP personnel assigned to 105 buildings; T&T personnel in central shops; reactor tech personnel as designated by supervision.	(c)	(c)	(c)	(c)	(c)
U	**773-A.** Radiation control and maintenance.	1	1	N/A	1	N/A
V	**773-A.** Area Maintenance Mechanics.	1	1	1	1	N/A
W	**773-A.** Special group.	(d)	(d)	(d)	(d)	(d)
X	**700 Area.** Shop personnel provide samples as considered advisable by 3/700-Area survey.	(e)	(e)	(e)	(e)	(e)

a. N/A = not applicable; C&D = Construction and Demolition; T&T = Transportation and Traffic.
b. NP was performed when requested by area HP. Neptunium has never been detected without at least an equal amount of plutonium.
c. Except A-Line where operators were sampled weekly.
d. Except casting area where operators were sampled monthly.
e. Samples also analyzed for IA.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-4. Early 1971 bioassay frequencies (samples or counts per year by analysis type) [DuPont 1971a].[a,b]

Category	Description	H3 samples	Pu samples	FP samples	EU samples	U samples	Am/Cm/Cf samples	EU counts	Pu/Am/Cm/Cf counts
A	**Minimum potential (except HTO).** Personnel assigned to 284-F & -H, 704-F & -H, 706-F & -H, 717-F, and nonprocess sections of other facilities; patrolmen.	N/A	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A
B	**221-F & -H fourth level.** Separations supervision; all separations technology personnel, control room operators, janitors, and clerical personnel.	N/A	1	1	N/A	N/A	N/A	N/A	N/A
C	**221-H and H-Area outside facilities.** All operators (except control room and sample aisle), HP personnel, and selected power, E&I and Maintenance personnel assigned to 221-H process areas; all personnel assigned to H-Area outside facilities.	2	1	2	1	N/A	N/A	N/A	N/A
D	**221-H sample aisle and 772-F.** All sample aisle operators; selected 772-F laboratory personnel.	N/A	2	2	2	N/A	1	N/A	1
E	**221-H B-Line, 221-F B-Line, JB-Line & 235-F.** All personnel assigned to process sections in building 235-F; and all assigned personnel in other facilities.	N/A	2	2	N/A	N/A	N/A	N/A	1
F	**221-F, 723-F, and 643-G.** All operators (except control room and sample aisle), HP personnel, and selected power, E&I and Maintenance personnel assigned to 221-F process areas; all personnel assigned to 723-F and 643-G.	N/A	1	2	N/A	N/A	N/A	N/A	N/A
G	**221-F sample aisle.** All 221-F sample aisle operators.	N/A	2	2	N/A	N/A	2	N/A	1[c]
H	**F-Area outside facilities**. All assigned personnel.	N/A	1 ea. 3 yr	2	N/A	4[d]	N/A	N/A	N/A
J	**772-F (excluding UO_3 section).** All assigned personnel.	N/A	2	2	1	1	N/A	N/A	N/A
K	**313-M.** All assigned personnel.	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A
L	**322-M.** All assigned personnel. **320-M.** All laboratory and selected radioactive material personnel. **773-A.** Reactor engineering group and 777-M assigned personnel.	N/A	1 ea. 3 yr	N/A	1	4	N/A	N/A	N/A
M	**322-M.** Personnel processing samples from field. **772-F, UO_3 section.** All assigned personnel.	N/A	1 ea. 3 yr	1	1	4	N/A	N/A	N/A
N	**321-M.** All assigned personnel.	N/A	1	N/A	4[e]	N/A	N/A	2[f]	N/A
T	**100 Areas, 105 Buildings**. Reactor department personnel from C&D crews, purification, and pump room observation; control room and monitor operators; all 100-Area HP, Maintenance, and T&T personnel; all E&I personnel assigned to 105 buildings; T&T personnel in central shops; and selected reactor tech and 400-Area personnel.	(g)	N/A	1[h]	N/A	N/A	N/A	N/A	N/A
V	**773-A.** Analytical chemistry, high level caves, building services, radiation control, and Maintenance personnel.	N/A	1 ea. 3 yr	1	N/A	N/A	2	N/A	1

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Category	Description	H3 samples	Pu samples	FP samples	EU samples	U samples	Am/Cm/Cf samples	EU counts	Pu/Am/Cm/Cf counts
W	**773-A.** Selected clerical and supervisory personnel	N/A	1 ea. 3 yr	N/A	N/A	N/A	1	N/A	N/A
X	**232-H, 234-H, 237-H, & 238-H.** All assigned personnel. **241-H & 244-H.** Selected personnel.	(g)	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A
N/A	700 Area shop personnel provide samples as considered advisable by HP.	(i)	(i)	(i)	(i)	(i)	(i)	(i)	(i)

a. N/A = not applicable; C&D = Construction and Demolition; T&T = Transportation and Traffic.
b. NP was performed when requested by area HP. Neptunium has never been detected without at least an equal amount of plutonium.
c. Selected personnel.
d. Except A-Line where operators were sampled weekly.
e. Except casting area where operators were sampled monthly.
f. Only personnel assigned to casting areas.
g. Samples also analyzed for IA.
h. Sample frequency established by local procedures.
i. 700 Area shop personnel provided samples as considered advisable by HP.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-5. Late 1971 bioassay frequencies (samples per year or counts per year by analysis type) [DuPont 1971b].[a,b]

Category	Description	H3 samples	Pu samples	FP samples	EU samples	U samples	Am/Cm/Cf samples	EU counts	Pu/Am/Cm/Cf counts
A	**Minimum potential (except HTO).** Personnel assigned to 284-F & -H, 704-F & -H, 706-F & -H, 717-F, and nonprocess sections of other facilities; patrolmen.	N/A	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A
B	**221-F & -H fourth level.** Separations supervision; all separations technology personnel, control room operators, janitors, and clerical personnel.	N/A	1	1	N/A	N/A	N/A	N/A	N/A
C	**221-H and H-Area outside facilities.** All operators (except control room and sample aisle), HP personnel, and selected power, E&I and Maintenance personnel assigned to 221-H process areas; all personnel assigned to H-Area outside facilities.	2	1	2	1	N/A	N/A	N/A	N/A
D	**221-H sample aisle.** All 221-H sample aisle operators; selected 772-F laboratory personnel.	N/A	2	2	2	N/A	N/A	N/A	1
E	**221-F sample aisle.** All 221-F sample aisle operators; selected 772-F personnel.	N/A	2	2	N/A	N/A	2	N/A	N/A
F	**221-F, 723-F, and 643-G.** All operators (except control room and sample aisle), HP personnel, and selected power, E&I and Maintenance personnel assigned to 221-F process areas; all personnel assigned to 723-F and 643-G.	N/A	1	2	N/A	N/A	N/A	N/A	N/A
G	**221-H B-Line, 221-F B-Line, JB-Line, 235-Fe.** All personnel assigned to process sections in building 235-F, and all assigned personnel in other facilities.	N/A	2	2	N/A	N/A	N/A	N/A	1
H	**F-Area outside facilities**. All assigned personnel.	N/A	1 ea. 3 yr	2	N/A	4[c]	N/A	N/A	N/A
J	**772-F (excluding UO_3 section).** All assigned personnel.	N/A	2	2	1	1	N/A	N/A	1[d]
K	**313-M.** All assigned personnel.	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A
L	**322-M.** All assigned personnel, including personnel processing samples from field. **320-M.** All laboratory and selected RADIOACTIVE MATERIAL personnel. **773-A.** Reactor engineering group and 777-M assigned personnel.	N/A	1 ea. 3 yr	N/A	1	4	N/A	N/A	N/A
M	**322-M.** Personnel processing samples from field. **772-F, UO_3 Section.** All assigned personnel.	N/A	1 ea. 3 yr	1	1	4	N/A	N/A	N/A
N	**321-M.** All assigned personnel.	N/A	1	N/A	4[e]	N/A	N/A	2[f]	N/A
T	**100 Areas, 105 Buildings**. Reactor department personnel from C&D crews, purification, and pump room observation; control room and monitor operators; all 100-Area HP, Maintenance, and T&T personnel; all E&I personnel assigned to 105 buildings; T&T personnel in central shops; and selected reactor tech and 400-Area personnel.	(g)	N/A	1[h]	N/A	N/A	N/A	N/A	N/A

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Category	Description	H3 samples	Pu samples	FP samples	EU samples	U samples	Am/Cm/Cf samples	EU counts	Pu/Am/Cm/Cf counts
V	**773-A.** Analytical chemistry, high level caves, building services, radiation control, and Maintenance personnel.	N/A	1 ea. 3 yr	1	N/A	N/A	2	N/A	1[d]
W	**773-A.** Selected clerical, supervisory personnel, and selected 100-Area personnel.	N/A	1 ea. 3 yr	N/A	N/A	N/A	1	N/A	N/A
X	**232-H, 234-H, 237-H, & 238-H.** All assigned personnel. **241-H & 244-H.** Selected personnel.	(g)	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A
N/A	**700 Area.** Shop personnel provide samples as considered advisable by HP.	(i)	(i)	(i)	(i)	(i)	(i)	(i)	(i)

a. N/A = not applicable; C&D = Construction and Demolition; T&T = Transportation and Traffic.
b. NP was performed when requested by area HP. Neptunium has never been detected without at least an equal amount of plutonium.
c. Except A-Line where operators were sampled weekly.
d. Selected personnel.
e. Except casting area where operators were sampled monthly.
f. Only personnel assigned to casting areas.
g. Sample frequency established by local procedures.
h. Samples also analyzed for IA.
i. 700 Area shop personnel provided samples as considered advisable by HP.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-6. 1976 bioassay frequencies (samples per year or counts per year by analysis type) [DuPont 1976].[a]

Personnel work assignment	Pu samples	EU samples	U samples	IA/FP samples	Am/Cm/Cf samples	Sr samples	H3 samples	FP samples	Days counts	Shift counts
Minimum Potential. Personnel working in tritium facilities, 200-FH facilities not mentioned below, 723-A (EED), and 305-M. Selected 100-Area and 773-A personnel.	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	(b)	N/A	1 ea. 3 yr[c]	1 ea. 3 yr
221-FH. All operators, Separations Technology, HP, and 4th-Level personnel; E&I, Maintenance, Clerical, and Service Department personnel assigned to process areas. **241-FH, 211-FH, 723-F, A-Line, 643-G & 244-H.** All assigned personnel. **772-F & 235-F.** Personnel assigned to nonprocess areas. **Patrol & T&T**. All personnel assigned to 200-FH Areas. **773-A.** Selected clerical and supervisory personnel. 100-Areas. Selected personnel.	1	(d)	(e)	N/A	(f)	(g)	N/A	N/A	1	2
221-HB Line, 221-FB Line, JB-Line. All assigned personnel. **235-F.** Personnel assigned to process areas. **772-F.** Personnel assigned to process areas. **773-A.** Selected ACD, SED, SCD, NMD, HLC, Radiation Control, Building Services, and Maintenance personnel.	4	(d)	N/A	N/A	(f)	N/A	N/A	(c)	1[h]	2
313-M. All assigned personnel.	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A
322-M & 772-F (UO_3 Section). All assigned personnel. **320-M.** All laboratory and selected radioactive material personnel. **773-A.** Reactor Engineering and 777-M personnel.	1 ea. 3 yr	1	4	N/A	N/A	N/A	N/A	N/A	(i)	(i)
321-M. All assigned personnel except those in Casting Area.	1	4	N/A	N/A	N/A	N/A	N/A	N/A	1 ea. 3 yr	1

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Personnel work assignment	Pu samples	EU samples	U samples	IA/FP samples	Am/Cm/Cf samples	Sr samples	H3 samples	FP samples	Days counts	Shift counts
Reactor Department personnel from CH purification and pump room observation; control room and monitor operators; all 100-Area HP, Maintenance, and T&T personnel; E&I and service personnel assigned to 105 buildings; T&T personnel in central shops and 618-G; selected reactor tech, project and 400-Area personnel.	1[c]	N/A	N/A	N/A	N/A	N/A	(b)	N/A	1[j]	1[j]
321-M. All personnel assigned to Casting Area.	1	12	N/A	N/A	N/A	N/A	N/A	N/A	2	2

a. ACD = Analytical Chemistry Division; HLC = high-level cave; N/A = not applicable; NMD = Nuclear Materials Division; SED = Separation Engineering Division; SCD = Separation Chemistry Division; T&T = Transportation and Traffic.
b. Sample frequency established in local procedures.
c. Selected personnel.
d. Selected personnel in 221-H, 211-H, and 772-F sampled for EU four times a year.
e. A-Line assigned personnel in F-Area sampled weekly; samples collected after day(s) of rest and before exposure.
f. Selected personnel in 221-F, 211-F, and 773-A sampled for Am-Cm once a year.
g. Selected personnel assigned to waste management work sampled for Sr once a year.
h. All B-Line and JB-Line personnel and 772-F laboratory attendants counted twice a year.
i. 322-M personnel processing 200-Area samples and 772-F (UO_3 Section) personnel counted once a year.
j. Selected day and all shift personnel; urine sample not required if in vivo count scheduled.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-7. 1985 bioassay frequencies (samples per year or counts per year by analysis type) [DuPont 1985b].[a,b]

Personnel work assignment	Pu samples	EU samples	NU samples	FP/IA samples	Am/Cm/Cf samples	Np samples	Sr samples	In vivo counts[c]
100-400 Areas. Selected day personnel and all shift Reactor Department CH, purification, pump observation room, and monitor operators.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1
100-400 Areas. Reactor control room operators, HP, Maintenance, T&T, E&I, and service personnel assigned to 105 Building, T&T personnel in Central Shops and 618-G; selected Reactor Tech, Project, and selected 400-Area personnel.	1 ea. 3 yr	N/A	N/A	1	N/A	N/A	N/A	N/A
100-400 Areas. Maximum potential. Selected personnel.	1	N/A	N/A	N/A	N/A	N/A	N/A	1
100-400 Areas. Other personnel assigned to 105 Building. Selected 400 Area personnel.	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A
200 Area. Personnel working in tritium facilities or 200-FH facilities not mentioned below.	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A	1
211-FH, 723-F, 643-G, A-Line, 241-FN, 244-H. All Separations operators; Sep. Tech, HP, and other 4th level personnel; E&I, Maintenance, clerical, and service department personnel assigned to process areas.	1	N/A	N/A	N/A	N/A	N/A	N/A	1
235-F, 772-F. Selected personnel.	1	N/A	N/A	N/A	N/A	N/A	N/A	1
221-F. Selected personnel.	1	N/A	N/A	N/A	1	N/A	N/A	1
221-H. Selected personnel.	1	4	N/A	N/A	N/A	N/A	N/A	1
643-G. Selected personnel assigned to waste management work.	1	N/A	N/A	N/A	N/A	N/A	1	1
221-FB-Line, JB-Line. All assigned personnel.	2	N/A	N/A	N/A	N/A	N/A	N/A	1
235-F. Personnel assigned to process areas.	2	N/A	N/A	N/A	N/A	1	N/A	1
772-F. Personnel assigned to laboratories in the PUREX and Pu sections.	2	1	N/A	N/A	N/A	N/A	N/A	1
221-F. Selected personnel.	2	N/A	N/A	N/A	2	N/A	N/A	1
221-H, 772-F. Selected personnel.	2	4	N/A	N/A	N/A	N/A	N/A	1
221-HB-Line. All assigned personnel.	4	N/A	N/A	N/A	N/A	N/A	N/A	2
300 Areas, 313-M. All assigned personnel.	N/A	N/A	4	N/A	N/A	N/A	N/A	1
322-M. UO_3 Sections and other selected personnel.	1	1	4	N/A	N/A	N/A	N/A	1
322-M. All other assigned personnel.	1 ea. 3 yr	1	4	N/A	N/A	N/A	N/A	1
320-M. All laboratory and selected radioactive material personnel.	N/A	1	4	N/A	N/A	N/A	N/A	1
321-M. All personnel assigned to charge prep, casting, and machining areas.	1	12	N/A	N/A	N/A	N/A	N/A	2
321-M. All other assigned personnel.	1	4	N/A	N/A	N/A	N/A	N/A	1
773-A. Minimum potential.	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A	1
773-A. Selected ACD, SED, SCD, NMD, HLC, Radiation Control, Building Services, and Maintenance personnel.	2	N/A	N/A	N/A	N/A	N/A	N/A	1
773-A. Reactor Engineering and 777-M personnel.	1 ea. 3 yr	1	4	N/A	N/A	N/A	N/A	1
773-A. Selected clerical and supervisory personnel.	1	N/A	N/A	N/A	N/A	N/A	N/A	1
773-A. Maximum potential. Selected personnel.	2	2	4	N/A	2	N/A	N/A	1

a. N/A = not applicable; T&T = Transportation and Traffic.
b. This 1985 procedure indicates it is a duplicate of a 1978 procedure, so these frequencies apply for at least the 1978 to 1985 period.
c. The count frequency for shift employees was twice a year unless they only receive triennial plutonium urine bioassay.

ATTACHMENT B
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table B-8. 1989 bioassay frequencies (samples per year or counts per year by analysis type)[a] [DuPont no date a].

Personnel work assignment	Pu samples	EU samples	NU samples	Am/Cm/ Cf samples	Np samples	Sr samples	In vivo counts
100-400 Areas, All reactor area departments and construction. Selected day personnel and all shift Reactor Department CH, purification, pump observation room, and monitor operators. Maintenance, T&T, E&I, and service personnel assigned to 105 building, T&T personnel in Central Shops and 618-G; selected Reactor Tech, Project, and selected 400-Area personnel.	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A
100-400 Areas, All reactor area departments and construction. HP, selected CH.	1	N/A	N/A	N/A	N/A	N/A	1
211-H. Selected personnel.	1	4	N/A	N/A	N/A	N/A	1
643-G. Selected personnel assigned to waste management work.	N/A	4	N/A	N/A	N/A	1	1
FB-Line. Operators and first line supervisors. SWE Mechanics.	4	N/A	N/A	N/A	N/A	N/A	1
FB-Line. Other assigned personnel.	N/A	4	N/A	N/A	N/A	N/A	1
HB-Line. Operators.	4	N/A	N/A	N/A	1	N/A	1
HB-Line. Other assigned personnel.	1	N/A	N/A	N/A	1	N/A	1
235-F. Operators.	4	N/A	N/A	N/A	1	N/A	1
235-F. Other assigned personnel.	1	N/A	N/A	N/A	1	N/A	1
A-Line (F). All assigned personnel.	1	N/A	12	N/A	N/A	N/A	1
772-F. Personnel assigned to laboratories in the PUREX and Pu sections.	2	1	N/A	N/A	N/A	N/A	1
221-F. Selected personnel.	1	N/A	N/A	N/A	N/A	N/A	1
221-H. Selected personnel.	2	4	N/A	N/A	N/A	N/A	1
313-M. All assigned personnel.	N/A	N/A	4	N/A	N/A	N/A	N/A
322-M. All assigned personnel.	1	4	4	N/A	N/A	N/A	1
320-M. All laboratory and selected radioactive material personnel.	N/A	4	4	N/A	N/A	N/A	1
321-M. All personnel assigned to charge prep, casting, and machining, and assembly weld areas.	1	12	N/A	N/A	N/A	N/A	1
773-A. Minimum potential.	1 ea. 3 yr	N/A	N/A	N/A	N/A	N/A	N/A
773-A. Selected ACD, SED, SCD, NMD, HLC, Radiation Control, Building Services, and Maintenance personnel.	2	N/A	N/A	1	N/A	N/A	1
773-A. Reactor Engineering and 777-M personnel.	1 ea. 3 yr	1	4	N/A	N/A	N/A	N/A
773-A. Selected clerical and supervisory personnel.	1	N/A	N/A	N/A	N/A	N/A	1
773-A. Maximum potential. Selected personnel.	2	2	4	2	N/A	N/A	1
221-S. All assigned personnel.	1	N/A	N/A	N/A	N/A	1	1
250-S. All assigned personnel.	1	N/A	N/A	N/A	N/A	1	1
210-Z. All assigned personnel.	1	N/A	N/A	N/A	N/A	1	1
247-F. Personnel who perform work in process core.	N/A	12	N/A	N/A	N/A	N/A	1
247-F. Personnel who do not perform work in process core.	N/A	4	N/A	N/A	N/A	N/A	1

a. N/A = not applicable; T&T = Transportation and Traffic; E&I = Electrical and Instrumentation.

ATTACHMENT C
EVALUATION OF HIGH-VARIABILITY AMERICIUM DATA

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ATTACHMENT C
EVALUATION OF HIGH-VARIABILITY AMERICIUM DATA (continued)

There have been several documents written about the variability of the SRS americium logbook data [SC&A 2014, 2019, 2020; ORAUT 2019; NIOSH 2019, 2020b]. Because the americium logbook data were reentered, the variability should be reassessed. NIOSH and SC&A have used the coefficient of variation (CV), also known as the relative standard deviation, as a metric to assess variability [ORAUT 2019; SC&A 2019; NIOSH 2020b]. The CV is the standard deviation divided by the absolute value of the mean and can be calculated for any result with multiple measurements.

Americium Data Details
This analysis focuses on the within-sample variability, which is the variability between measurements taken on the same disc. Only rows where the following conditions are met are considered:

- Not LIP (lost in process), and
- More than one non-blank disc result.

Of the 19,081 rows in the americium logbook dataset, 5,573 satisfy the two criteria listed above. For each of those rows, the mean (average of all nonblank disc results) and CV were calculated.

Variability Assessment
Variability can be assessed by looking at a plot of CV versus the absolute value of the mean. Figure C-1 is the full-scale plot, Figure C-2 is a zoomed version, and Figure C-3 is the full-scale plot on a log-log scale. Naturally, as the mean increases the CV decreases. The vast majority of the points behave as expected based on the formulation of the CV. The line [0.25 + 1/abs(mean)] was chosen to determine which disc results warranted closer inspection. As mentioned in NIOSH [2020b], there is no known criterion to deem any set of disc results as excessively variable. This line is not intended to try to do that; it is included to identify results for review, which are those that that fall outside (above or to the right and indicated by the red points) of the coefficient of variation inspection line.

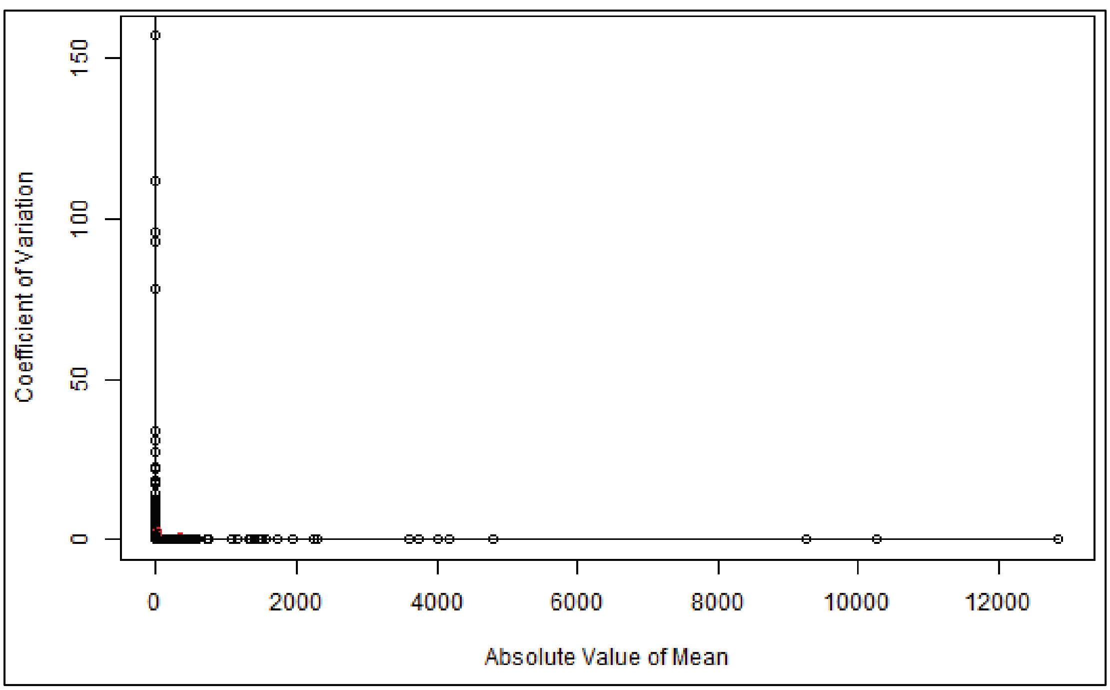

Figure C-1. CV versus absolute mean value for disc results.

ATTACHMENT C
EVALUATION OF HIGH-VARIABILITY AMERICIUM DATA (continued)

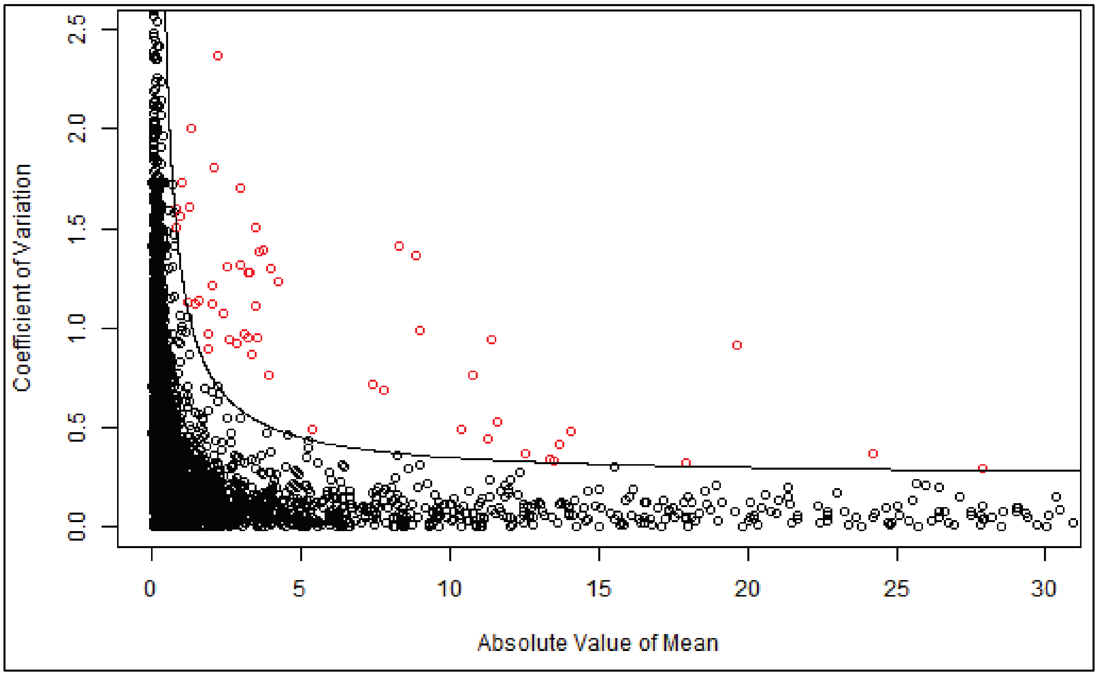

Figure C-2. CV versus absolute mean value for disc results, zoomed scale. Note that there are 6 points above the line that are not shown on this plot, with absolute value of the mean ranging from 58 to 328.

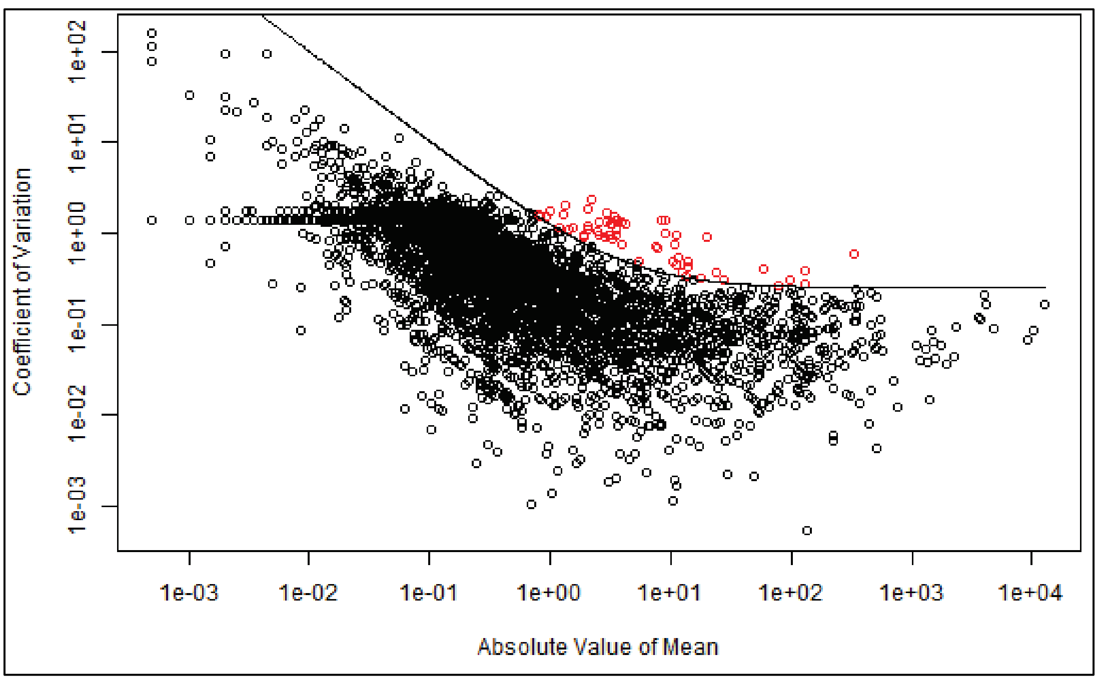

Figure C-3. CV versus absolute mean value for disc results, log-log scale.

Review of Disc Results

Using the line in the plots, there are 60 reviewed observations (out of 5,573, which is just over 1%) that are above and to the right of the line. While no single cause for the observed variability in these

ATTACHMENT C
EVALUATION OF HIGH-VARIABILITY AMERICIUM DATA (continued)

results could be identified, there were a few notable patterns. Of the 60 results that were reviewed, 51 had bottle dates in four fairly short periods.

Table C-1. Summary of bottle dates for 51 of 60 reviewed results.

Period	Number of reviewed results
08/20/1969–11/21/1969	6
02/09/1970–05/28/1970	11
01/19/1972–03/29/1972	9
05/17/1986–08/15/1986	25

The 25 results in the 05/17/1986–08/15/1986 period are from [redacted] workers, [redacted] of whom had 15 results with large reported plutonium results for the same samples. Problems with the alpha counter were noted with 5 results, and for 10 of the results it appears that a relatively high result from one count was not included in the final reported result.

In general, nothing about the 60 results that were reviewed indicated any systematic issue with the analytical procedure used for americium.

Conclusion
The second major conclusion from NIOSH’s previous white paper [NIOSH 2020b, p. 8] states:

> *In general, the original bioassay results of record at a site that were used to demonstrate compliance with the DOE regulations in place at the time of the analyses are considered to be the best available data to use for dose reconstruction and generation of co-exposure models. Limited review of that data is performed as a confirmatory measure.*

This analysis of variability serves as part of the limited review to be used as a confirmatory measure of fitness for use in co-exposure modeling. Nothing in this analysis suggests there is an issue with the within-sample variability of the SRS americium logbook data.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021

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ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

D.1 SOURCE DATA AND DATA PREPARATION INSTRUCTIONS

SOURCE DATA

All files in this section are in ORAUT [2022] in the \source data\ subfolder. Text in bold are the designations used to refer to the files throughout the instructions.

Bioassay Data:

- **NOCTS In-vitro Data:** SRS combined in-vitro data 051717.xlsx,
- **NOCTS H3 data:** SRS NOCTS Tritium_052710_postQA.mdb, using the *QC copy of SRS NOCTS Tritium_052710* table,
- **Np data:** Compiled_SRS Np Logbook_WHC_07202011r0 Mike.xlsx,
- **Np data2:** Np data new data entry 2013-09-10_review 10616.xlsx,
- **WBC data:** SRS combined in-vivo data 083117.xlsx,
- **MFPG WHC data:** Reviewed_MFP&G data for Board_032916.xlsx,
- **Am data:** REVIEWED_Am Final Compiled_SRS WHC_06302011r2Ready Updated rev4_062416.xlsx, and
- **Rev 6 Am data:** SRS Am – Review Details – All with Emp – 2021-08-31.csv.

Bioassay Correction Files:

- **NOCTS H3 corrections:** Tritium data corrections 2016-07-12.xlsx,
- **Np corrections:** Np logbook data corrections 2016-10-03.xlsx,
- **NOCTS In-vitro corrections 1:** In-vitro stat corrections 2017-08-02.xlsx,
- **NOCTS In-vitro corrections 2:** In-vitro stat corrections 2018-11-15.xlsx,
- **NOCTS In-vivo corrections:** In-vivo stat corrections 2017-11-09.xlsx,
- **WBC corrections:** WBC data corrections 2016-09-15.xlsx,
- **Am corrections:** Am logbook data corrections 2016-08-01.xlsx, and
- **MFPG corrections:** MFP&G data corrections 2016-06-22.xlsx.

Occupation Tables:

- **CTW Master Update Part 1:** Compiled CTW Master Update Part 1 with names_071516.xlsx,
- **CTW Master Update Part 2:** MOT Update Part 2_completed_rereviewed 090616.xlsx,
- **CTW Master Update Part 2 corrections:** MOT Update Part 2 corrections.xlsx,

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- **CTW Master Update Part 3:** Np data 2 nulls.xlsx,
- **CTW Master Update Part 4:** COMPILED SRS MOT_ 032717 MM updated rev1.xlsx,
- **MOT Corrections 1:** MOT corrections 2018-03-06.xlsx,
- **MOT Corrections 2:** MOT corrections 2018-08-23.xlsx,
- **MOT Corrections 3:** MOT corrections 2018-09-17.xlsx,
- **MOT Corrections 4:** MOT corrections 2018-09-24.xlsx, and
- **MOT Corrections 5:** MOT corrections 2018-10-02.xlsx.

Other Files:

- **Chelation Data:** SRS Chelation Data_Payroll ID's added_082514.xlsx,
- **Chelation Data for Am:** SRS Chelation Data_Payroll ID's update_23Aug2021 jmm.xlsx,
- **SRS NOCTS Names:** NioshClaims_With_Names.csv,
- **SRS NOCTS SSNs:** SRS SSNs.csv, and
- In-vitro nuclide list.xlsx.

Corrections and CTW Designations

The files listed above are combined to create files to be used for the individual nuclide co-exposure studies. Once corrections and CTW updates have been made, rename the files.

Renamed files, to be used with the individual nuclide sections below, are as follows and are available in ORAUT [2022] in the \Files Ready for Cleanup and Stat Analysis\ subfolder:

- **WBC data updated:** SRS combined in-vivo data subset 092518 with CTW,
- **NOCTS In-vitro Data updated:** SRS combined in-vitro data 091818 with CTW,
- **Np data updated:** SRS Np 1 Logbook In Vitro Data_100218_with CTW, and
- **Np data updated2:** SRS Np 2 Logbook In Vitro Data_100218_with CTW.

Data Corrections

For each applicable data source, make corrections as listed in the associated corrections file.

- Replace individual cell contents based on cell contents in the corrections file.
- If a cell in the corrections file contains "blank," then delete that cell's contents in the source data file.

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SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- If the corrections file comments column contains the word “exclude” or “remove” then do not use that line for the statistical analysis.
- Rows are identified by the Unique ID column except as otherwise noted.

1. Correct the **Np data** with the **Np corrections** file.
2. Correct the **WBC data** with the **WBC corrections** (identify lines by the “Unique # for Rick” column) and the **NOCTS In-vivo corrections** files.
3. Correct the **Am data** with the **Am corrections** file.
4. Correct the **MFPG data** with the **MFPG corrections** file.
5. Correct the **NOCTS In-vitro data** with the **NOCTS In-vitro corrections 1** and **2** files.
6. Correct the **NOCTS H3 data** with the **NOCTS H3 corrections** file.
7. Correct the **CTW Master Update Part 2** file with the **CTW Master Update Part 2 Corrections** file.

D.2 MASTER OCCUPATION TABLE INSTRUCTIONS

1. Merge the following files into one master occupation table **(CTW Master)**.
   a. Np data,
   b. WBC data,
   c. MFPG WHC data,
   d. Am data, and
   e. CTW Master Update Part 1, 2, 3, and 4.

Table D-1 lists the mapping of column identifiers from each of the source files to the CTW Master table. If a cell in a listed column of the source file is blank (blank or no characters other than space) and there is a second column identified in parentheses, use the value from the cell in that column instead. For the first and middle name initials, import only the first character of the name from the source files that provide the full first and middle name.[2]

[2] For the purposes of this evaluation, no distinction is made regarding CTW employer, whether prime contractor or subcontractor.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

Table D-1. CTW Master Table cross-reference.[a]

Master	Np data	WBC data	MFPG WHC data	Am data	CTW Master Update 1 and 2	CTW Master Update 3	CTW Master Update 4
PRID	Corrected PRID (Payroll ID#)	Corrected PR # (PR)	Corrected PR # (PR)	Changed Payroll ID# (Payroll ID#)	PRID	PRID	C PRID (PRID)
Last Name	Corrected Last Name (Employee Last Name)	Corrected last name (Last name)	Last name	Corrected Last Name (Employee Last Name)	Last Name	Last Name	Last.name
First Initial	Corrected FI (Employee First Initial)	First name	First Name	Corrected First Initial (Employee First Initial)	First Initial	First Initial	First.name
Middle Initial	Corrected MI (Employee Middle Initial)	Corrected middle name (Middle Name)	Middle Name	Corrected Middle Initial (Employee Middle Initial)	Middle Initial	Middle Initial	Middle.name
SSN	N/A	N/A	N/A	N/A	SSN	N/A	N/A
Occupation Title	Corrected Occupation Title (Occupation Title)	Corrected Occupation (Occupation Title)	Corrected Occupation Title (Occupation Title)	Changed Occupation Title (Occupation Title)	Corrected Occupation Title (Occupation Title)	Rev4Occ	C Job Title (Job Title)
Date	Bottle Date (Received Date)	Date	Date	Bottle Date	Date	Bottle Date	Date
NIOSH ID	N/A	Claim	Claim #	NIOSH ID	NIOSH ID	N/A	Claim
SRDB Ref ID	SRDB Ref ID	N/A	N/A	SRDB Ref ID	SRDB Ref ID	N/A	N/A
CTW	N/A	N/A	N/A	N/A	CTW	N/A	N/A
WkHxFile	Link to EDAR & WkHx Images	Link to EDAR & WkHx Images	Link to EDAR & WkHx Images	Link to EDAR & WkHx Images	EDAR.file	OccFile	C Job Hist Source (WkHxFileName)
WkHxPage	Page[b]	Page[c]	Page[d]	Page[e]	Page[f]	OccPage	WkHxFilePage[g]

a. SSN = Social Security Number; N/A = not applicable.
b. Page in column 18.
c. Page in column 14.
d. Page in column 23.
e. Page in column 19.
f. Page in column 15.
g. Only if the WkHxFile source is the WkHxFileName column, otherwise leave blank.

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SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

2. Remove duplicate lines.

3. Remove lines where the occupation is blank.

4. Use the first/middle/last name information (corrected and original) to assign NIOSH ID numbers to CTW Master Table rows without a NIOSH ID number where possible. Do not overwrite claim numbers found in the original files.

5. For each row with a NIOSH ID number and no SSN, look up the SSN in the SRS NOCTS SSNs file and add to the CTW Master Table where possible.

6. MOT corrections:

   a. Change PRID [redacted] to [redacted].

   b. For PRID [redacted], change occupation to [redacted].

   c. Change PRID [redacted] to [redacted].

   d. Change PRID “[redacted]” to [redacted].

   e. Make the changes identified in the MOT CORRECTIONS 1 through 5 files.

7. For all rows where the PRID prefix = “3-“, set CTW = Null.

8. For all rows where ([PRID prefix is 4 or ≥ “6“ except “30”] or any title listed in Table D-2) and excluding any title in Table D-3:

   a. Set CTW = ‘Y’.

   b. Otherwise, set CTW = ‘N’.

Table D-2. CTW occupation titles.[a]

Occupation title	Occupation title
*maintenance man	laborer
boilermaker	maintenance
carpenter	maintenance mechanic
concrete	maintenance mechanic a
concrete worker	mechanic
construction	millwright
construction worker	painter
crane operator	pipe fitter
ctw	pipefitter
driver	plumber
e&i tech	rigger
electrician	roll 5
heavy equipment operator	sheetmetal
insulator	sheetmetal worker
iron worker	Welder

a. Ignore capitalization differences.

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Table D-3. nonCTW occupation titles.[a]

Occupation title	Occupation title
Administrative Assistant	Laundry
Administrator	Layout
Assistant	Machinist
Cafeteria	Manager
CATI - Machinist	Material Control
Clerical	Operator
Crane Process Operator	Pilot
Designer	QA
Engineer	Radiographer
Escort	Reactor Operator
Foreman	Security
Geologist	Specialist
HP	Supervisor
Human Resources	Technician
Instructor	

a. Ignore capitalization differences.

9. If the PRID is a SSN, ignore the PRID field for CTW determination.

10. Overwrite CTW results as follows:

    a. Claim [redacted], for all dates, CTW = “N”,

    b. Claim [redacted], for all dates, CTW = “N”,

    c. Claim [redacted], CTW = “Y” before 02/01/1984, “N” on 02/01/1984 and after,

    d. PRID [redacted], for all dates, CTW = “Y”,

    e. PRID [redacted], CTW = “Y” on 11/19/1974,

    f. PRID [redacted], CTW = “Y” on 07/13/1982,

    g. PRID [redacted], CTW = “Y” on 02/09/1983,

    h. Claim [redacted], PRID [redacted] or [redacted], nonCTW after 05/27/1973,

    i. Claim [redacted], PRID [redacted] or [redacted], nonCTW after 06/04/1972,

    j. Claim [redacted], PRID [redacted] or [redacted], nonCTW after 06/02/1968,

    k. Claim [redacted], PRID [redacted] or [redacted], nonCTW after 05/06/1973,

    l. Claim [redacted], PRID [redacted], for all dates, nonCTW,

    m. Claim [redacted], PRID, nonCTW after 04/15/1973, and

    n. Claim [redacted], PRID [redacted], nonCTW after 11/02/1975.

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SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

D.3 CTW DESIGNATION INSTRUCTIONS

1. For each radionuclide data set used for the co-exposure study, create a new column of data labeled "Rev4CTW."
2. For each line of data in the data set, look up the CTW designation in the **CTW Master** file for that person and date.[3]
   a. Match the person based on the following fields given in preference order:
      i. NIOSH ID,
      ii. PRID, and
      iii. Last name and First/Middle initial.
   b. Find the CTW designation date for that person in the following priority order:
      i. Same date,
      ii. Most closely preceding date, and
      iii. Most closely following date (within 5 years).
   c. Use the CTW designation on above date to update the data set. (Note: There should be exact date matches for all dates in the Am, Np, and WBC data files.)
   d. If the person or a suitable CTW designation date cannot be found in the CTW Master file, mark the CTW designation as NULL.
3. Generate a list of all records where the Rev4CTW designation is NULL.
4. Manually determine the PRID and occupation for each NULL record and generate a CTW Master Update file with the new information.
5. Update the CTW Master Table to include the data in the newly generated CTW Master Update file.
6. Repeat Steps 2-5 until no records have a Rev4CTW designation of NULL.

D.4 RADIONUCLIDE INSTRUCTIONS

Note: The column indicating a "less than" result has a header of "<" in some files and "X." in others. This document refers to the column as "X."

3 For the purposes of this evaluation, no distinction is made regarding CTW employer, whether prime contractor or subcontractor.

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SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

D.4.1 All Nuclides

Correct illegible dates (illegible fields are indicated with Xs for radionuclides other than Am):

- Exclude records with an illegible year.
- If only the day of the month is illegible, assume the 15th.
- If only the month is illegible, assume July.
- If the month and day are illegible, assume July 1.

D.4.2 Mixed Fission Products (MFPBeta/Strontium)

New corrections file: *In-vitro stat corrections 2018-12-05.xlsx* may be found in ORAUT [2022] in the \source data\ subfolder.

Data Selection

- Use NOCTS In-vitro Data updated as the data source.
- Select records from 01/01/1955 through 12/31/1965 with an Isotope that indicates an MFP result. Refer to *In-vitro nuclide list.xlsx* for the complete list of MFP codes to be used.
- Exclude records:
  - With a blank Result and a blank X. field,
  - With non-numeric results (e.g., LIP, rerun, lost), with the exception of “DL”,
  - If the Units field contains:
    - “LIP” or “IA”,
    - Mass in the denominator (varying gram quantities). These are assumed to be fecal samples,
  - If Date is blank or nonsensical, or
  - With X. = “<” and Result =
    - 300, or
    - 500.

Note: This step is used to eliminate gross gamma results listed as the same isotope as gross beta results.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

Data Cleanup

- If the Result field is blank and the X. field = “<”, assign Result as follows:
  - 1955–1961: 30.
  - 1962–1965: 100.
- If Result = DL (ignore capitalization differences), replace it with the number “1.”
- Ignore (delete) uncertainties in results, e.g., “± 19.”
- If Units is blank or contains no volume, assign Units as follows:
  - 1955–1959: dpm/750 ml,
  - 1960–03/31/1966:
    - If result is “<30” or “<50”: dpm/500 ml,
    - If result is “<100”, “<500”, or “<60”: dpm/1.5L, and
    - If X. is blank: dpm/1.5L.
- Incident corrections:
  - Claim [redacted]: incident on [redacted]. Infer a result of <60 dpm/1.5L on [redacted].

Data Adjustments

- Convert all results to units of dpm/day (dpm/1.5L).
  - Do not adjust results with volumes ≥ 1.4 liter. These are assumed to represent a full day’s voiding.
  - Normalize results with volumes < 1.4 liter to 1.5 liters (assumed to be one day’s voiding).

Statistical Analysis

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. The periods for which a similar method and reporting was used and which could be combined to develop an imputation model are:
  - 1955–1961, and
  - 1962–1965.
- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053 as follows:
  - Evaluate two strata: 1) CTW and 2) nonCTW.

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SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

D.4.3 Plutonium

New corrections file: *In-vitro stat corrections 2018-11-15.xlsx* may be found in ORAUT [2022] in the \source data\ subfolder.

Data Selection

- Use NOCTS In-vitro Data updated as the data source.
- Select records from 01/01/1955 through 12/31/1990 with an Isotope that indicates a total plutonium or Pu-239 result. Refer to *In-vitro nuclide list.xlsx* for the complete list of Pu codes to be used.
- Exclude records:
  - With a blank Result and a blank X. field.
  - With non-numeric results (e.g., LIP, rerun, lost).
  - If the Units field contains:
    - "LIP" or "IA,"
    - Mass in the denominator (varying gram quantities). These are assumed to be fecal samples.
  - If Date is blank or nonsensical.
  - With activity units of pCi, nCi, or μCi. These are assumed to be fecal samples.
  - With a date on or within 100 days following chelation for an individual. Use **Chelation Data** referenced in the Source Data section above. Match individuals based on SSN.
  - Claim [redacted]: Incident mid-1982. Exclude data from 10/24/1982 through 01/06/1983.
  - All results for claim [redacted] beginning in Oct. 1962. Significant [redacted] incurred at this time so results are not representative of coworkers (co-exposure intake model assumes inhalation intakes).

Data Cleanup

- Ignore (delete) uncertainties in results, e.g., "± 19."
- Assume the Units for Unique ID [redacted] are dpm/mL (i.e., 0.28 dpm/1,340 mL).
- If Result is blank or 0 and the X. column contains "<", assume Result is:
  - 0.05 from 1954 through 05/01/1962, and
  - 0.1 for 05/02/1962 and after.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Designation of missing or incomplete (no volume) units:
  - If Isotope is generic plutonium (i.e., Pu, PU, or any result with no atomic mass #), assume dpm/1.5L, and
  - If Isotope is isotope specific (e.g., Pu-239, Pu 238/239), assume dpm/L.
- Treat negative Result values as censored results, censored at the absolute value of the Result [1].
- A “+” in the X. column is treated as a blank (i.e., an uncensored result).
- Incident corrections:
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.05 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of 0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.1 dpm/day on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <0.18 dpm/day on [redacted].

Data Adjustments

- Convert all results to units of dpm/day (dpm/1.5L).
  - Do not adjust results with volumes ≥ 1.4 liter. These are assumed to represent a full day’s voiding.
  - Normalize results with volumes < 1.4 liter to 1.5 liters (assumed to be one day’s voiding).

Statistical Analysis

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. Gross alpha and isotopic plutonium results are imputed separately.
  - The periods for which a similar method and reporting was used and which could be combined to develop an imputation model for gross alpha Pu results are:

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

    - 1954–1959,
    - 1960–05/01/1962,
    - 05/02/1962–1965, and
    - 1966–1990.
  - Isotopic Pu (any variation of “Pu239”),
    - 1981–1990.

- Additional data adjustment: beginning on 01/01/1981, correct isotopic Pu results (any variation of “Pu239”) to Pu gross alpha by multiplying by 1.69 (10-year 12% Pu mix ratio).
  - “Pu238/239” (or similar variants) are assumed to be Pu gross alpha results and are not adjusted.

- Perform the statistical analysis for 1955 through 1990 in accordance with the TWOPOS method in the latest version RPRT-0053 evaluating two strata: 1) CTW and 2) nonCTW.

D.4.4 Uranium

Data Selection

- Use NOCTS In-vitro Data updated as the data source.

- Select records from 01/01/1953 through 12/31/1990 with an Isotope that indicates a uranium result. Refer to *In-vitro nuclide list.xlsx* for the complete list of U codes to be used. Note that mass and activity measurements will be combined into one data set.

- Exclude records:
  - With a blank Result and a blank X. field.
  - With non-numeric results (e.g., LIP, rerun, lost).
  - If the Units field contains:
    - “LIP” or “IA,”
    - Mass in the denominator (varying gram quantities). These are assumed to be fecal samples.
  - If Comments.from.page contains “IA.”
  - If Date is blank or nonsensical.

Data Cleanup

- If Units is blank or nonsensical:

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Replace “?” or other special character with “u” (micro).
- If result is “<5”, assign Units = ug (mass units).
- If result is “<1”, assign Units = dpm (activity units).
- If the result is not “<5” or “<1” and
  - Isotope = EU (any capitalization variation), assign Units = dpm (activity units).
  - Isotope ≠ EU, then Units = ug (mass units).

- If Result = 0 and Units = ug/L, set X. = < and Result = 5. (*Result is assumed to be censored*.)
- If Result is blank and the X. column contains “<”, assume Result is:
  - 5 if Units includes “ug” (results in units of mass).
  - 1 if Units includes “dpm” or “d/m” (results in units of activity).
- Ignore (delete) uncertainties in results, e.g., “± 19.”
- A “+” in the X. column should be treated as a blank (i.e., an uncensored result).
- Incident corrections:
  - Claim [redacted]: Incident on [redacted]. Infer a result of <1 dpm/1.5L on [redacted].
  - Claim [redacted]: Incident on [redacted]. Infer a result of <5 ug/L on [redacted].

Data Adjustments

- If Units includes “ug” (results in units of mass):
  - 1953–07/10/1961:
    - Multiply Result by 1.5 (all Units are assumed to be per liter regardless of stated volume).
    - If Units ≠ ug/1.5L, replace Units with ug/1.5L.
  - 07/11/1961–1990: If Units ≠ ug/1.5L, replace Units with ug/1.5L (all Units are assumed to be per 1.5 liter regardless of stated volume).
- If Units includes “dpm” or “d/m” (results in units of activity):
  - If no volume is included in the Units, assume 1.5L.
  - Do not adjust results with volumes ≥ 1.4 liter. *These are assumed to represent a full day’s voiding*.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Normalize results with volumes < 1.4 liter to 1.5 liters (*assumed to be one day's voiding*).

Statistical Analysis

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. Results with mass and activity units are imputed separately.
  - If Units = ug/1.5L (mass), the periods for which a similar method and reporting was used and which could be combined to develop an imputation model are:
    - 1953–1981,
    - 1982–1985, and
    - 1986–1990.
  - If Units = dpm/1.5L (activity), the periods for which a similar method and reporting was used and which could be combined to develop an imputation model are:
    - 1953–04/1962,
    - 05/1962–1981,
    - 1982–1985, and
    - 1986–1990.
- Additional data adjustment: If Units = ug/1.5L (results in units of mass), convert Result to Units of dpm/day (activity):
  - 1953–1967: Multiply Result by 1.52 dpm/ug (i.e., assume natural uranium).
  - 1968–1990: Multiply Result by 0.826 dpm/ug (i.e., assume DU).
- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053 as follows:
  - Evaluate two strata: 1) CTW and 2) nonCTW.
  - For nonCTW, evaluate individual years.
  - For CTW, combine (*note that there are insufficient results for 1953–1954*):
    - 1979–1980,
    - 1981–1982,
    - 1983–1984,
    - 1985–1986,

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- 1987–1988, and
- 1989–1990.

D.4.5 Cesium-137

New corrections file: *In-vivo stat corrections 2018-12-11.xlsx* may be found in ORAUT [2022] in the \source data\ subfolder.

Data Selection

- Use **WBC Data updated** as the data source.
  - Select records with Dates from 01/01/1960 through 12/31/1990.
  - Select rows with Nuclide = Cs-137. The result is found in the column headed Result..nCi.
- Exclude records:
  - With a reason of:
    - “New”,
    - “New Hire”, or
    - “New Employee”,
  - If Date is blank or nonsensical, or
  - With Nuclide = Cs-137 where the first character of Result..nCi. = X or an X appears in the value to the left of a digit (e.g., “0.X2”).
- For a Claim/Date combination with no Nuclide = Cs-137 record but with a record for another nuclide other than chest count radionuclides (Am, Cm, Pu, EU, U, U-234, U-235, U-238), infer a single Cs-137 result. Include Form type in the inferred record.
  - Do *not* infer a result if all Nuclides for the date are blank and Detector includes the word “Crystal,” “Phoswich,” or “Phos.” (*These are indicative of chest counts rather than WBCs.*)
  - If date is <01/01/1989, assign Result..nCi. = <1.
  - If date is >12/31/1988, assign Result..nCi. = <2.2.

Data Cleanup

- If Comment includes “MDA activity used,” consider the result to be censored.
- When Result..nCi. contains a trailing X character (e.g., “6.5XX”), truncate after the last digit (6.5XX becomes 6.5).
- For multiple rows with the same Claim and Date values and Nuclide = Cs-137:

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- If multiple rows have the same Result..nCi., use only one of those results.
- If values of Result..nCi. are not equal, average the results.
- If at least one row has a Cs-137 Result..nCi. value, do not infer results for any others with a blank Result..nCi. (next step).

- If Result..nCi. is blank:
  - Apply MDA..95.CL..nCi. value as the censoring level.
  - If MDA..95.CL..nCi. is also blank:
    - If date is <01/01/1989, assign Result..nCi. = <1.
    - If date is >12/31/1988, assign Result..nCi. = <2.2.

Statistical Analysis

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. The form types for which a similar method and reporting was used and which could be combined to develop an imputation model are:
  - **WBCD**. This form was in use from approximately 1960 through the mid-1970s and was used with the 40-cm arc geometry.
  - **BB (through 01/1974)**. This form was untitled and was used in the mid- and late 1970s. The 40-cm arc geometry was being used before February 1974.
  - **BB (02/1974 and later).** A bed geometry was used after January 1974.
  - **IVCR**. This was in use from the late 1970s through late 1980s.
  - **SSI**: Used from 1975–1977.
  - **ABACOS**. This is the FASTSCAN report and was used from 1986 through 1990.
- Assign rows with Form type = blank, “In Vivo Request,” or “Request“ to the following categories:
  - 1960 through 11/1974: **WBCD**,
  - 12/1974 through 05/1979: **BB (02/1974 and later)**,
  - 06/1979 through 10/1989: **IVCR**, and
  - 11/1989 through 12/1990: **ABACOS**.
- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053:

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Before 1989, use a generic censoring level of <1.0 for negative or zero TWOPOS results. For 1989 and 1990, use <2.2.
- Evaluate two strata: 1) CTW and 2) nonCTW.
  - For CTW, combine the years (note that there are no CTW results in 1960):
    - 1964–1966,
    - 1967–1968,
    - 1969–1971, and
    - 1972–1973.
  - For nonCTW, combine the years:
    - 1960–1961,
    - 1965–1966, and
    - 1969–1970.

D.4.6 Cobalt-60 (Mixed Fission Products Gamma)

New corrections file: *In-vitro stat corrections 2018-12-05.xlsx* may be found in ORAUT [2022] in the \source data\ subfolder.

Data Selection

- Use **NOCTS In-vitro Data** with corrections applied as the data source.
- Select records from 01/01/1966 through 12/31/1970 with Isotope =
  - FP (IA),
  - FP(IA),
  - FPIA,
  - IAFP,
  - FP-IA,
  - FP/IA,
  - IA,
  - IA-G, and
  - IA GAMMA.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Exclude records:
  - With a blank Result,
  - With a nonsensical date,
  - With Units = dpm/1.5L and Result ≤ 250 (*these are assumed to be beta results*), or
  - If Comment includes "beta".

Data Cleanup

- If Units is blank, assign Units = nCi/1.5L.

Data Adjustments

- If Units includes "dpm" in the numerator, divide Result by 2,220 to get Units of nCi.
- Divide all Results by 2 (*to account for the 2 gamma rays emitted by Co-60*).

Statistical Analysis

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. Gross gamma results are only evaluated for a short (5-year) period, during which the gross beta method did not change. It is presumed that the gross gamma method also did not change during this period. Therefore, the period for which the data could be combined to develop an imputation model is:
  - 1966–1970.
- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053 as follows:
  - Evaluate two strata: 1) CTW and 2) nonCTW.
  - For both strata, evaluate individual years.

D.4.7 Neptunium

Two bioassay types (in vivo and in vitro) are used for neptunium analysis; they are addressed separately here.

IN VIVO BIOASSAY
Data Selection

- Use **WBC Data updated** as the data source.
  - Select records from 01/01/1970 through 12/31/1990.
  - For records with the same Claim, Date, and Page:
    - Form.Type = "WBCD" and Nuclide = "I-131" and "K-40" form a matched pair (one I-131 record and one K-40 record). If one these is missing, exclude from the analysis.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- ➤ Exclude lines with a blank net c/m field.
- ➤ For each set of lines with the same claim-page-nuclide combination and identical net c/m results, use only one line.

- o Form.Type = “BB” and Nuclide = “I-131”, and
- o Form.Type = “IVCR” and Nuclide = “Cr-51”.

- Exclude records:
  - – If any values necessary to complete these calculations are missing,
  - – With a date on or within 100 days following chelation for an individual. Use **Chelation Data** referenced in the Source Data section above. Match individuals based on SSN,
  - – With Claim = [redacted] and Date = [redacted] (*analyzer malfunction*),
  - – With Claim = [redacted] and Date = [redacted] (*analyzer malfunction*),
  - – With Claim = [redacted] and Date = [redacted] (*analyzer malfunction*), or
  - – With Claim = [redacted] and Date = [redacted] (*analyzer malfunction*).

Data Adjustments

- Convert the data to nCi Np-237 as follows:
  - – If Form.Type = WBCD:
    nCi Np-237 = 0.243 × [I-131 “NET c/m” − (K-40 “NET c/m” × 0.389)].
  - – If Form.Type = “BB” and Date < 01/01/1975:
    nCi Np-237 = 0.01215 × (I-131 “DIFF counts”).
  - – If Form.Type = “BB” and Date > 12/31/1974:
    nCi Np-237 = 0.0125 × (I-131 “DIFF counts”).
  - – If Form.Type = “IVCR”:
    nCi Np-237 = 0.211
    × Cr-51 “MDA @95% CL (nCi)”
    × Cr-51 “DIFF counts”
    ÷ Cr-51 “MDA @95% CL (counts)”.

Statistical Analysis

- There are no censored data so multiple imputation is not needed.
- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053 as follows:
  - – For TWOPOS results of 0 (uncensored zero), replace results with <0.007 nCi.*

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Evaluate two strata: 1) CTW and 2) nonCTW.
  - For nonCTW, evaluate individual years. Note that 1990 was not fit because there were no data meeting the selection criteria.
  - For CTW, combine:
    - 1970–1972,
    - 1976–1977, and
    - 1988–1989.

* This value is derived as follows: The average Cr-51 MDA is 423 counts and 14 nCi. A conversion constant of 0.211 and DIFF = 1 (the smallest possible positive value) yields a minimum positive activity of 0.007 nCi.

IN VITRO BIOASSAY
Data Selection

- Use **Np data updated** and **Np data2 updated** as the data sources.
- Select records from 01/01/1961 through 12/31/1969.
  - For **Np data updated,** date = Received.Date. If Received Date is blank, use Bottle.Date. (*This is done for consistency; only Bottle Date was reported for most years.*)
  - For **Np data2 updated,** date = Bottle.Date (*this is the only date in the file*).
- Exclude **Np data updated** records with:
  - Rev4CTW = blank,
  - Comment = “No Np result” or similar,
  - Np..results is blank,
  - Date is blank or has an illegible year.
  - Np..results contains an “X” and does not include “<”,
  - A date on or within 100 days following chelation for an individual. Use **Chelation Data** referenced in the Source Data section above. Match on Payroll.ID, ignoring prefix, or
  - row.ID = [redacted] (*considered to be a false positive result*).

Data Cleanup

Np data updated

- All records are assumed to be in units of dpm/1.5L.
- If Np..results = “<0.0X” or “<0.XX” replace value with “<0.05”.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- For rows with Np..results = "<1", replace value with "<0.1" (*logbook entry error/illegibility of decimal place*).

Np data2 updated

- For rows with multiple reported dpm.1.5L..x. (where x is 1 or greater) values, average all values to determine the final result for the row.
  - Set censored values equal to the censoring level before averaging.

Statistical Analysis

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. The periods for which a similar method and reporting was used and which could be combined to develop an imputation model are:
  - 1961–04/1962, and 05/1962 where Np..results = "<0.05", and
  - 05/1962 where Np..results = "<0.1", and 06/1962 through 1969.
- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053 as follows:
  - Evaluate two strata: 1) CTW and 2) nonCTW.
  - For both strata, evaluate individual years. *Note that CTW 1964–1969 are not fit because there are only 16 results in the period.*

The following sections are unchanged from the Revision 3 analyses.

D.4.8 <u>Tritium</u>

NOCTS H3 Data:

- MDA values:
  - Use the result "<X" values where available if "X" is >0,
  - Otherwise use generic MDAs of:
    - 1 µCi/l through 1980,
    - 0.5 µCi/l for 1981 through 1985, and
    - 0.1 µCi/l for 1986 and after.
  - For reported positive, nonzero values less than the generic MDA, use the reported value as the MDA.
- Use the "Date" (column D) as the date of sample collection.
- Use the Claim # field as the individual identifier.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Data set exclusions and revisions:
  - ID [redacted]: Change result to “<0.5”,
  - Exclude ID [redacted] (blank result),
  - Exclude ID [redacted] (blank result),
  - Change all “<0.05” and “< 0.05” results to “<0.5”, and
  - Exclude all data from Claim # [redacted] (not an SRS worker).
- For each sample date, determine the individual’s CTW designation as described above.
  - Look up the individual name using the SRS NOCTS Names file as needed to assist with CTW determination.
- Calculate annual doses for each claimant in accordance with OTIB-0011 with the following assumptions:
  - Evaluate each individual’s CTW and nonCTW data, designated using the CTW designations determined in the previous step, separately and treat as two different workers.
  - If there are more than 90 days between samples, use a Type 3 analysis under the assumption that the person is not routinely monitored.
  - If there is a single non-detect urine sample in a calendar year, do not calculate a dose for that sample because it is assumed to not be part of routine monitoring.
  - Order samples on the same date from lowest to highest.
  - Assign all dose as if it occurred on the bioassay date.
- Statistical analysis:
  - Evaluate CTW and nonCTW strata separately for 1954 through 1990.
  - Sum dose for each individual for each year. Exclude from the statistical analysis any individual with an annual dose of less than 0.001 rem at three significant digits (i.e., less than 0.0005 rem).
  - Calculate GM and GSD values for the total annual doses using RPRT-0053 methodology.

D.4.9 <u>Americium</u>

Am logbook data:

- Dataset rows will be identified by their DetailID # (DetailID1).

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Do not use records:
  - If the “Am_report_IsLIP” field is True,
  - If the “Am_report” and all “discResult” fields are blank,
  - With the following anywhere in the “remarks” field,
    - “DTPA”,
    - “Am DNR”,
    - “Lost”,
    - “Am DNR “ (Note that there is an extra space after the R in the spreadsheet),
    - Do not report #6 until rerun and found valid,
    - DTPA Program, or
    - Rerun #7 (Am) lost.
- Individual discResults for which “Am_discResult_X_IsLip” is TRUE (other “discResult” values for that record are still used).
  - Data exclusions:
    - empid [redacted], incident on [redacted], exclude all results for [redacted],
    - empid [redacted], exclude result on [redacted], false positive,
    - empid [redacted], exclude result on [redacted], false positive,
    - empid [redacted], exclude result on [redacted], false positive,
    - empid [redacted], ingestion intake on [redacted], exclude all results for [redacted],
    - empid [redacted], Pu wound intake on [redacted], exclude all results for [redacted],
    - With a type of “DTPA” or similar, and
    - Within 100 days after receiving chelation as indicated in the Chelation Data spreadsheet. Match results to the chelation spreadsheet using last name and PRID. Disregard PRID prefixes for matching bioassay results to the Chelation Data spreadsheet. If the changedPrid field is blank, use the prid field instead.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Volume corrections:

  The following applies to each row of the dataset where unassociated rows are the only row in their block and where rows that are associated with one another are in the same block. For each block, calculate the following summary statistics:

  – Mean disc result: the average of the individual disc results from all lines in the block, calculated as mean(Am_discResult1, …, Am_discResult10).

  – Censored disc result: the mean disc result is considered censored if every nonblank disc result in the block is marked as censored.

  – Mean report value: the average of the individual report values from all lines in the block, calculated as mean(Am_report). Note that for unassociated rows this will simply be the report value.

  – Censored report: the mean report value is considered censored if every nonblank report value in the block is marked as censored. Thus, if two associated rows both have a report value listed, and one is censored and one is uncensored, the block is considered uncensored.

  – Volume: sum the sample volumes of all rows within the block.

  – Date: the earliest bottle date in the block.

  – Detail ID: the minimum Detail ID in the block.

  – Acidified volume (*a_h_*): the acidified volume associated with the Detail ID for the block.

  – Create a Multiplier column and populate it as follows:

- For each row with an uncensored mean disc result and an uncensored mean report value, do the following:

  – Calculate each of the following multipliers:

    1. Multiplier =1,
    2. Multiplier = 300 ÷ *a_h_*,
    3. Multiplier = 250 ÷ *min*(*volume*,250),
    4. Multiplier = 1.5, and
    5. Multiplier = 1.5 × 250 ÷ *min*(*volume*,250).

  – Calculate the absolute value of the difference between each of the 5 multipliers listed above and the “empirical” multiplier, which is the mean report value divided by the mean disc result.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

  - Assign the Multiplier with the smallest absolute error.

- For all other rows, assign a Multiplier of 1.

- Manual adjustments to Multiplier column, which override any Multiplier chosen above:

  - Detail ID’s 17785-17787 should be assigned a Multiplier of 3.5.

  - Detail ID’s 16160-16162 and 19683-19690 should be assigned a multiplier of 30.

  - Remarks that contain “300/XXX” where XXX is a numeric value should be assigned a multiplier of 300/XXX, except for Detail ID’s 19647 and 19653.

  - Remarks that contain “250/XXX” where XXX is a numeric value should be assigned a multiplier of 250/XXX, except for Detail ID 4127.

  - Detail ID’s 5481-5486 should be assigned a multiplier of 5.

- Using the Multiplier variable described above, calculate the following variables for each block:

  - Adjusted Report: which is defined as the mean disc result multiplied by the Multiplier, unless the mean disc result is missing, in which case, use the mean report value.

  - Censored: which will be the censored disc result variable, unless the mean disc result is missing, in which case, use the censored report variable.

  - The values are in units of dpm/1.5L (i.e., dpm/day).

- Use the following censoring levels for negative/zero values:

  - 1963–1965: 2 dpm/1.5L,

  - 1966–1967: 3 dpm/1.5L,

  - 1968: 1 dpm/1.5L, and

  - 1969–1989: 0.3 dpm/1.5L.

- Evaluate the censored data using multiple imputation as described in ORAUT-RPRT-0096. The periods for which a similar method and reporting was used and which could be combined to develop an imputation model are:

  - 1963–1965,

  - 1966–1967,

  - 1968, and

  - 1969–1989.

ATTACHMENT D
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-TKBS-0003-7, REVISION 0, AUGUST 19, 2021 (continued)

- Perform the statistical analysis in accordance with the TWOPOS method in the latest version of RPRT-0053 as follows:

- Evaluate two strata: 1) CTW for 1965–1989 and 2) nonCTW for 1963–1989.

- For CTW, evaluate individual years except 1966–1967, 1983–1984, 1985–1986, and 1987–1989. For nonCTW, evaluate individual years except 1963–1964 and 1988–1989. Merge grouped years.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES

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The supporting data for the figures in this attachment are contained in ORAUT [2022] in the \intake modeling\ subfolder.

E.1 AMERICIUM INTAKE MODELING RESULTS

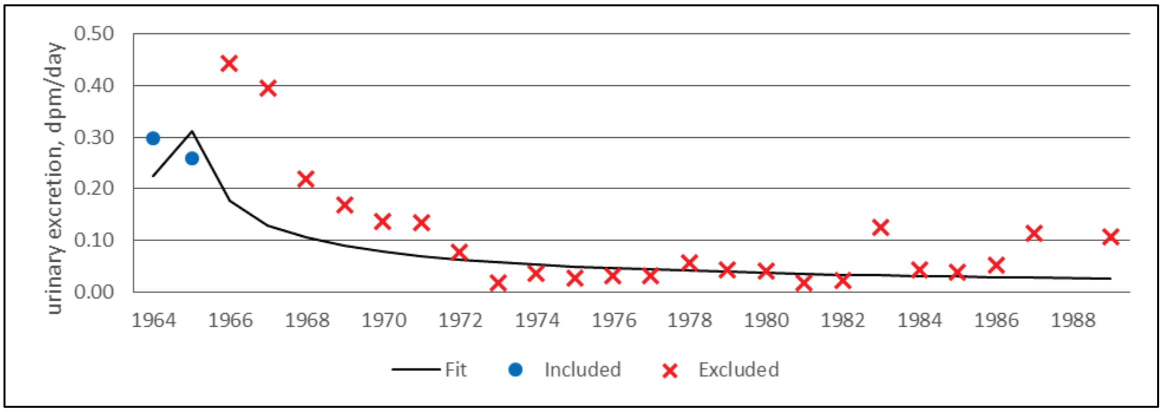

Figure E-1. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1963 to 1965, type M.

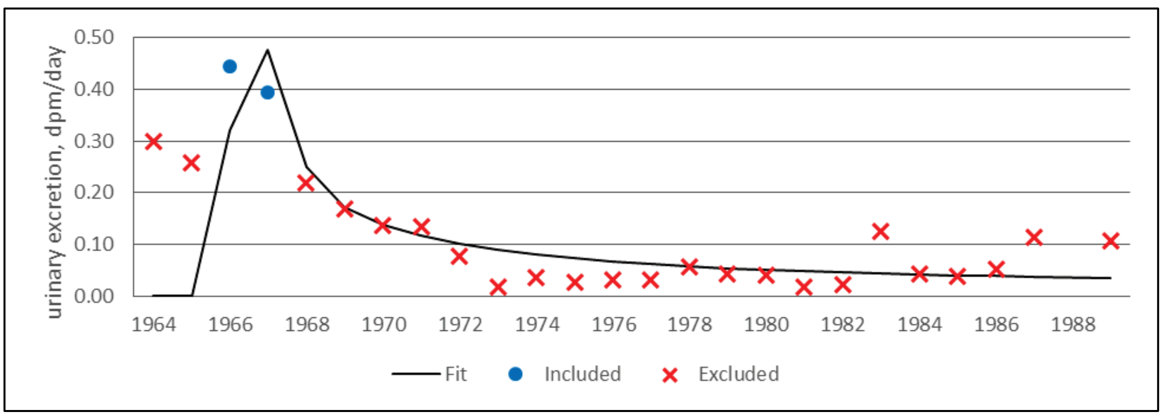

Figure E-2. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1966 to 1967, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

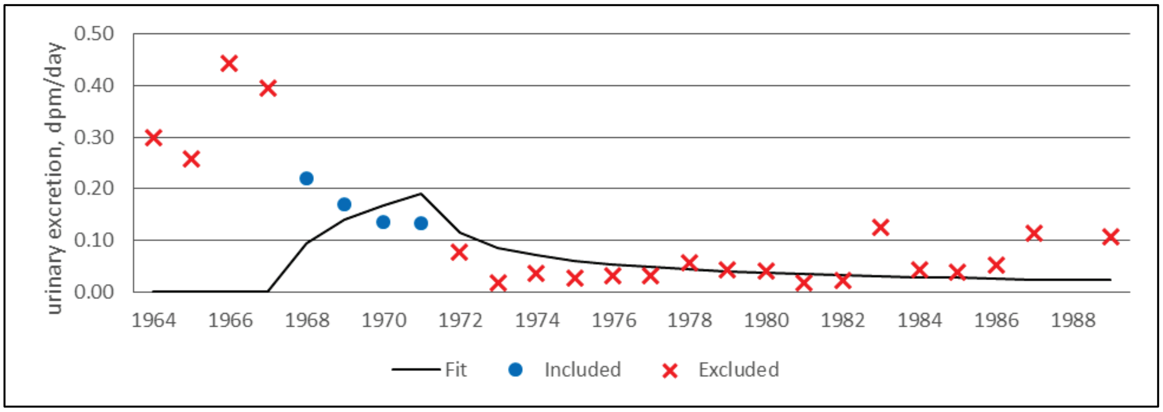

Figure E-3. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1968 to 1971, type M.

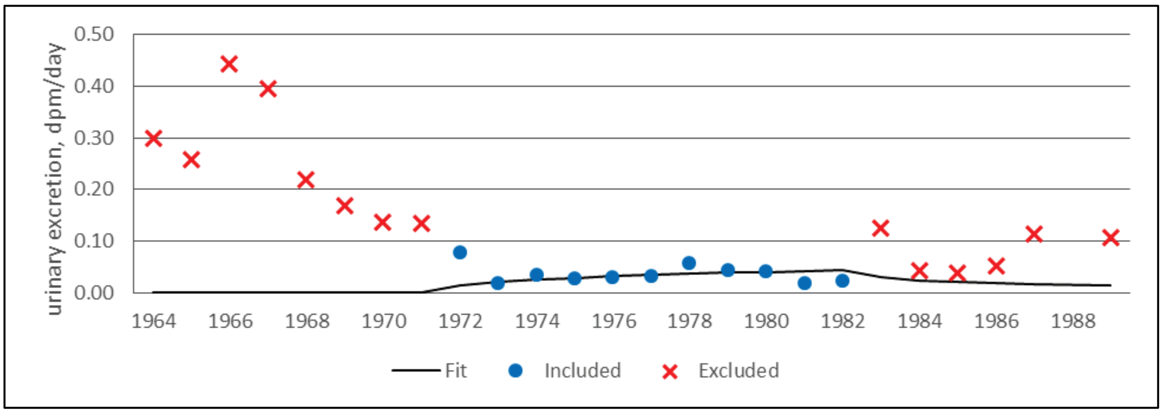

Figure E-4. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1972 to 1982, type M.

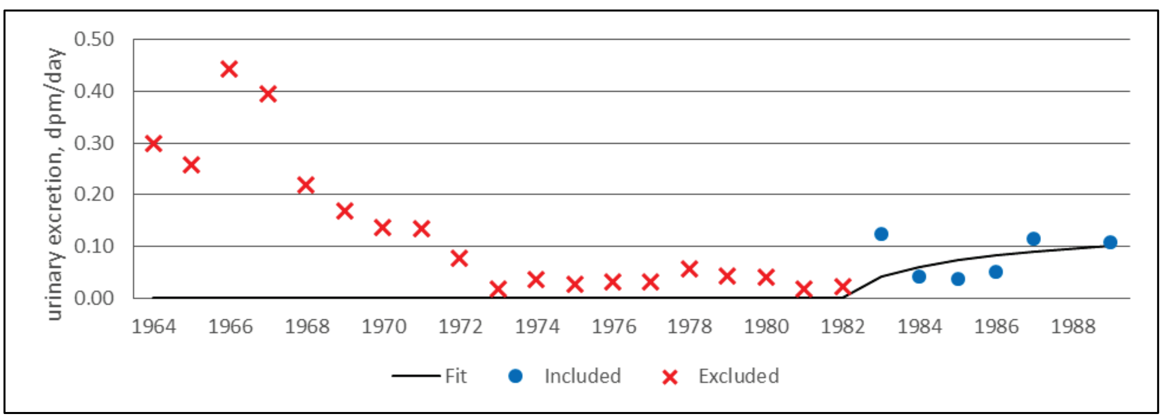

Figure E-5. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1983 to 1989, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

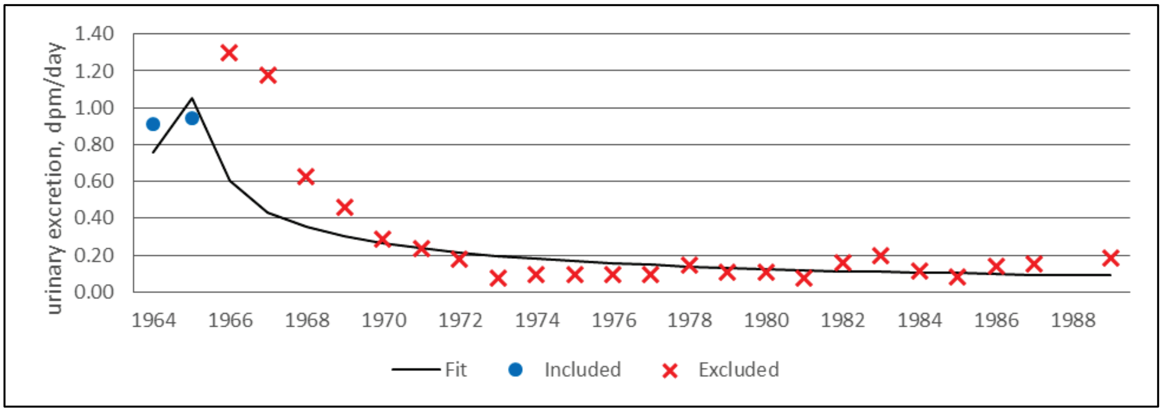

Figure E-6. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1963 to 1965, type M.

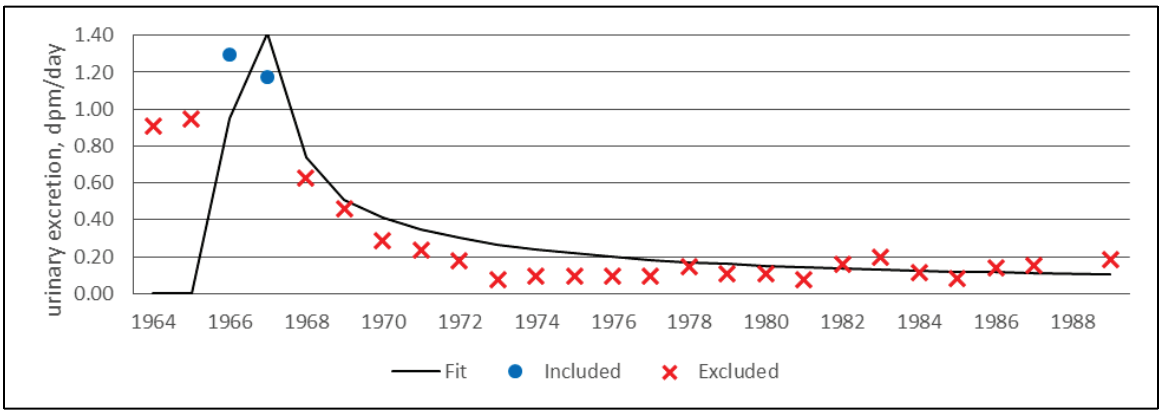

Figure E-7. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1966 to 1967, type M.

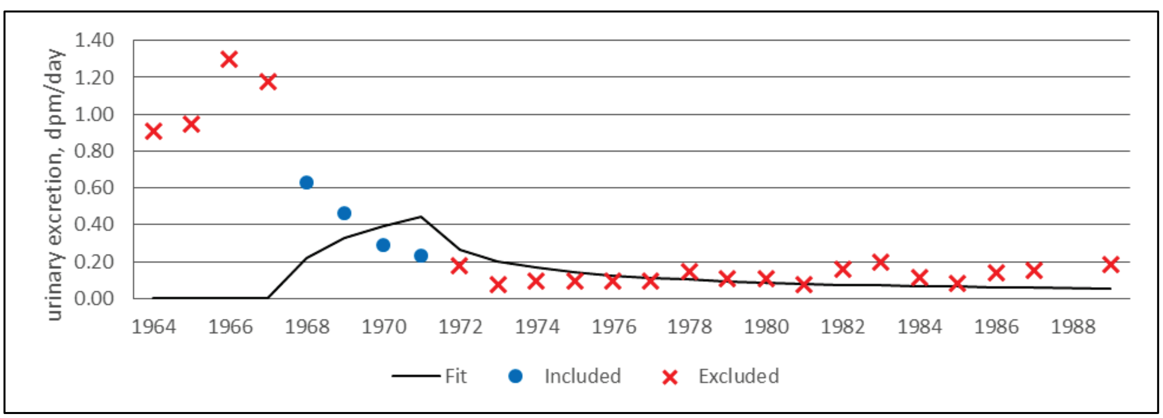

Figure E-8. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1968 to 1971, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

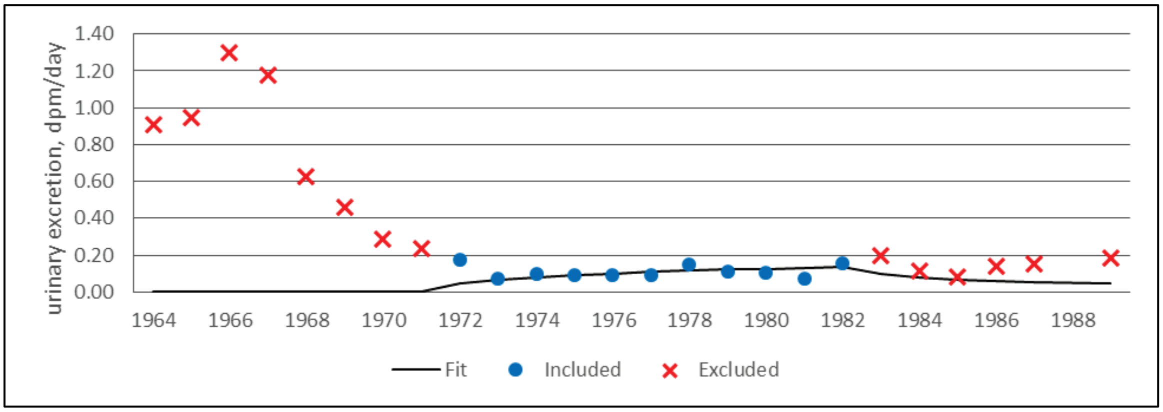

Figure E-9. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1972 to 1982, type M.

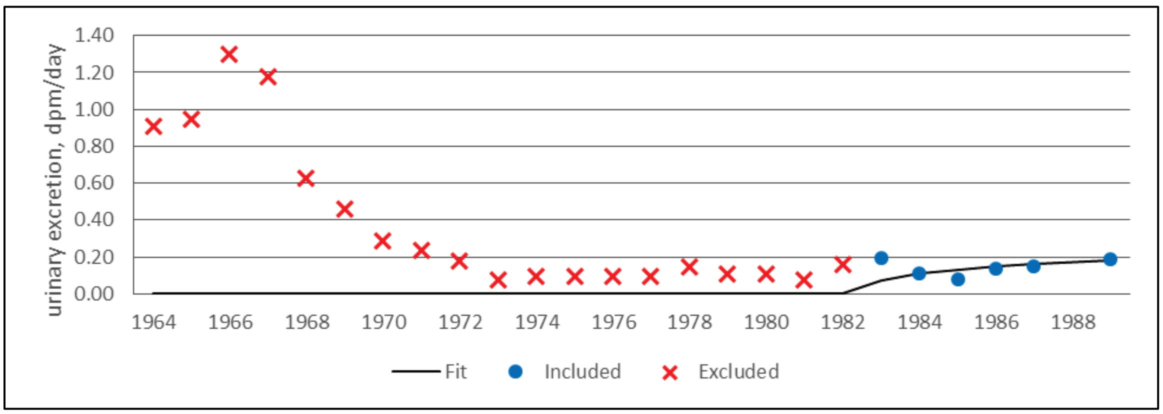

Figure E-10. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1983 to 1989, type M.

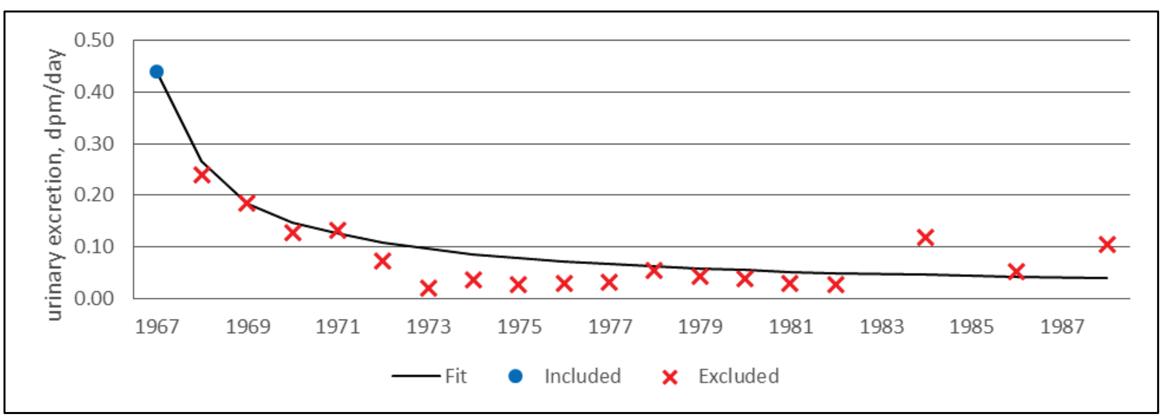

Figure E-11. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1966 to 1967, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

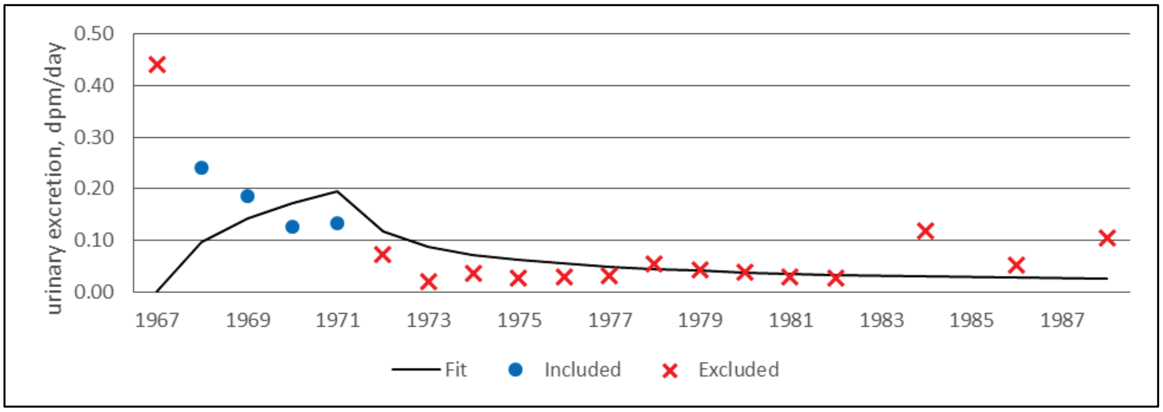

Figure E-12. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1968 to 1971, type M.

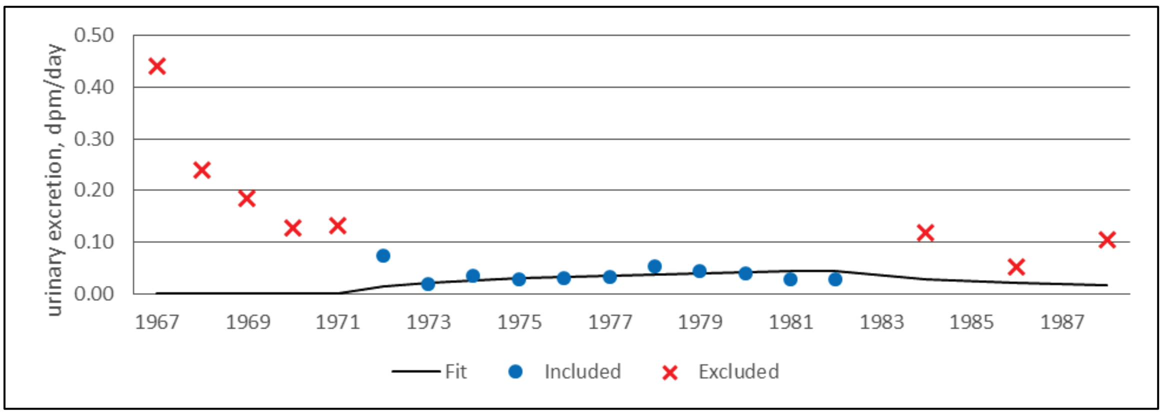

Figure E-13. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1972 to 1982, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

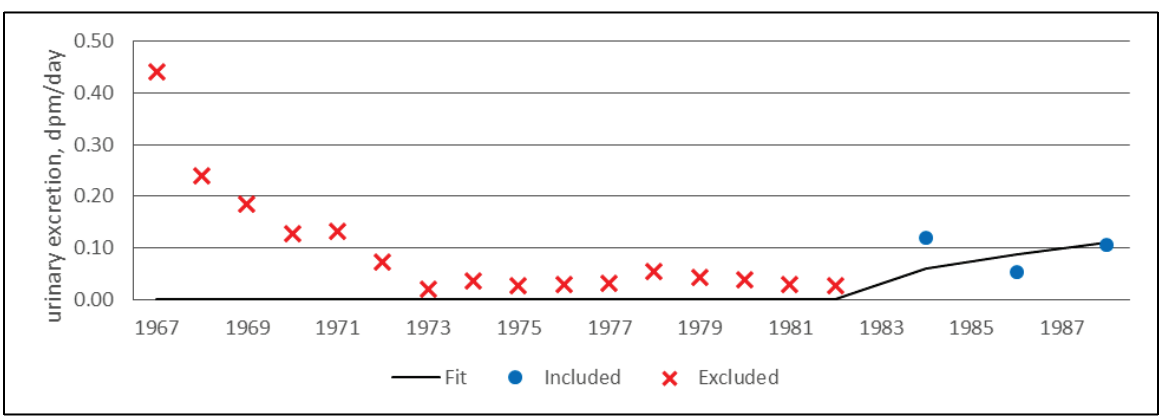

Figure E-14. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1983 to 1989, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

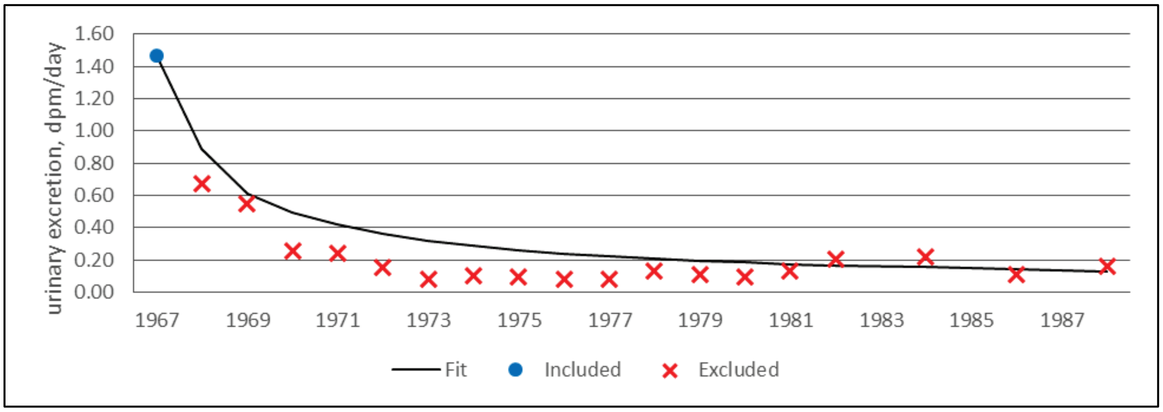

Figure E-15. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1966 to 1967, type M.

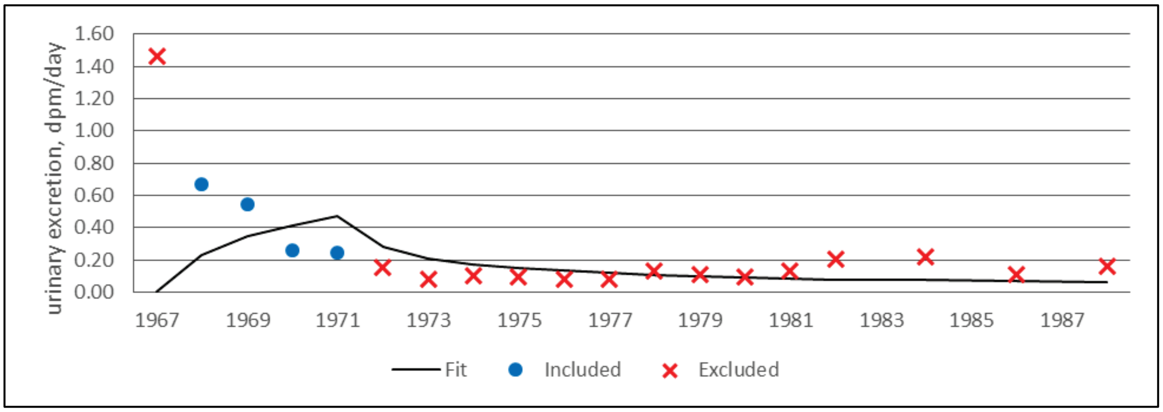

Figure E-16. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1968 to 1971, type M.

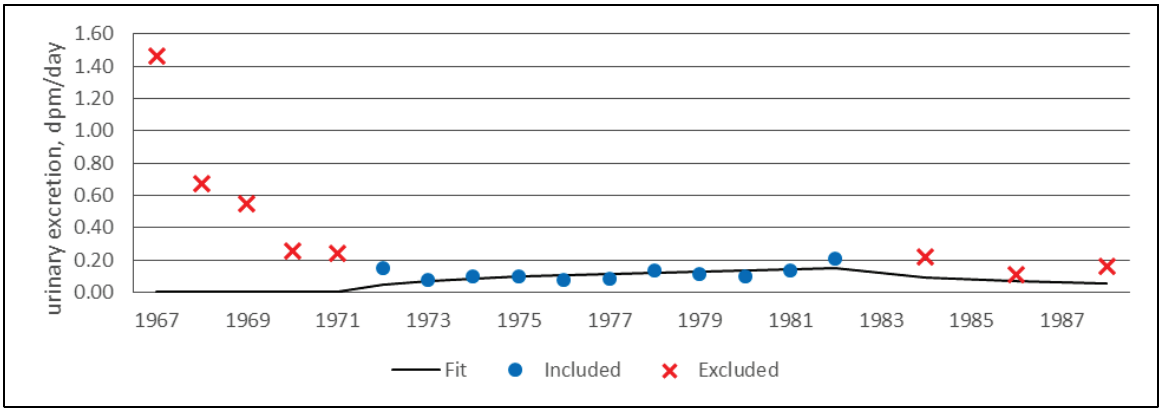

Figure E-17. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1972 to 1982, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

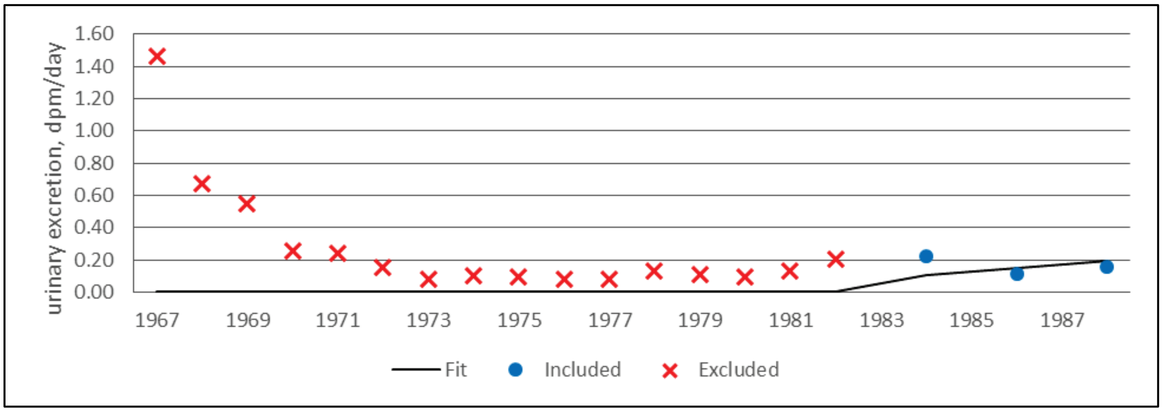

Figure E-18. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1983 to 1989, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

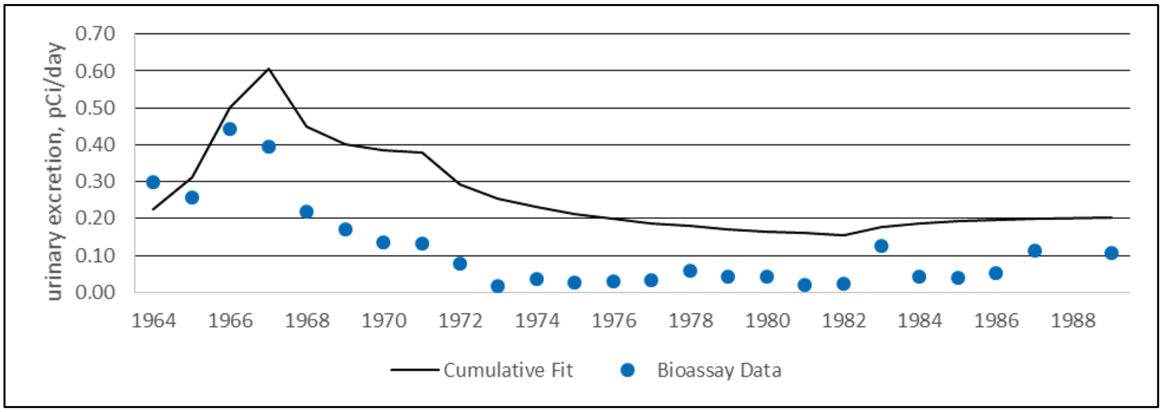

Figure E-19. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type M.

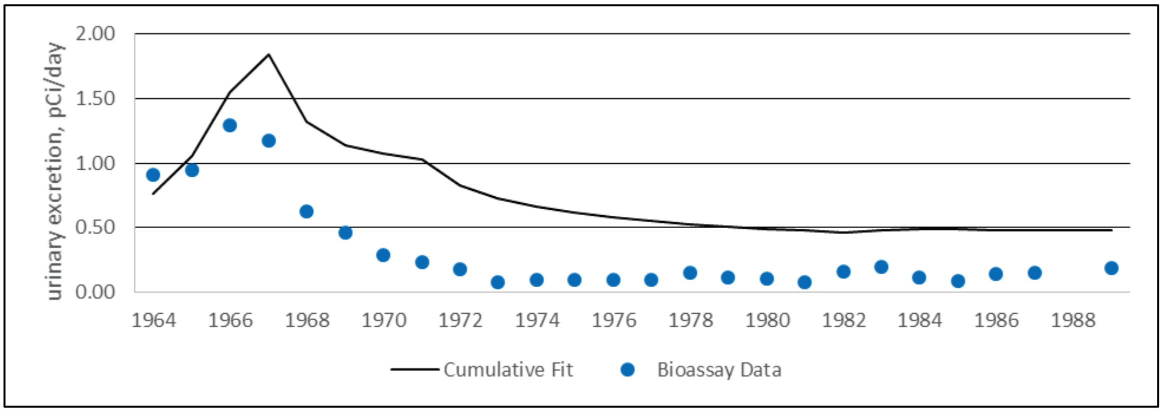

Figure E-20. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

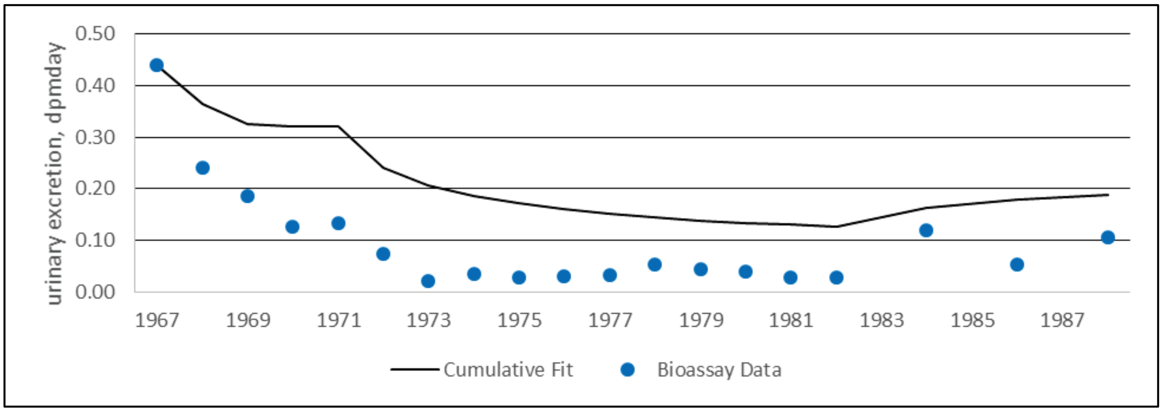

Figure E-21. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

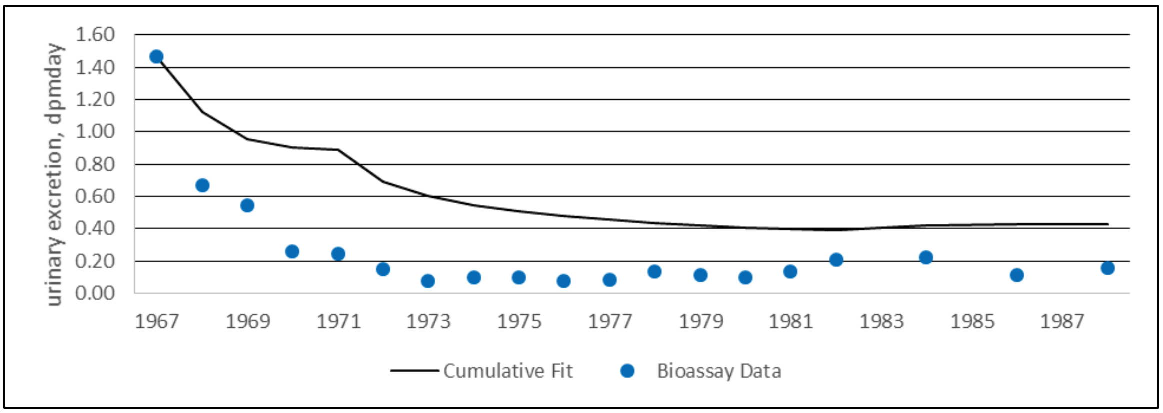

Figure E-22. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-1. Summary of ^{241}Am nonCTW intake rates (dpm/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1963	12/31/1965	31.32	105.9	3.38	3.38	232
01/01/1966	12/31/1967	57.61	170.3	2.96	3.00	351
01/01/1968	12/31/1971	16.86	39.51	2.34	3.00	102.7
01/01/1972	12/31/1982	2.61	8.158	3.13	3.13	17.0
01/01/1983	12/31/1989	7.359	13.24	1.80	3.00	44.8

Table E-2. Summary of ^{241}Am CTW intake rates (dpm/d) and dates.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1966	12/31/1967	61.38	203.9	3.32	3.32	442
01/01/1968	12/31/1971	17.33	41.57	2.40	3.00	106
01/01/1972	12/31/1982	2.697	8.694	3.22	3.22	18.5
01/01/1983	12/31/1989	8.248	14.21	1.72	3.00	50.3

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

E.2 PLUTONIUM INTAKE MODELING RESULTS

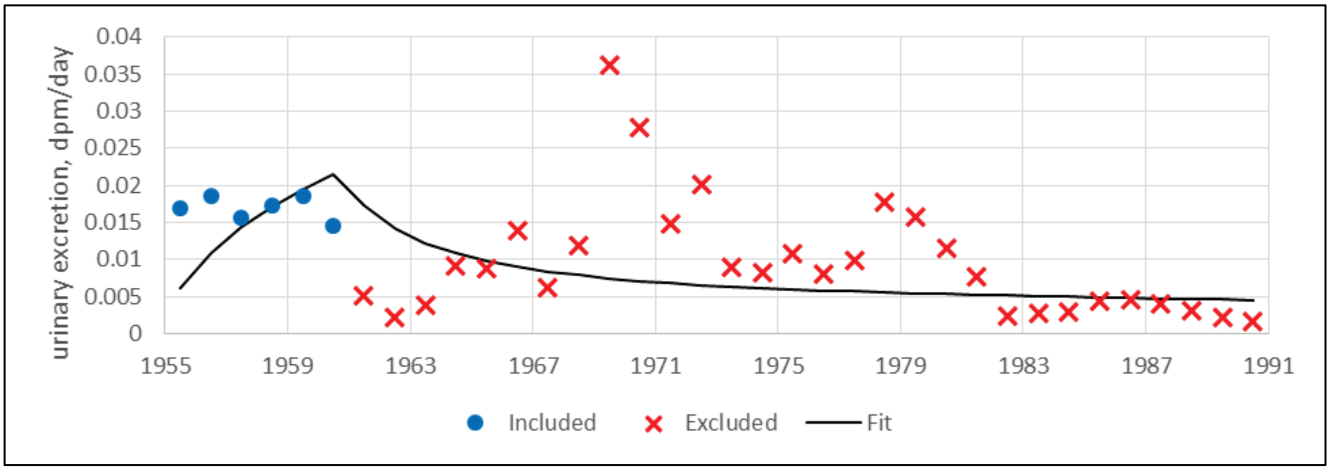

Figure E-23. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1960, type M.

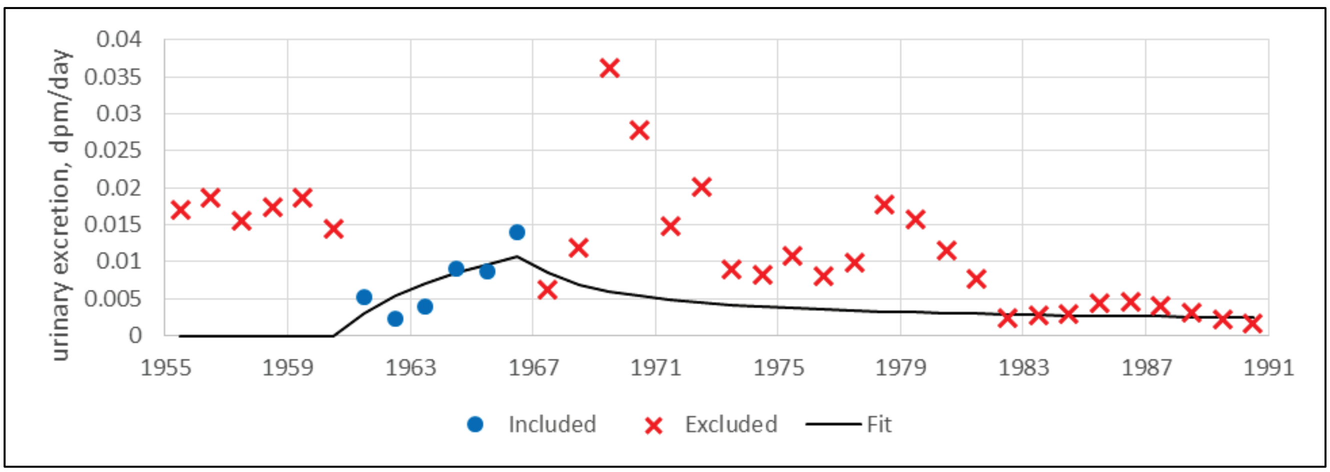

Figure E-24. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1966, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

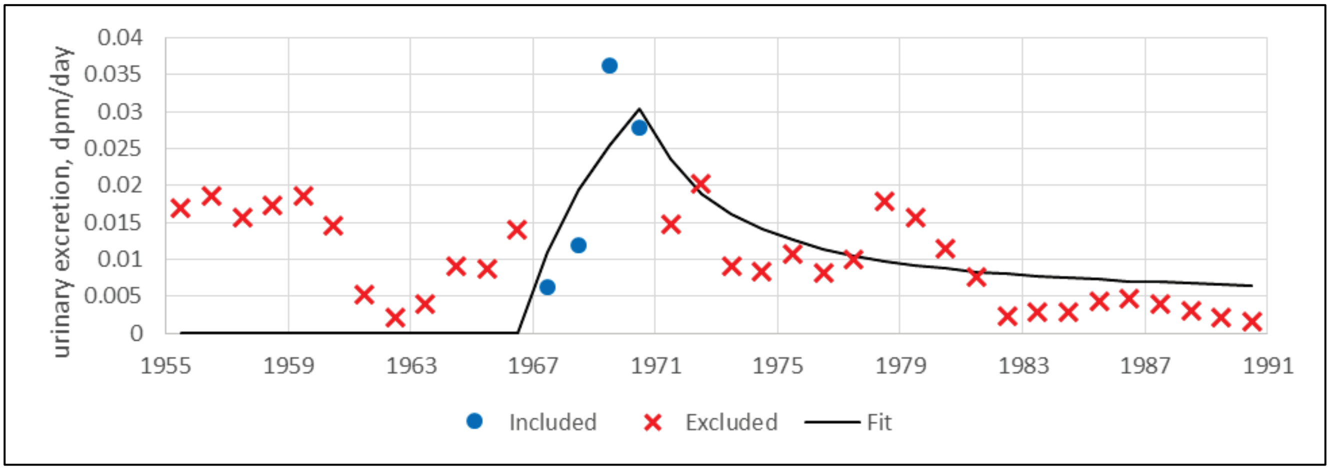

Figure E-25. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1970, type M.

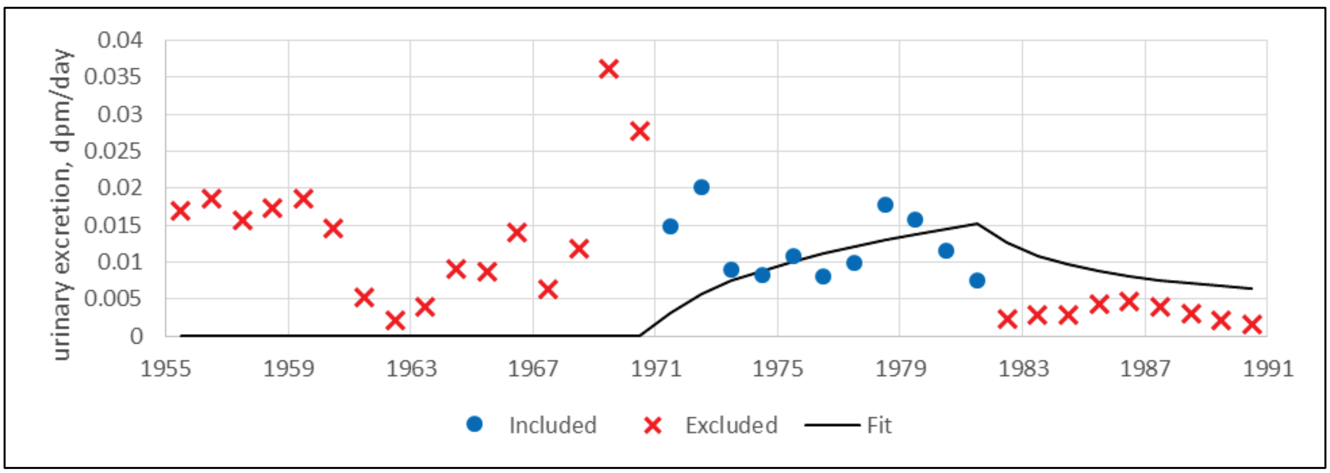

Figure E-26. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1971 to 1981, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

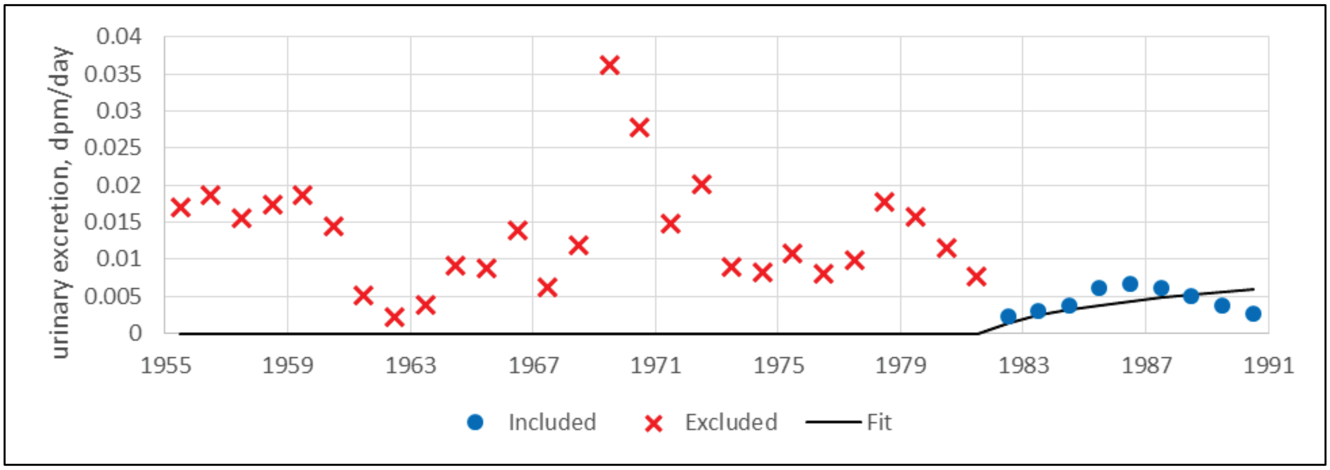

Figure E-27. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1990, type M.

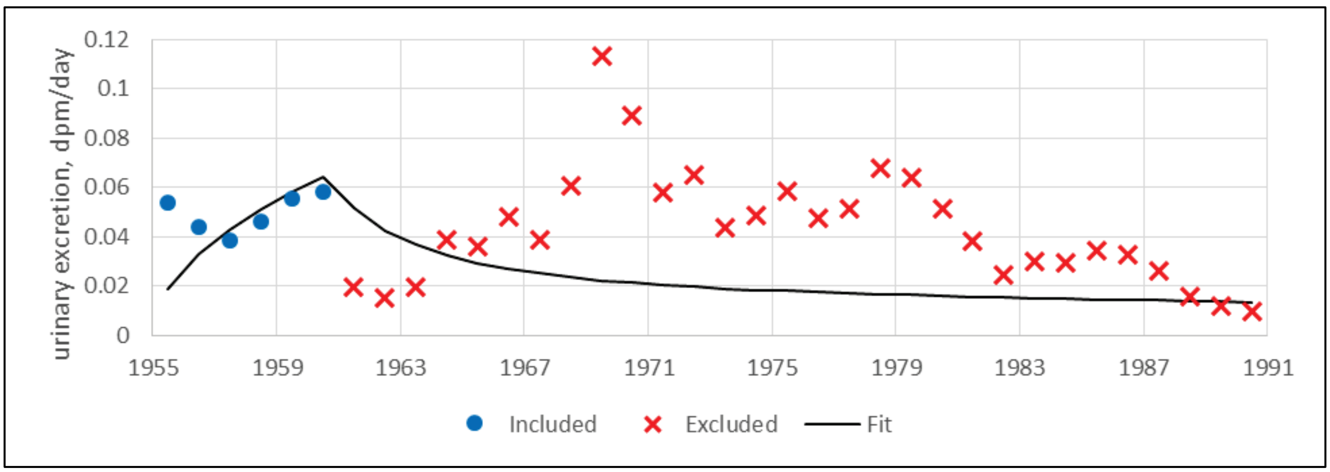

Figure E-28. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1960, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

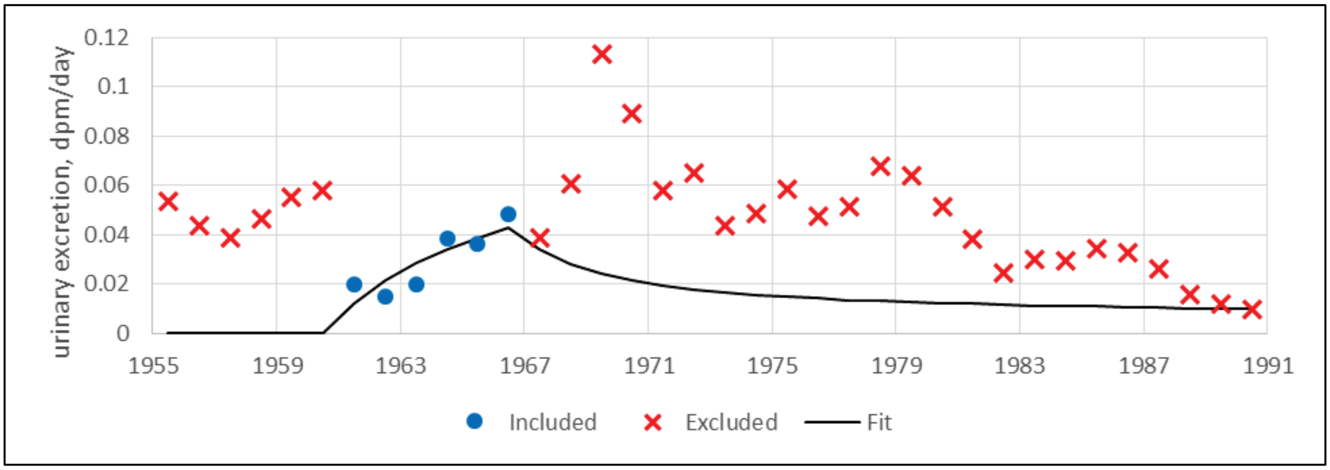

Figure E-29. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1966, type M.

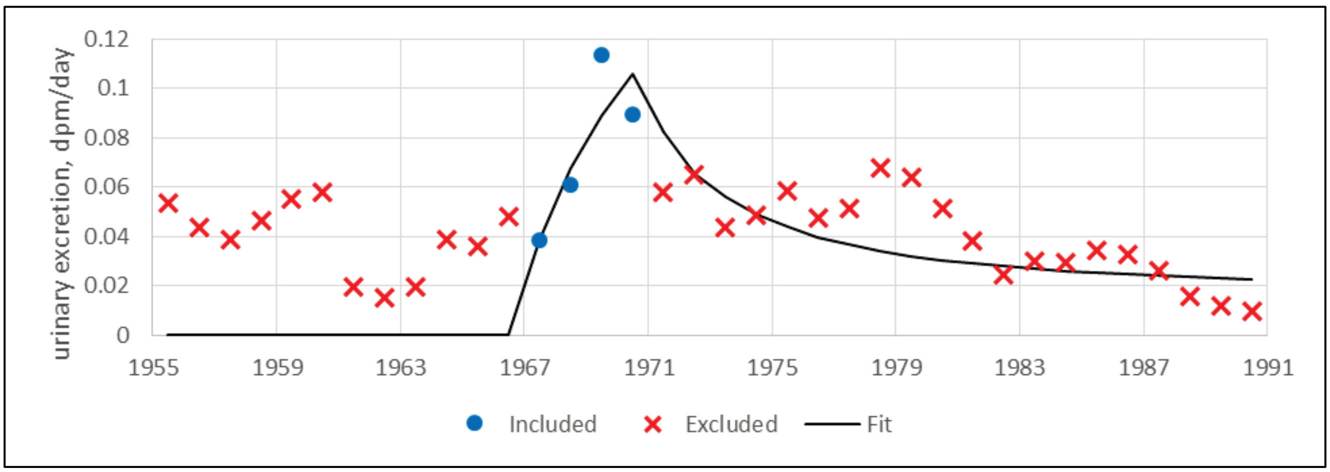

Figure E-30. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1970, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

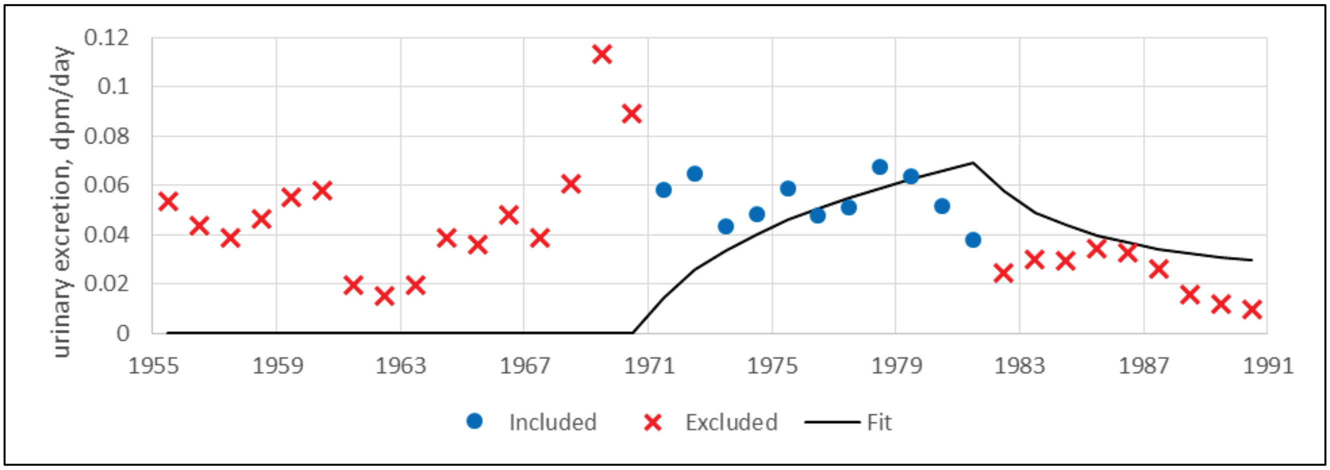

Figure E-31. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1971 to 1981, type M.

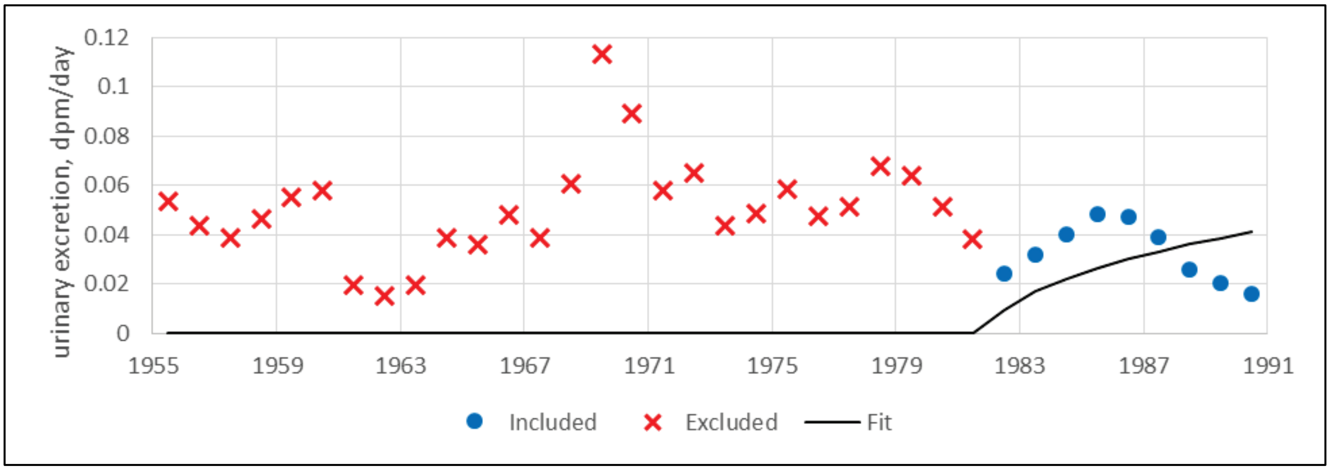

Figure E-32. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1990, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

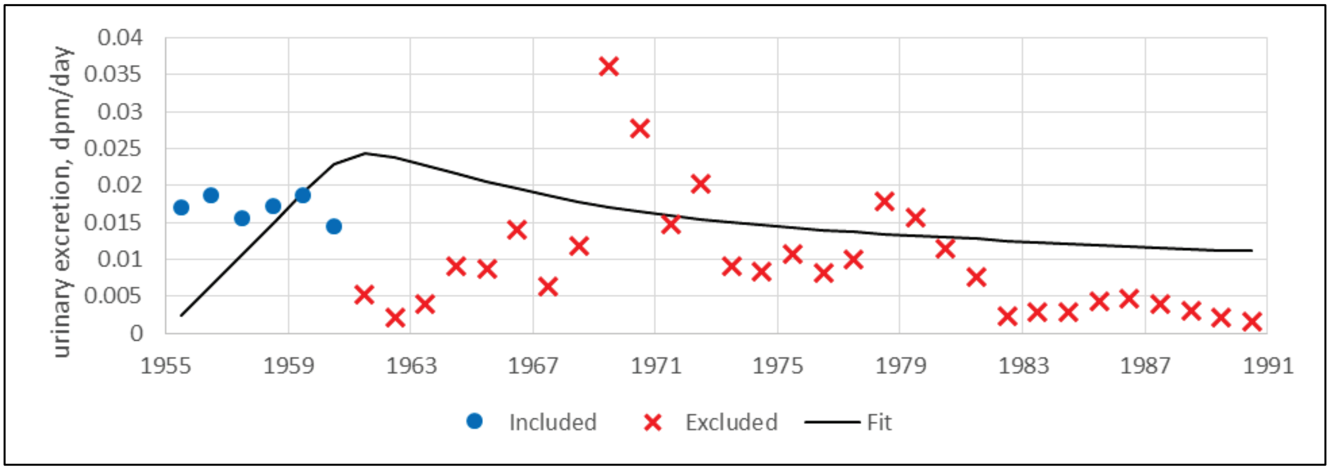

Figure E-33. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1960, type S.

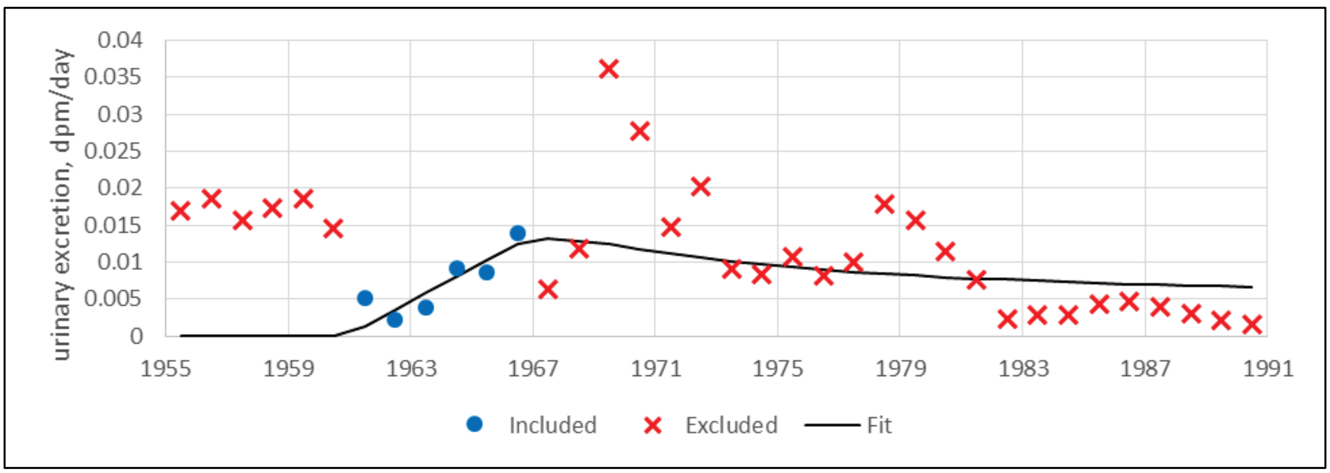

Figure E-34. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1966, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

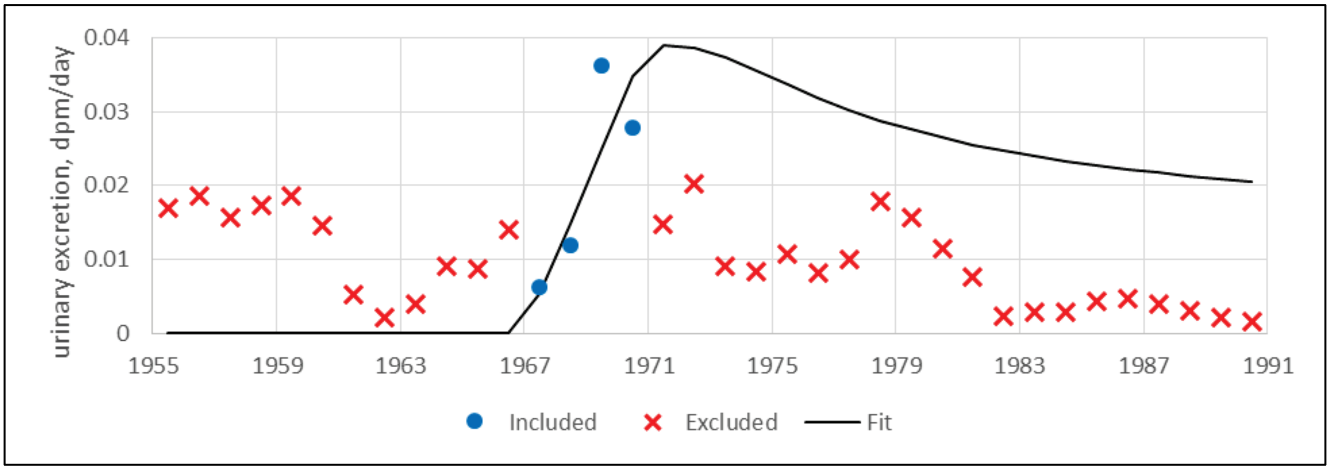

Figure E-35. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1970, type S.

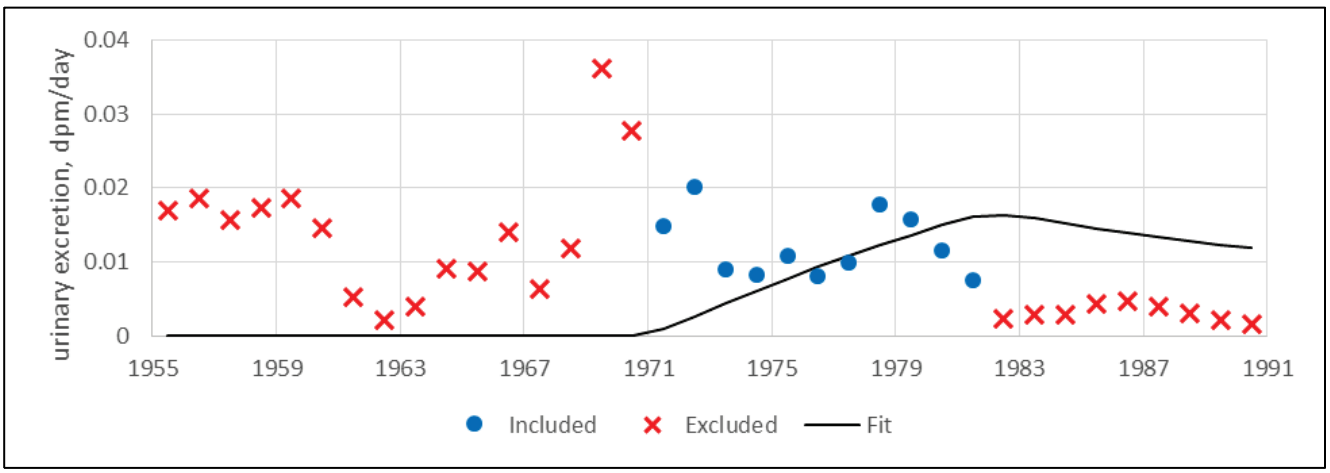

Figure E-36. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1971 to 1981, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

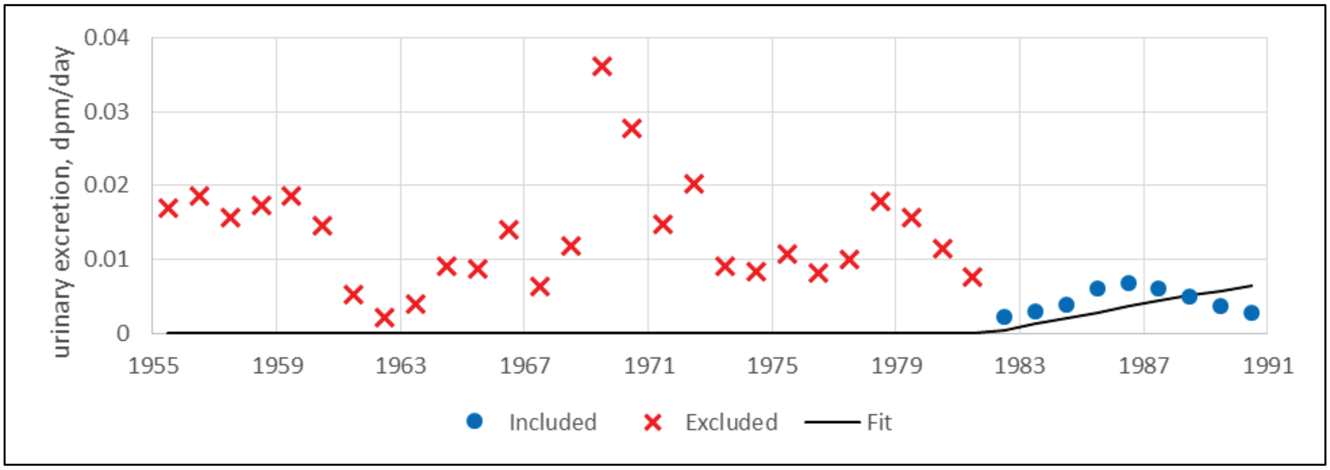

Figure E-37. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1990, type S.

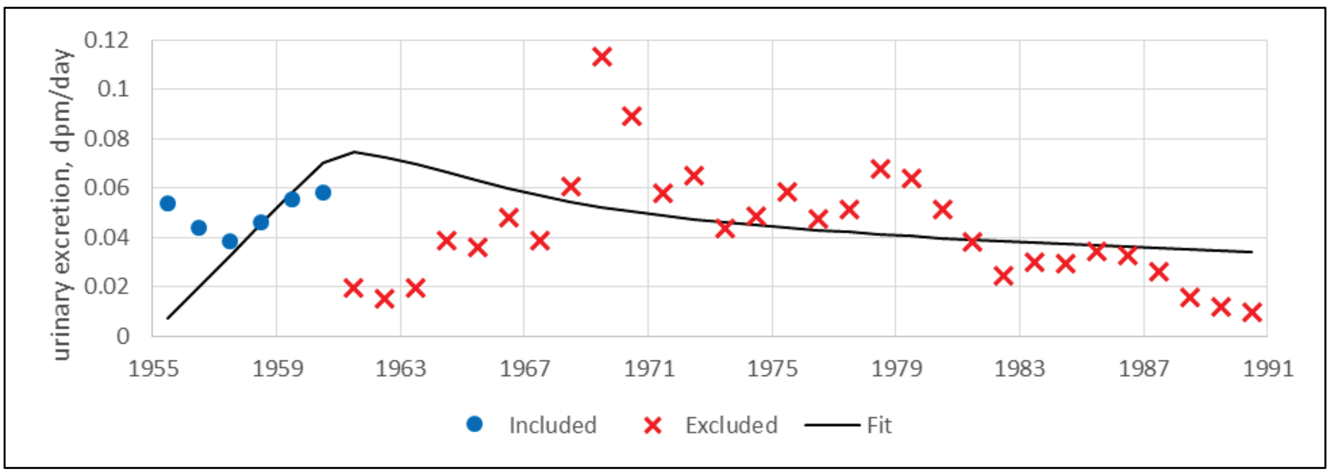

Figure E-38. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1960, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

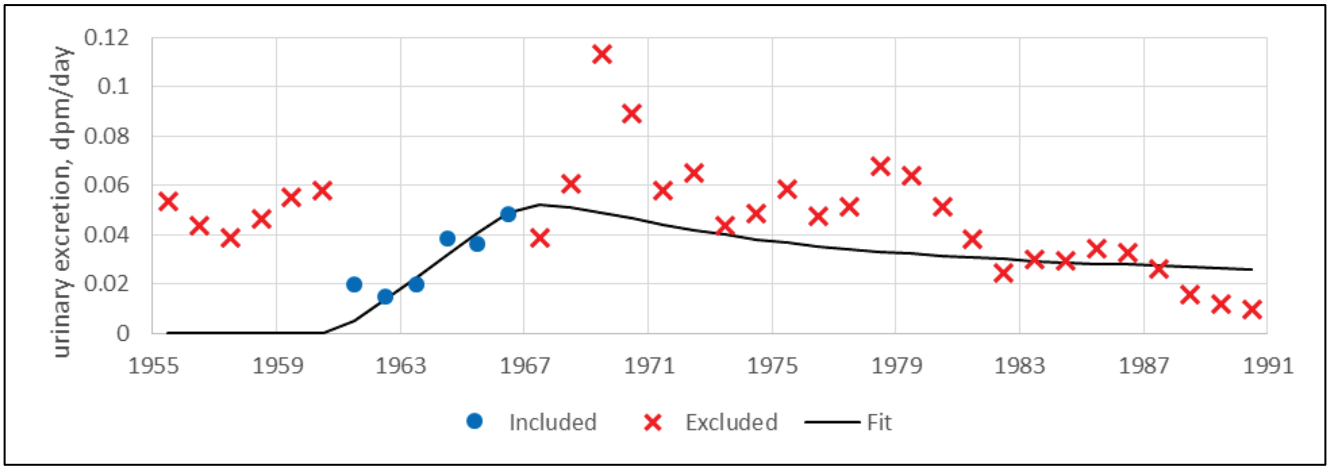

Figure E-39. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1966, type S.

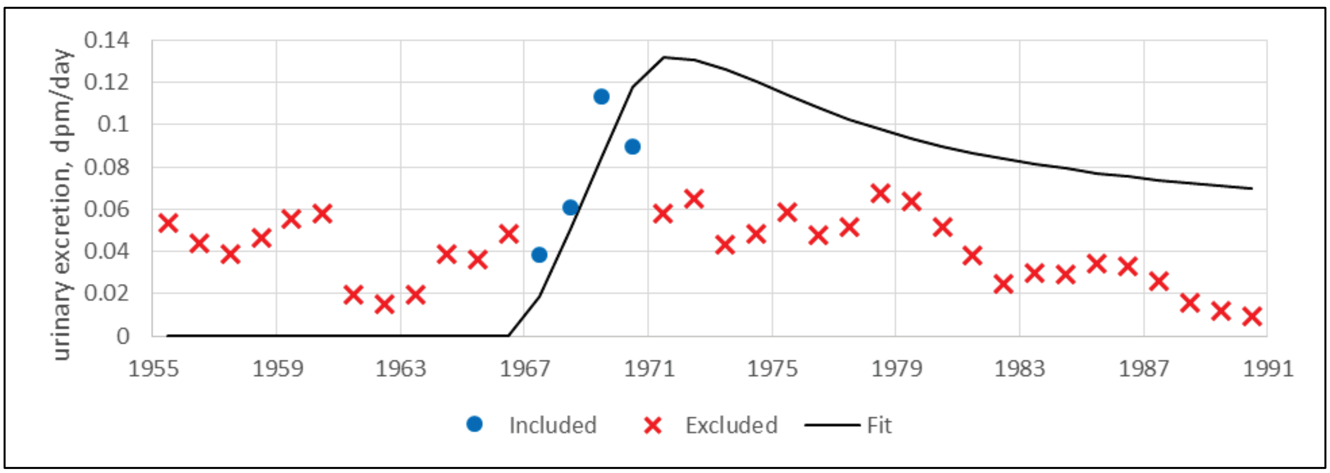

Figure E-40. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1970, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

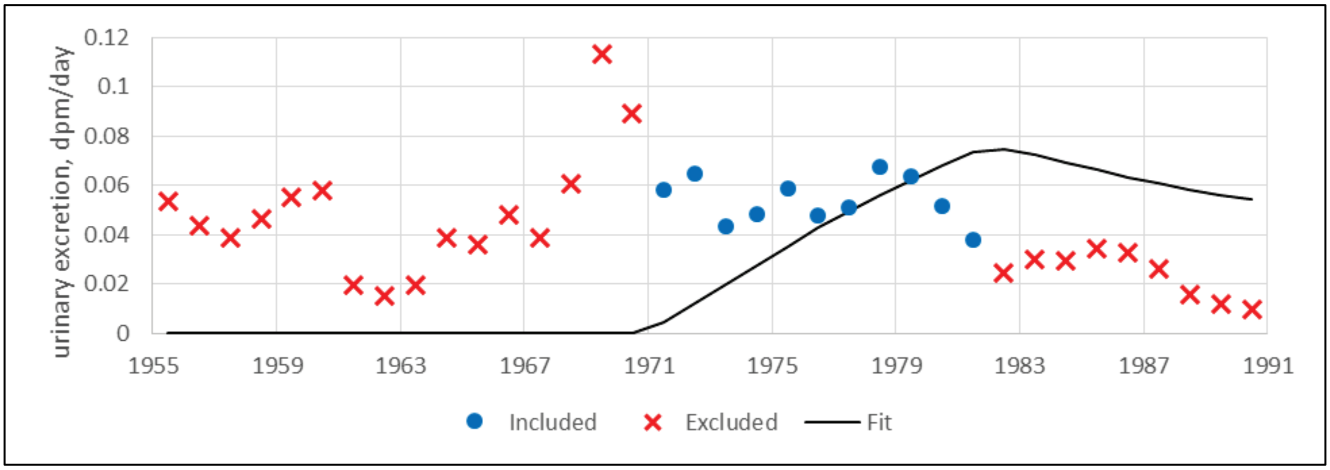

Figure E-41. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1971 to 1981, type S.

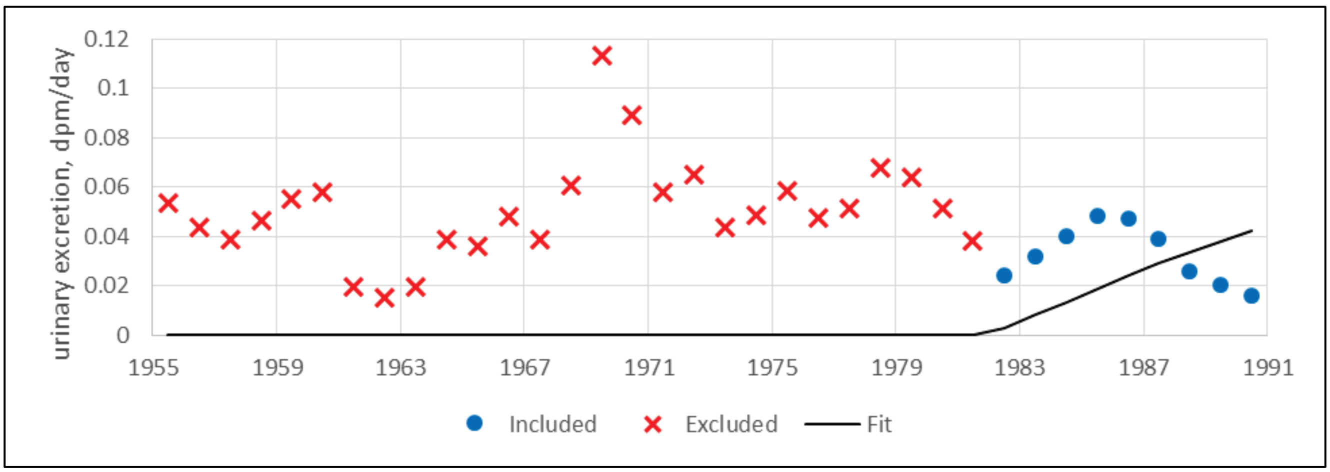

Figure E-42. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1990, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

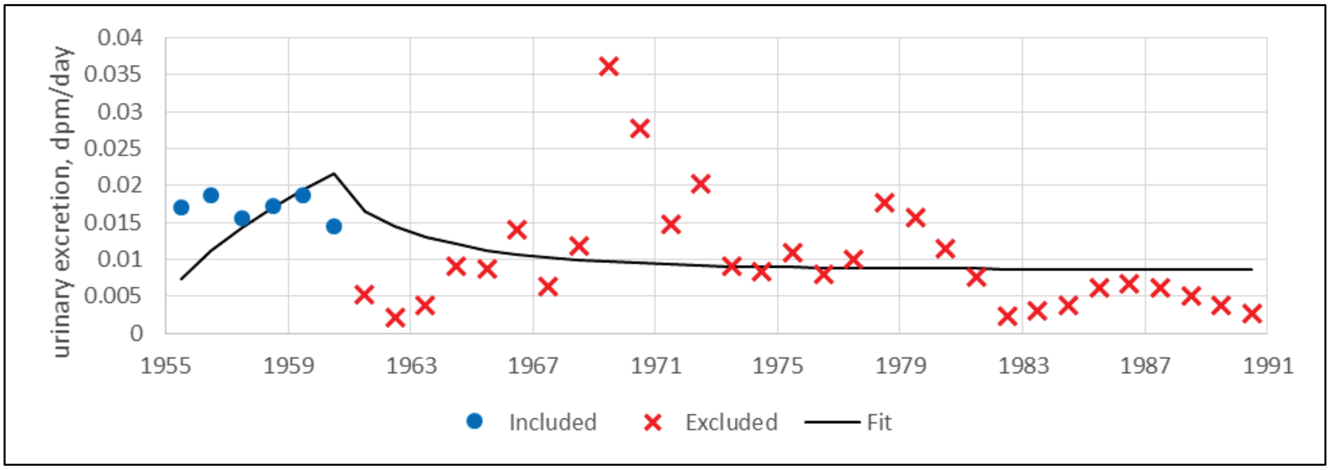

Figure E-43. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1960, type SS.

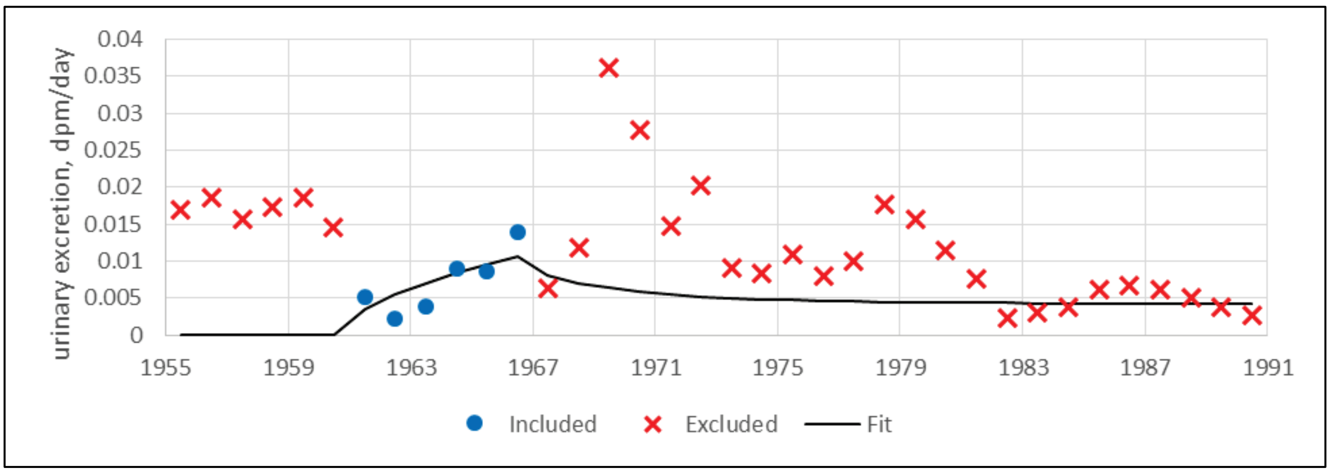

Figure E-44. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1966, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

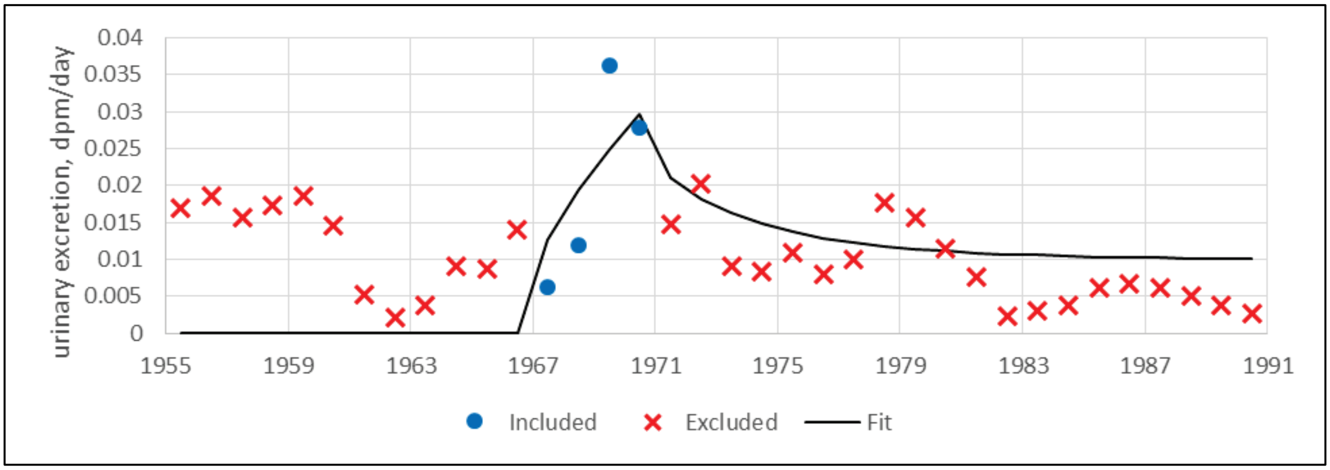

Figure E-45. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1970, type SS.

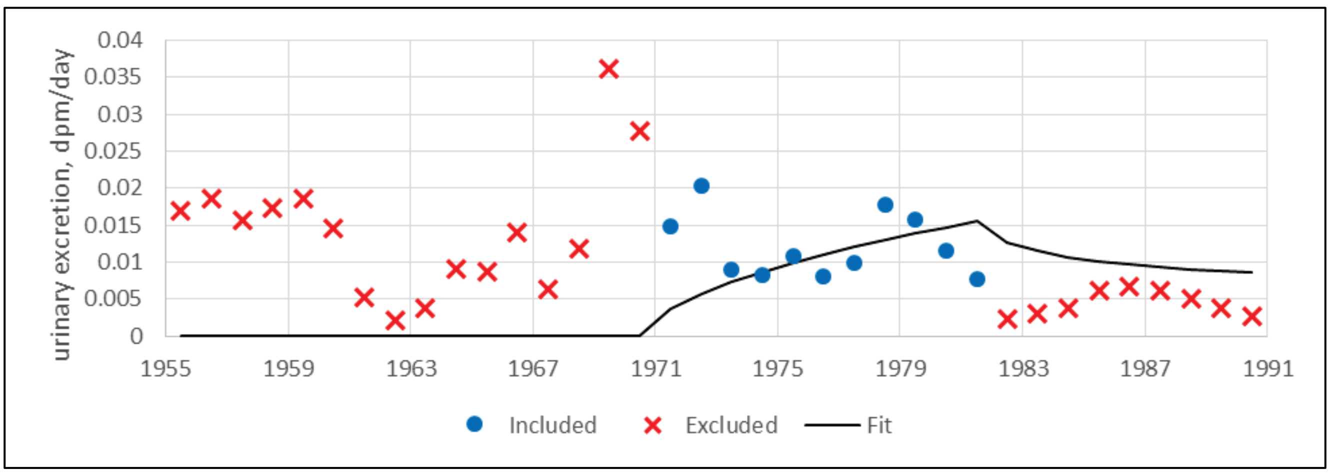

Figure E-46. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1971 to 1981, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

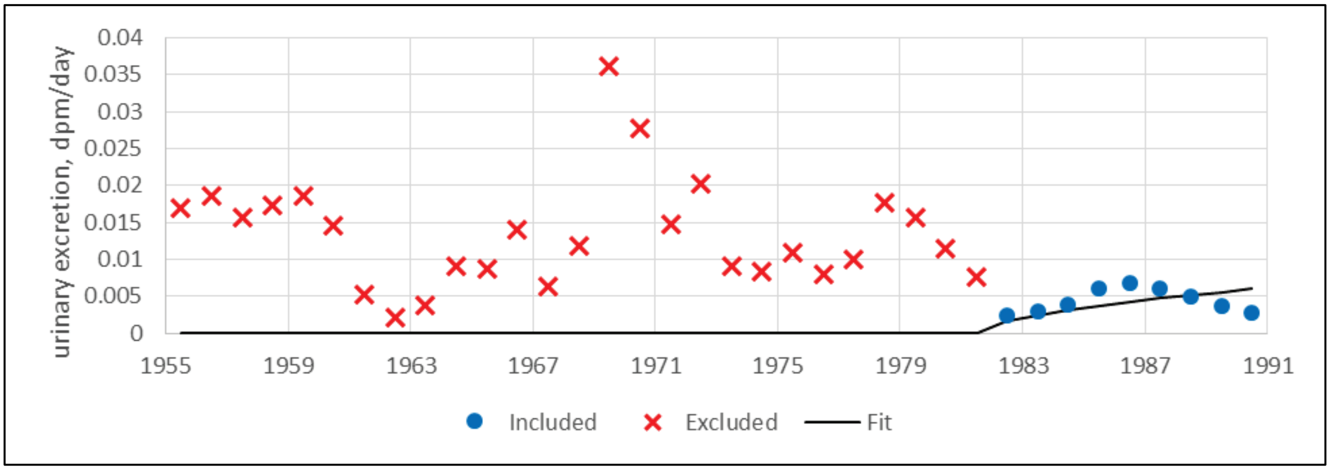

Figure E-47. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1990, type SS.

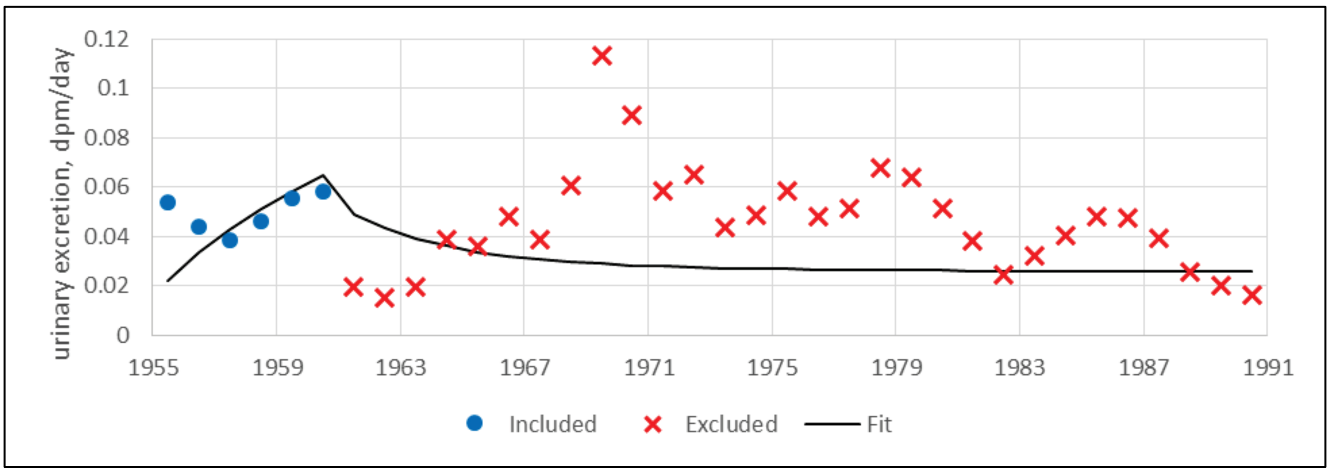

Figure E-48. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1960, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

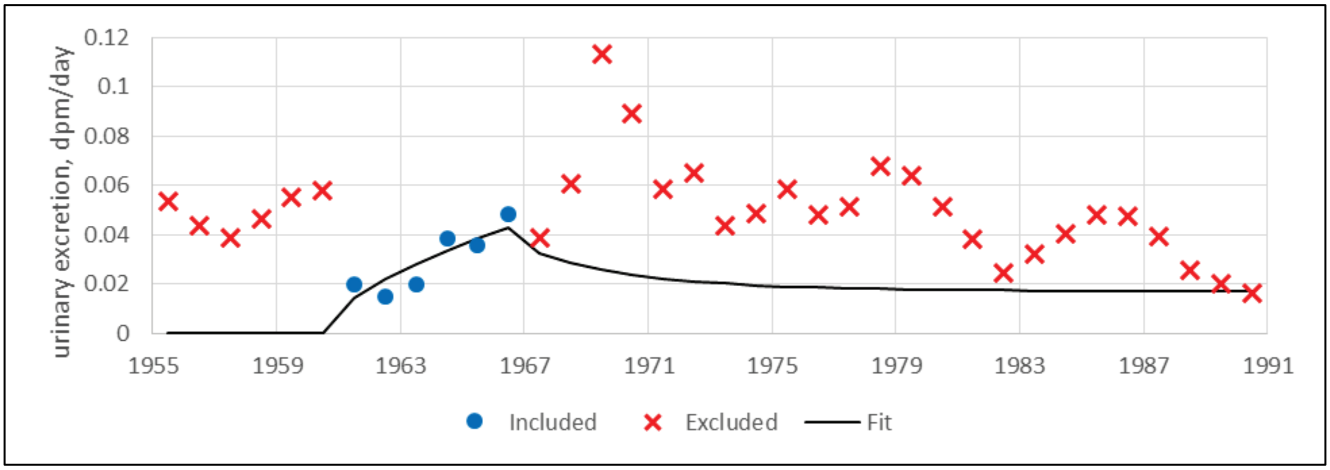

Figure E-49. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1966, type SS.

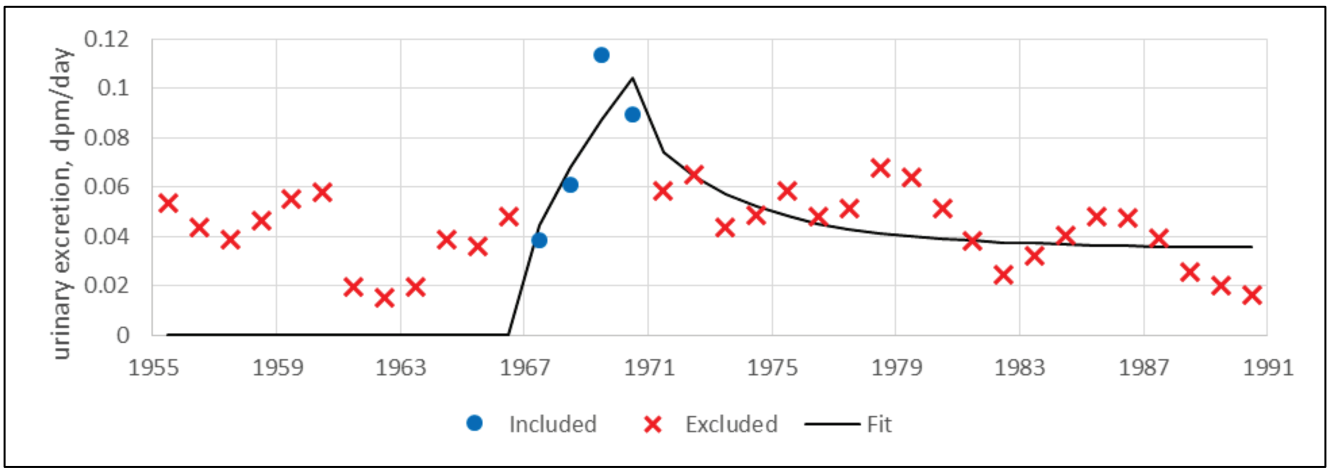

Figure E-50. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1970, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

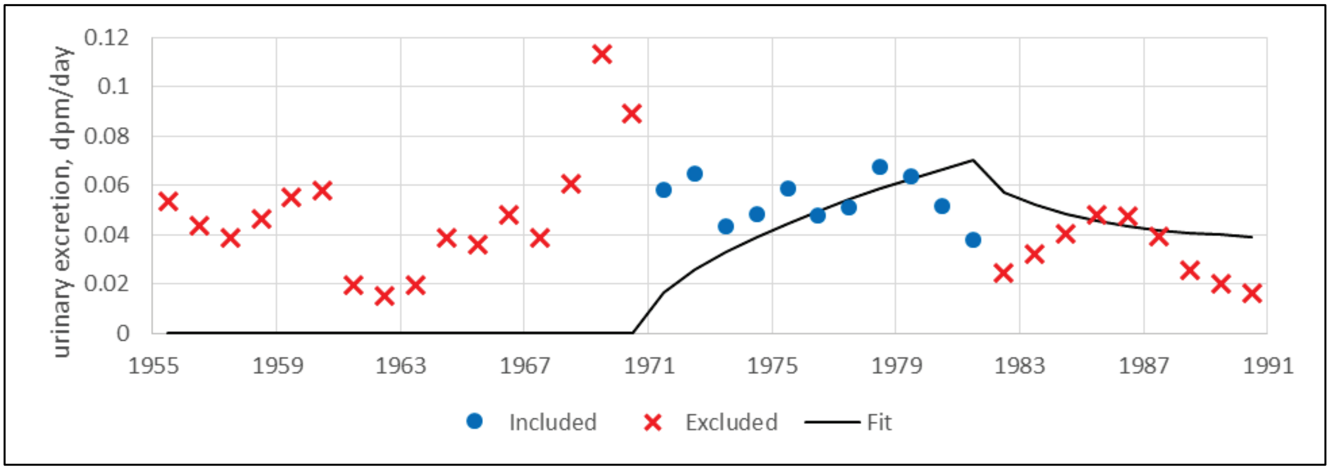

Figure E-51. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1971 to 1981, type SS.

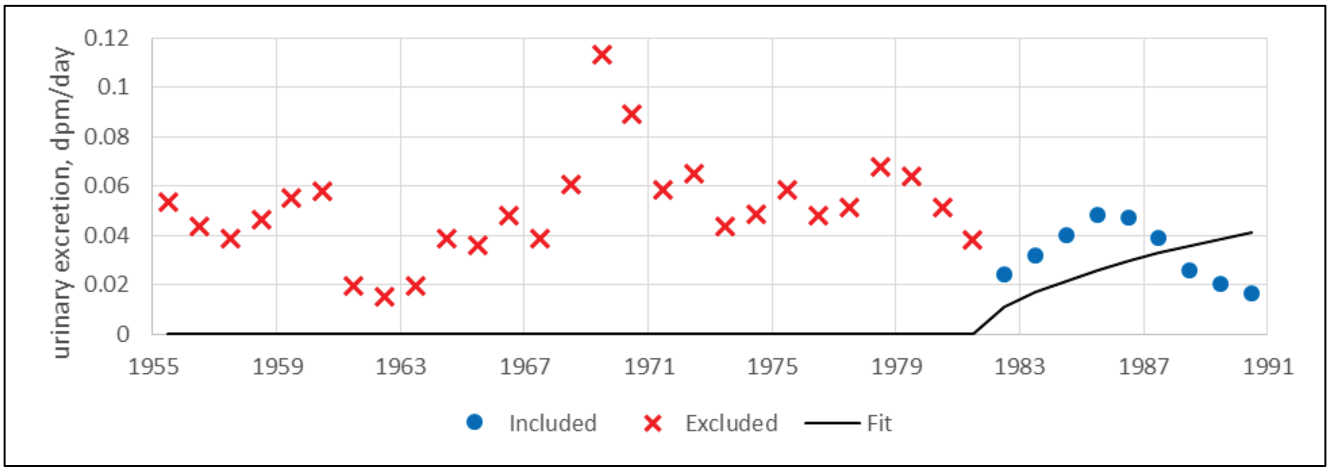

Figure E-52. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1990, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

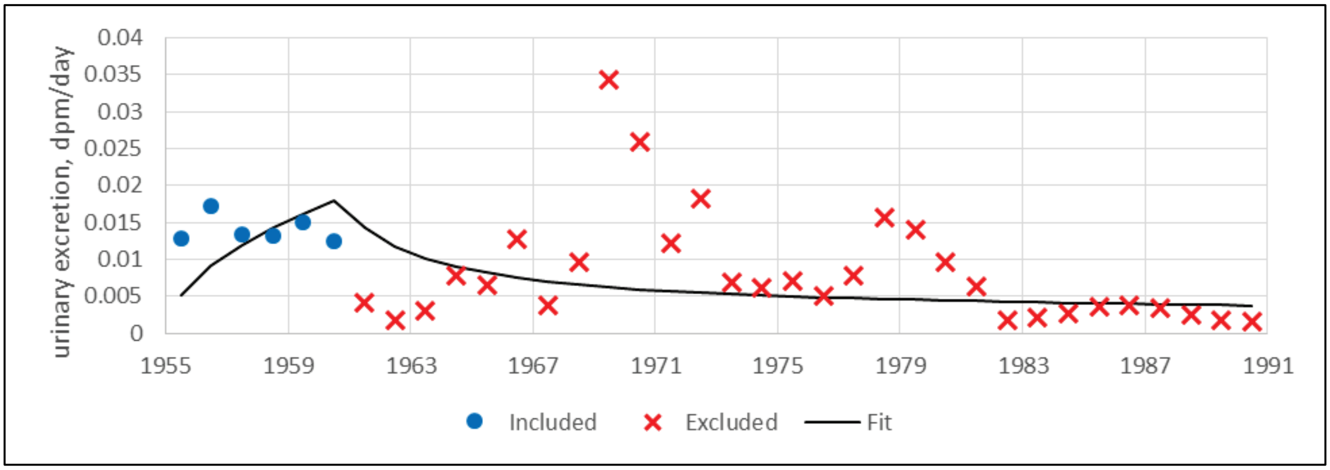

Figure E-53. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1960, type M.

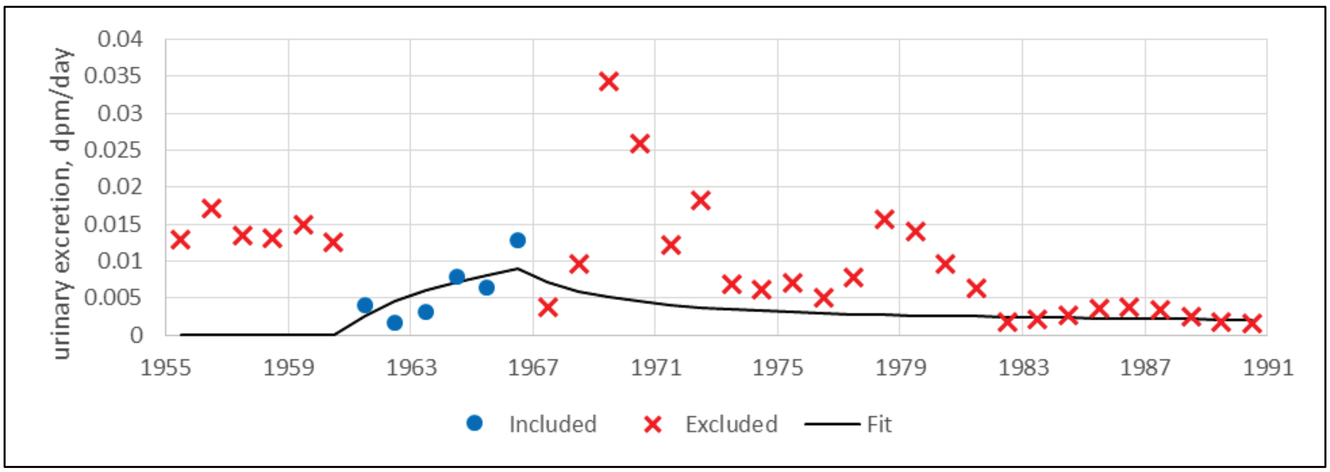

Figure E-54. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1966, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

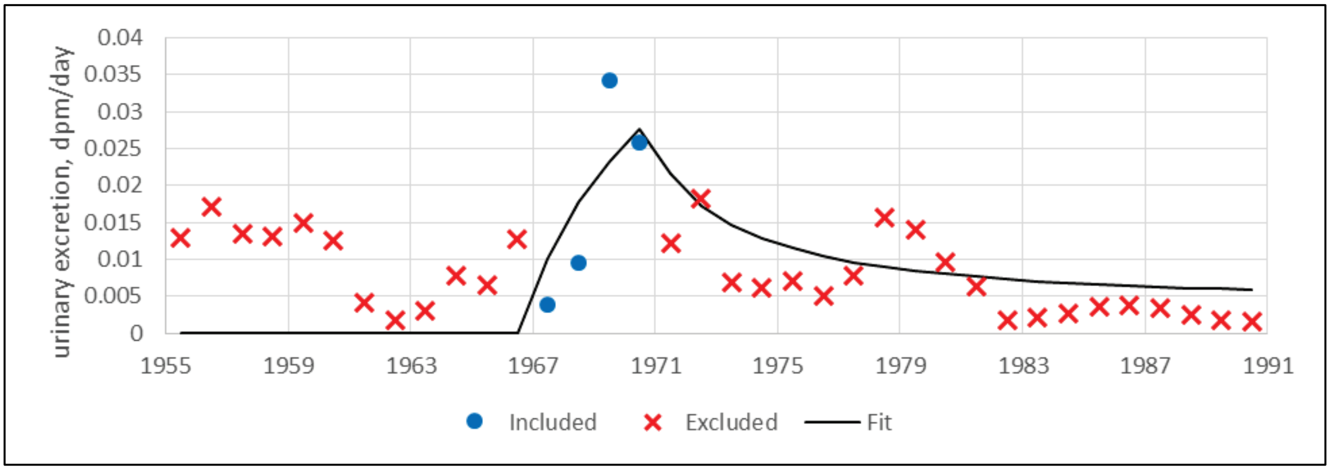

Figure E-55. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1970, type M.

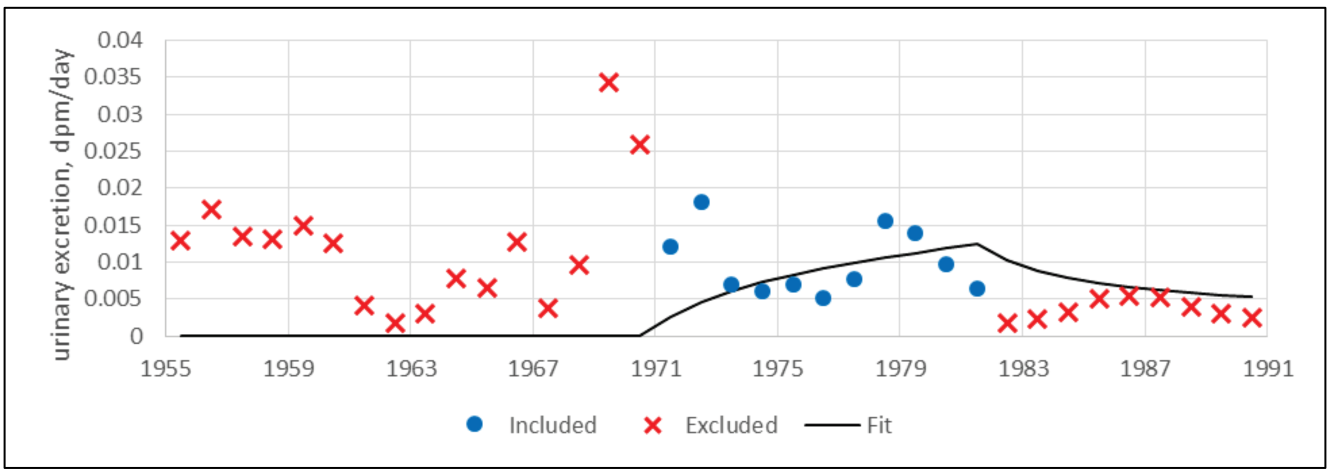

Figure E-56. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1971 to 1981, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

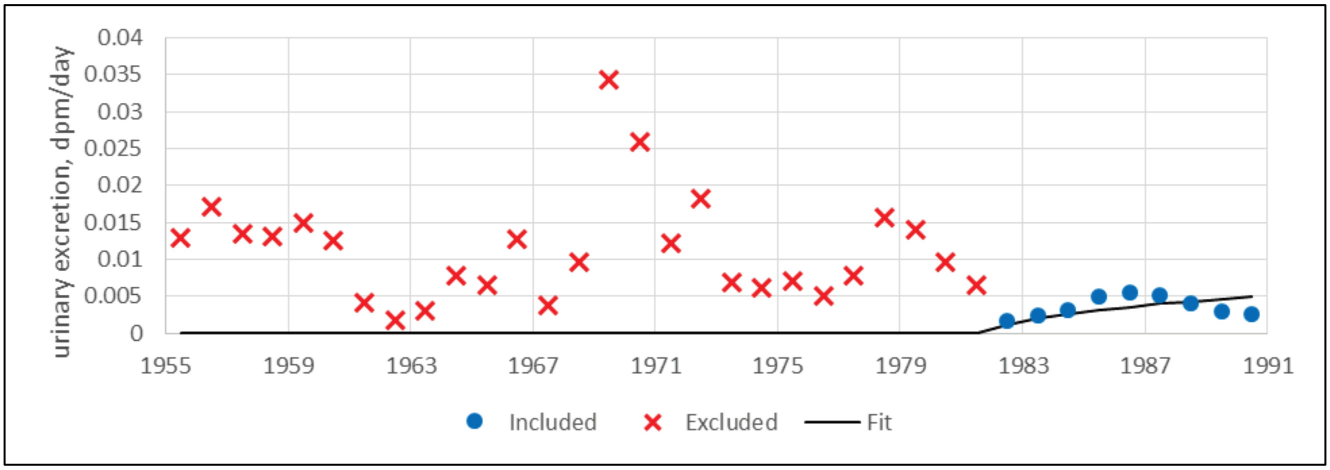

Figure E-57. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1982 to 1990, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

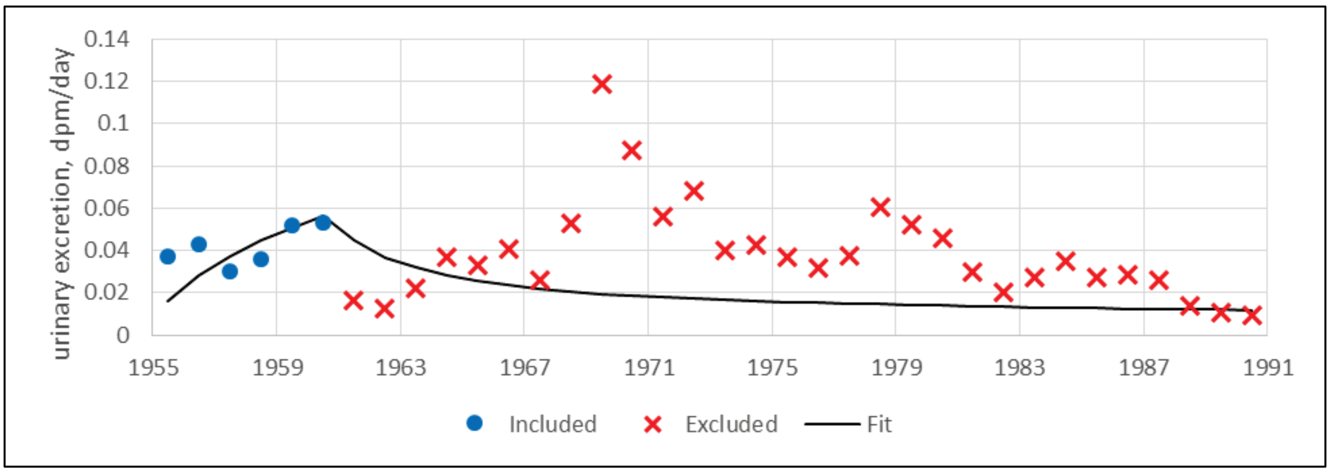

Figure E-58. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1960, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

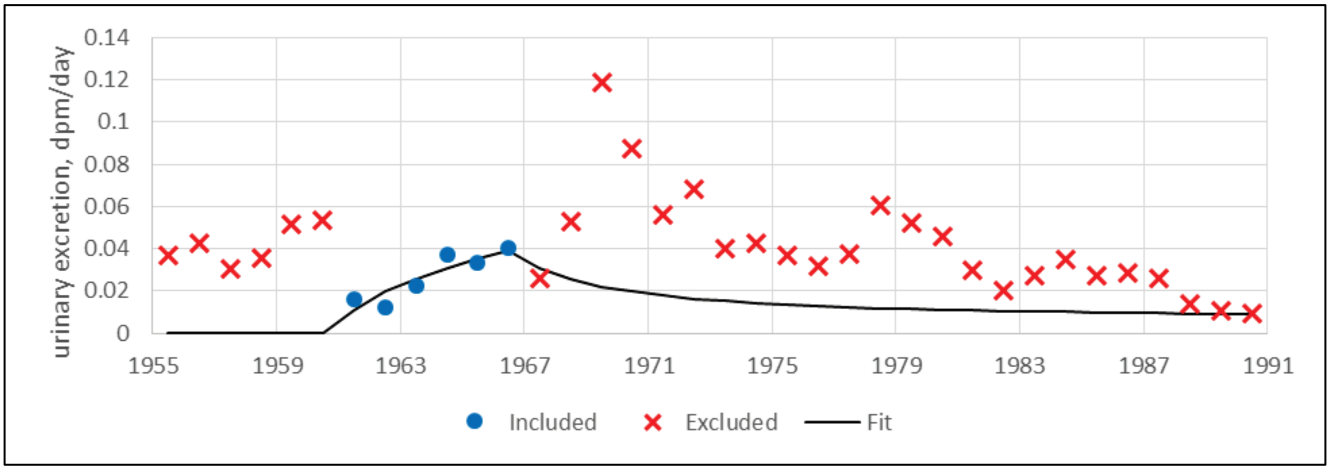

Figure E-59. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1966, type M.

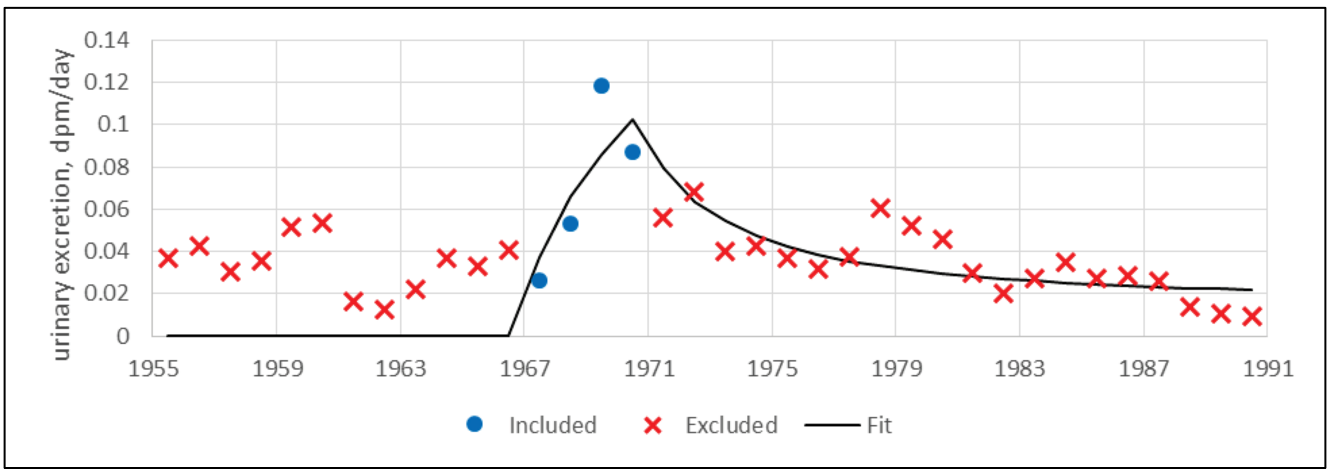

Figure E-60. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1970, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

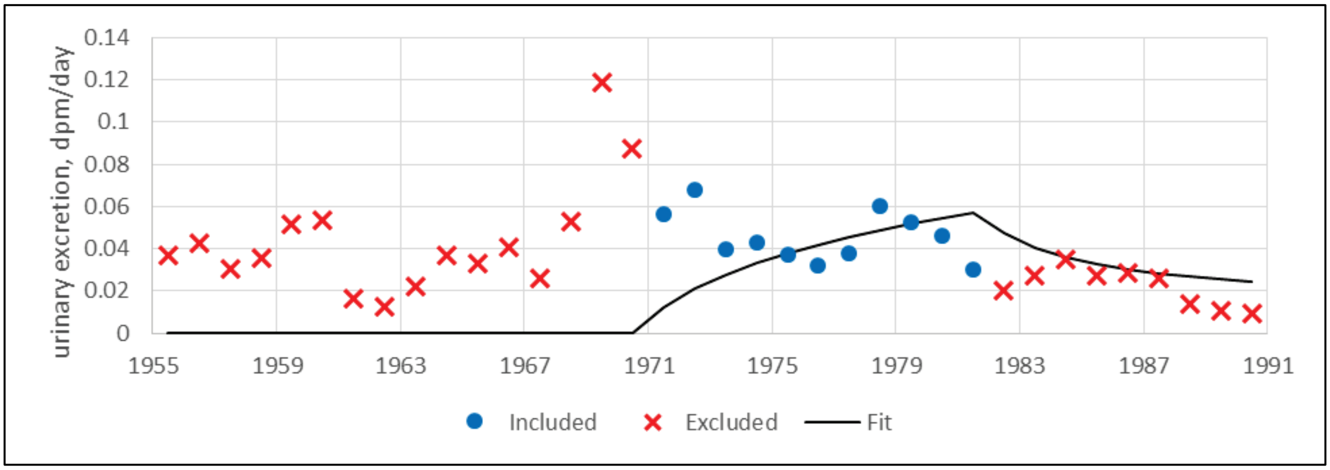

Figure E-61. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1971 to 1981, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

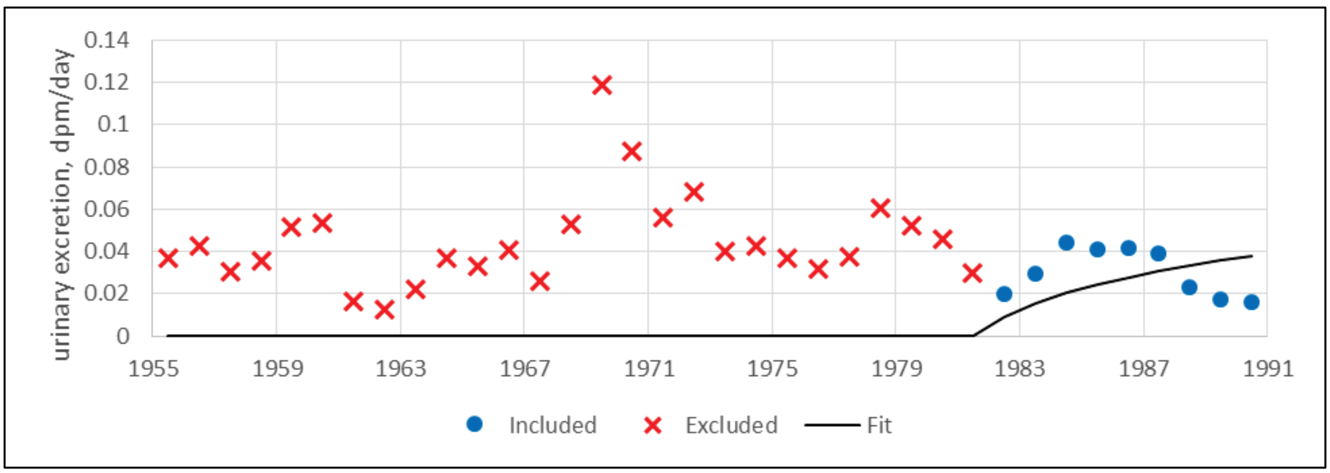

Figure E-62. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1982 to 1990, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

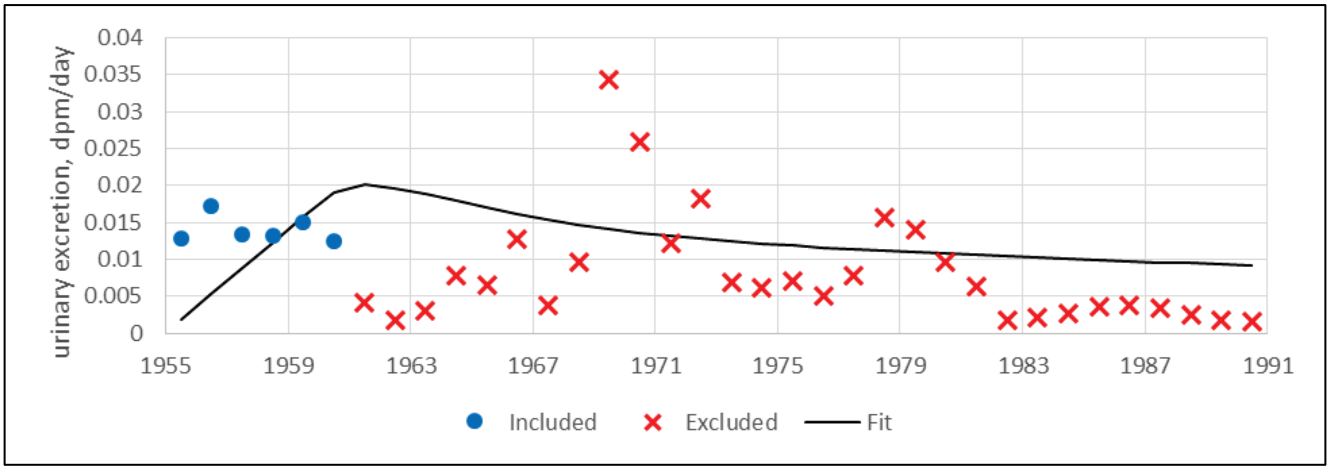

Figure E-63. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1960, type S.

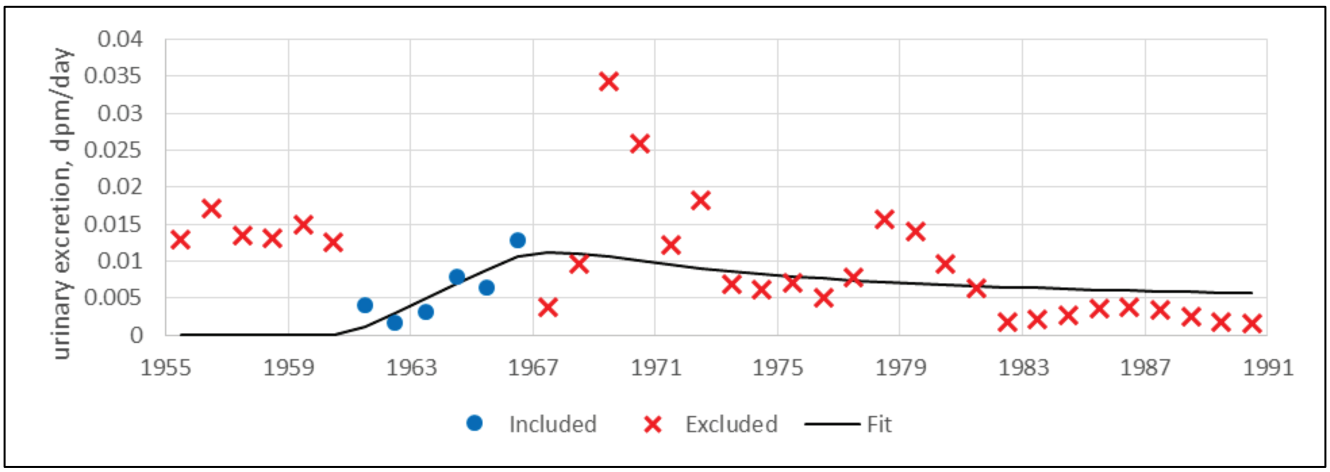

Figure E-64. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1966, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

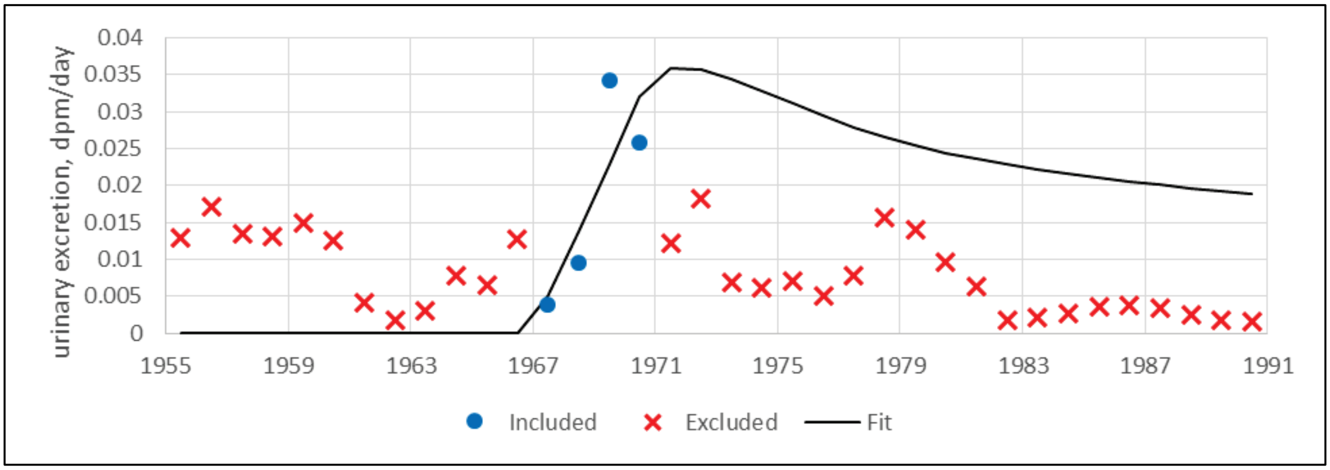

Figure E-65. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1970, type S.

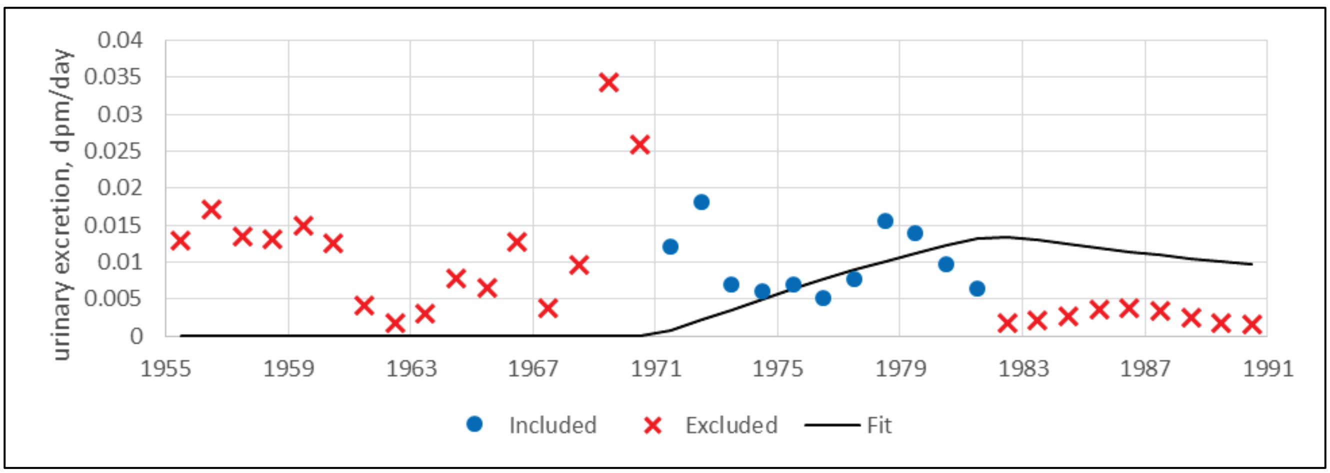

Figure E-66. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1971 to 1981, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

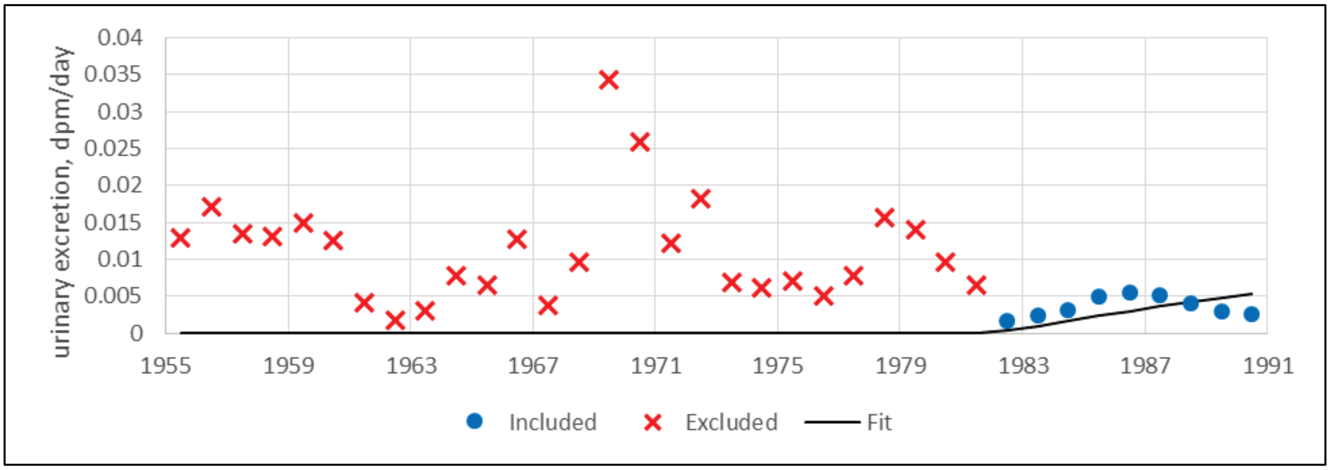

Figure E-67. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1982 to 1990, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

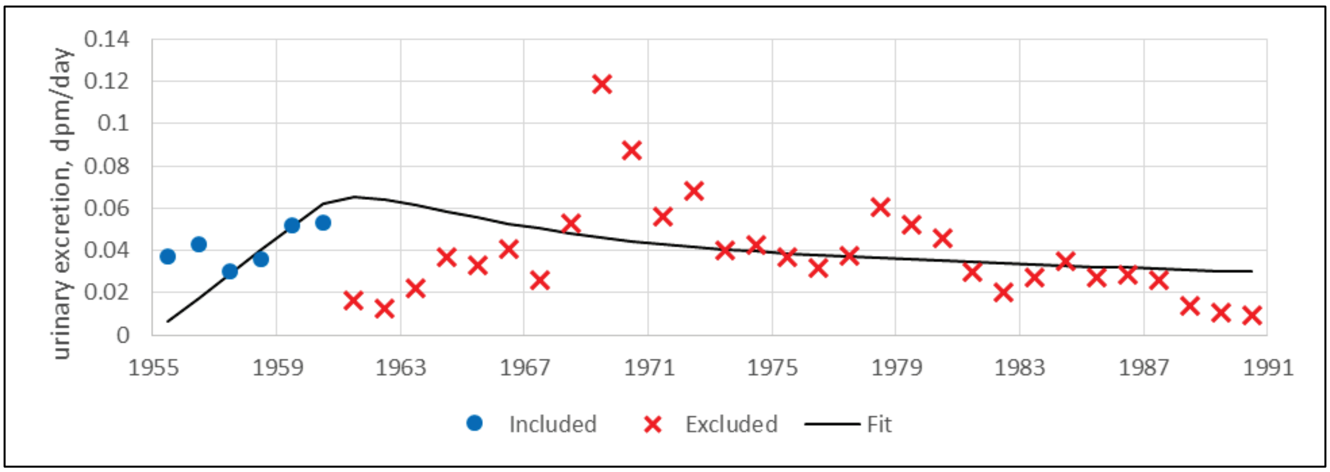

Figure E-68. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1960, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

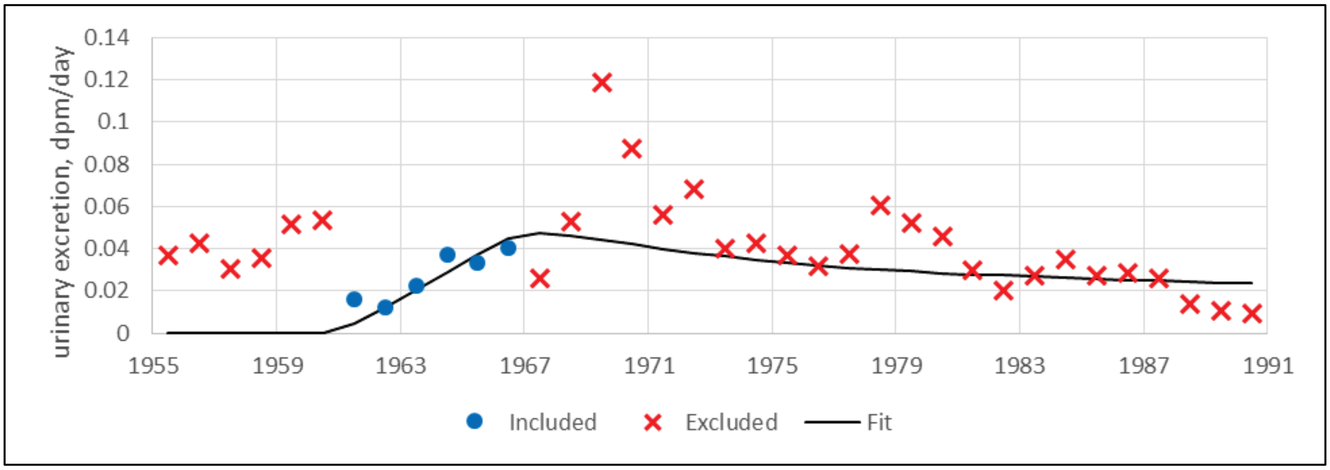

Figure E-69. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1966, type S.

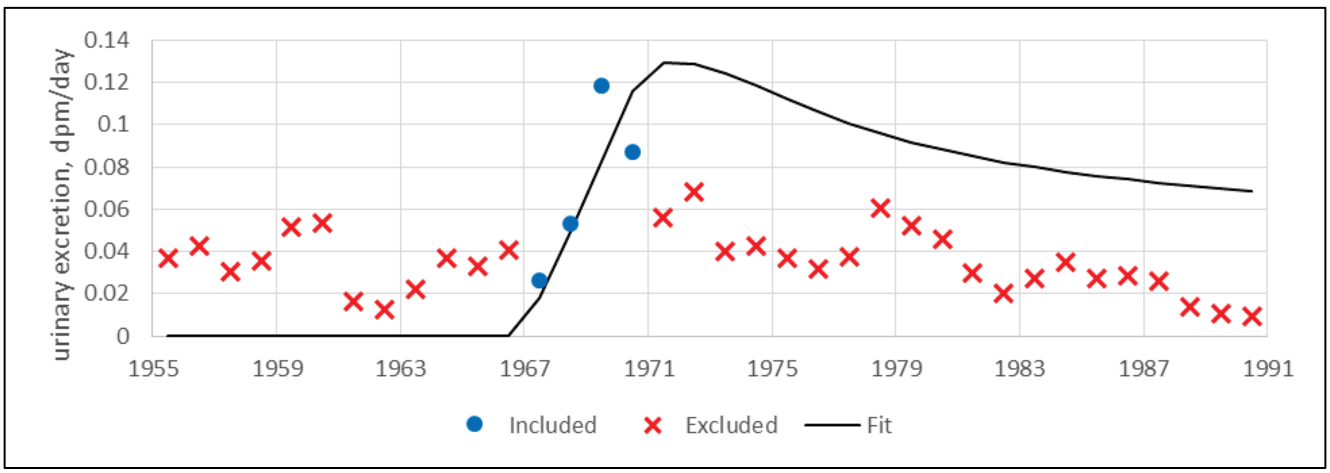

Figure E-70. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1970, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

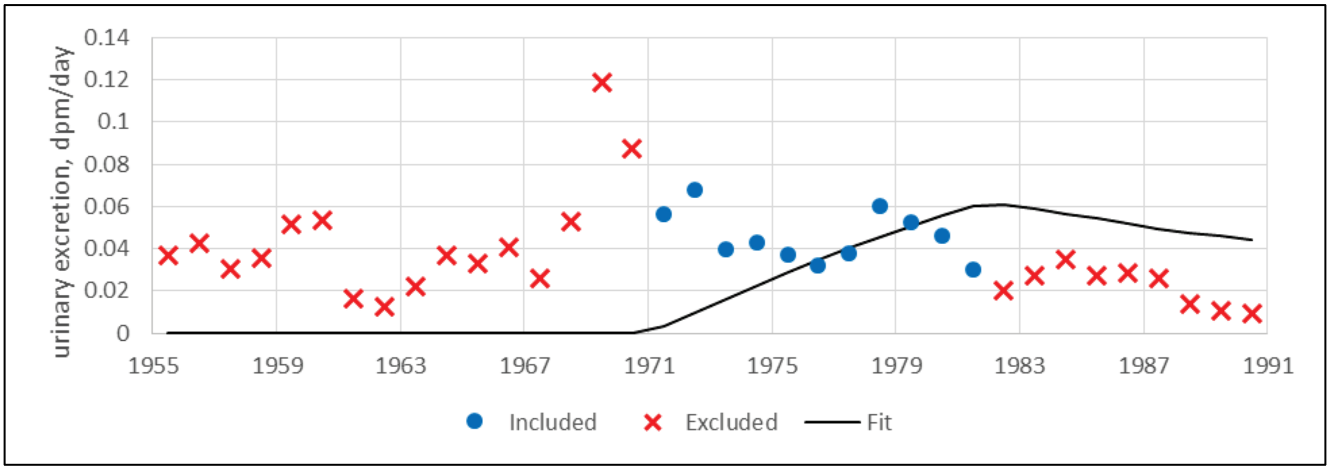

Figure E-71. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1971 to 1981, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

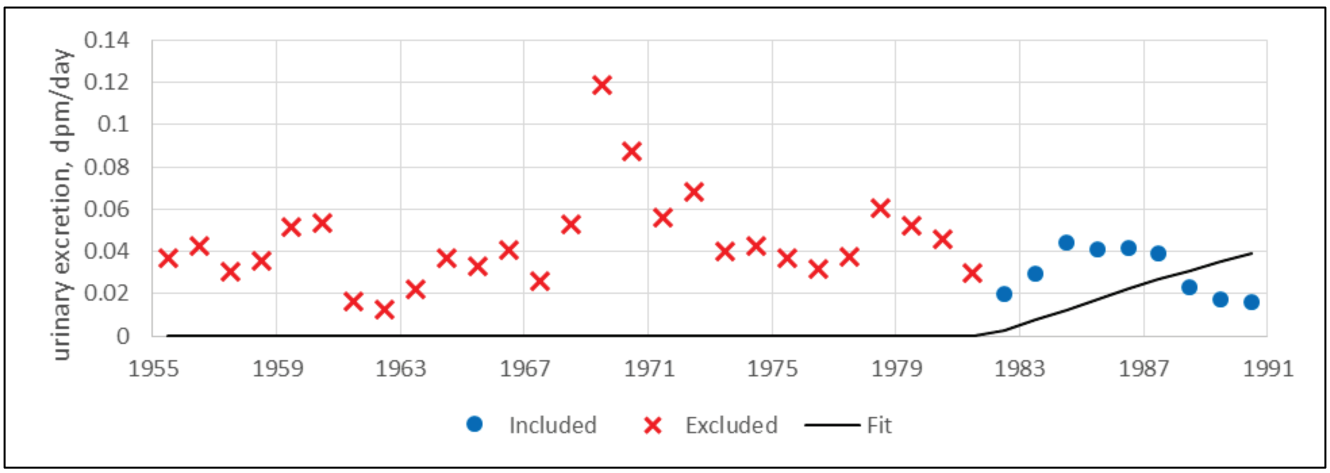

Figure E-72. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1982 to 1990, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

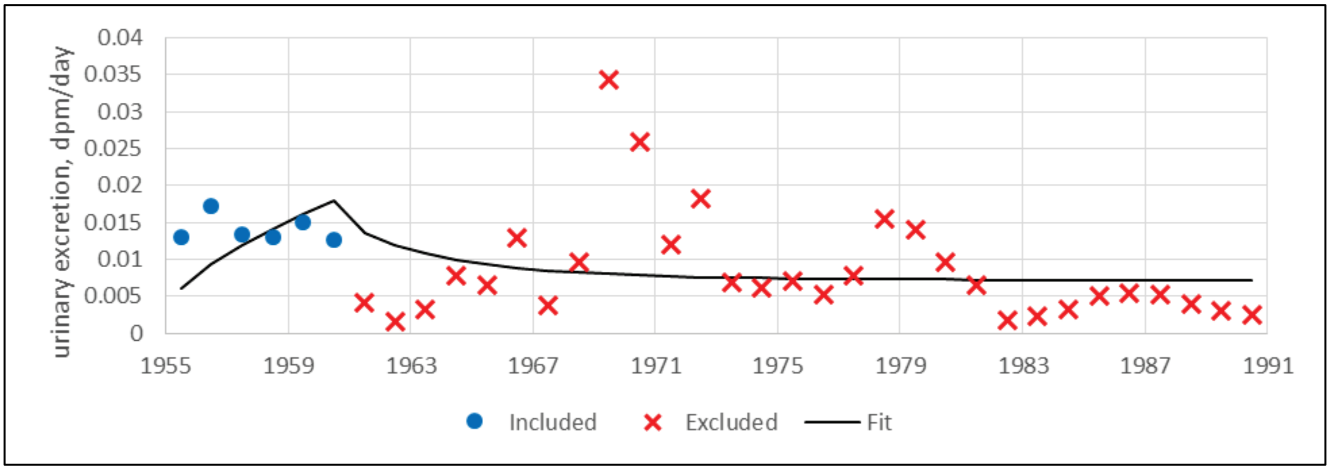

Figure E-73. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1960, type SS.

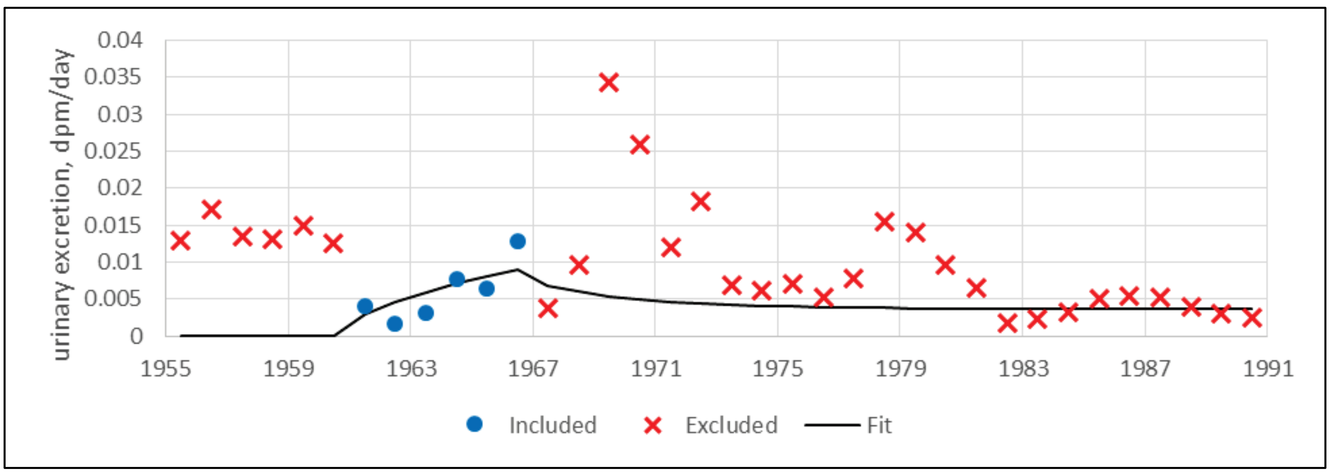

Figure E-74. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1966, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

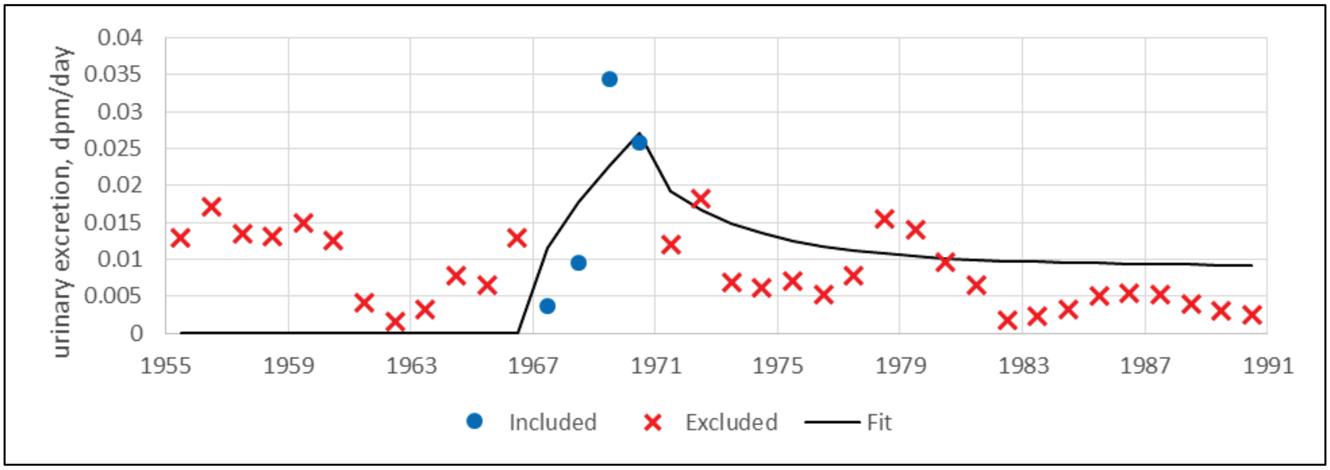

Figure E-75. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1970, type SS.

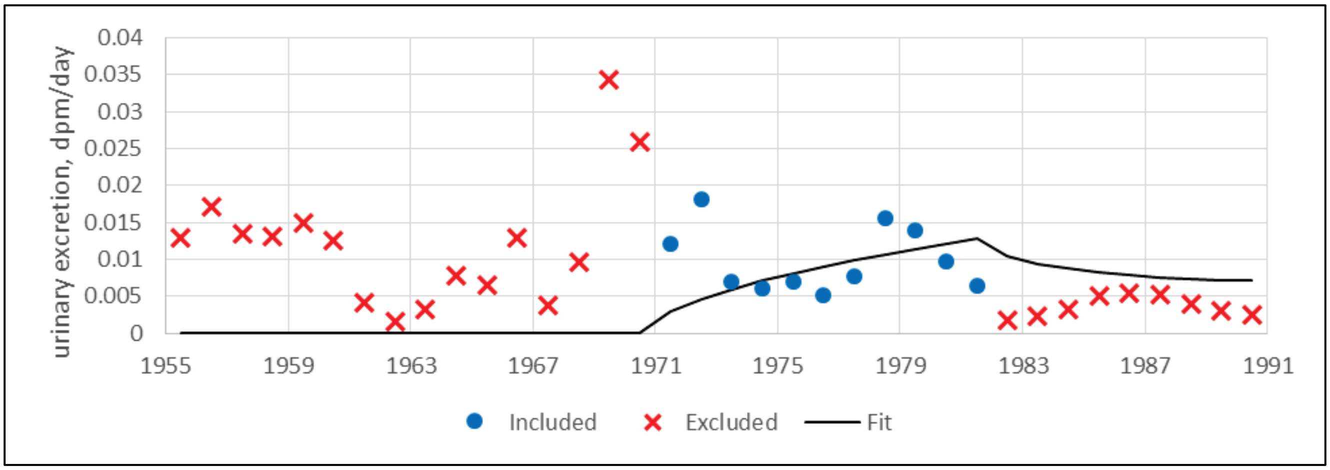

Figure E-76. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1971 to 1981, type SS. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

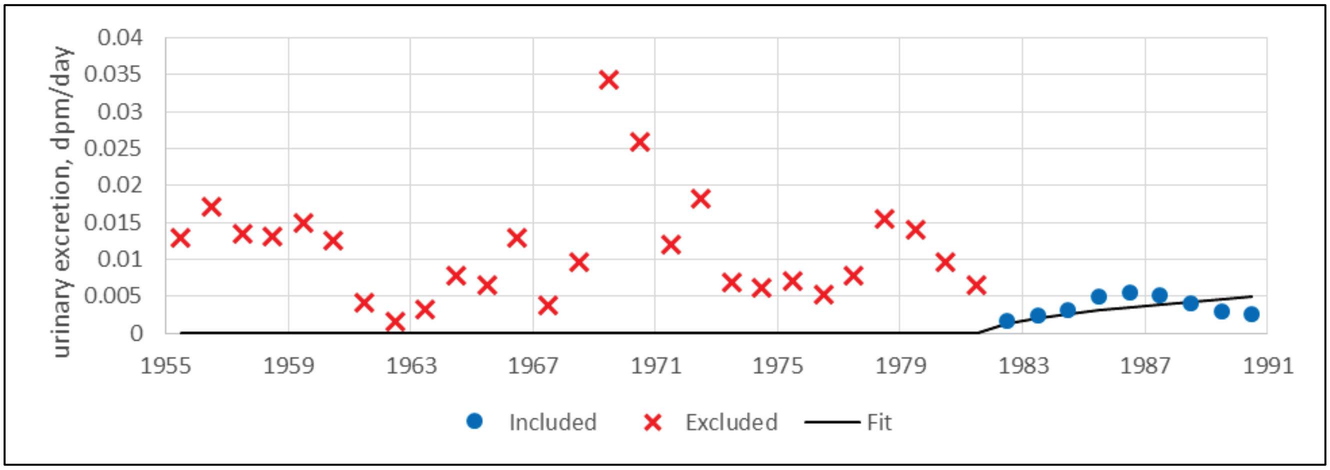

Figure E-77. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1982 to 1990, type SS. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

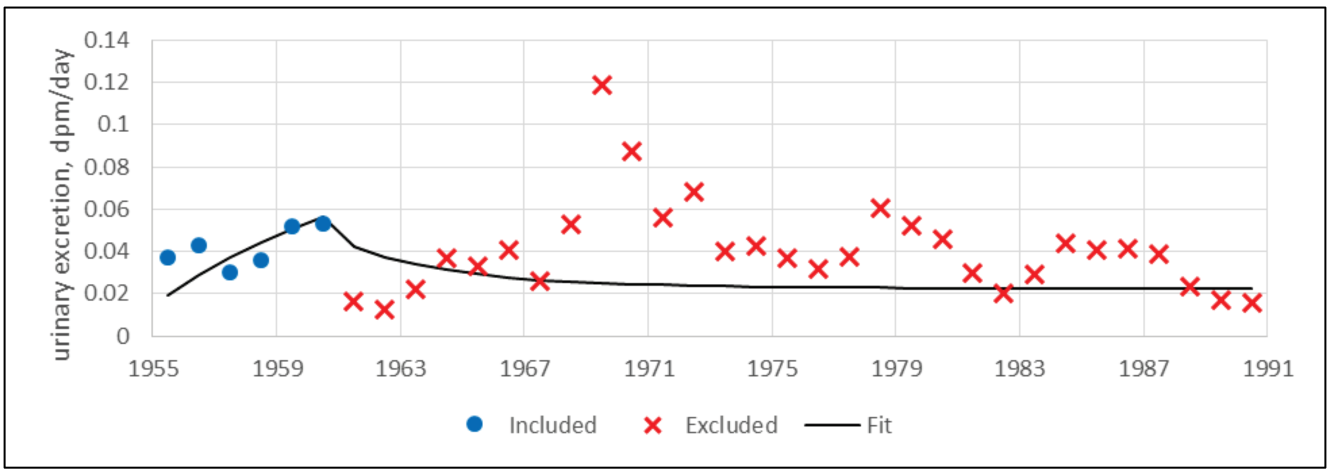

Figure E-78. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1960, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

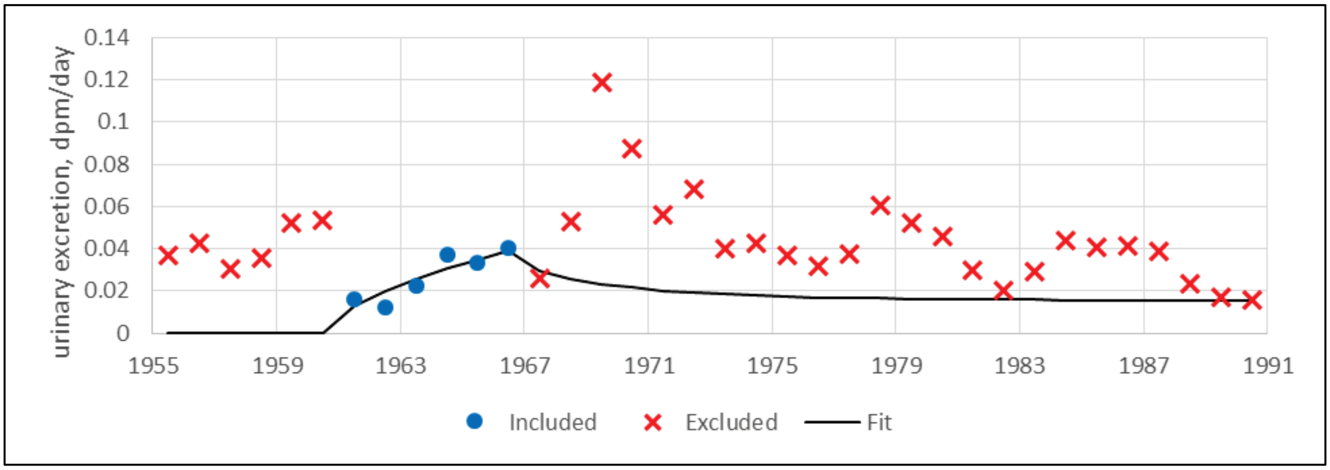

Figure E-79. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1966, type SS.

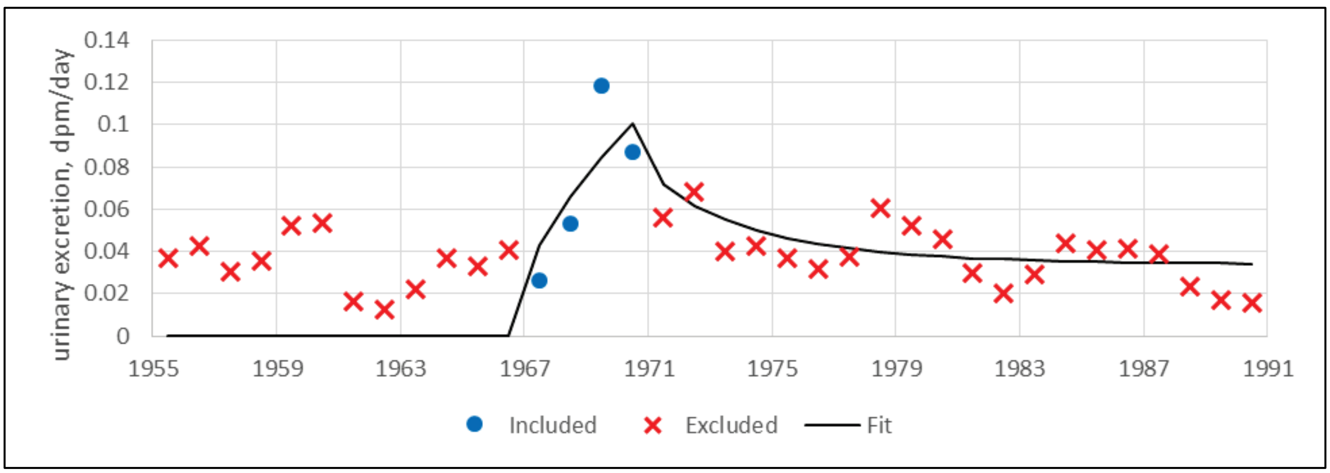

Figure E-80. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1970, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

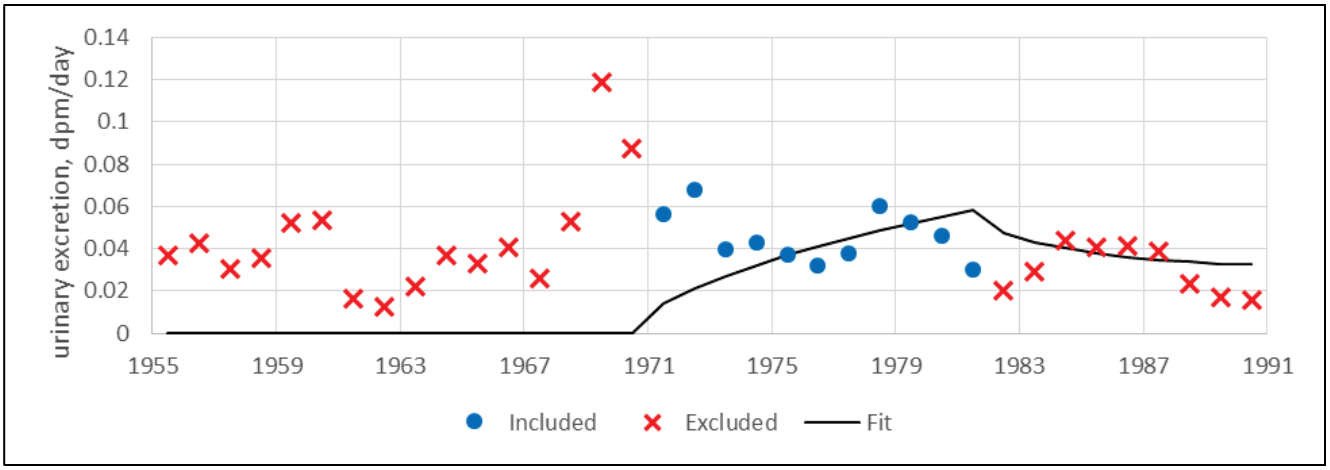

Figure E-81. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1971 to 1981, type SS. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

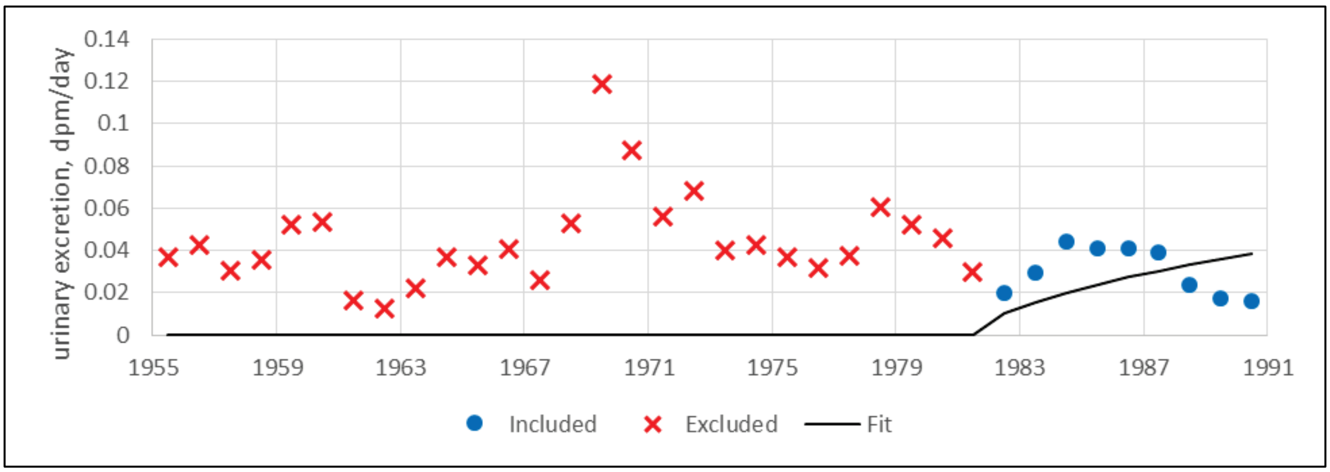

Figure E-82. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1982 to 1990, type SS. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

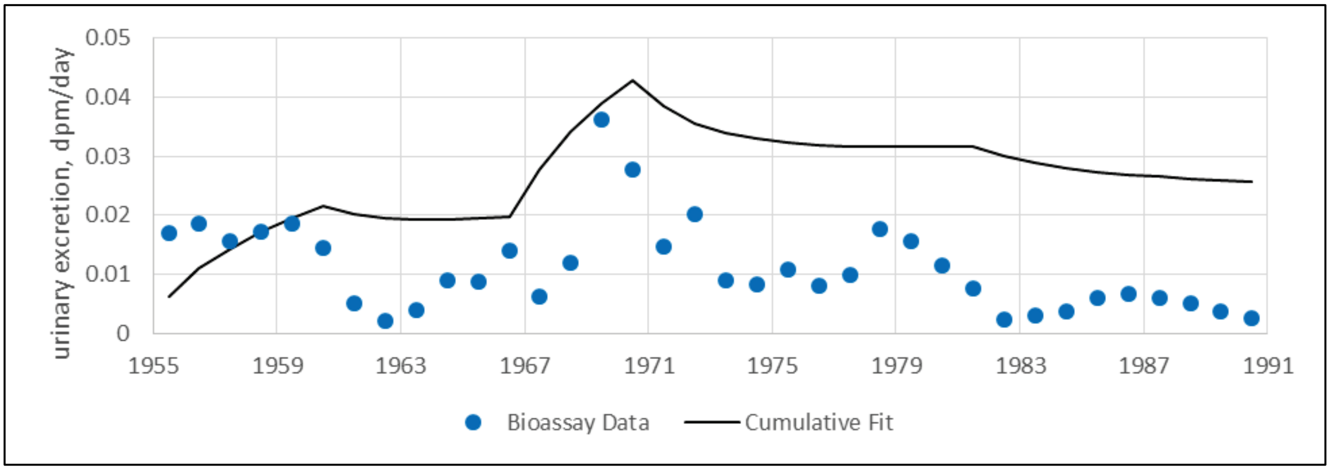

Figure E-83. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type M.

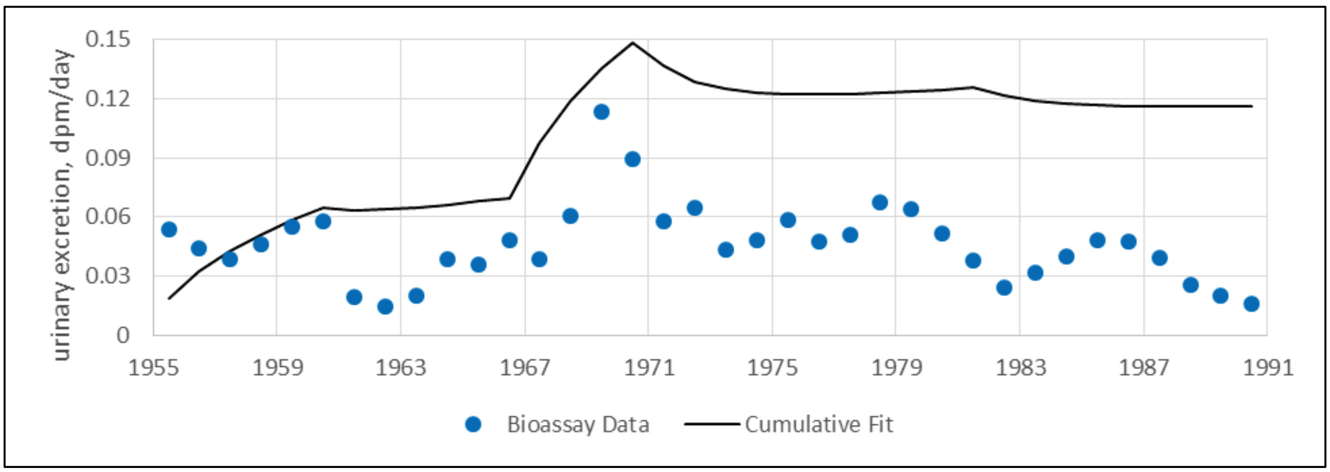

Figure E-84. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

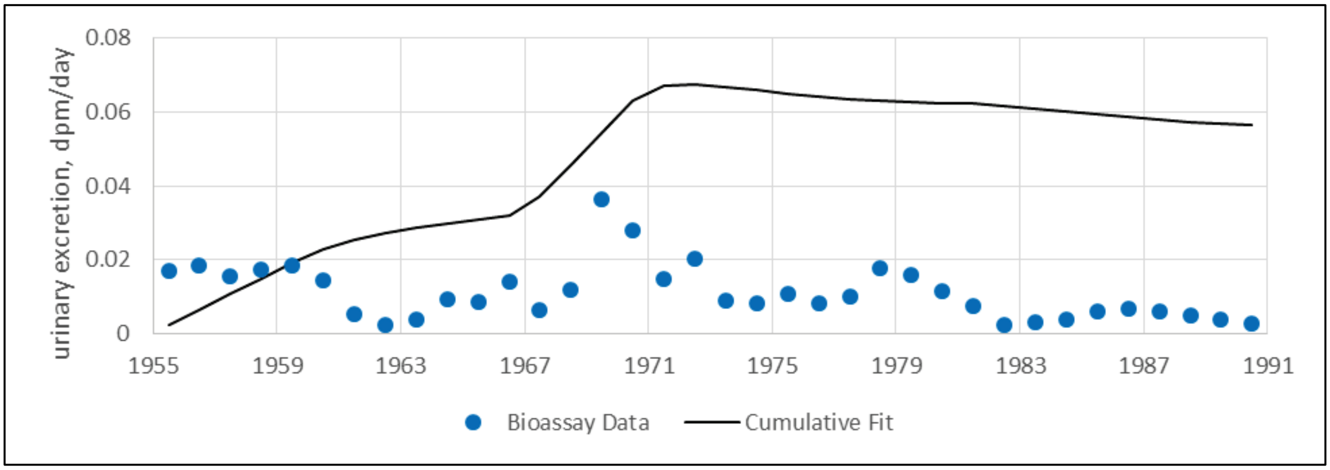

Figure E-85. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type S.

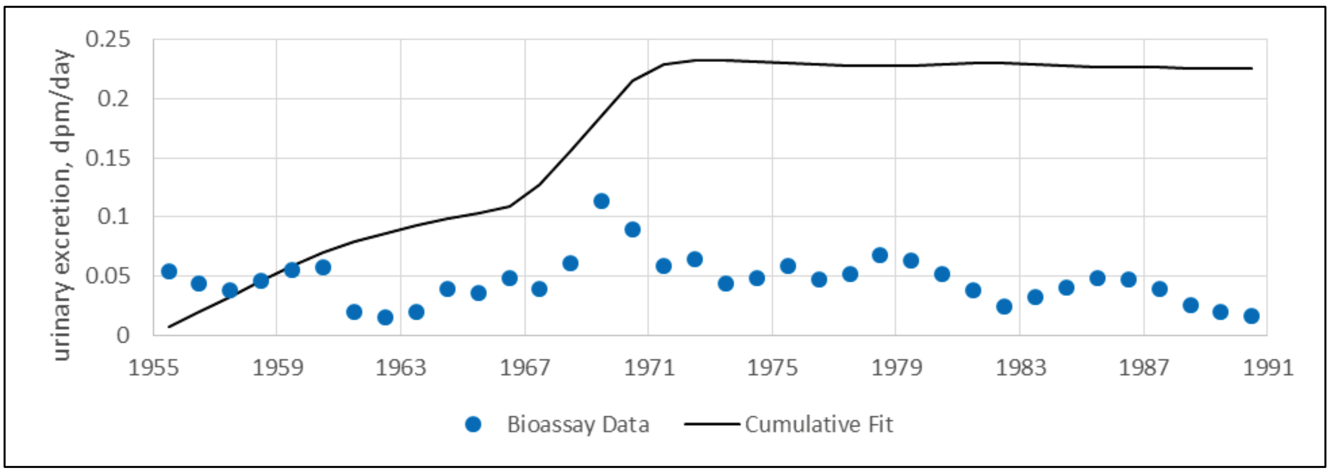

Figure E-86. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

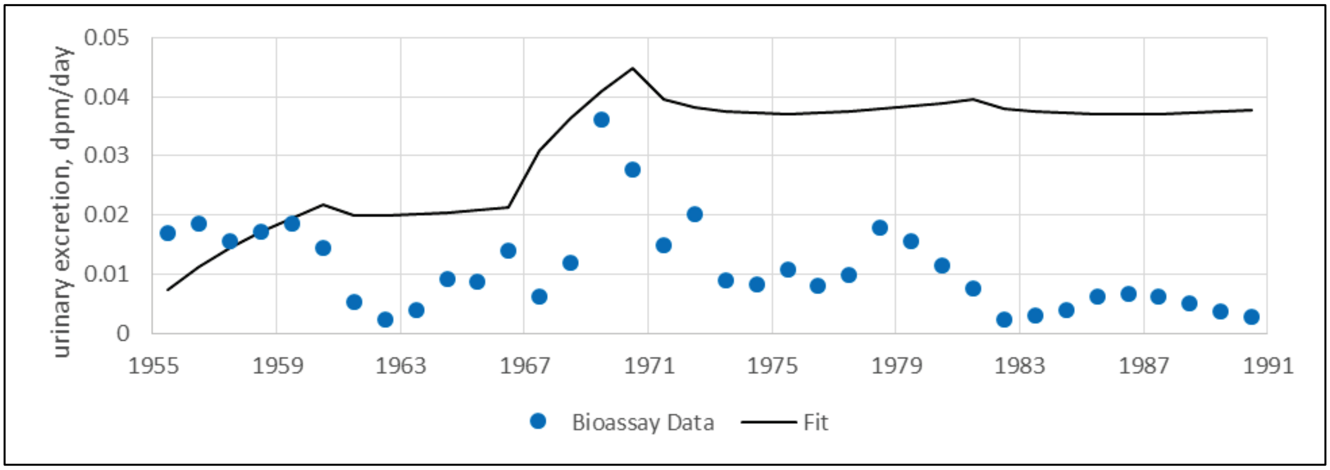

Figure E-87. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type SS.

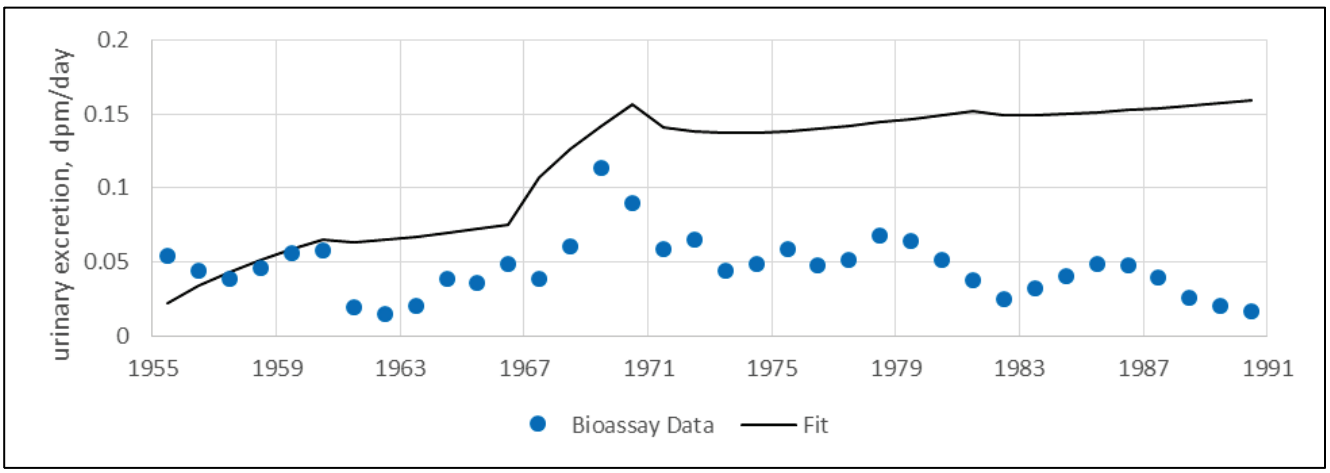

Figure E-88. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type SS.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

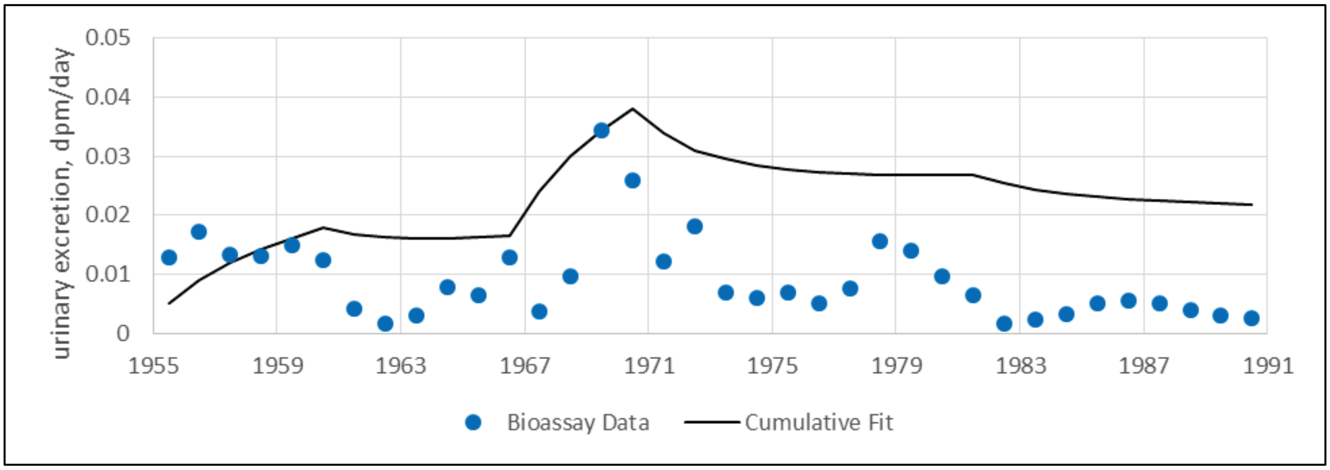

Figure E-89. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

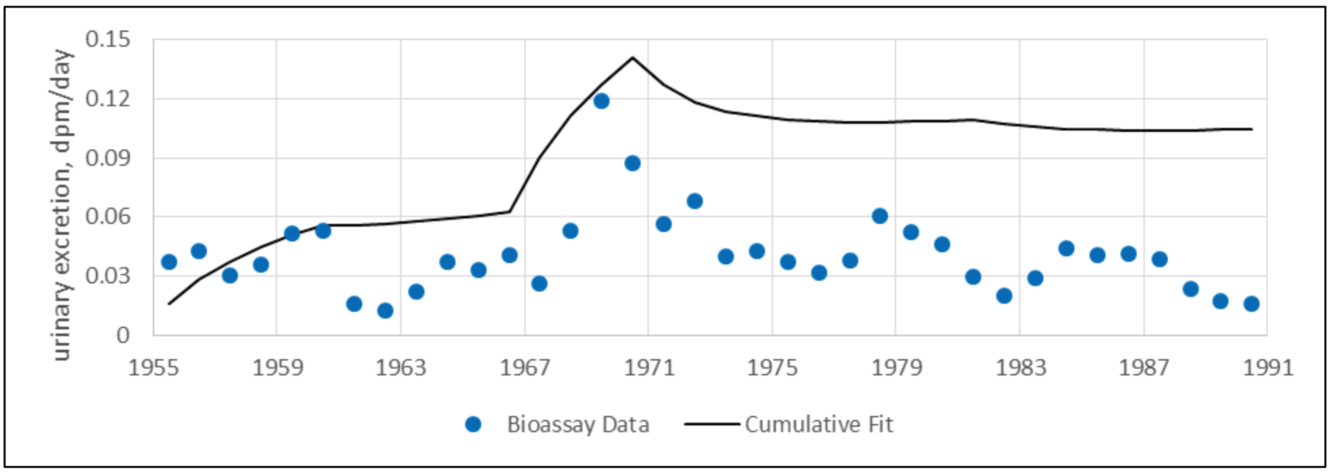

Figure E-90. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

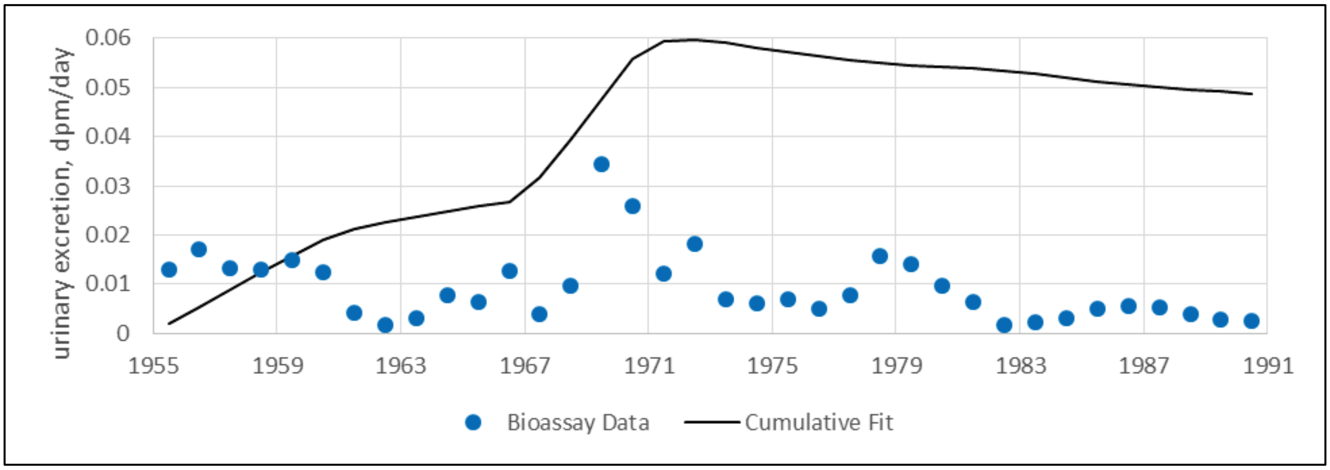

Figure E-91. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

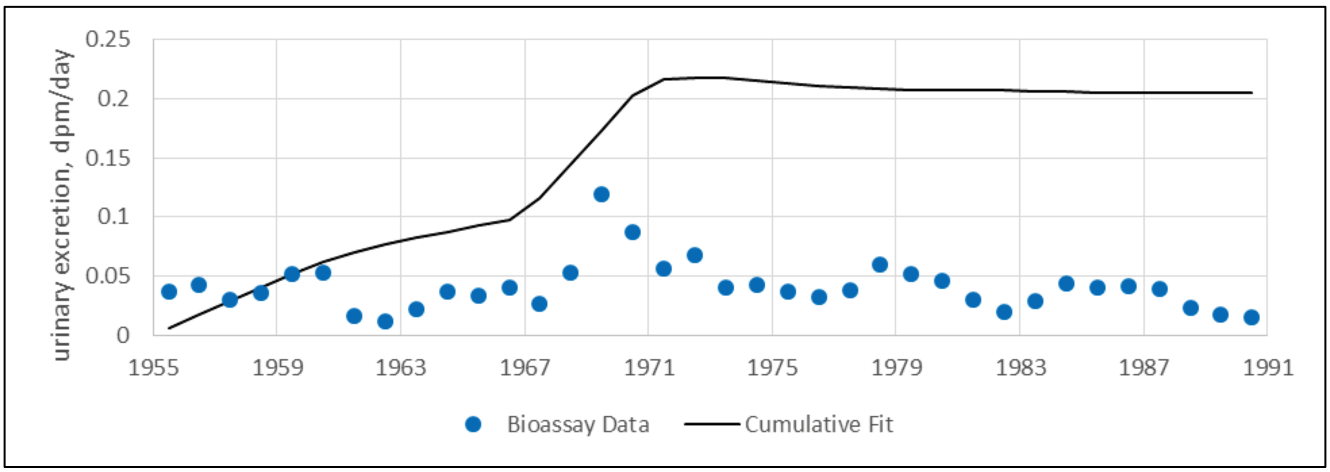

Figure E-92. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

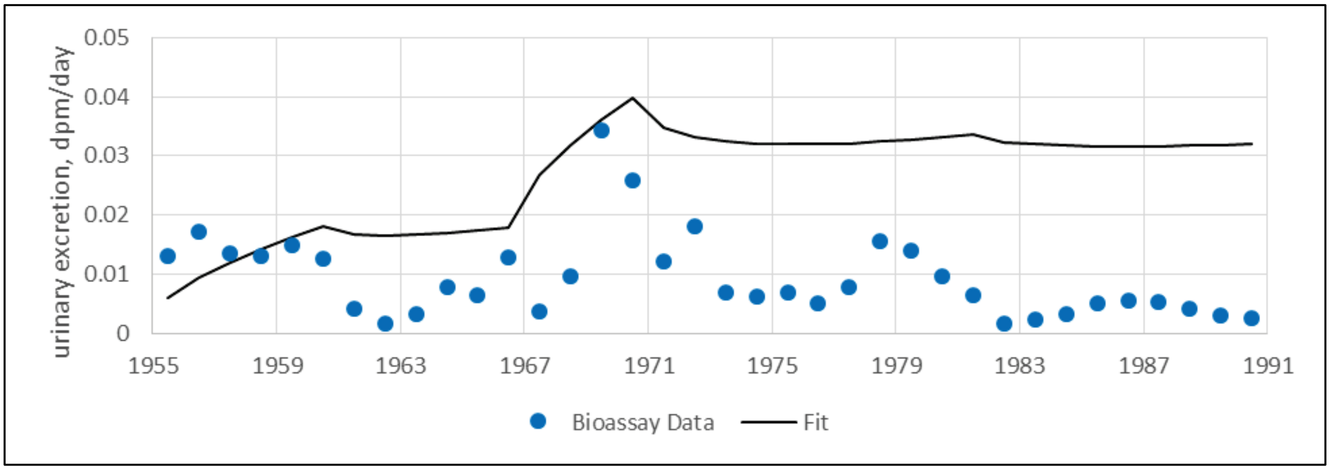

Figure E-93. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type SS. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

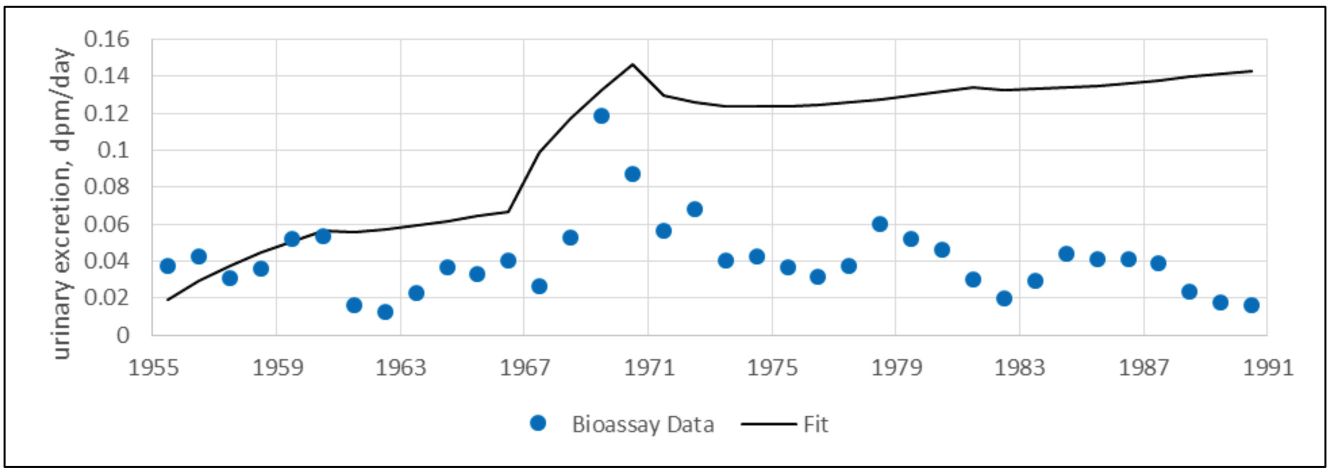

Figure E-94. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type SS. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-3. Summary of plutonium nonCTW intake rates (dpm/d) and dates, type M.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1960	3.265	9.742	2.98	3.00	19.90
01/01/1961	12/31/1966	1.606	6.453	4.02	4.02	15.83
01/01/1967	12/31/1970	5.778	20.17	3.49	3.49	45.17
01/01/1971	12/31/1981	1.692	7.678	4.54	4.54	20.37
01/01/1982	12/31/1990	0.7238	5.03	6.94	6.94	17.5

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

Table E-4. Summary of plutonium nonCTW intake rates (dpm/d) and dates, type S.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1960	66.17	202.9	3.07	3.07	417.98
01/01/1961	12/31/1966	36	141.9	3.94	3.94	343.71
01/01/1967	12/31/1970	154.5	524.1	3.39	3.39	1,152.33
01/01/1971	12/31/1981	27.02	123.3	4.56	4.56	328.24
01/01/1982	12/31/1990	12.56	83.44	6.64	6.64	283.0

Table E-5. Summary of plutonium nonCTW intake rates (dpm/d) and dates, type SS.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1960	454	1,360	3.00	3.00	2,766
01/01/1961	12/31/1966	222	893	4.02	4.02	2,192
01/01/1967	12/31/1970	787	2,770	3.52	3.52	6,237
01/01/1971	12/31/1981	230	1,040	4.52	4.52	2,752
01/01/1982	12/31/1990	99	687	6.94	6.94	2,397

Table E-6. Summary of plutonium CTW intake rates (dpm/d) and dates, type M.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1960	2.706	8.487	3.14	3.14	17.74
01/01/1961	12/31/1966	1.356	5.89	4.34	4.34	15.19
01/01/1967	12/31/1970	5.279	19.55	3.70	3.70	45.49
01/01/1971	12/31/1981	1.379	6.329	4.59	4.59	16.91
01/01/1982	12/31/1990	0.5974	4.65	7.78	7.78	17.5

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-7. Summary of plutonium CTW intake rates (dpm/d) and dates, type S.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1960	54.76	178.9	3.27	3.27	383.92
01/01/1961	12/31/1966	30.63	128.9	4.21	4.21	325.69
01/01/1967	12/31/1970	142.5	514.4	3.61	3.61	1,177.28
01/01/1971	12/31/1981	22.13	100.6	4.55	4.55	267.15
01/01/1982	12/31/1990	10.41	77.13	7.41	7.41	280.7

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-8. Summary of plutonium CTW intake rates (dpm/d) and dates, type SS.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1960	377	1,180	3.13	3.13	2,463
01/01/1961	12/31/1966	188	814	4.33	4.33	2,095
01/01/1967	12/31/1970	719	2,670	3.71	3.71	6,223
01/01/1971	12/31/1981	188	861	4.58	4.58	2,297
01/01/1982	12/31/1990	81.6	636	7.79	7.79	2,391

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

E.3 URANIUM INTAKE MODELING RESULTS

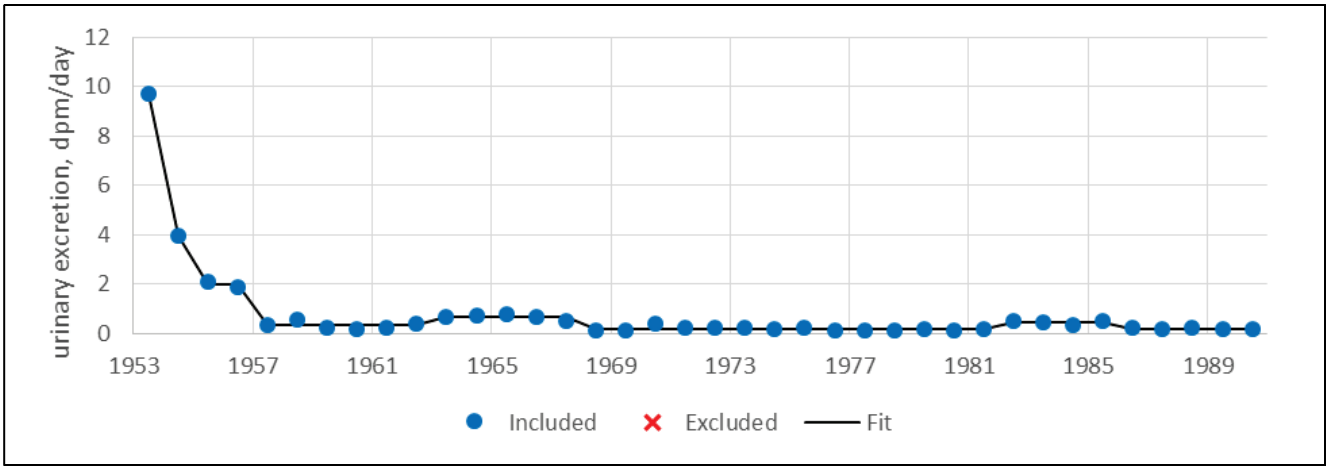

Figure E-95. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type F.

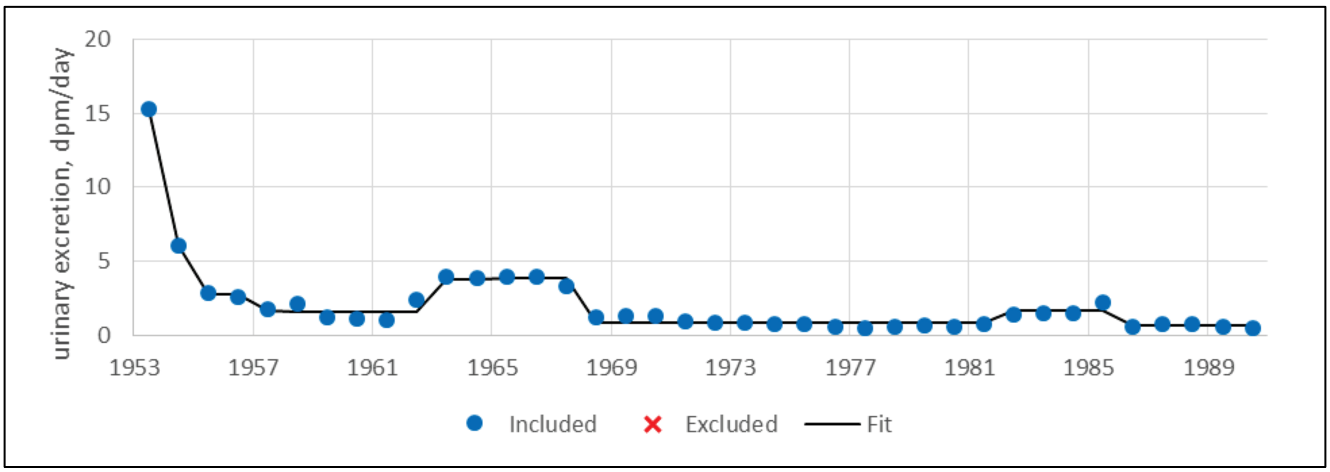

Figure E-96. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type F.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

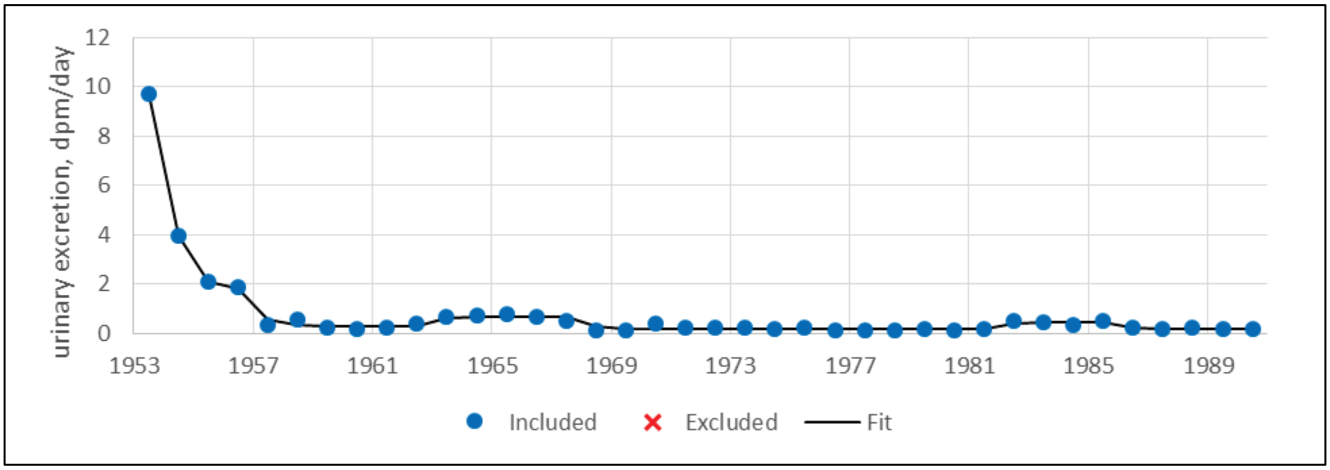

Figure E-97. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type M.

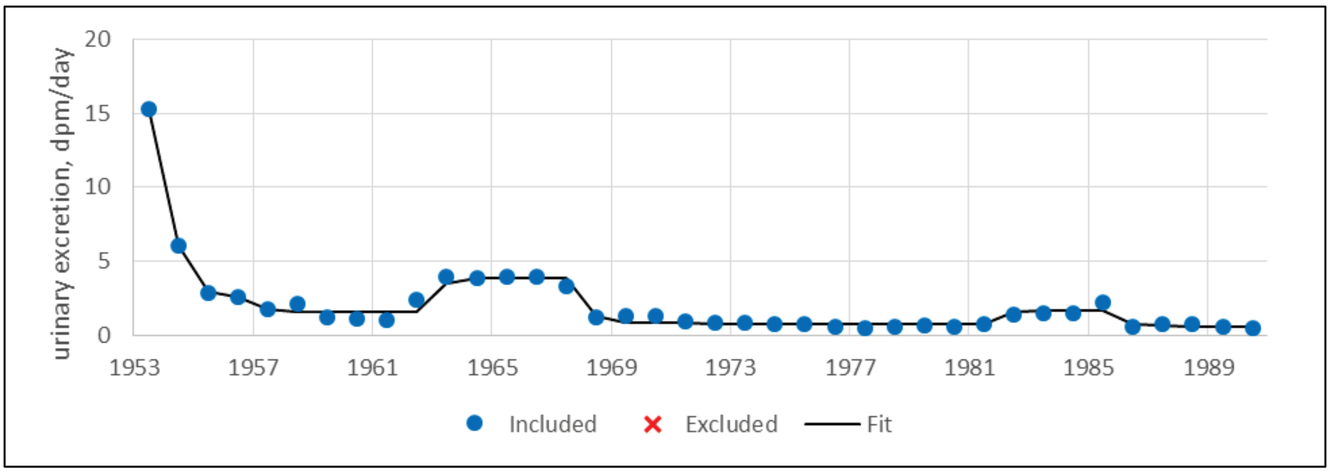

Figure E-98. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

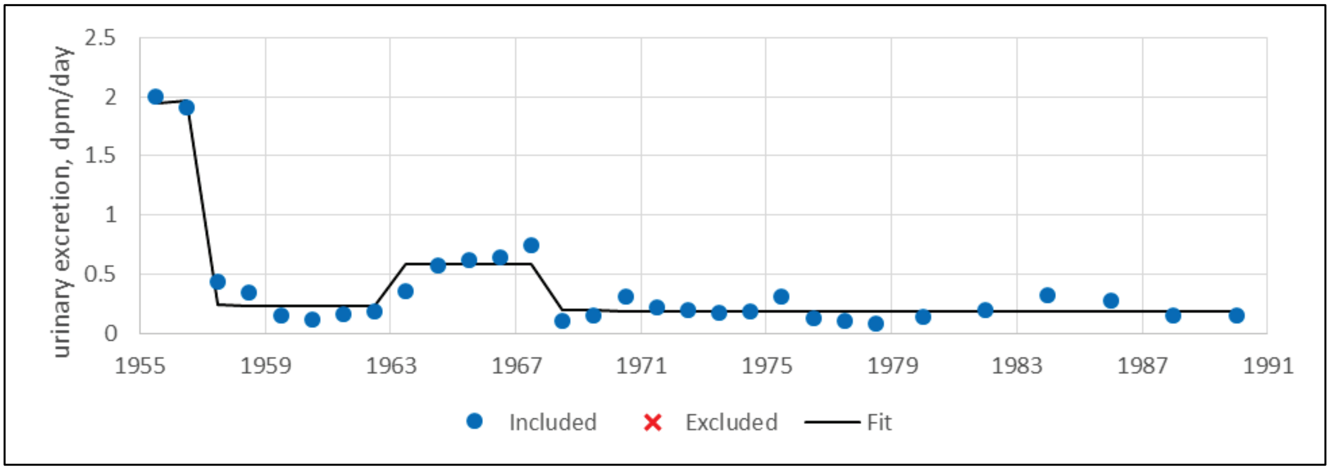

Figure E-99. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type F. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

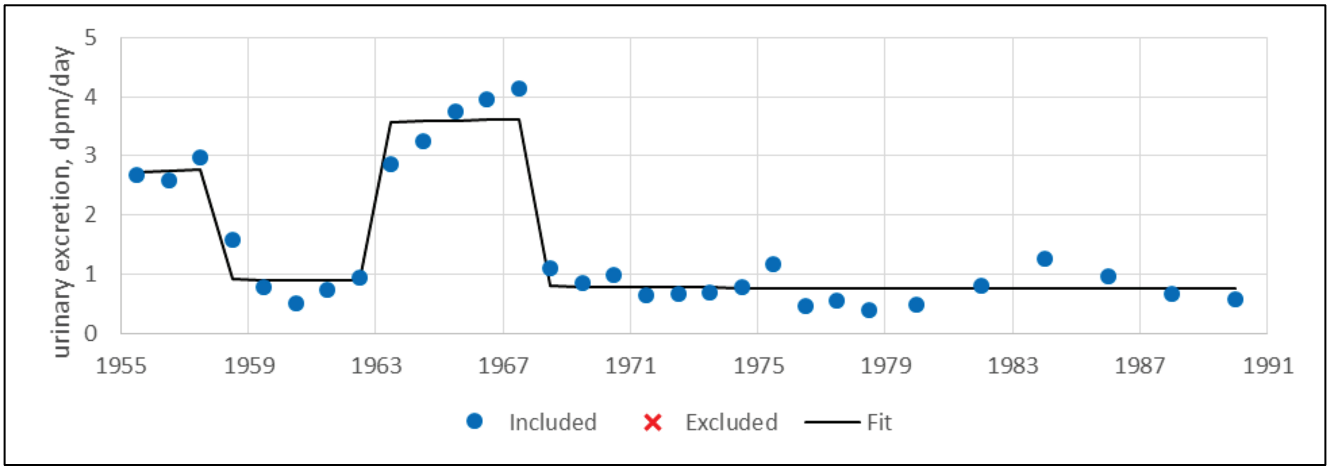

Figure E-100. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type F. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

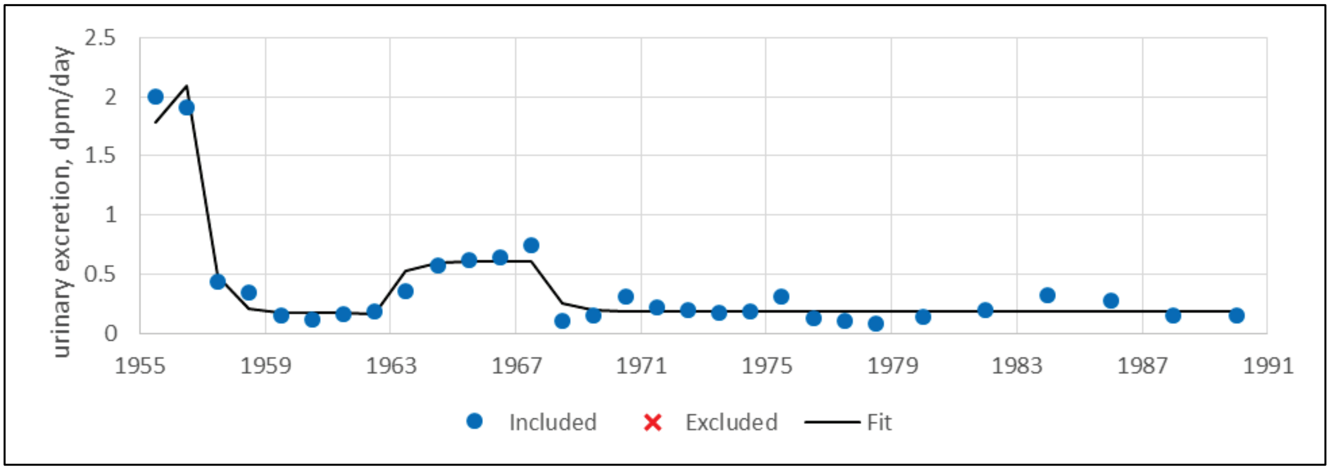

Figure E-101. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

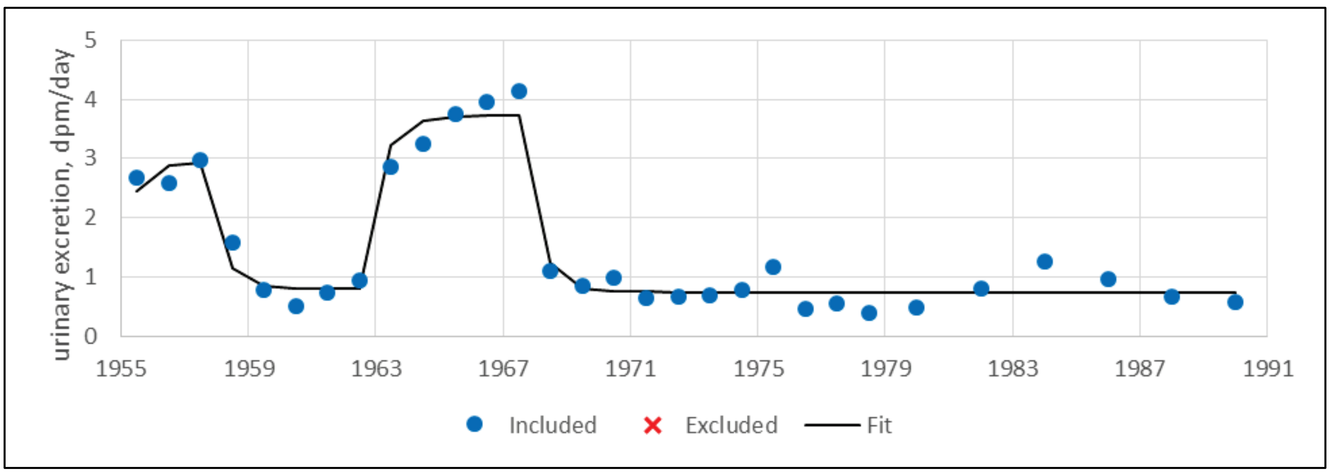

Figure E-102. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

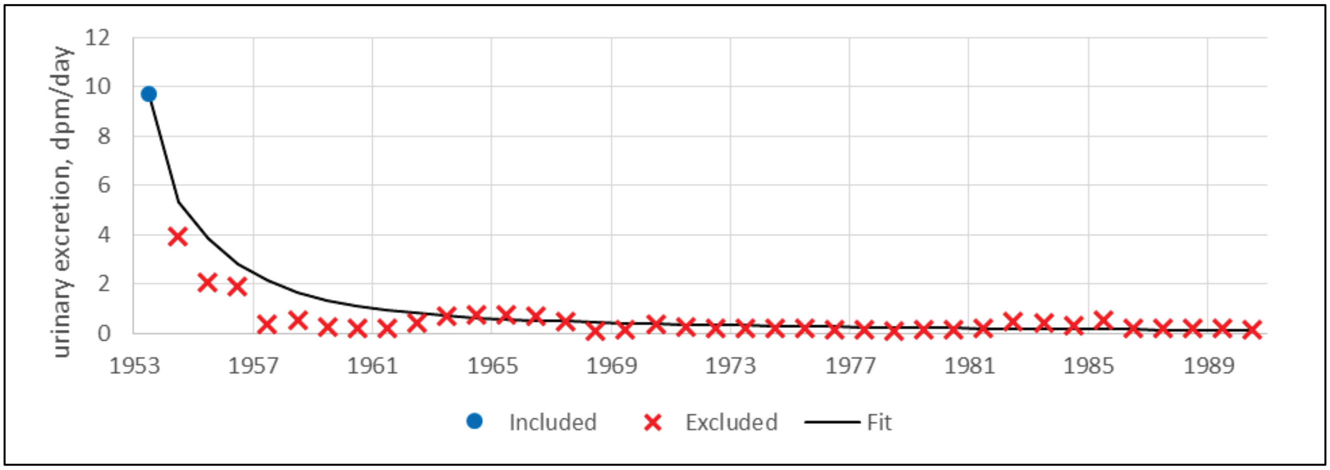

Figure E-103. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW, 1953, type S.

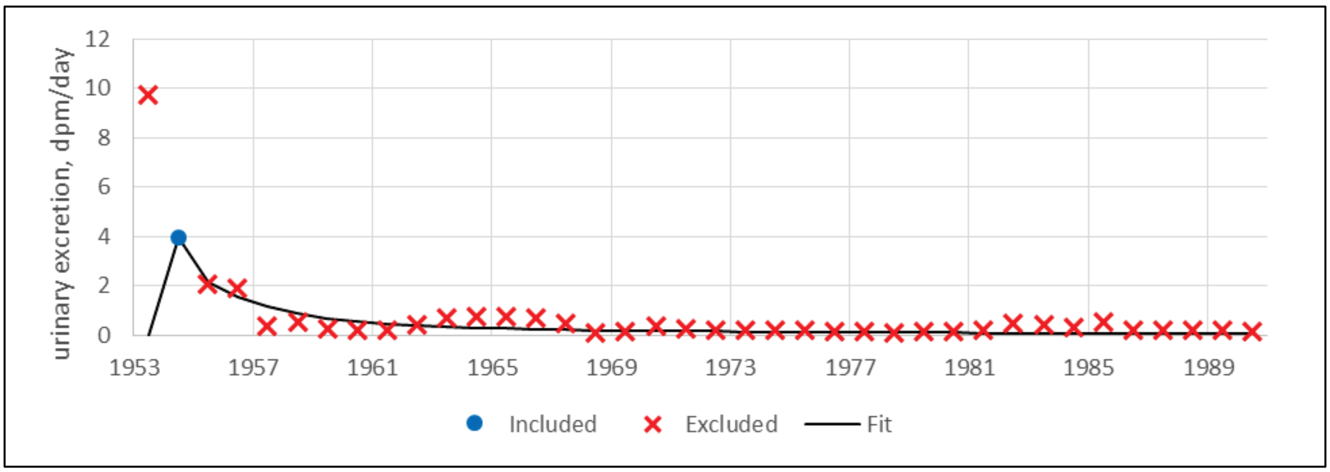

Figure E-104. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW, 1954, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

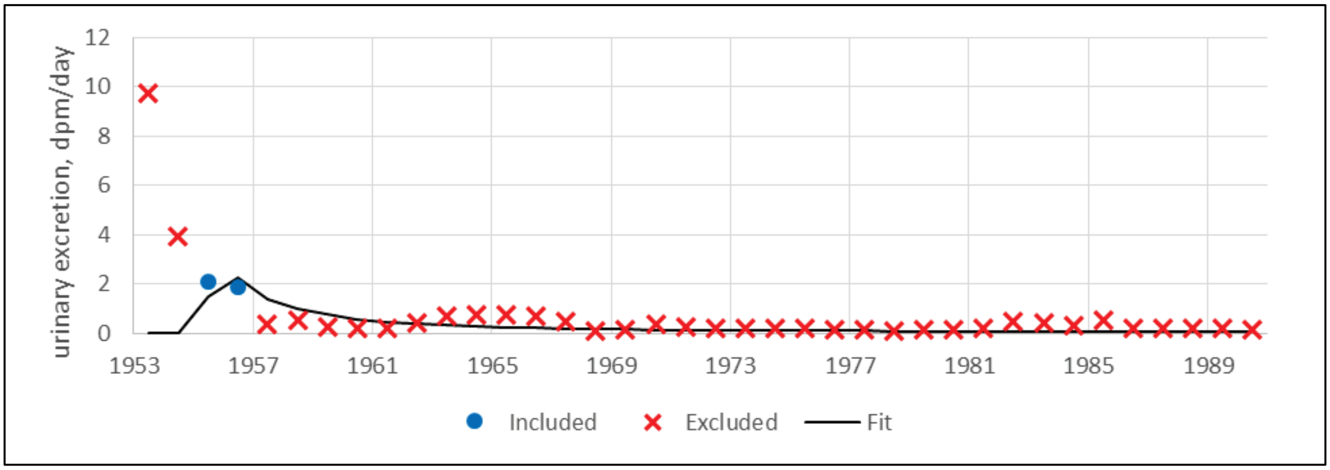

Figure E-105. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1956, type S.

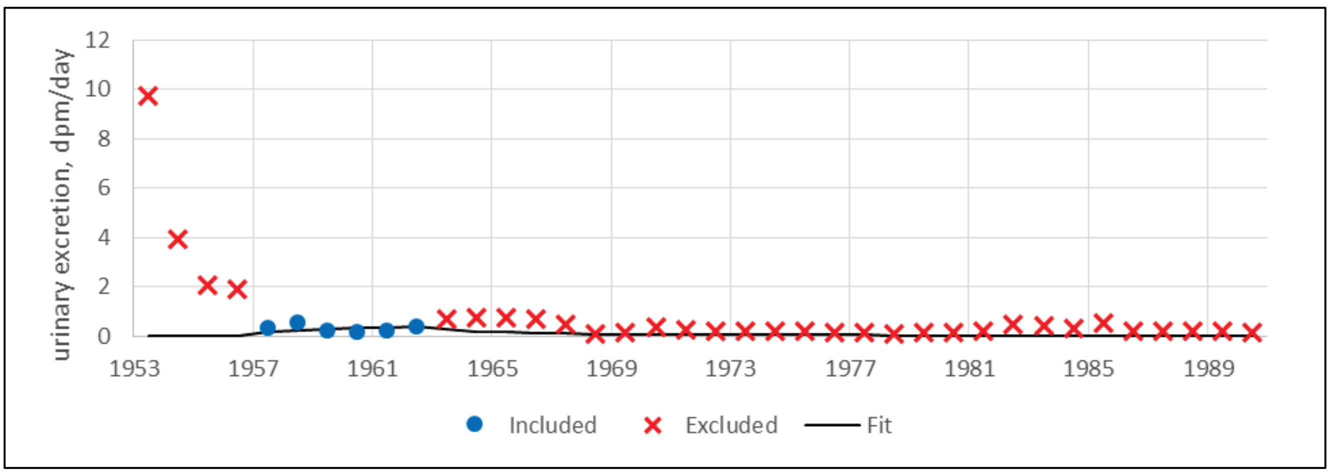

Figure E-106. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1957 to 1962, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

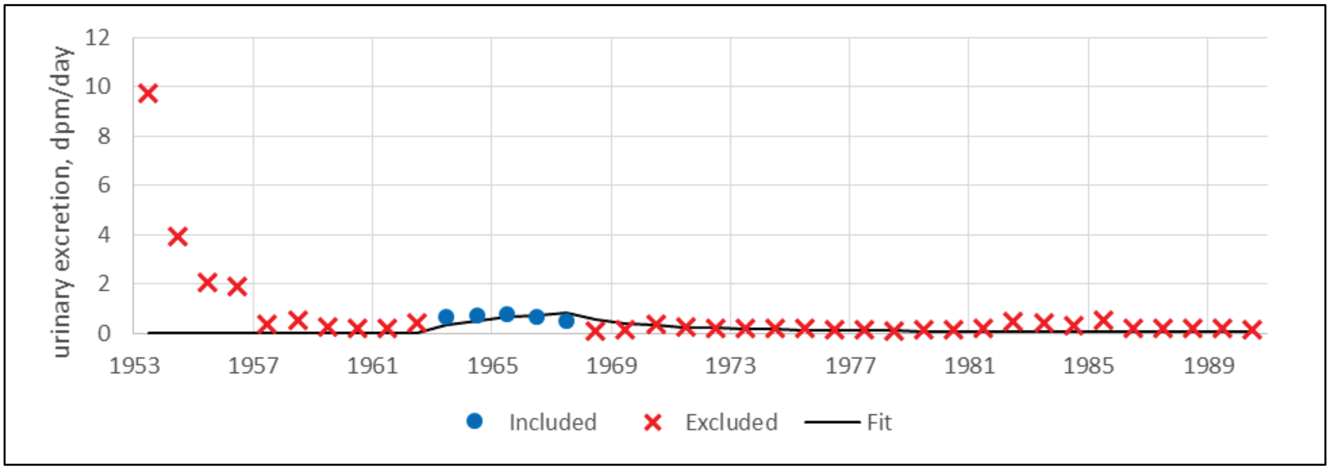

Figure E-107. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1963 to 1967, type S.

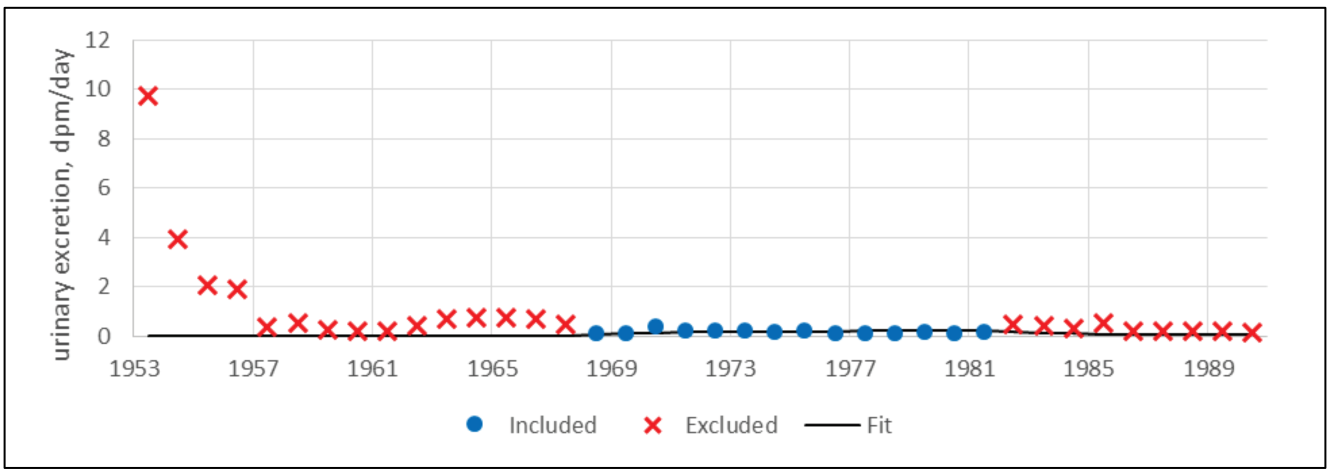

Figure E-108. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1968 to 1981, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

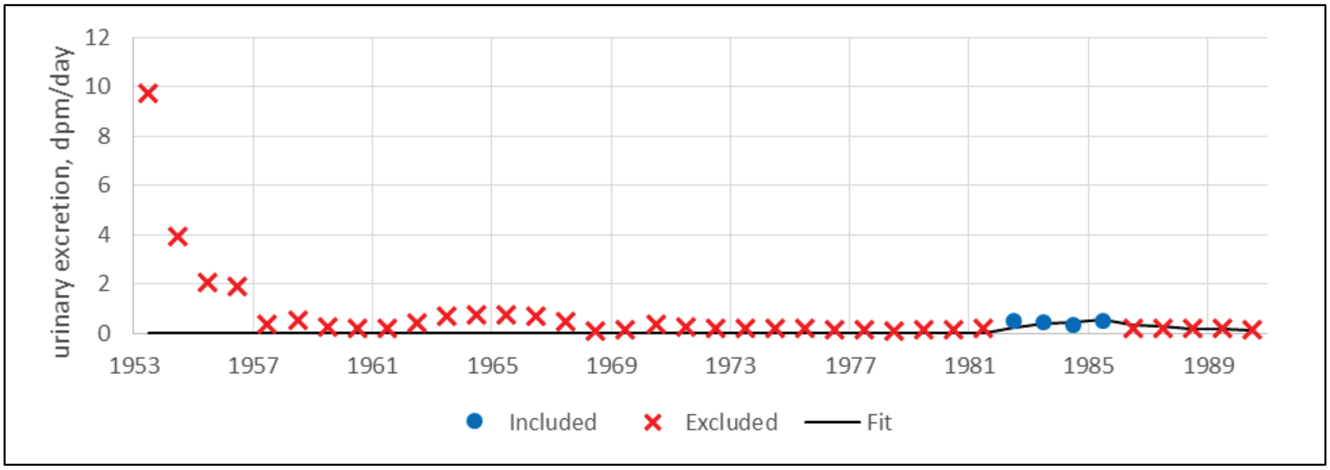

Figure E-109. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1985, type S.

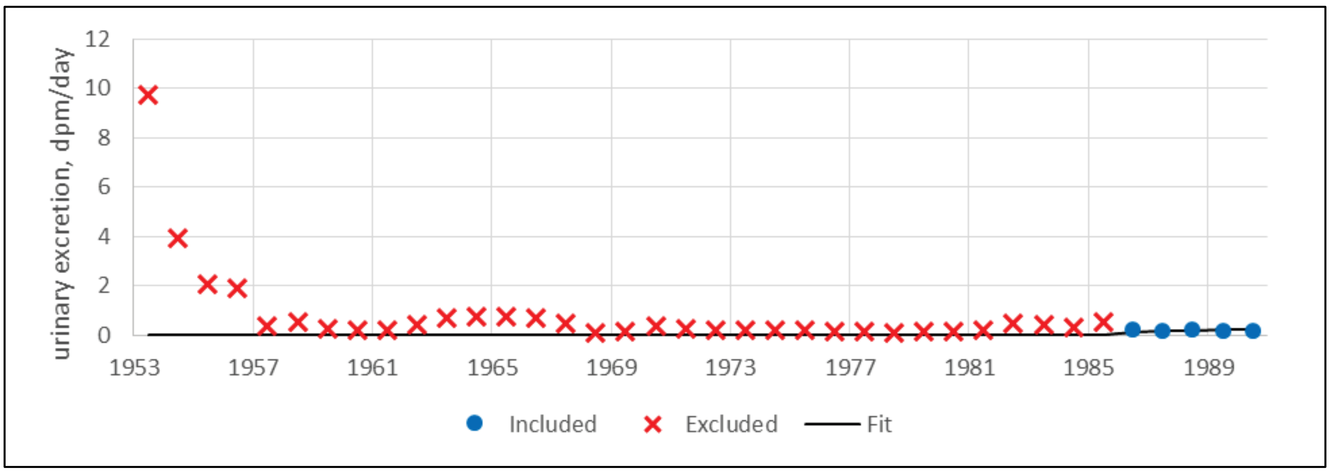

Figure E-110. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1986 to 1990, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

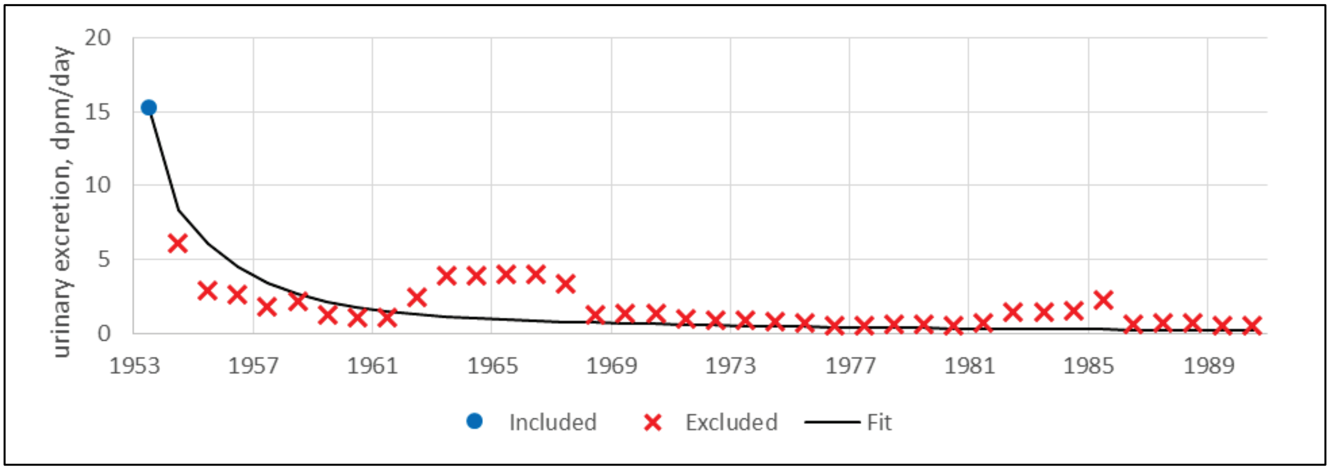

Figure E-111. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1953, type S.

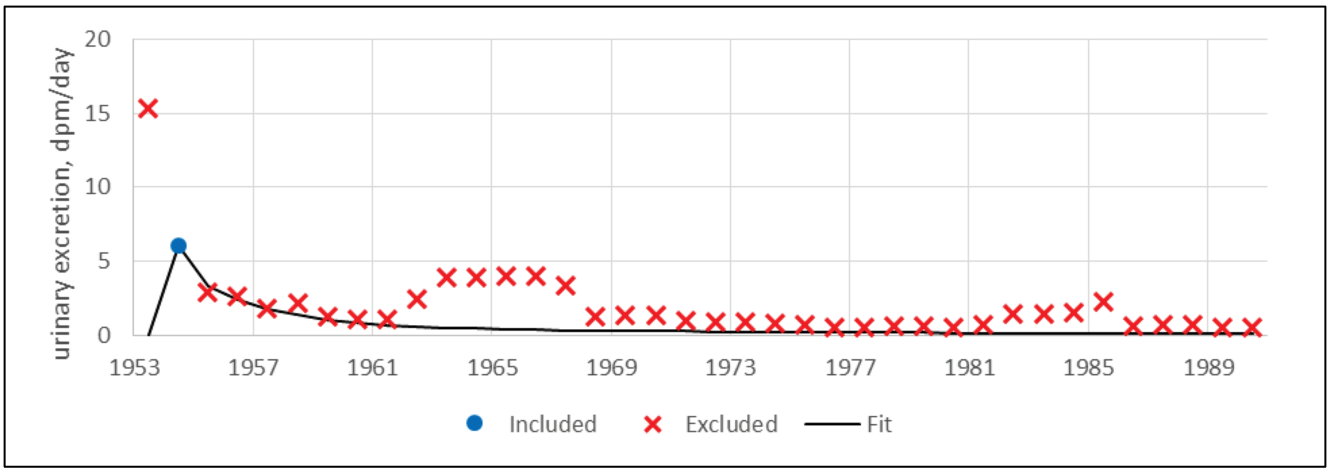

Figure E-112. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1954, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

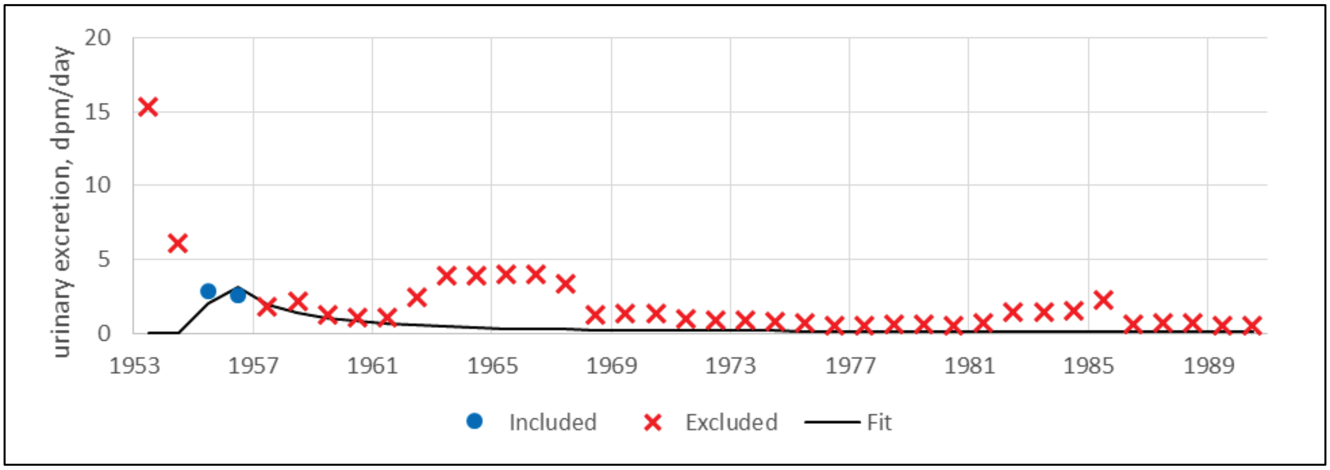

Figure E-113. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1956, type S.

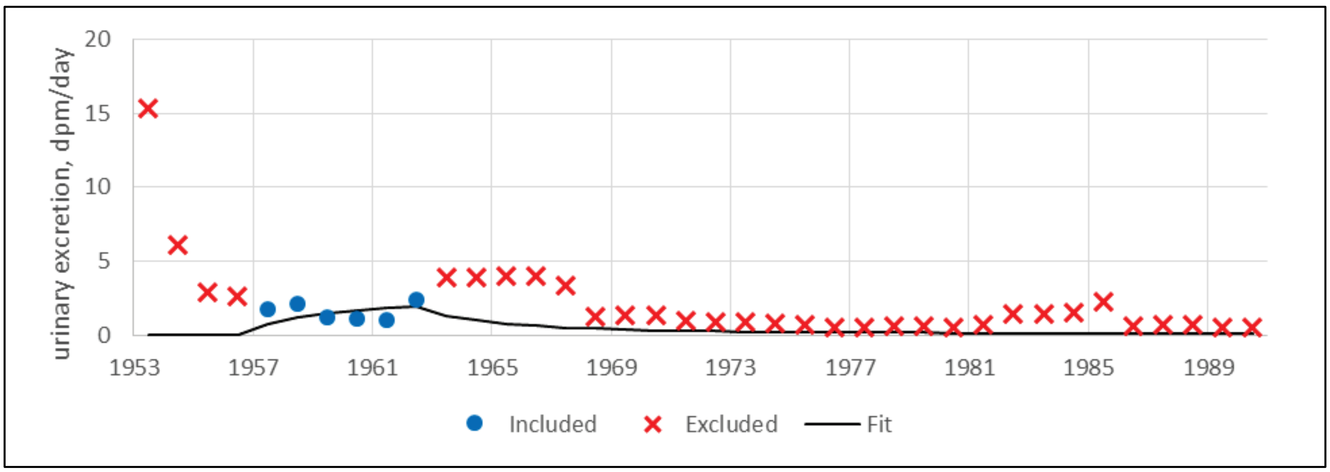

Figure E-114. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1957 to 1962, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

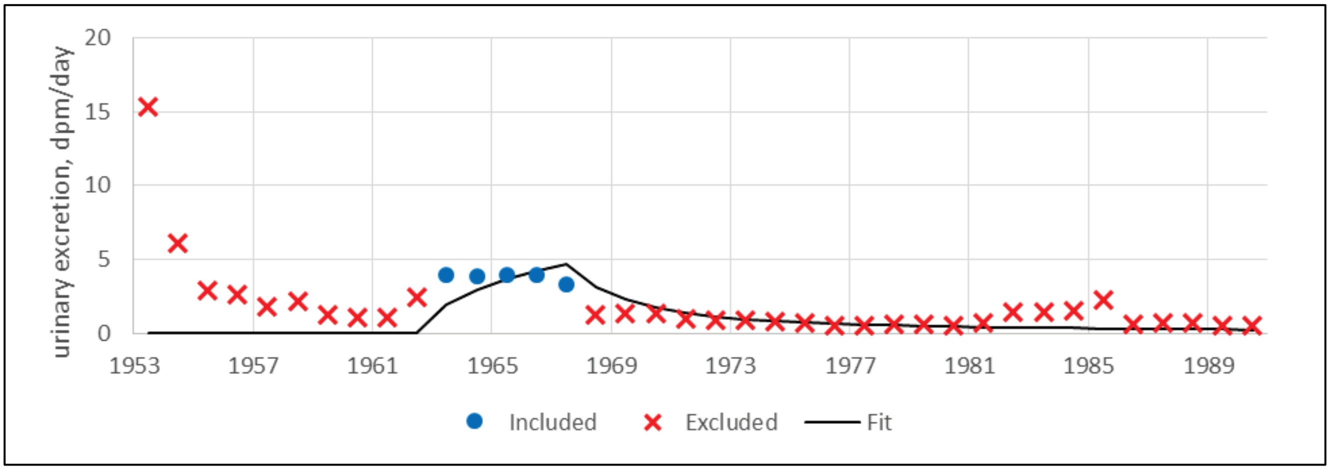

Figure E-115. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1963 to 1967, type S.

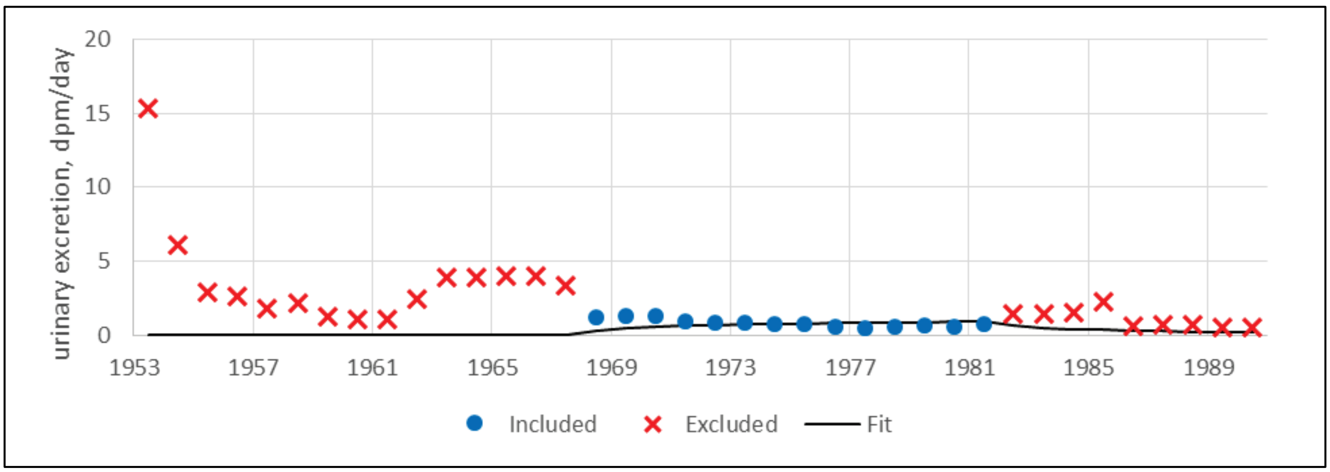

Figure E-116. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1968 to 1981, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

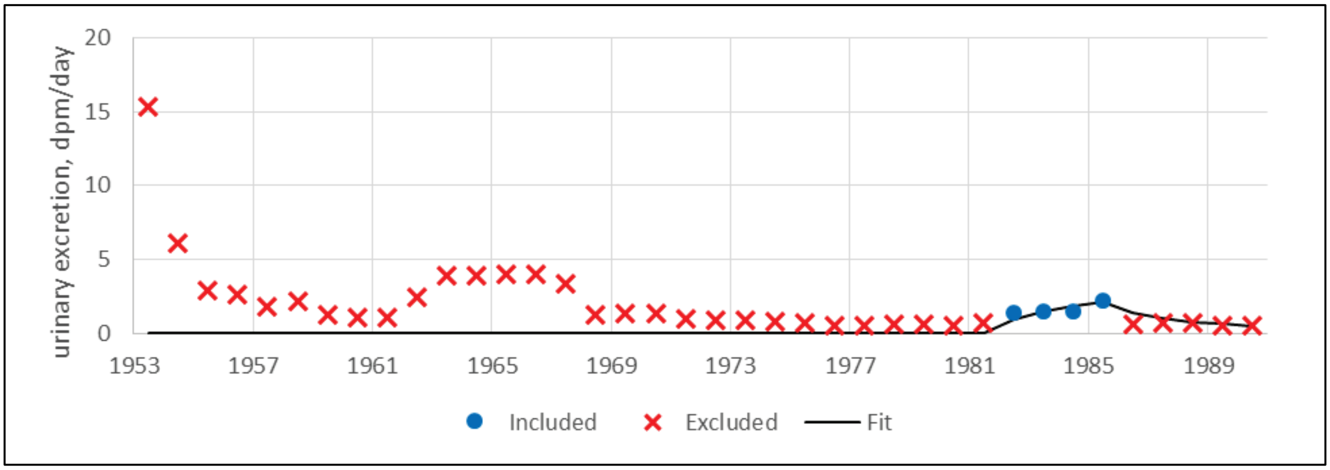

Figure E-117. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1985, type S.

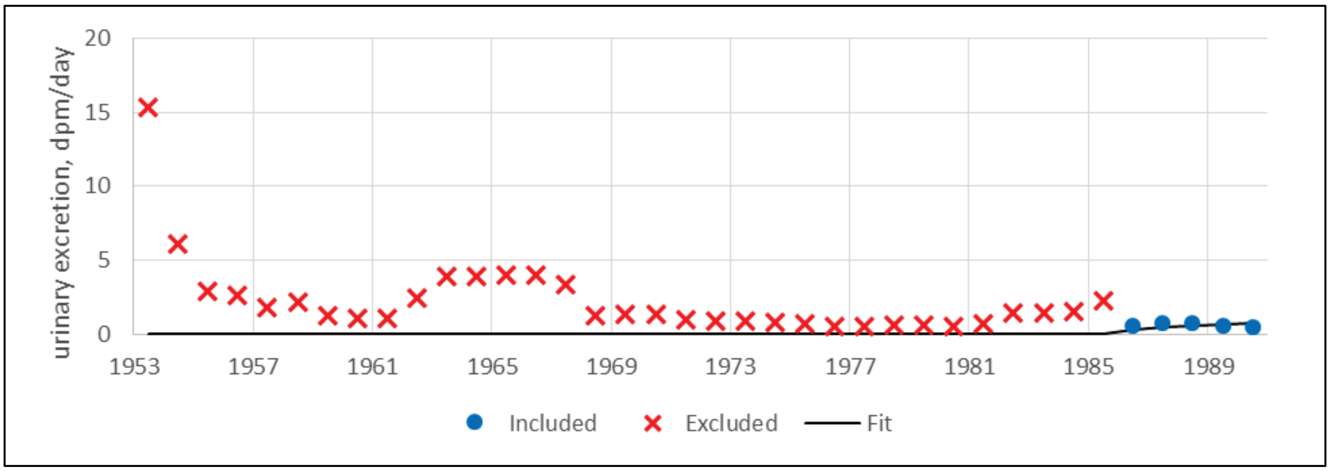

Figure E-118. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1986 to 1990, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

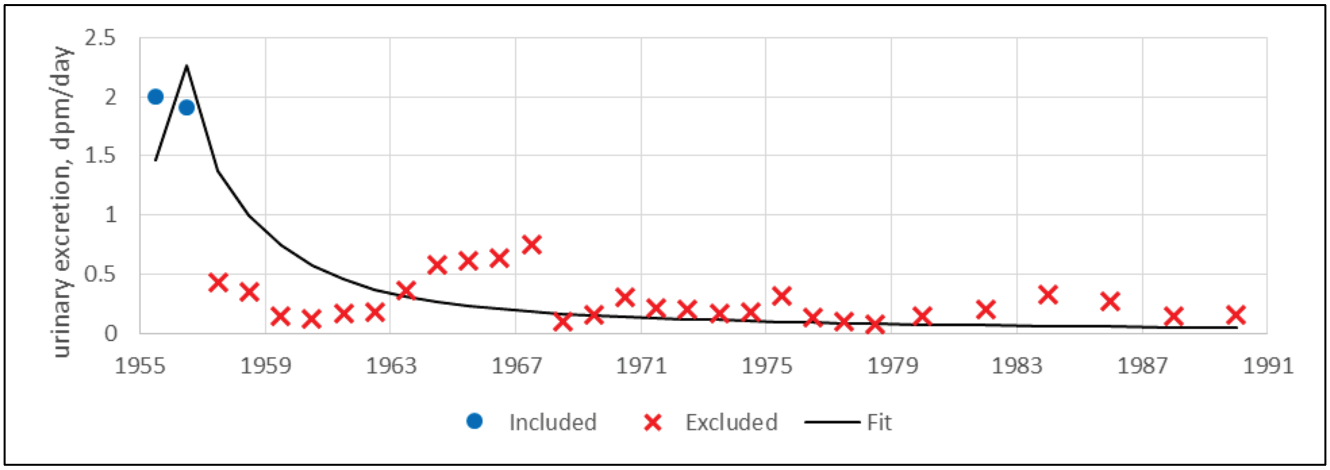

Figure E-119. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1956, type S.

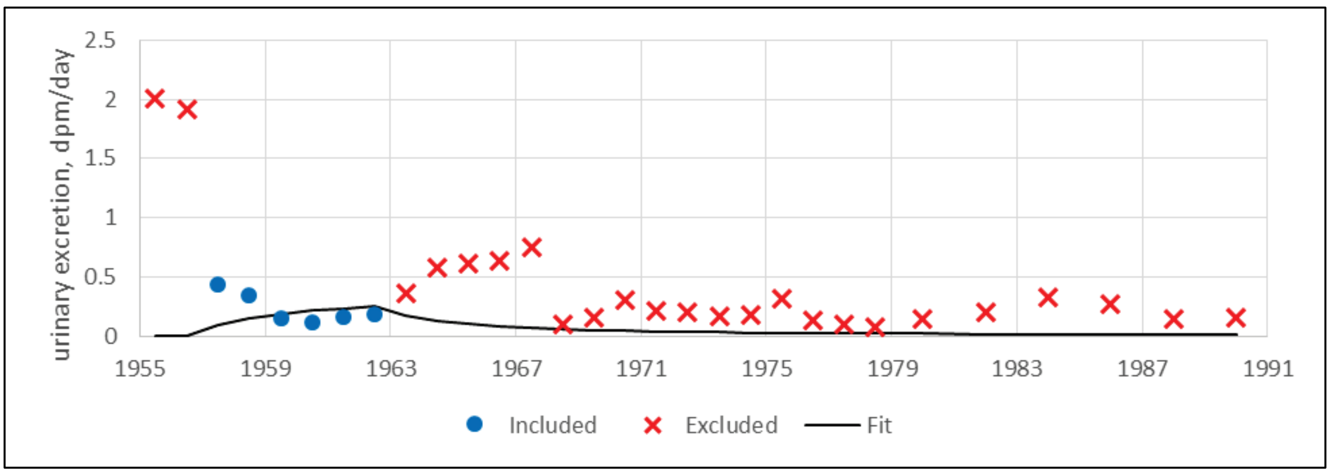

Figure E-120. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1957 to 1962, type S.

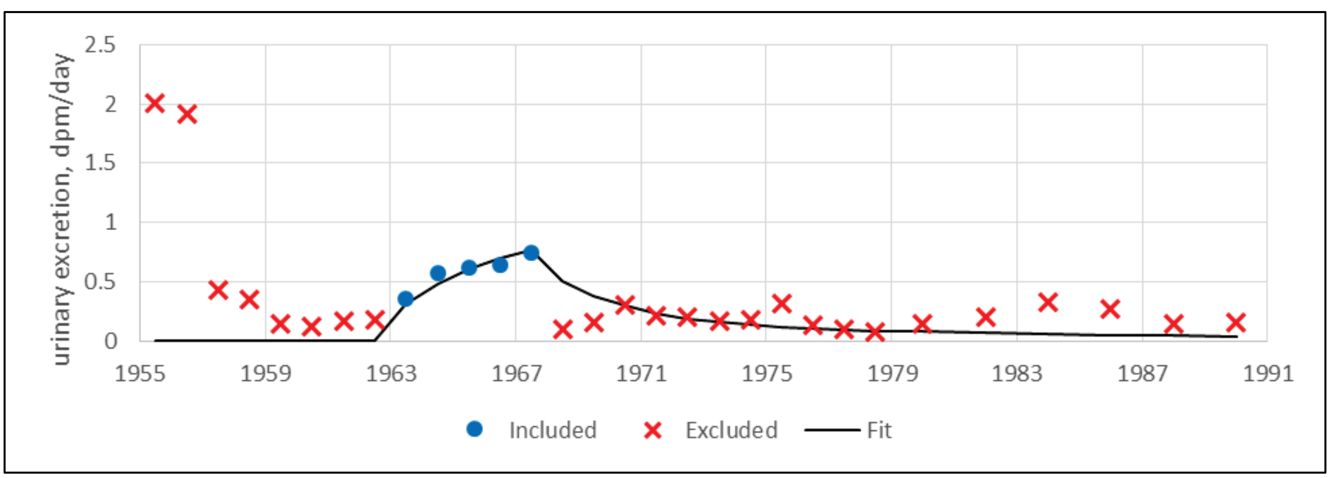

Figure E-121. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1963 to 1967, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

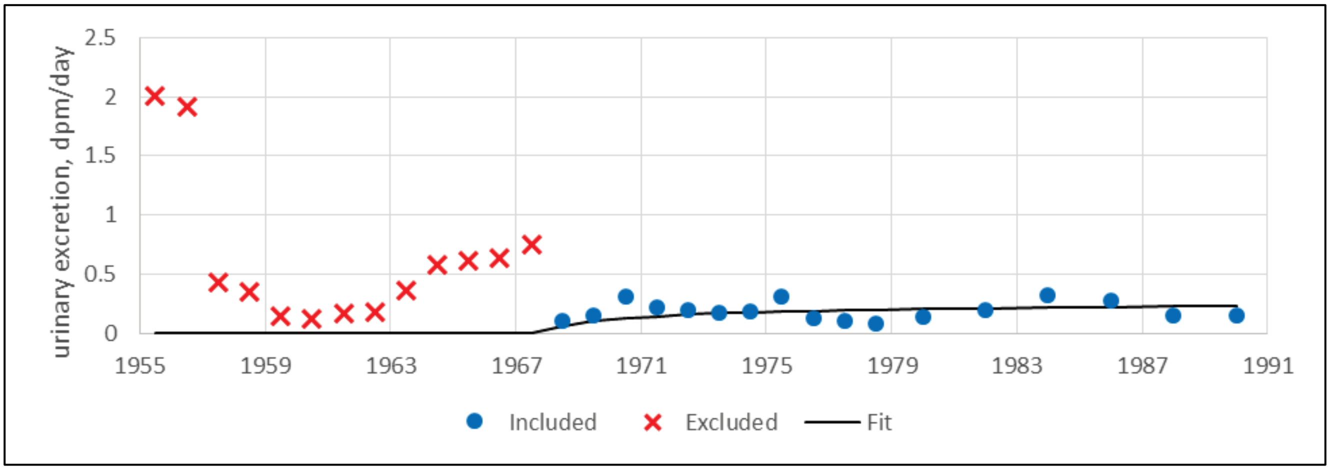

Figure E-122. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1968 to 1990, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

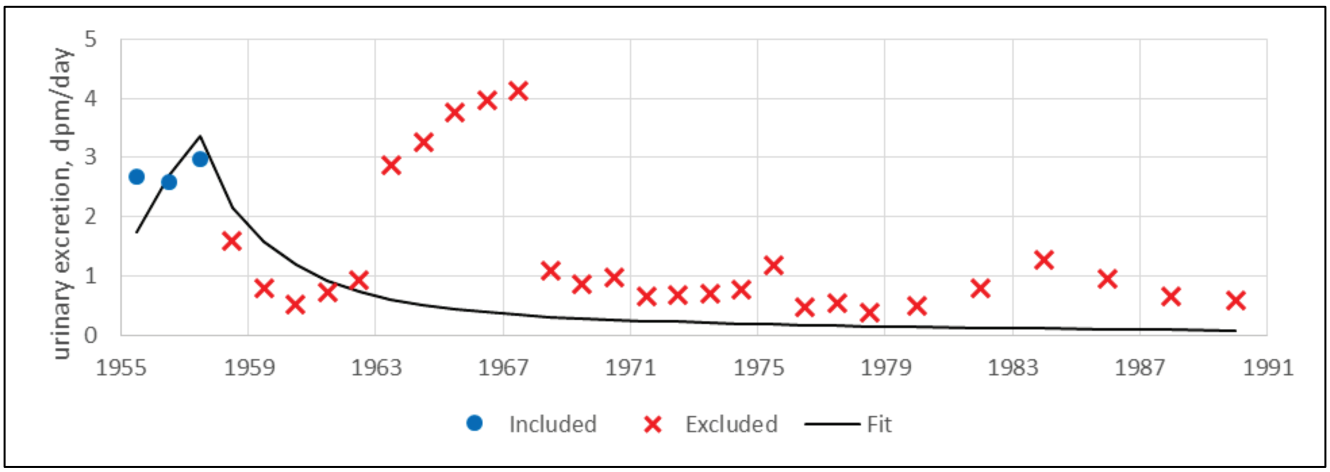

Figure E-123. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1957, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

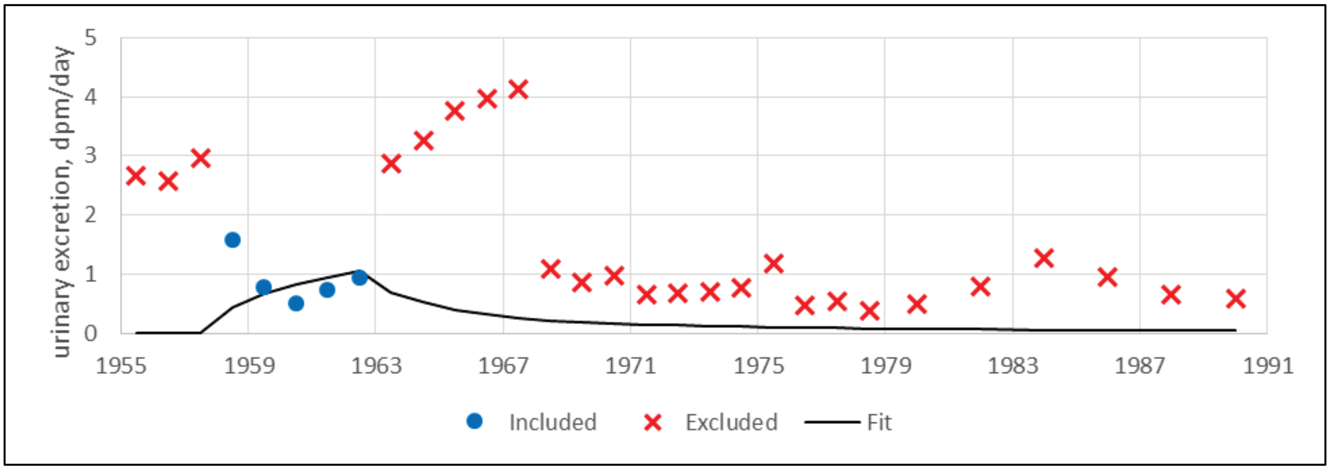

Figure E-124. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1958 to 1962, type S.

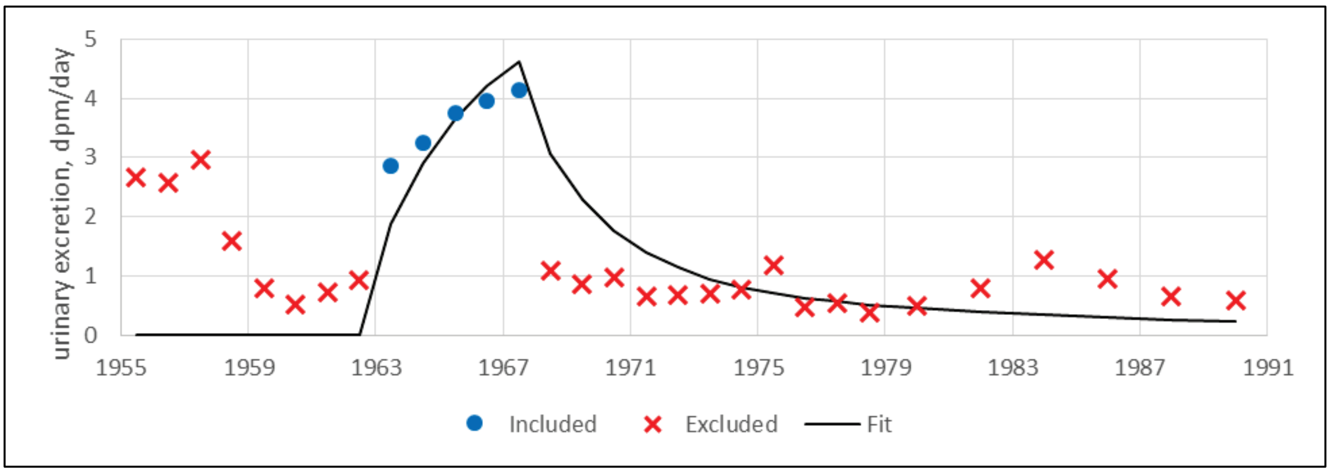

Figure E-125. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1963 to 1967, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

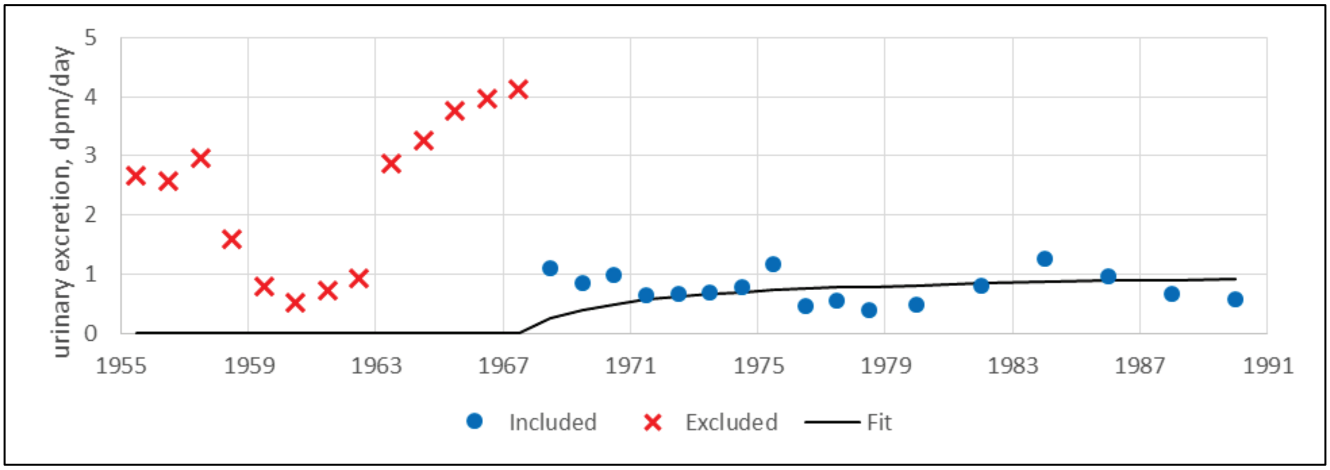

Figure E-126. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1968 to 1990, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

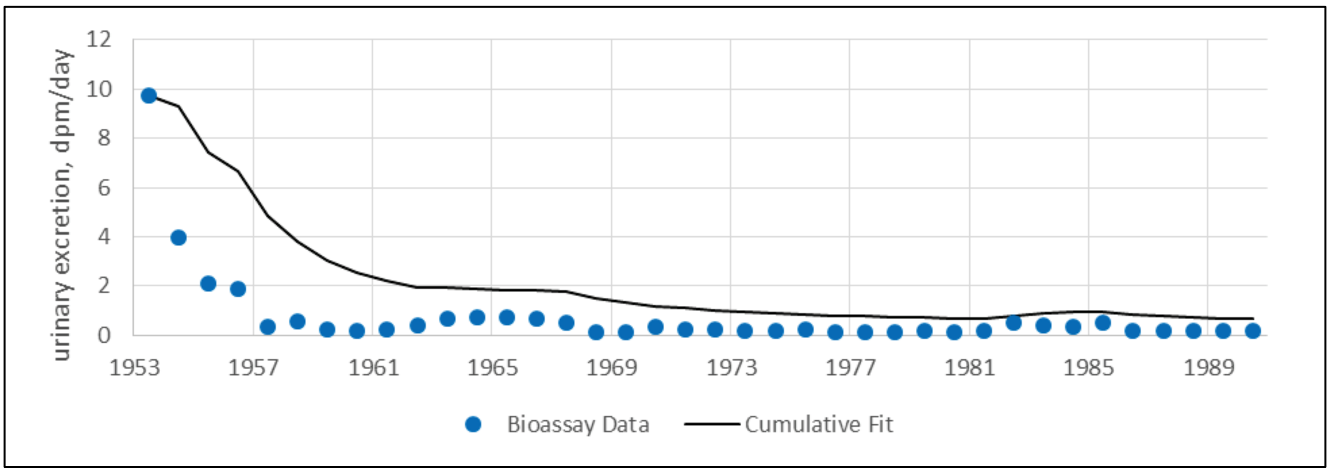

Figure E-127. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

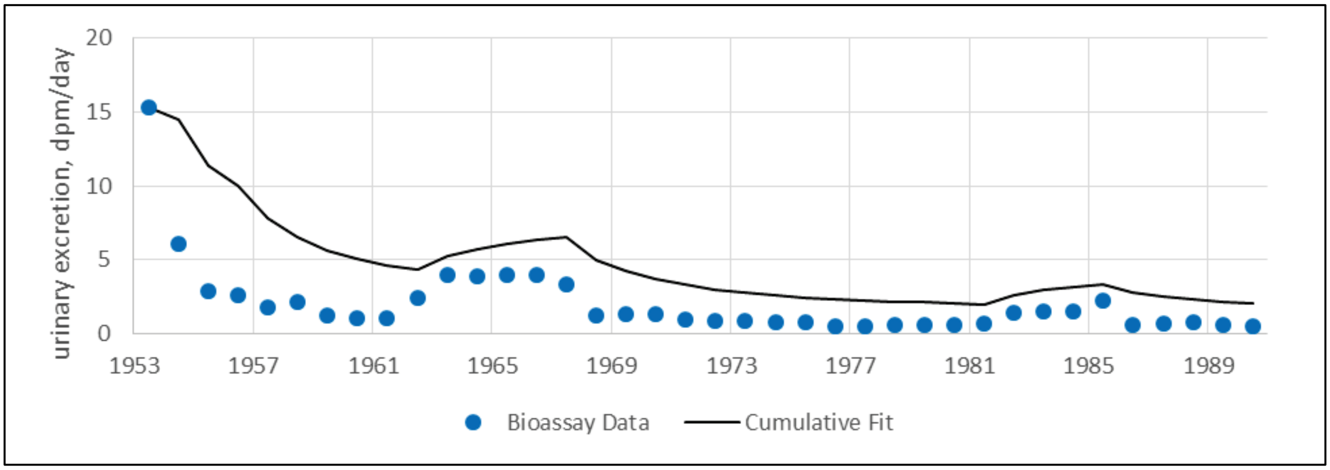

Figure E-128. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type S.

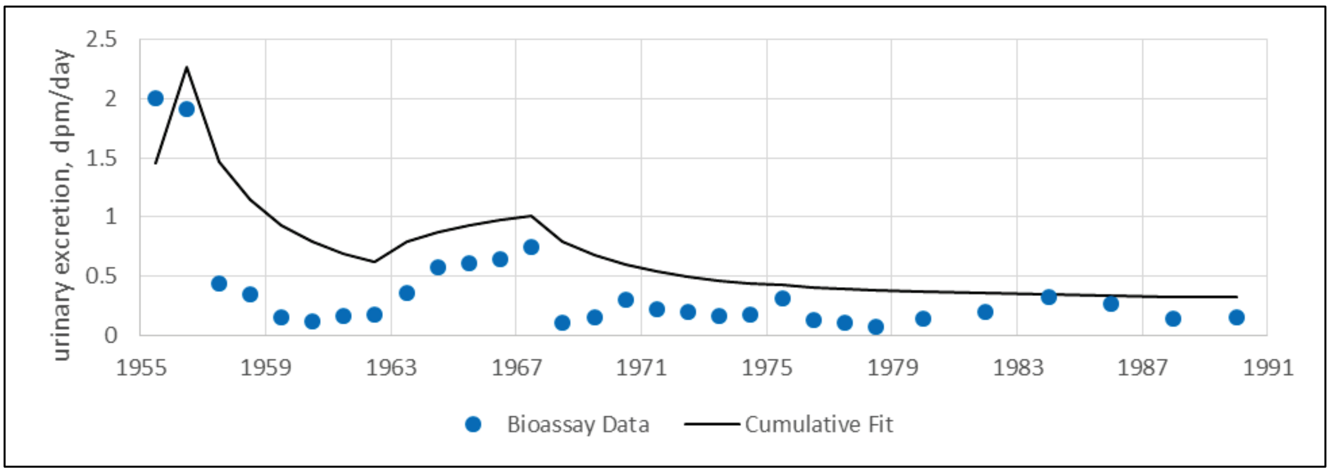

Figure E-129. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

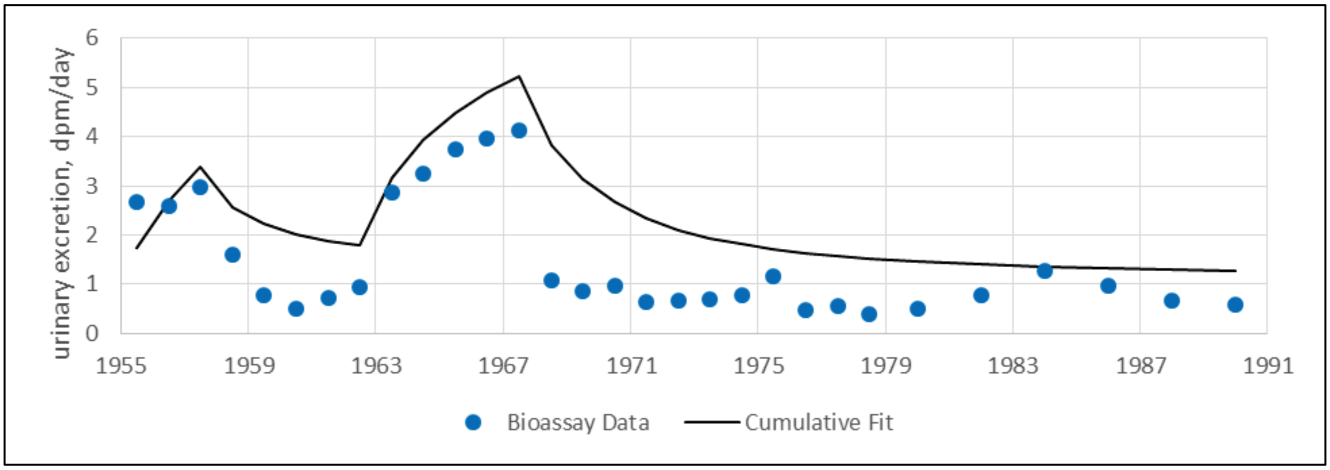

Figure E-130. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-9. Summary of uranium nonCTW intake rates (dpm/d) and dates, type F.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1953	12/31/1953	36.19	56.88	1.57	3.00	220.52
01/01/1954	12/31/1954	14.27	21.89	1.53	3.00	86.95
01/01/1955	12/31/1956	7.095	9.791	1.38	3.00	43.23
01/01/1957	12/31/1962	1.035	5.658	5.47	5.47	16.92
01/01/1963	12/31/1967	2.366	13.77	5.82	5.82	42.89
01/01/1968	12/31/1981	0.6054	2.778	4.59	4.59	7.42
01/01/1982	12/31/1985	1.556	5.93	3.81	3.81	14.05
01/01/1986	12/31/1990	0.646	2.087	3.23	3.23	4.45

Table E-10. Summary of uranium nonCTW intake rates (dpm/d) and dates, type M.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1953	12/31/1953	175.1	275.2	1.57	3.00	1,066.97
01/01/1954	12/31/1954	40.67	61.18	1.50	3.00	247.82
01/01/1955	12/31/1956	26.46	36.24	1.37	3.00	161.23
01/01/1957	12/31/1962	3.651	22.86	6.26	6.26	74.63
01/01/1963	12/31/1967	9.768	57.23	5.86	5.86	179.01
01/01/1968	12/31/1981	2.426	10.76	4.44	4.44	28.12
01/01/1982	12/31/1985	6.469	24.85	3.84	3.84	59.20
01/01/1986	12/31/1990	2.513	8.016	3.19	3.19	16.94

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

Table E-11. Summary of uranium nonCTW intake rates (dpm/d) and dates, type S.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1953	12/31/1953	5,477	8,607	1.57	3.00	33,373.92
01/01/1954	12/31/1954	2,222	3,412	1.54	3.00	13,539.68
01/01/1955	12/31/1956	826.2	1,144	1.38	3.00	5,034.42
01/01/1957	12/31/1962	81.69	418.3	5.12	5.12	1,199.50
01/01/1963	12/31/1967	185.7	1,068	5.75	5.75	3,300.78
01/01/1968	12/31/1981	36.33	152.6	4.20	4.20	385.10
01/01/1982	12/31/1985	133.8	535	4.00	4.00	1,307.91
01/01/1986	12/31/1990	53.03	171.6	3.24	3.24	365.99

Table E-12. Summary of uranium CTW intake rates (dpm/d) and dates, type F.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1956	7.243	10.12	1.40	3.00	44.13
01/01/1957	12/31/1957	0.7962	10.12	12.71	12.71	52.16
01/01/1958	12/31/1962	0.7962	3.232	4.06	4.06	7.98
01/01/1963	12/31/1967	2.124	13.12	6.18	6.18	42.46
01/01/1968	12/31/1990	0.6529	2.661	4.08	4.08	6.59

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-13. Summary of uranium CTW intake rates (dpm/d) and dates, type M.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1956	32.09	44.4	1.38	3.00	195.54
01/01/1957	12/31/1957	2.349	44.1	18.77	18.77	292.34
01/01/1958	12/31/1962	2.349	11.7	4.98	4.98	32.96
01/01/1963	12/31/1967	8.923	55.24	6.19	6.19	179.03
01/01/1968	12/31/1990	2.625	10.44	3.98	3.98	25.43

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-14. Summary of uranium CTW intake rates (dpm/d) and dates, type S.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1956	821.4	975.9	1.19	3.00	5,005.17
01/01/1957	12/31/1957	53.65	975.9	18.19	18.19	6,338.69
01/01/1958	12/31/1962	53.65	239.1	4.46	4.46	626.89
01/01/1963	12/31/1967	176.2	1,057	6.00	6.00	3,356.83
01/01/1968	12/31/1990	35.68	141.6	3.97	3.97	344.50

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

E.4 STRONTIUM INTAKE MODELING RESULTS

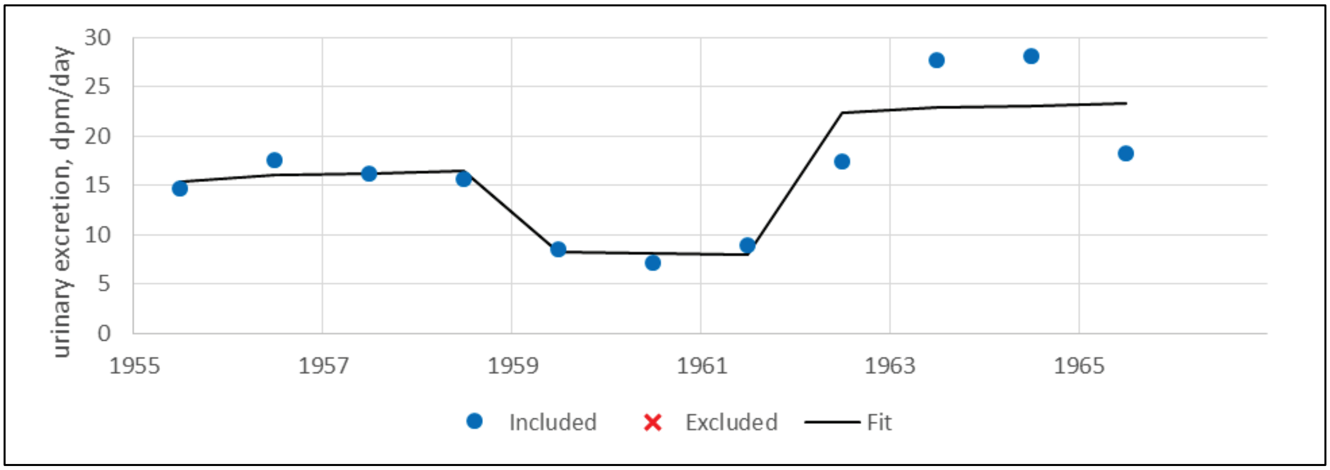

Figure E-131. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years.

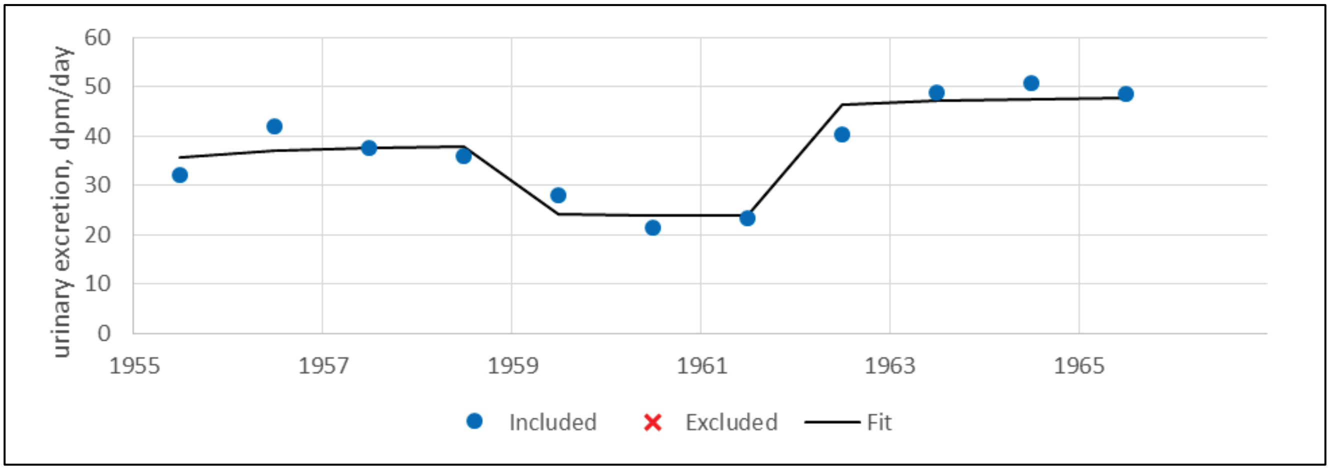

Figure E-132. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

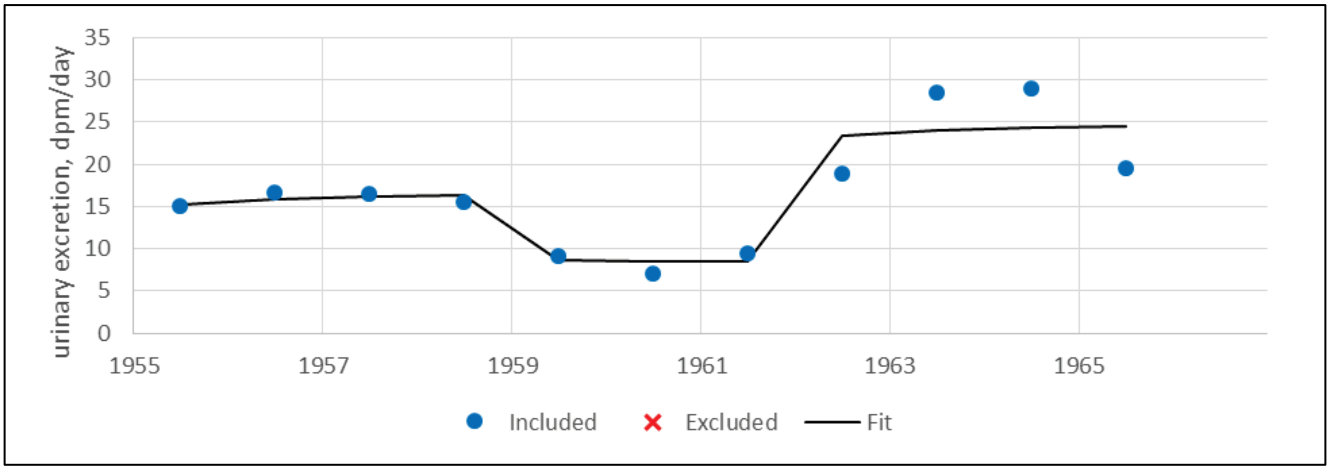

Figure E-133. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

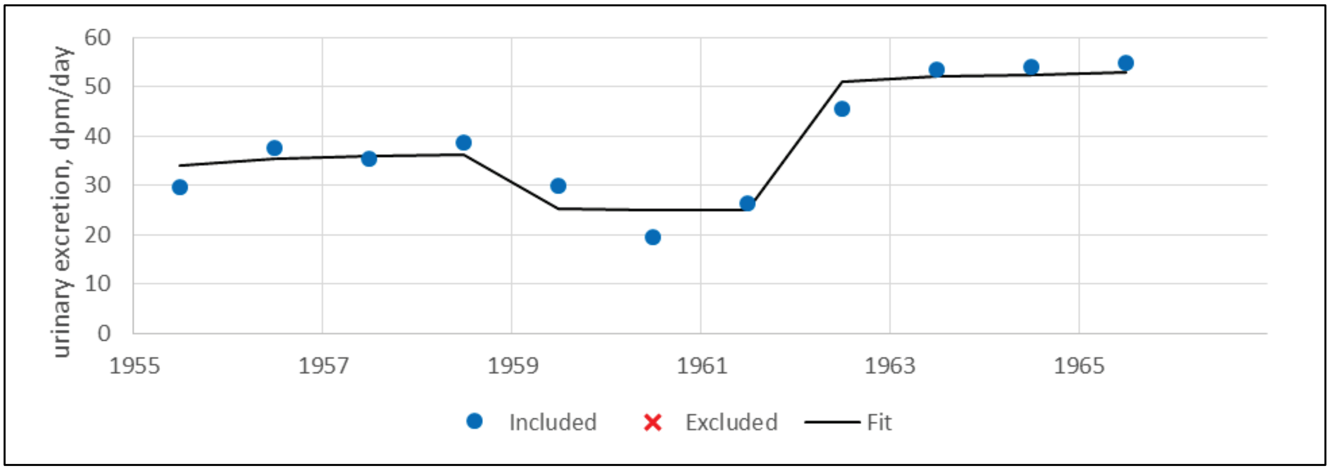

Figure E-134. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-15. Summary of FP (strontium) nonCTW intake rates (dpm/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1958	70.05	161.8	2.31	3.00	427
01/01/1959	12/31/1961	32.43	98.31	3.03	3.03	201
01/01/1962	12/31/1965	97.41	199.9	2.05	3.00	594

Table E-16. Summary of FP (strontium) CTW intake rates (dpm/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1958	69.46	154.9	2.23	3.00	423
01/01/1959	12/31/1961	34.33	103.4	3.01	3.01	211
01/01/1962	12/31/1965	102.2	220.8	2.16	3.00	623

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

E.5 COBALT-60 INTAKE MODELING RESULTS

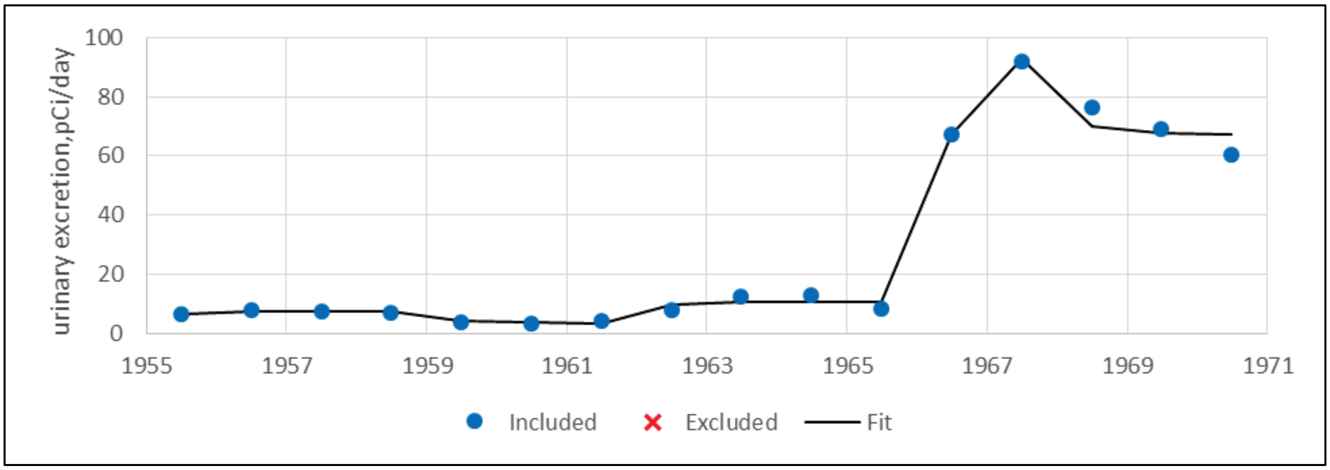

Figure E-135. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type M.

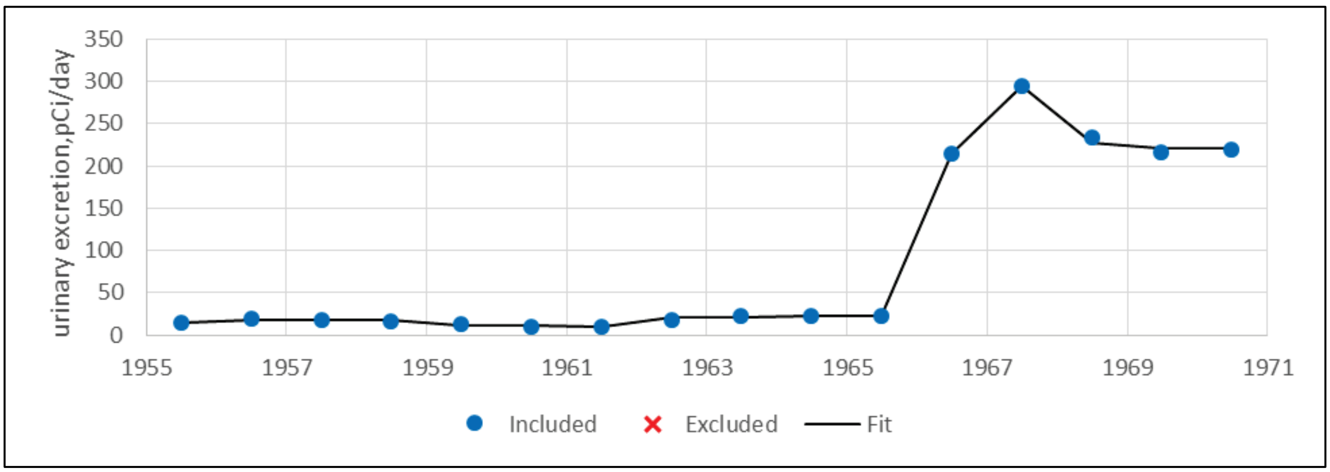

Figure E-136. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

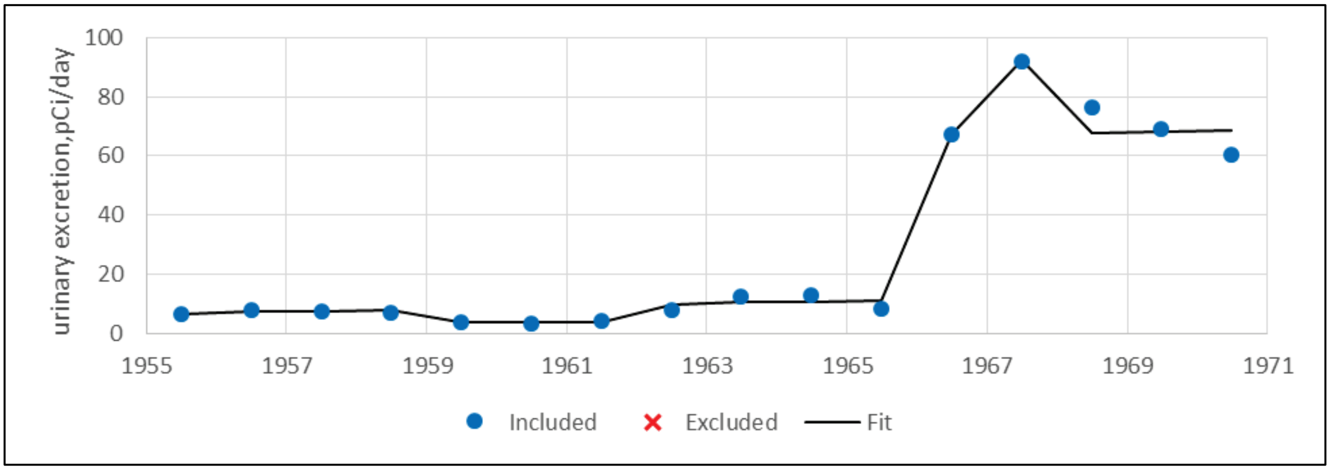

Figure E-137. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type S.

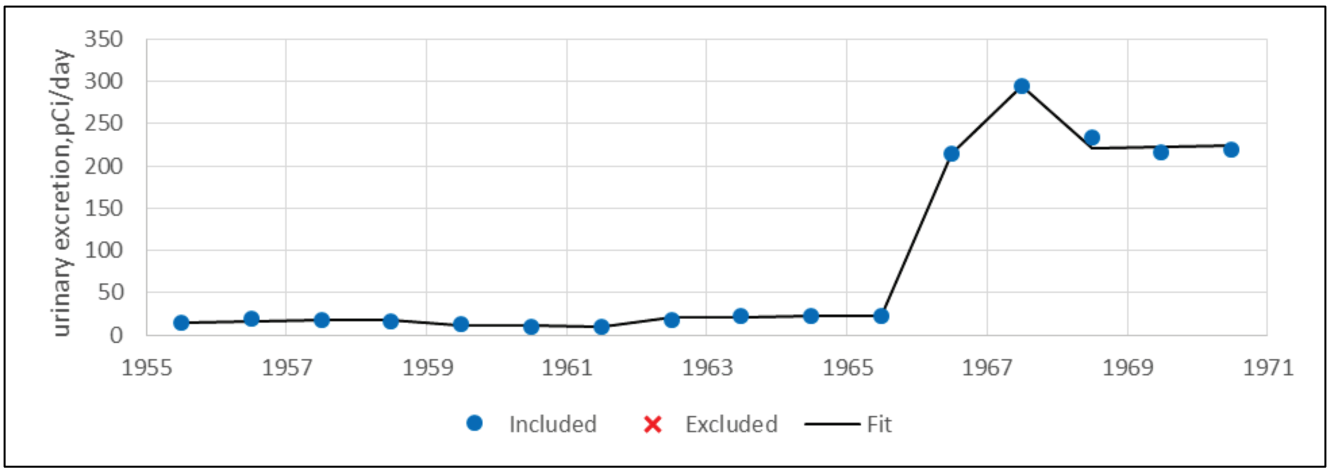

Figure E-138. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type S.

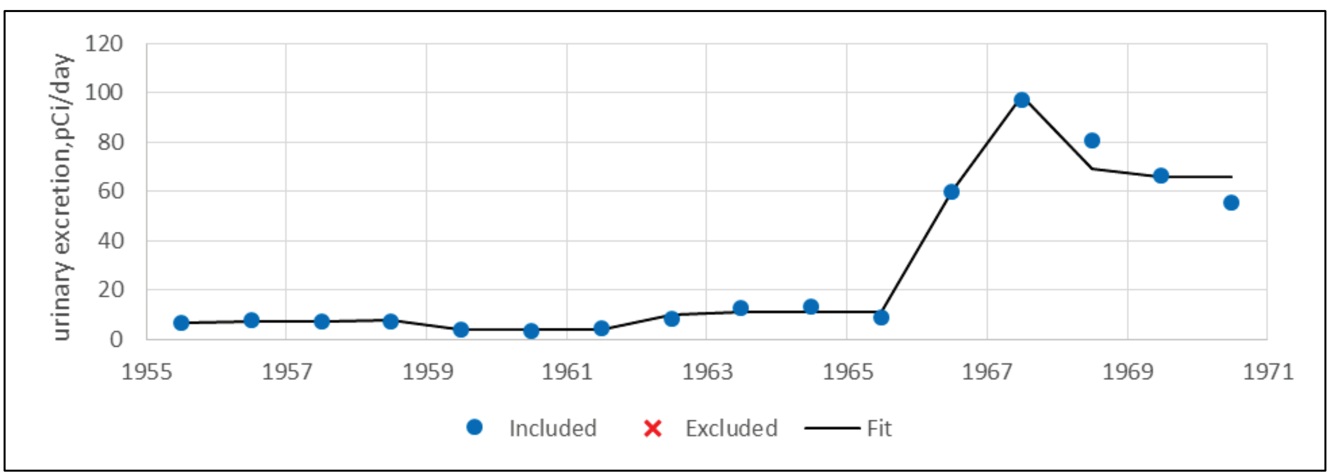

Figure E-139. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

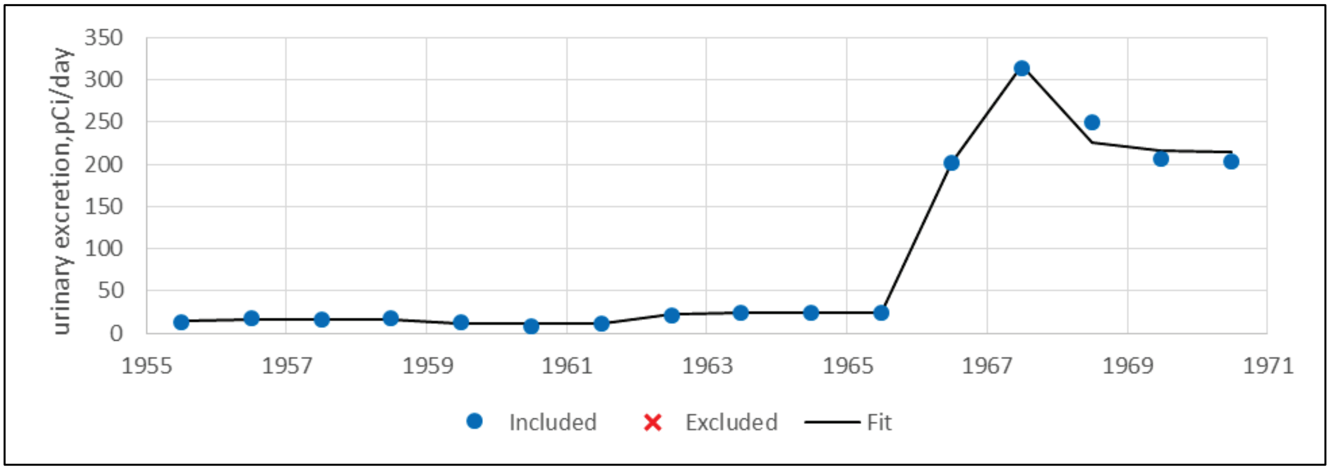

Figure E-140. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type M.

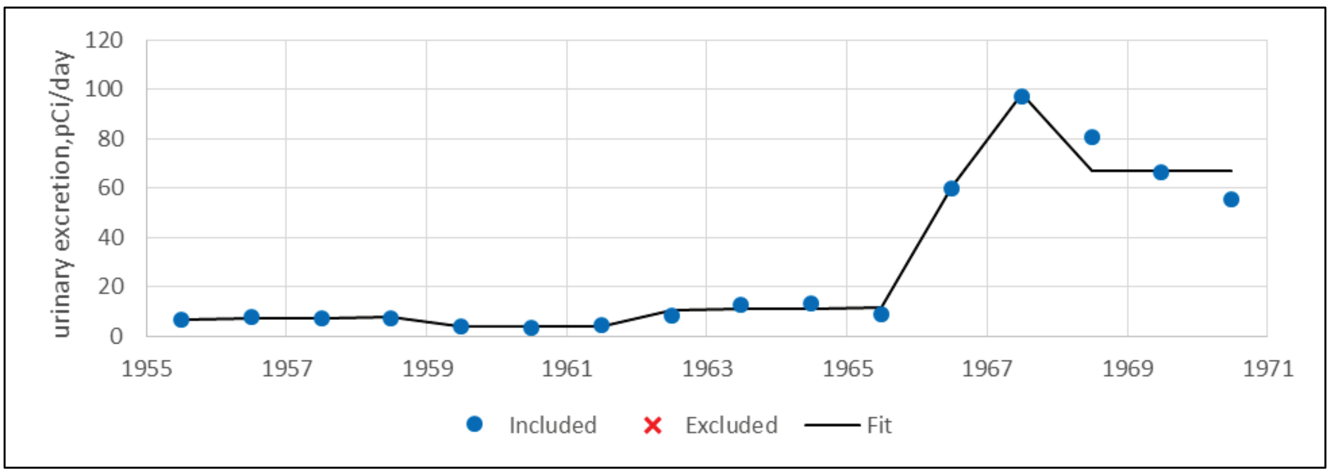

Figure E-141. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type S.

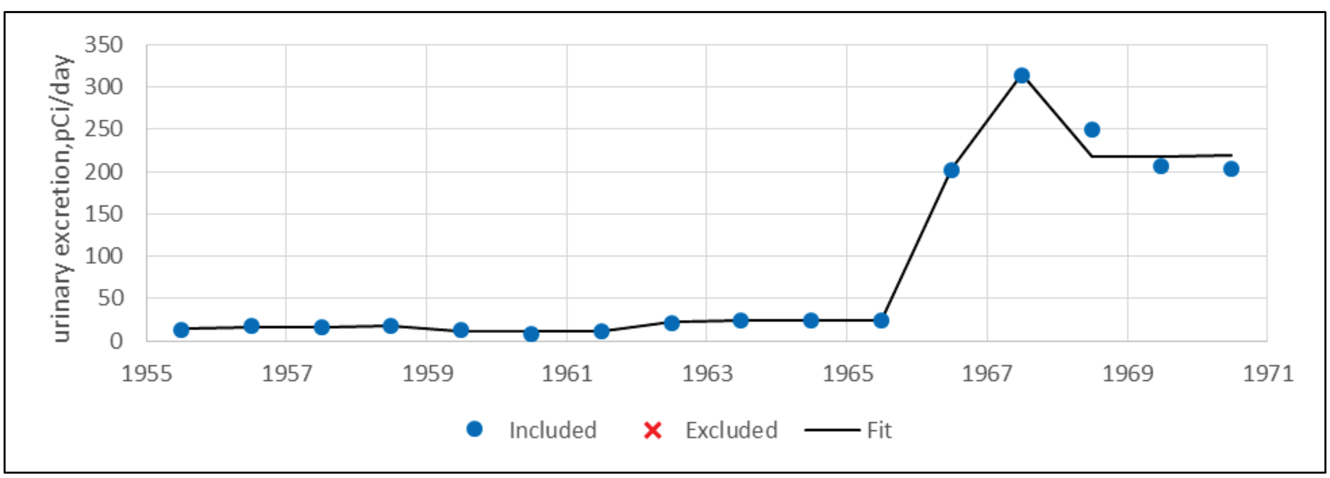

Figure E-142. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type S.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

Table E-17. Summary of ^{60}Co nonCTW type M intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1958	91.56	212.1	2.32	3.00	558
01/01/1959	12/31/1961	39.72	122.2	3.08	3.08	252
01/01/1962	12/31/1965	128.6	262.1	2.04	3.00	784
01/01/1966	12/31/1966	930	2,989	3.21	3.21	6,347
01/01/1967	12/31/1967	1,185	3,773	3.18	3.18	7,963
01/01/1968	12/31/1970	804.8	2,636	3.28	3.28	5,666

Table E-18. Summary of ^{60}Co nonCTW type S intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1958	365	844.4	2.31	3.00	2,224
01/01/1959	12/31/1961	146.6	457.5	3.12	3.12	953
01/01/1962	12/31/1965	503.2	1,020	2.03	3.00	3,066
01/01/1966	12/31/1966	3,654	11,730	3.21	3.21	24,889
01/01/1967	12/31/1967	4,760	15,250	3.20	3.20	32,316
01/01/1968	12/31/1970	3,137	10,300	3.28	3.28	22,175

Table E-19. Summary of ^{60}Co CTW type M intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1958	90.85	203.4	2.24	3.00	554
01/01/1959	12/31/1961	42.34	129.3	3.05	3.05	266
01/01/1962	12/31/1965	135	290.1	2.15	3.00	823
01/01/1966	12/31/1966	825.7	2,816	3.41	3.41	6,213
01/01/1967	12/31/1967	1,282	4,110	3.21	3.21	8,713
01/01/1968	12/31/1970	785.4	2,567	3.27	3.27	5,510

Table E-20. Summary of ^{60}Co CTW type S intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1955	12/31/1958	362.3	810	2.24	3.00	2,208
01/01/1959	12/31/1961	157.3	488.2	3.10	3.10	1,014
01/01/1962	12/31/1965	529.7	1,136	2.14	3.00	3,228
01/01/1966	12/31/1966	3,248	11,070	3.41	3.41	24,414
01/01/1967	12/31/1967	5,106	16,480	3.23	3.23	35,090
01/01/1968	12/31/1970	3,068	10,040	3.27	3.27	21,569

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

E.6 CESIUM-137 INTAKE MODELING RESULTS

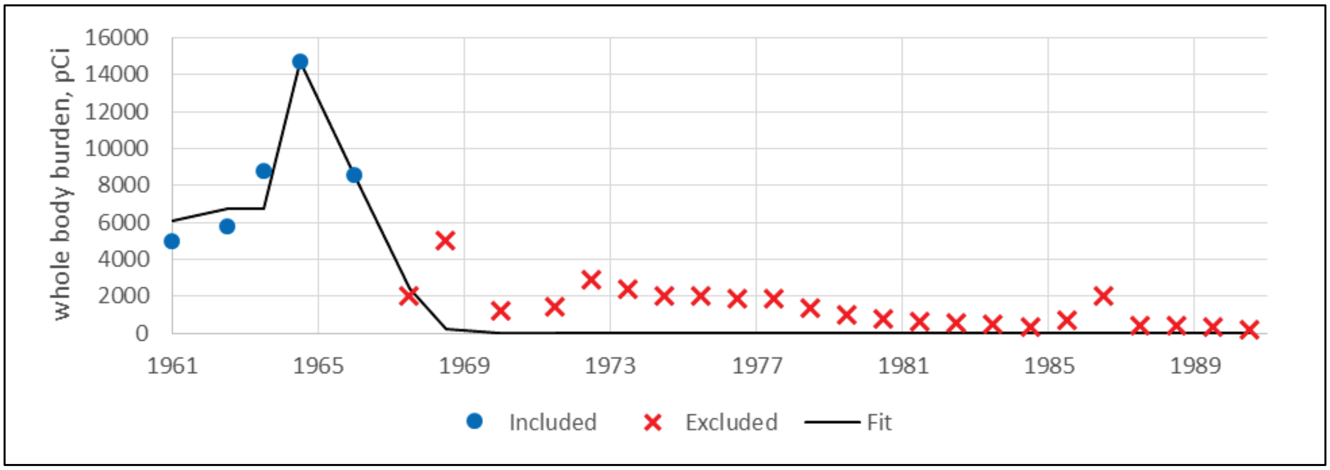

Figure E-143. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1960 to 1966, type F.

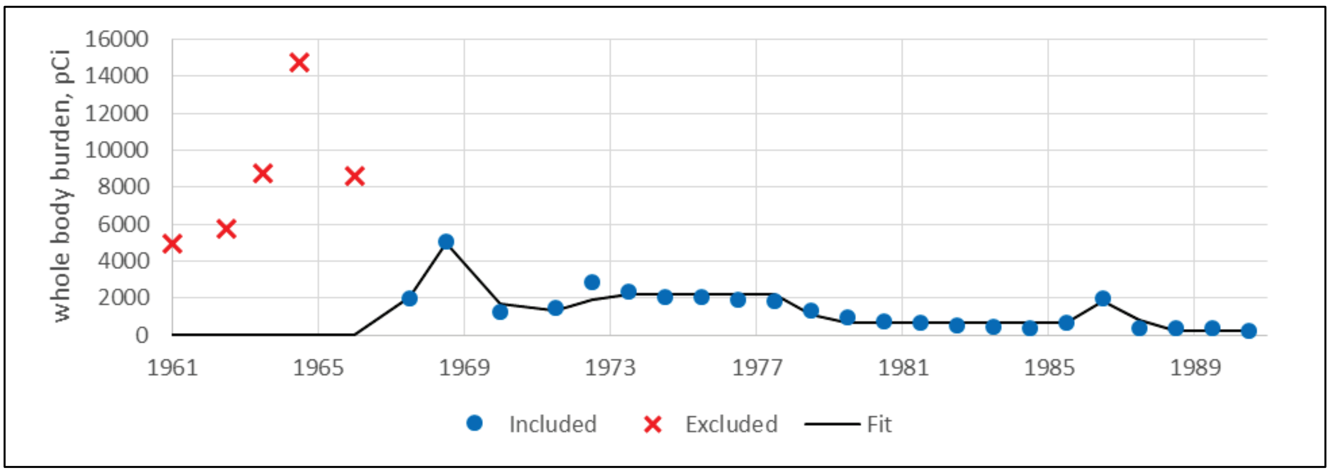

Figure E-144. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1990, type F.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

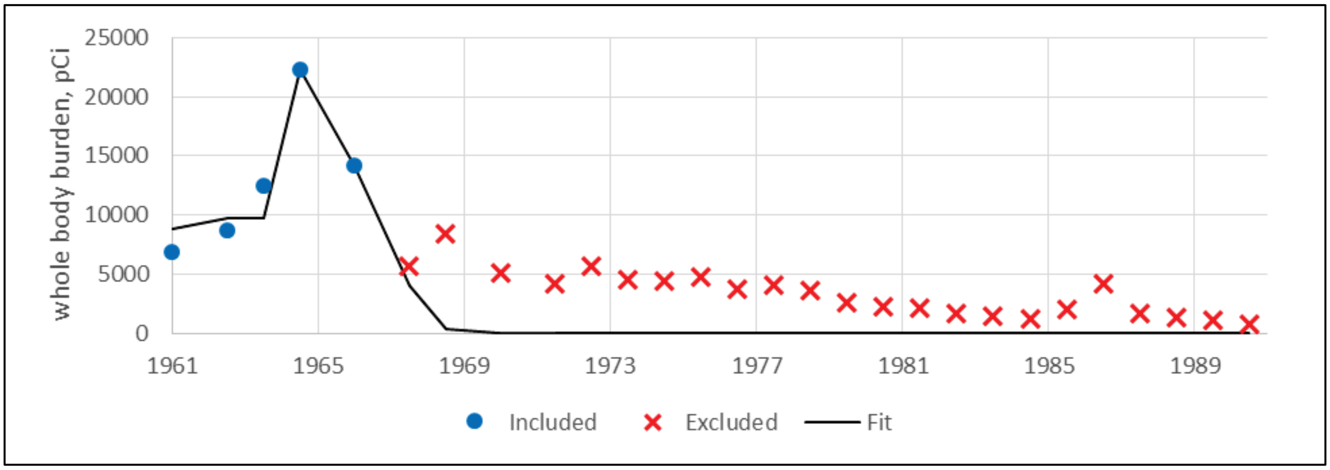

Figure E-145. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1960 to 1966, type F.

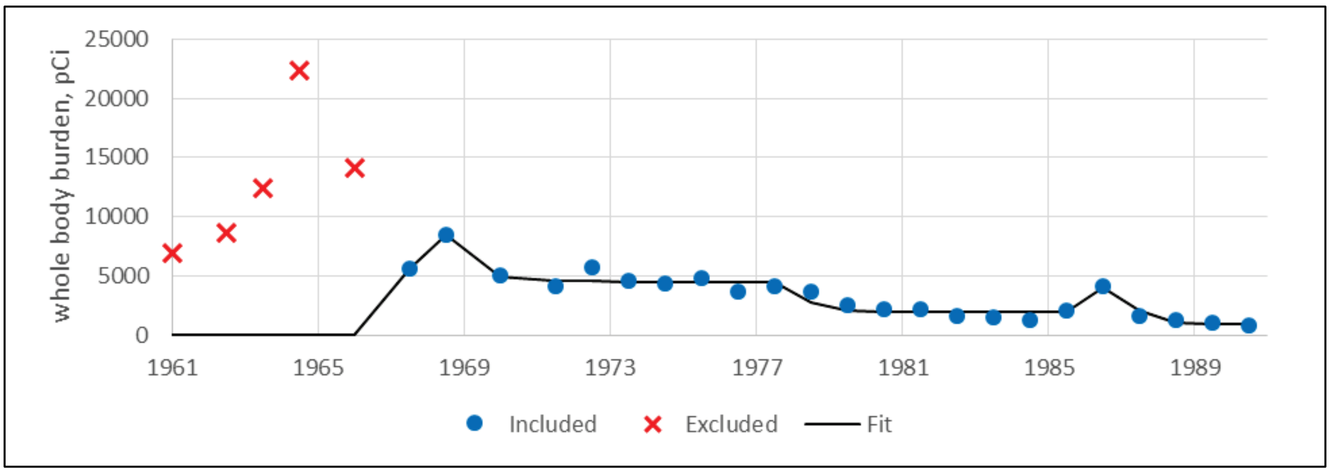

Figure E-146. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1990, type F.

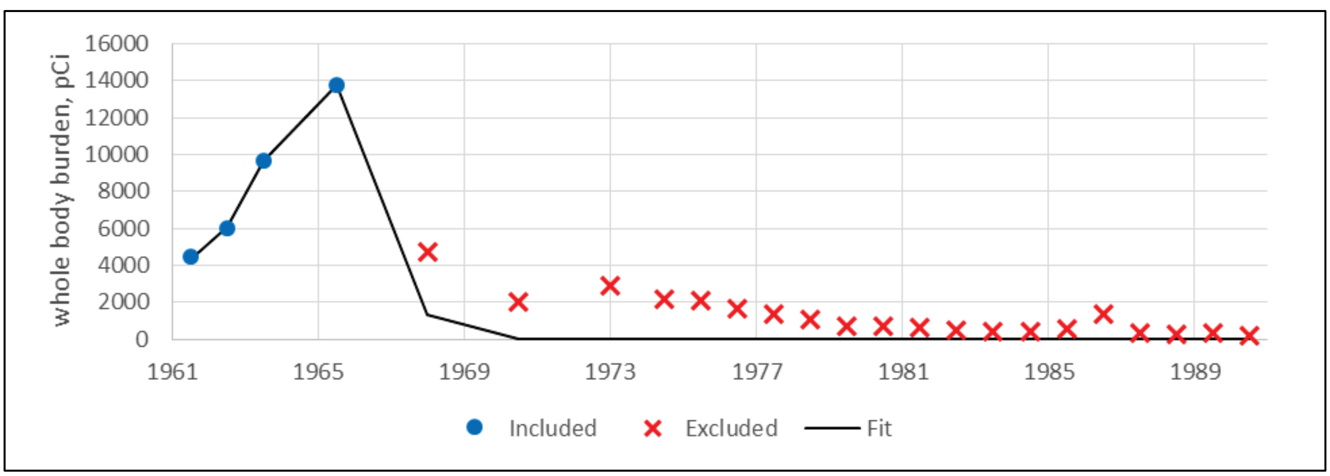

Figure E-147. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1960 to 1966, type F.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

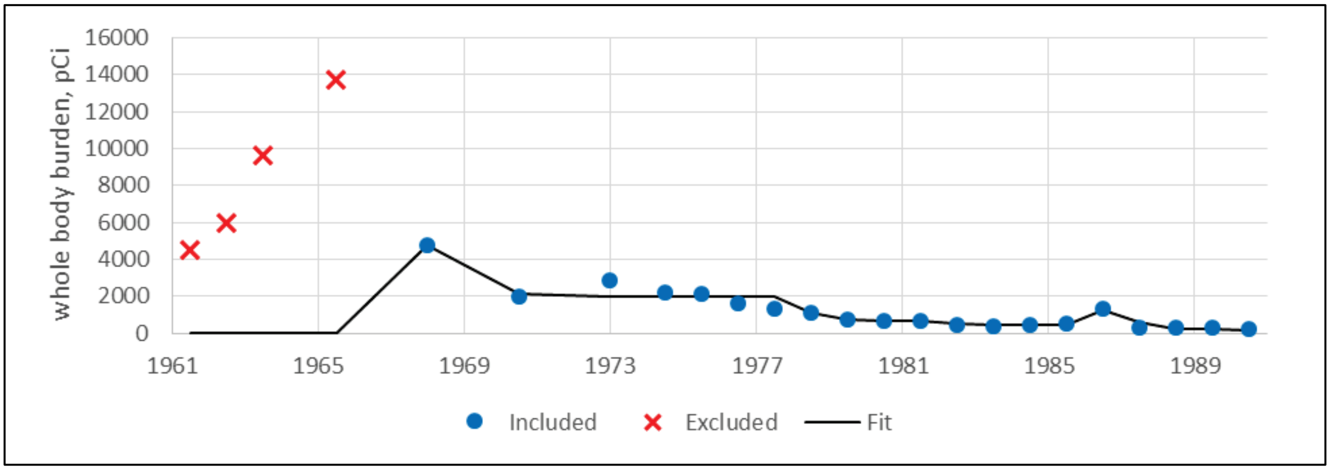

Figure E-148. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1990, type F. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

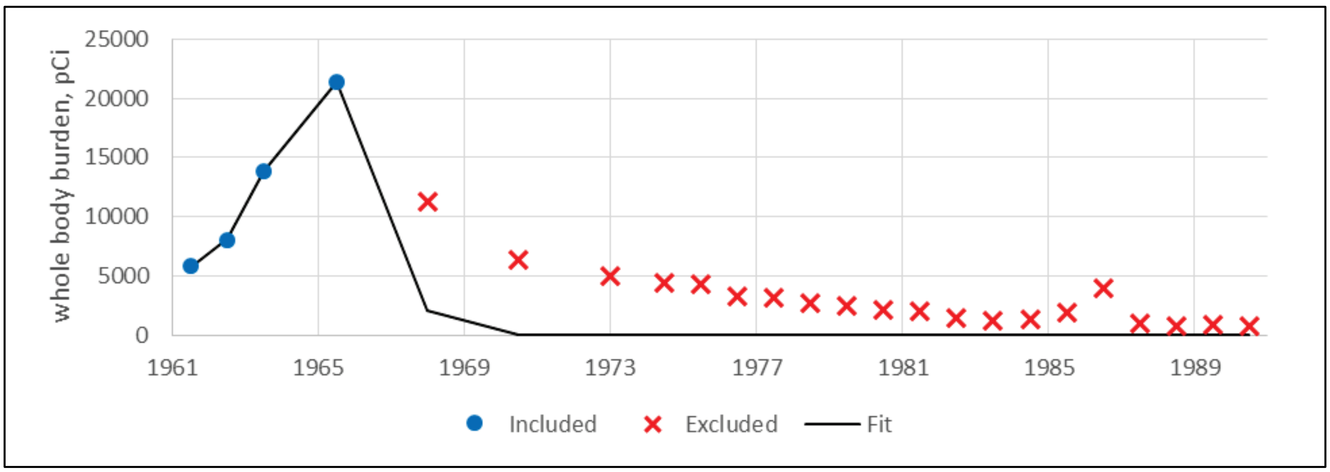

Figure E-149. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1960 to 1966, type F.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

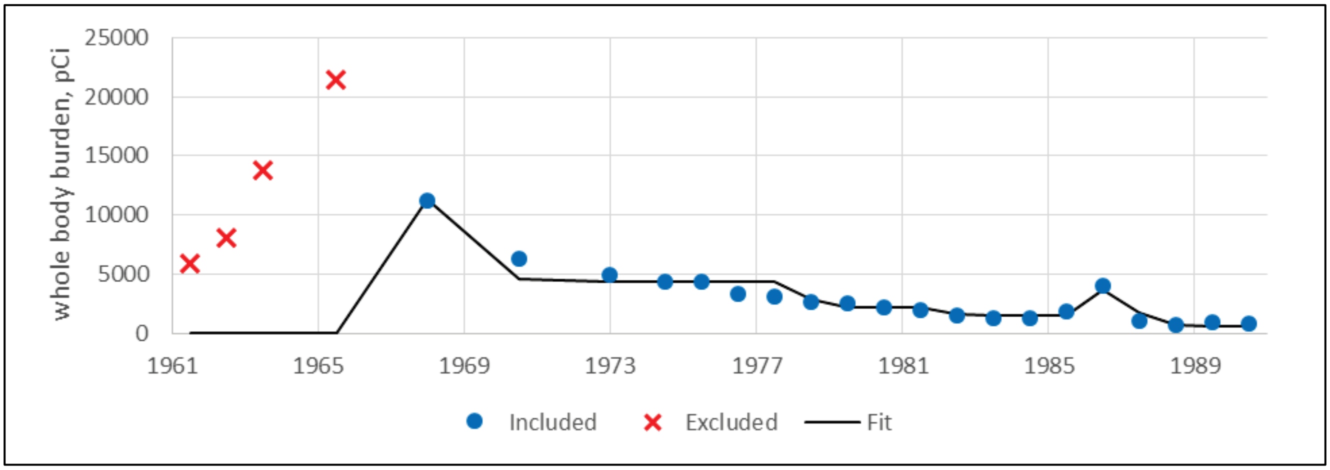

Figure E-150. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1990, type F. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

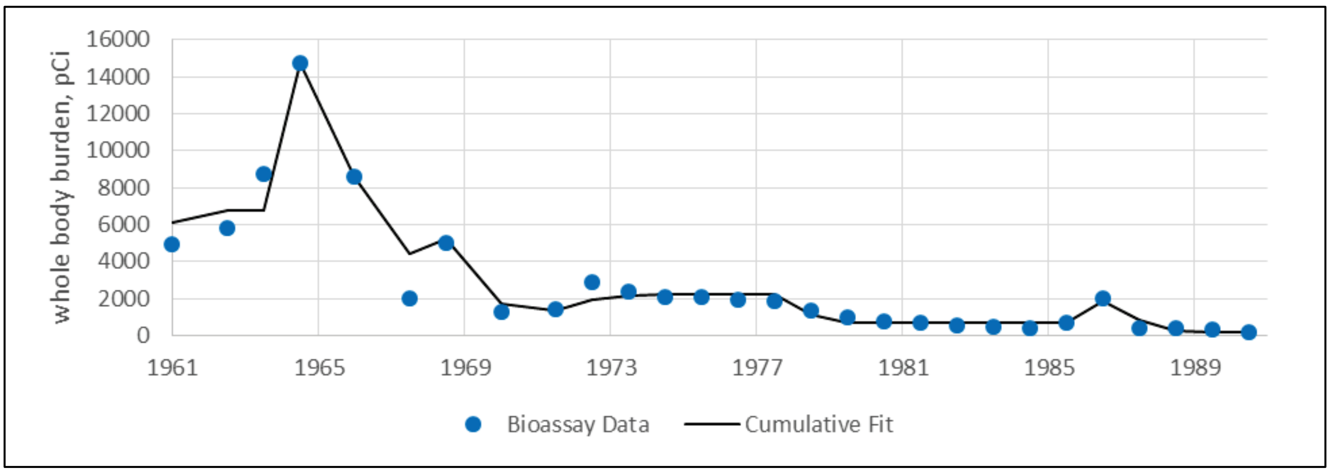

Figure E-151. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type F.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

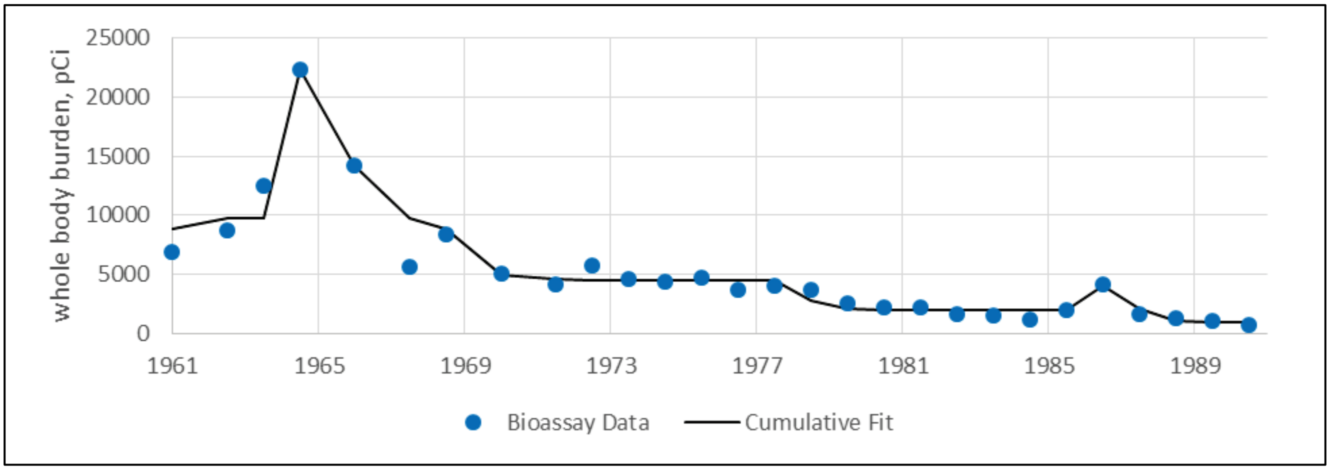

Figure E-152. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type F.

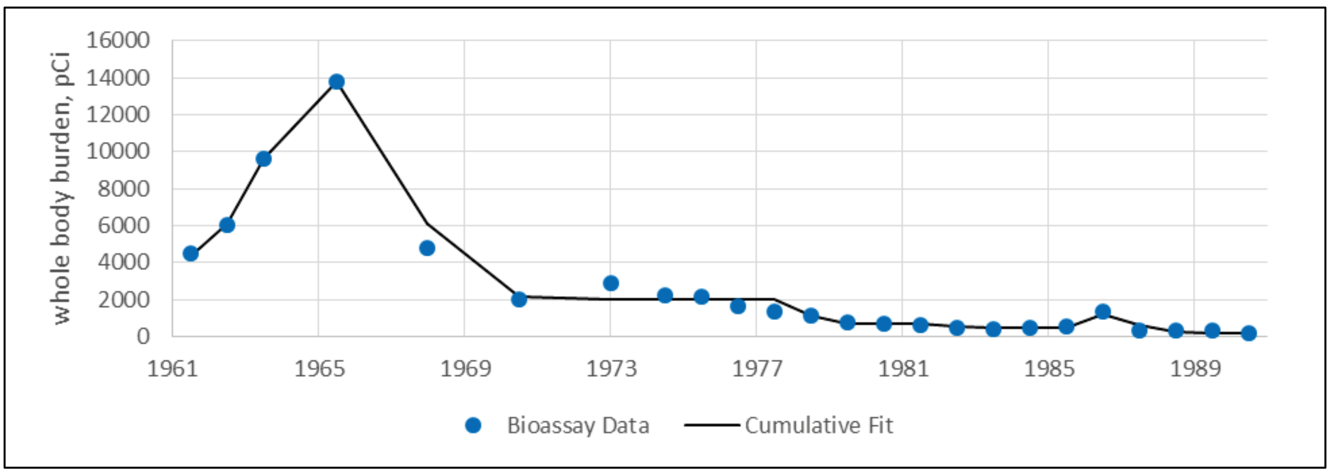

Figure E-153. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type F. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

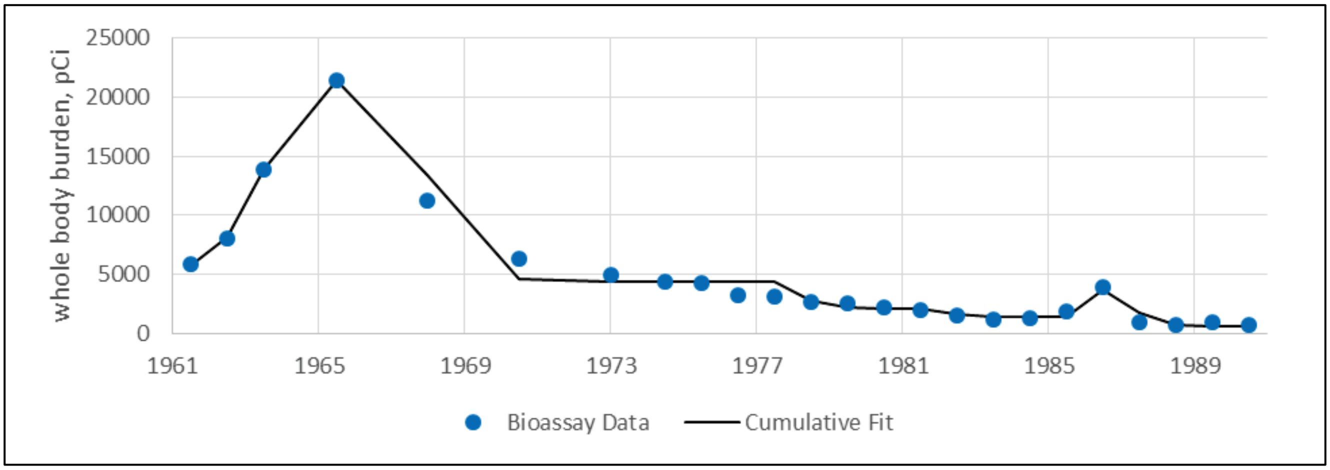

Figure E-154. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type F. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-21. Summary of ^{137}Cs nonCTW type F intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1960	12/31/1963	98.14	141.5	1.44	3.00	598.01
01/01/1964	12/31/1964	266.8	407.5	1.53	3.00	1,625.74
01/01/1965	12/31/1966	111.3	187.3	1.68	3.00	678.20
01/01/1967	12/31/1967	42.98	119.8	2.79	3.00	261.90
01/01/1968	12/31/1968	87.45	129.2	1.48	3.00	532.87
01/01/1969	12/31/1971	18.86	66.49	3.53	3.53	149.87
01/01/1972	12/31/1977	31.86	65.63	2.06	3.00	194.14
01/01/1978	12/31/1985	9.396	28.87	3.07	3.07	59.55
01/01/1986	12/31/1986	34.84	71.2	2.04	3.00	212.30
01/01/1987	12/31/1990	2.819	13.04	4.63	4.63	35.02

Table E-22. Summary of ^{137}Cs CTW type F intake rates (pCi/d) and dates.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1961	12/31/1962	91.38	122	1.34	3.00	556.82
01/01/1963	12/31/1963	162.6	237.9	1.46	3.00	990.80
01/01/1964	12/31/1966	201.2	313.8	1.56	3.00	1,226.01
01/01/1967	12/31/1968	76.32	182.2	2.39	3.00	465.05
01/01/1969	12/31/1977	29.21	62.96	2.16	3.00	177.99
01/01/1978	12/31/1981	9.72	31.15	3.21	3.21	66.04
01/01/1982	12/31/1985	6.556	20.9	3.19	3.19	44.15
01/01/1986	12/31/1986	22.95	67.8	2.95	3.00	139.85
01/01/1987	12/31/1990	2.697	8.476	3.14	3.14	17.74

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

E.7 NEPTUNIUM INTAKE MODELING RESULTS

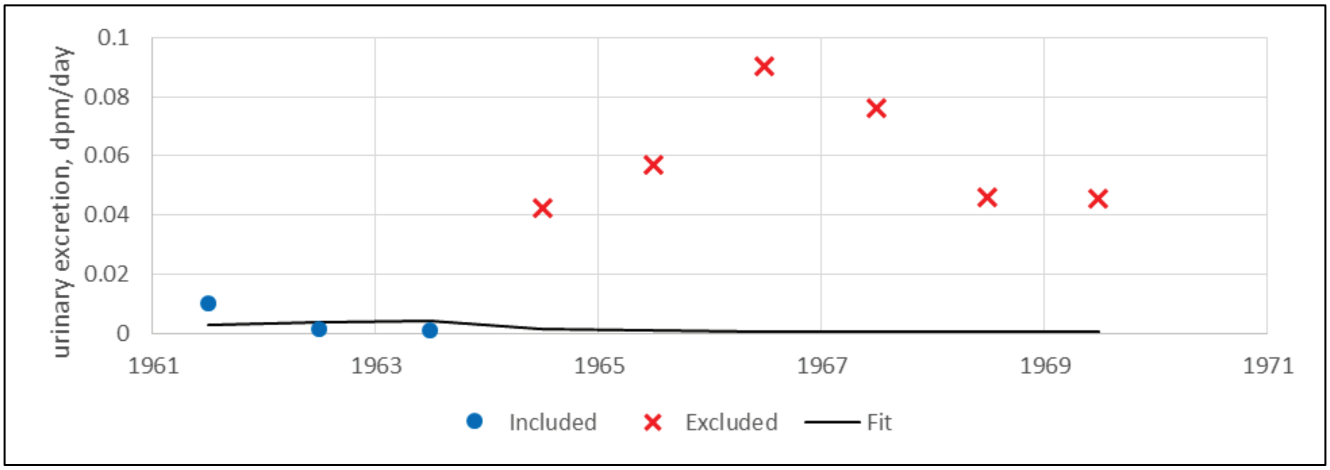

Figure E-155. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1963, type M.

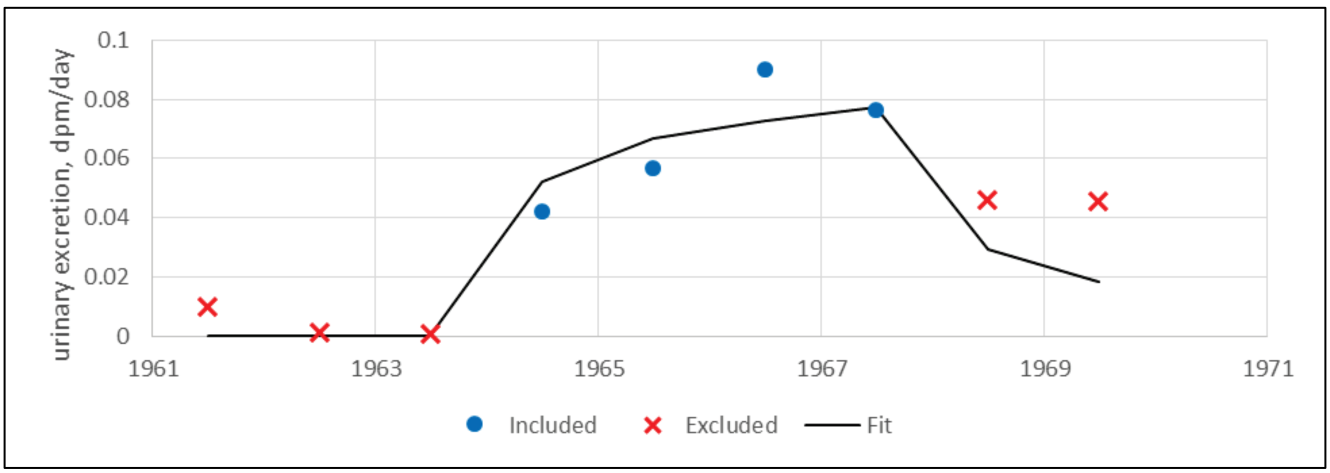

Figure E-156. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1964 to 1967, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

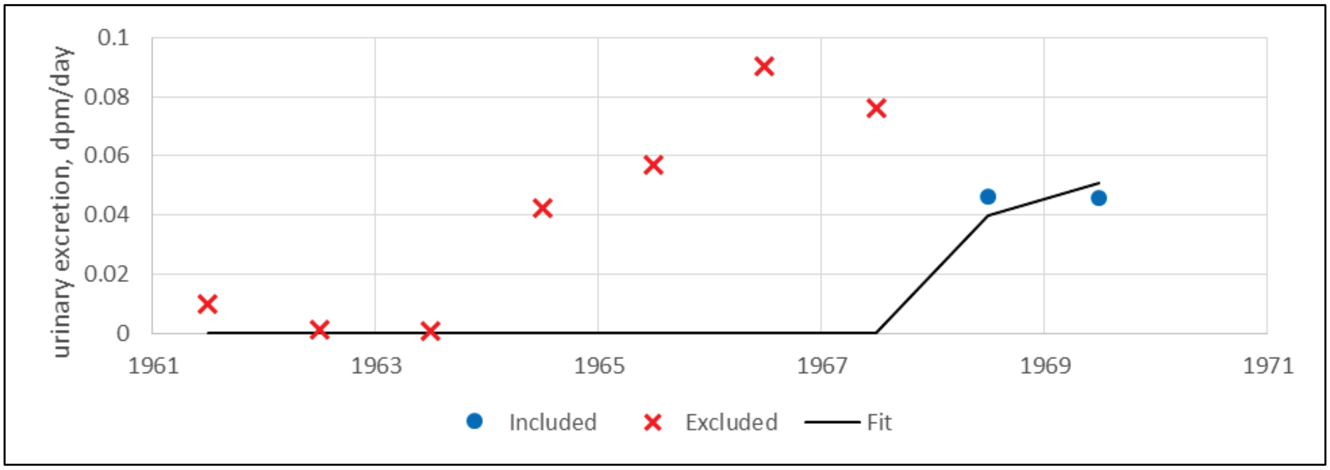

Figure E-157. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1968 to 1969, type M.

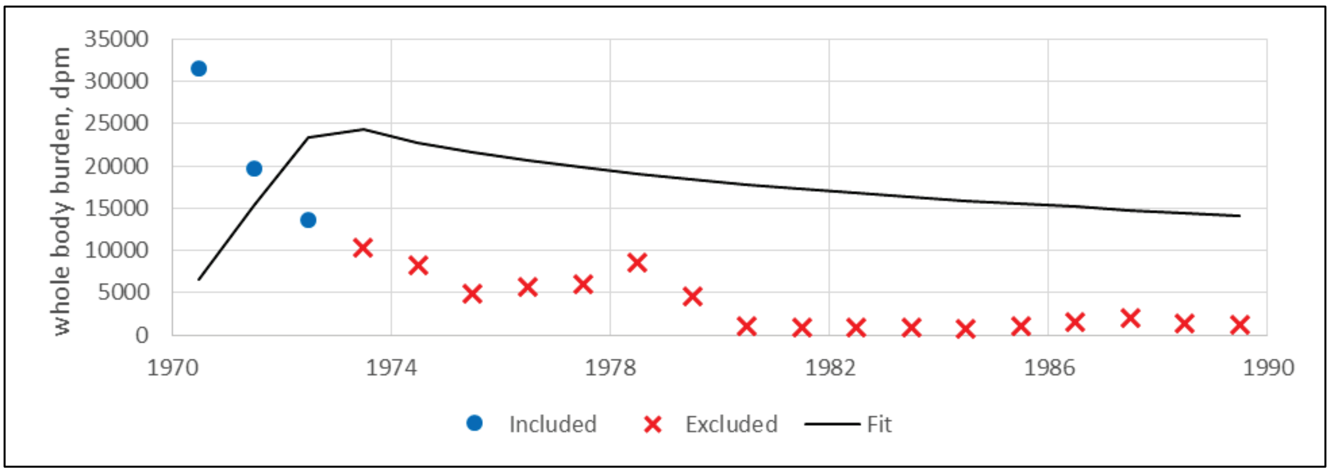

Figure E-158. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1970 to 1972, type M.

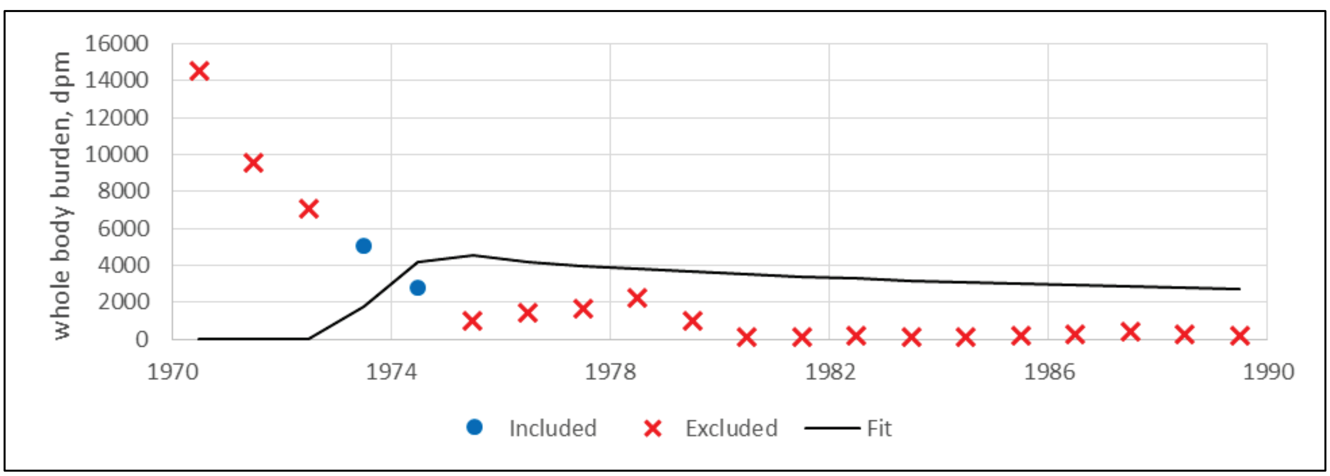

Figure E-159. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1973 to 1974, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

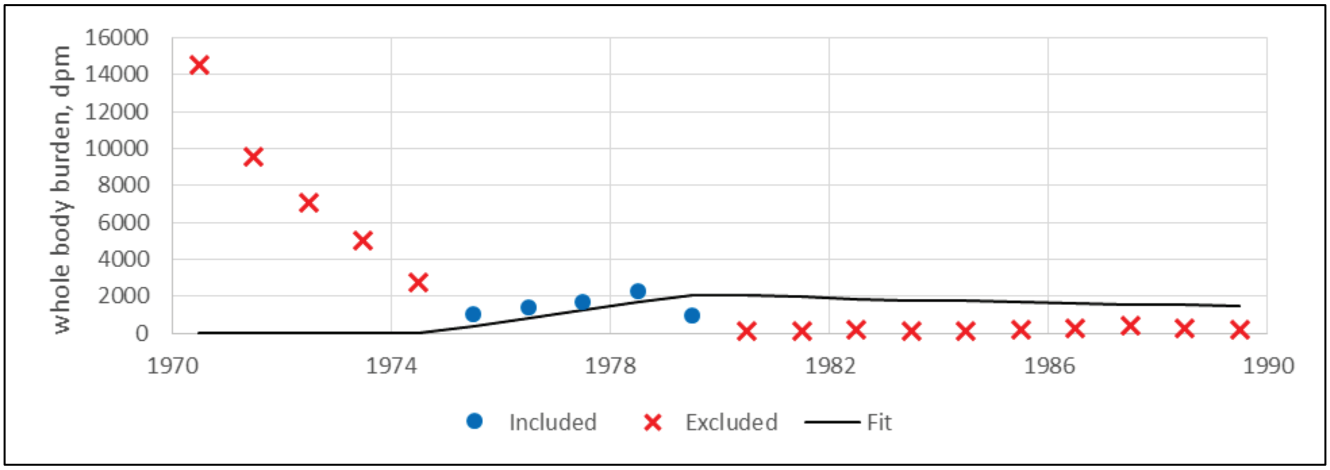

Figure E-160. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1975 to 1979, type M.

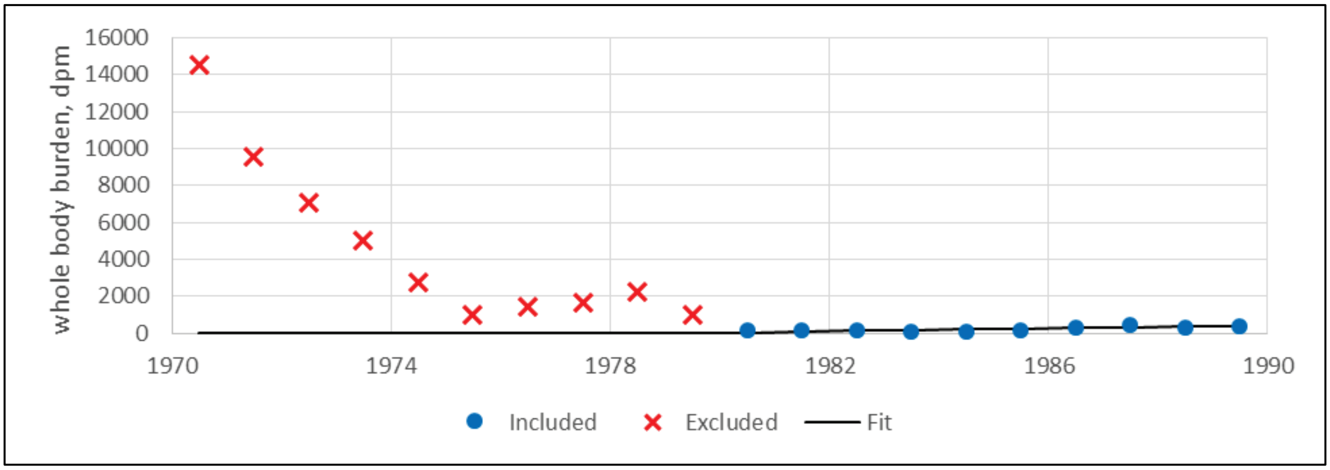

Figure E-161. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1980 to 1989, type M.

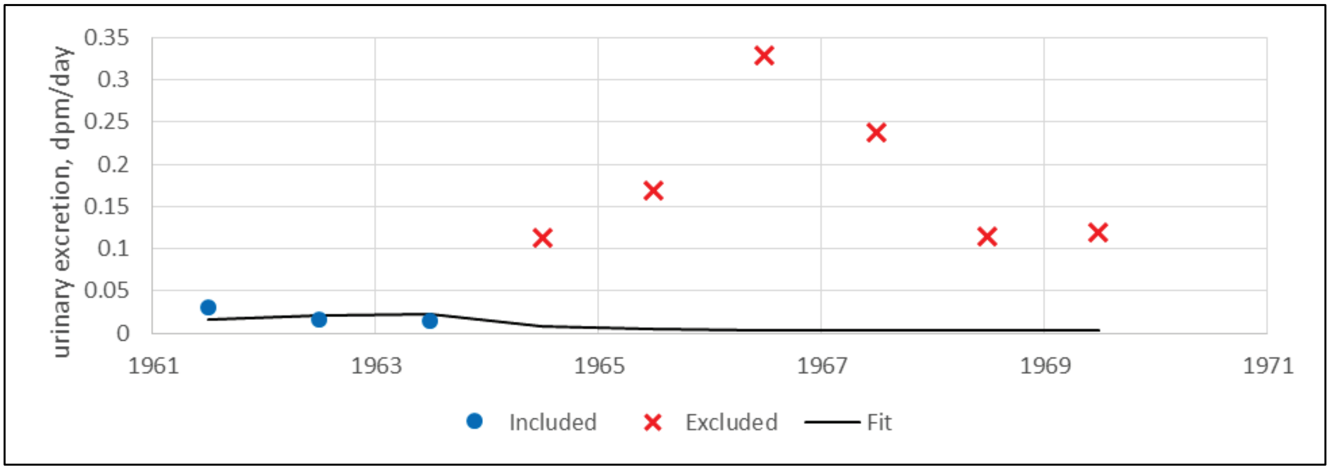

Figure E-162. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1963, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

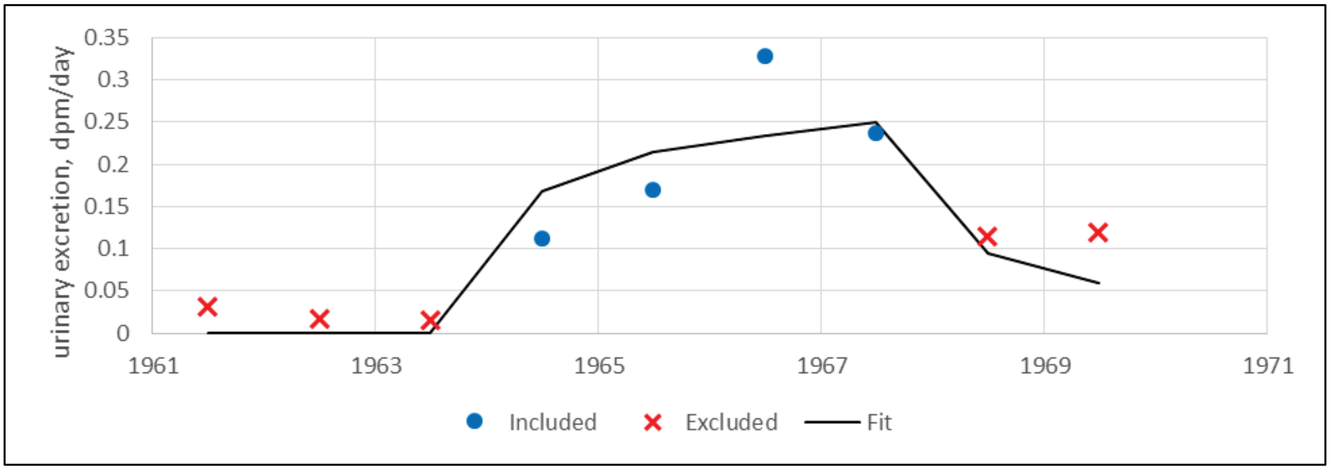

Figure E-163. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1964 to 1967, type M.

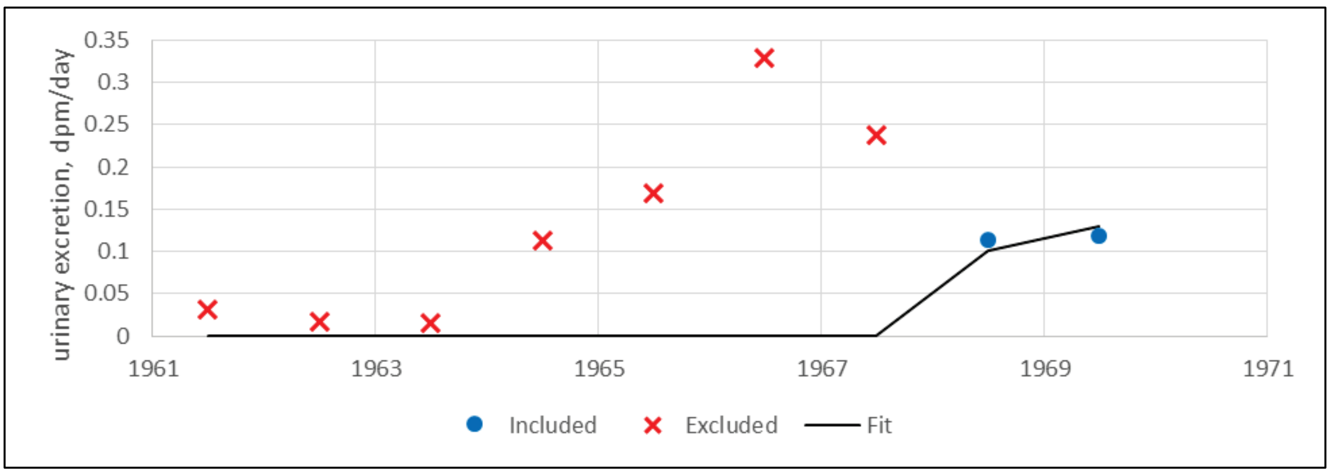

Figure E-164. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1968 to 1969, type M.

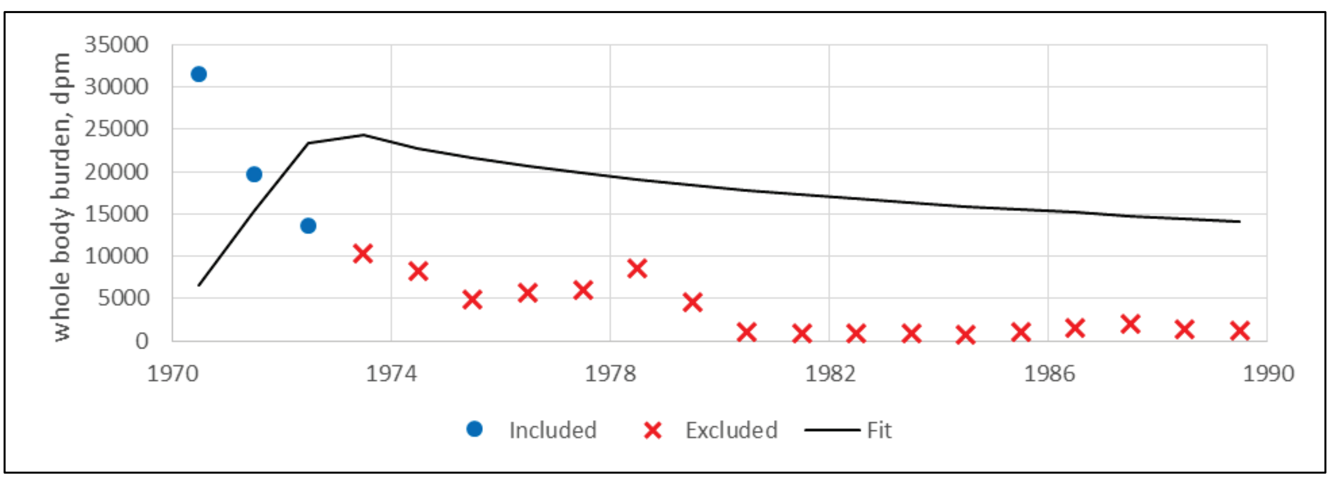

Figure E-165. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1970 to 1972, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

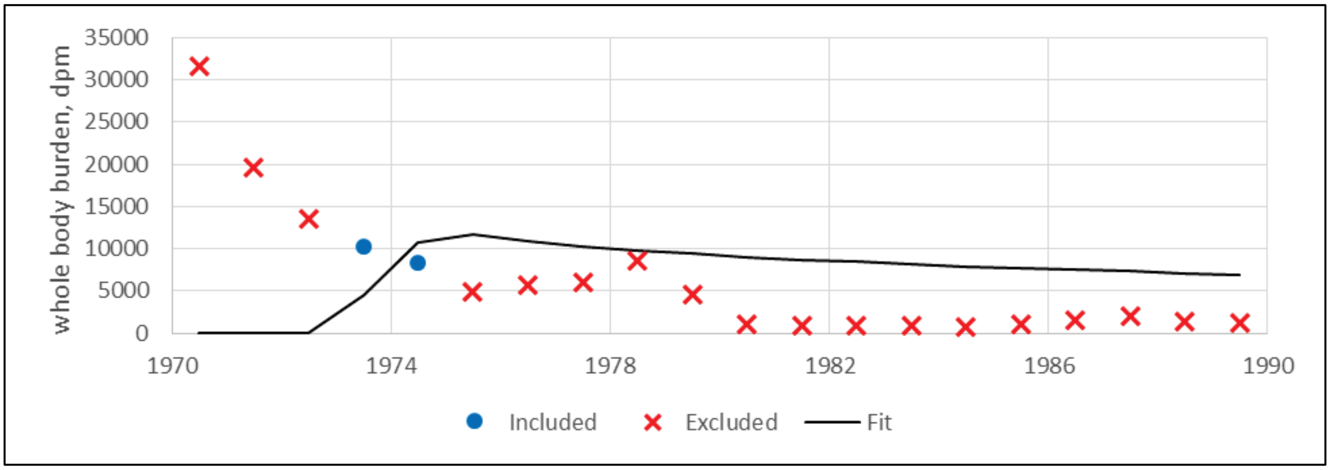

Figure E-166. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1973 to 1974, type M.

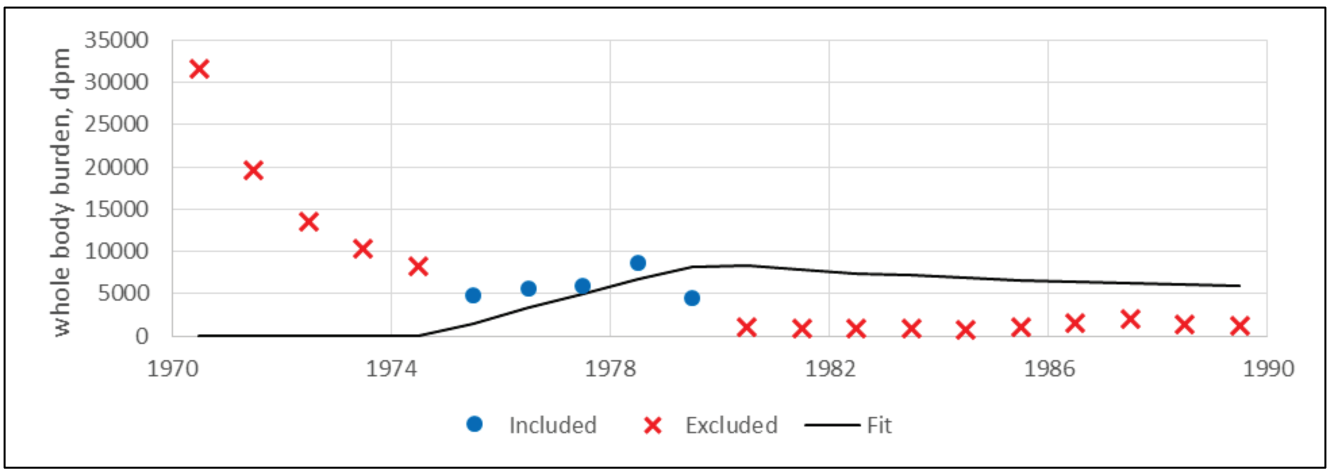

Figure E-167. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1975 to 1979, type M.

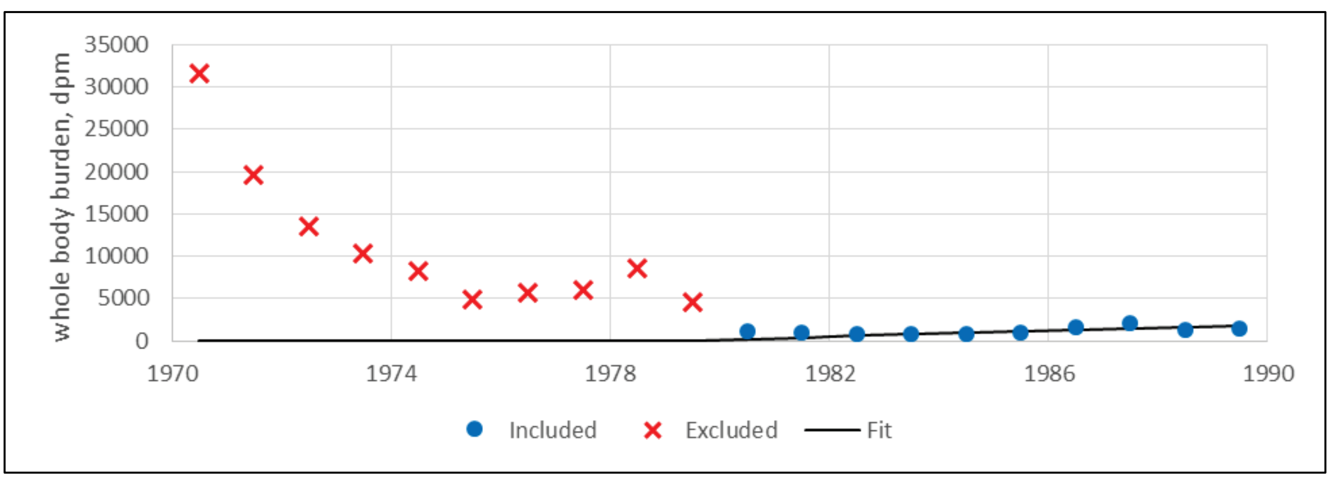

Figure E-168. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1980 to 1989, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

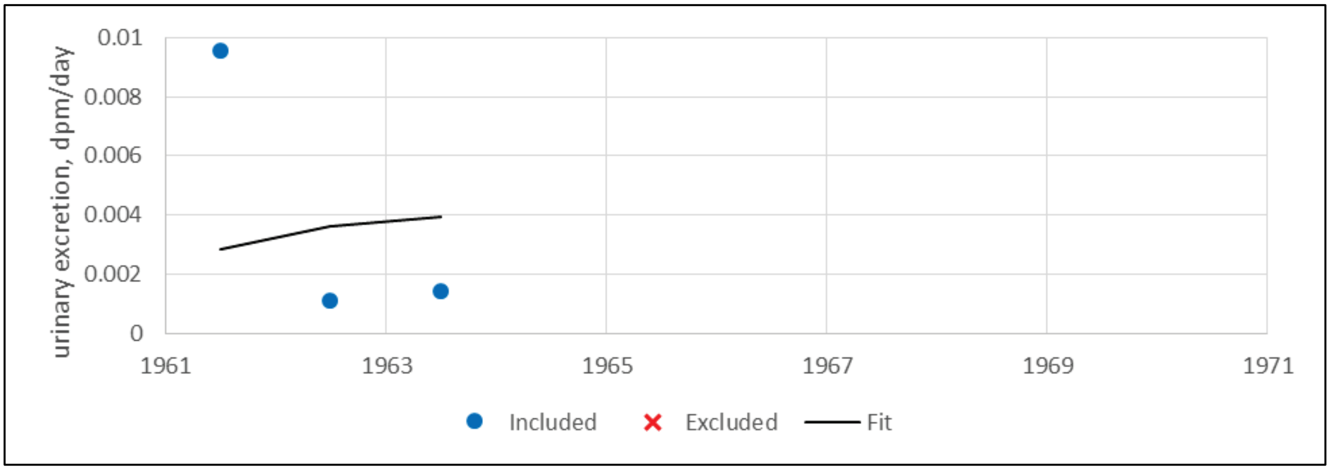

Figure E-169. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1963, type M.

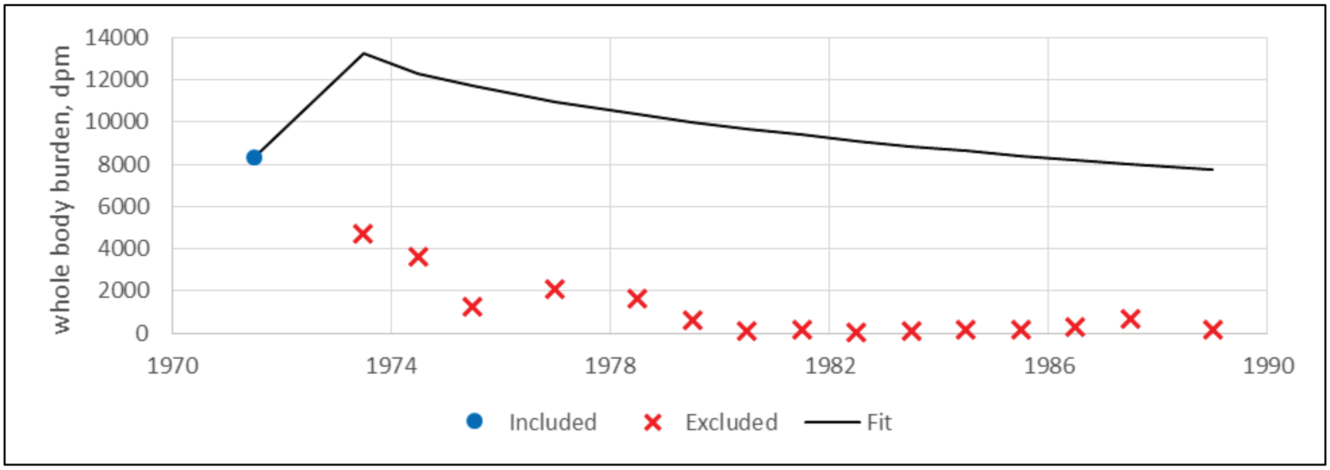

Figure E-170. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1970 to 1972, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

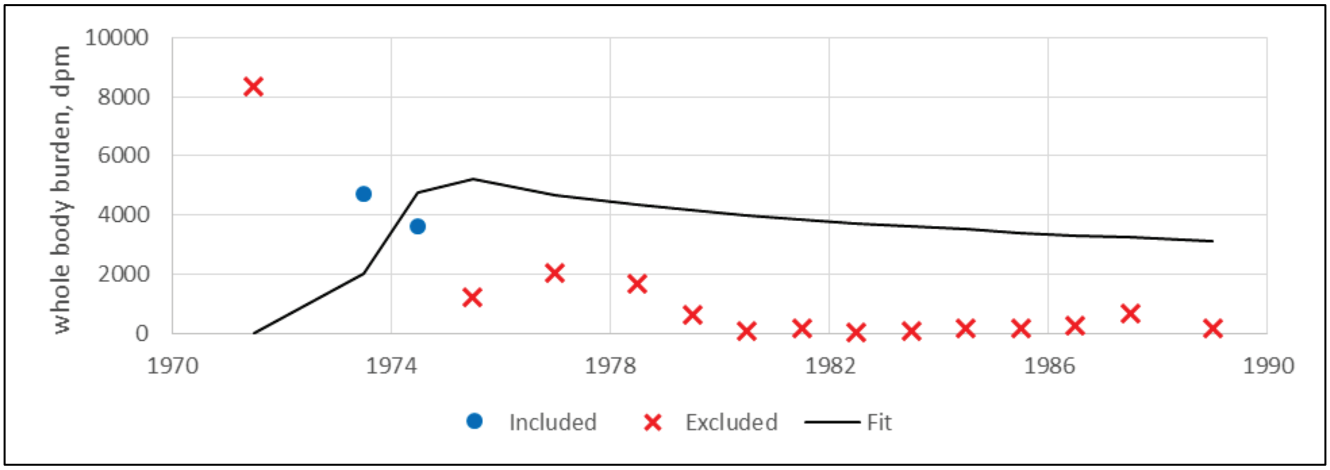

Figure E-171. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1973 to 1974, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

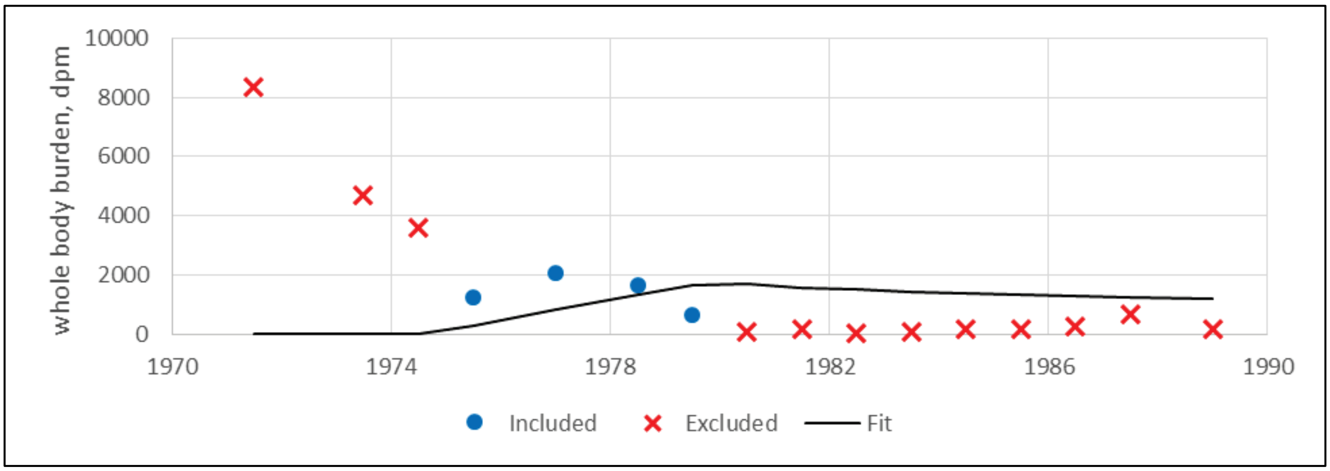

Figure E-172. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1975 to 1979, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

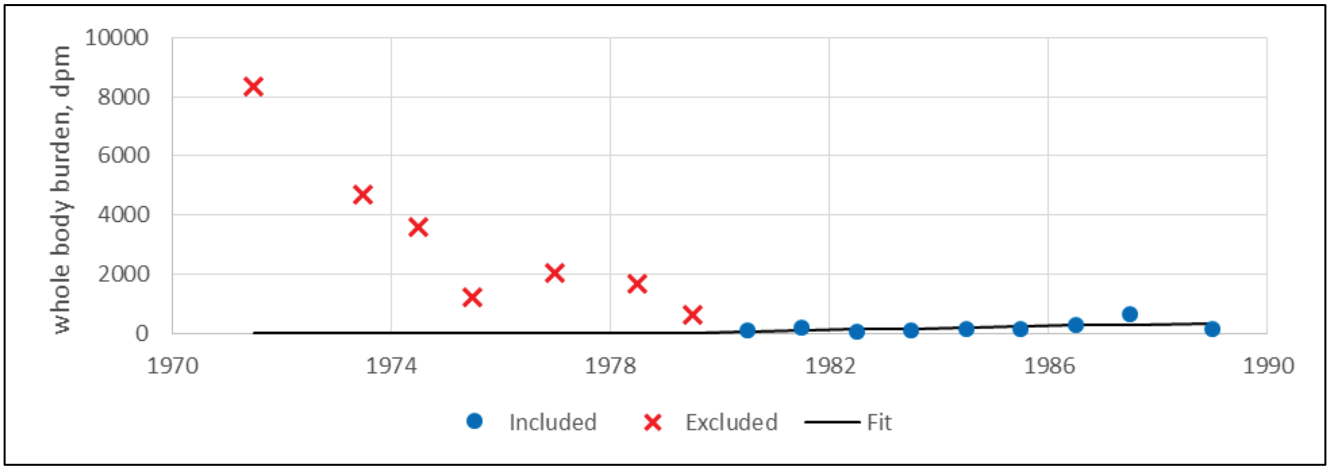

Figure E-173. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1980 to 1989, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

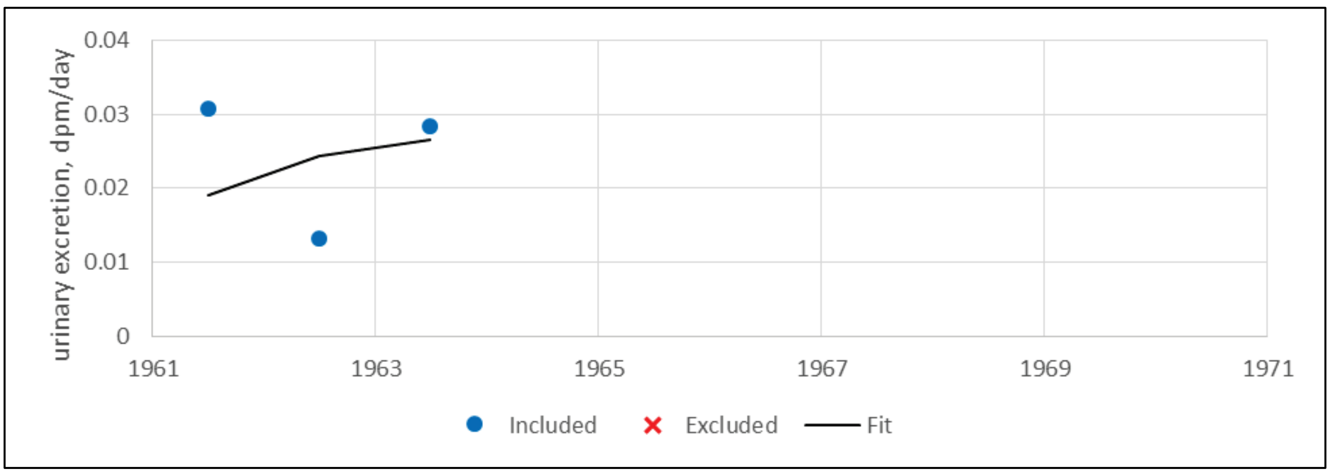

Figure E-174. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1963, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

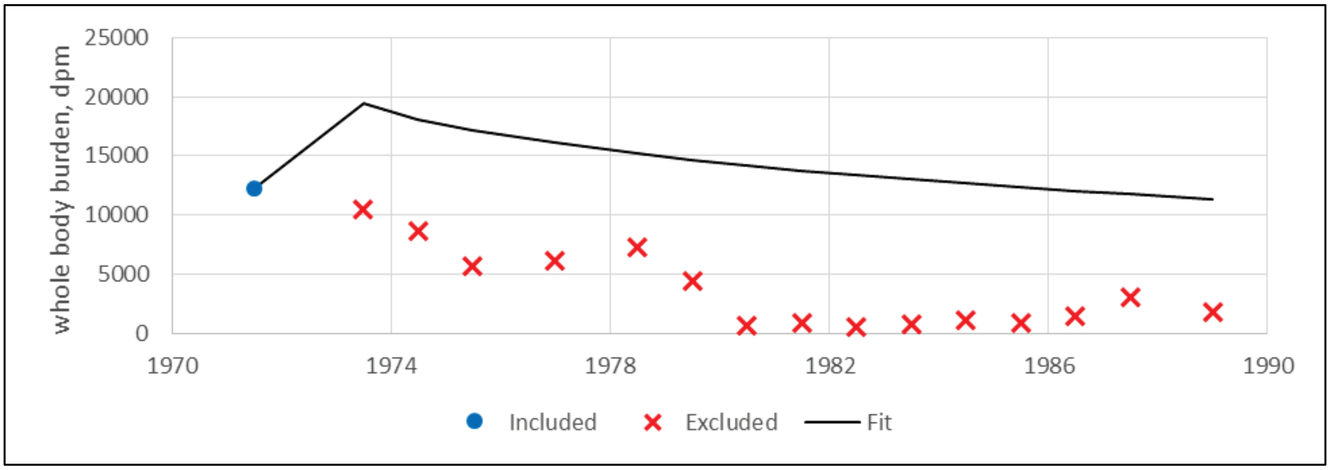

Figure E-175. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1970 to 1972, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

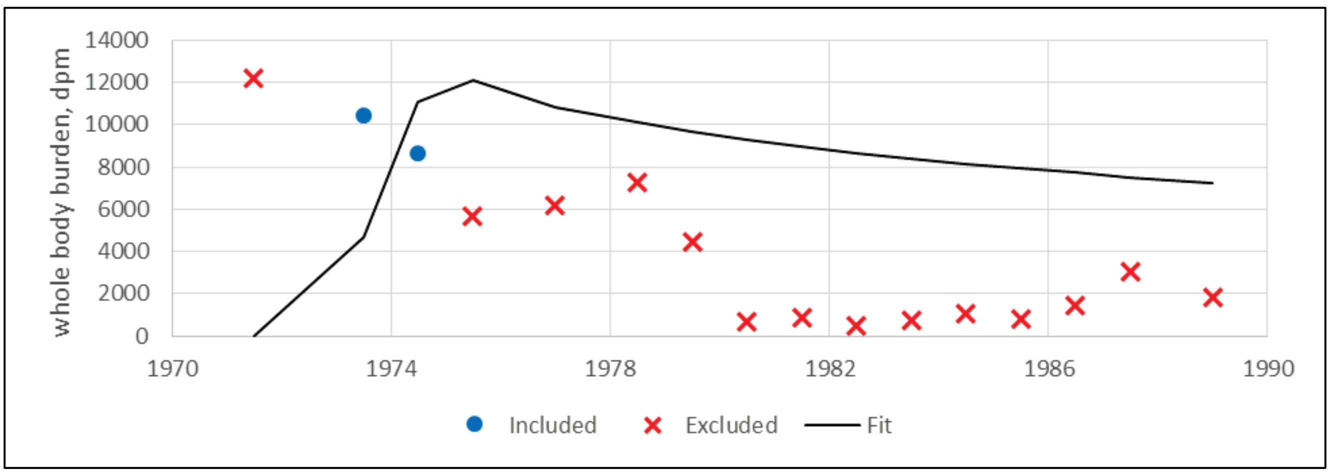

Figure E-176. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1973 to 1974, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

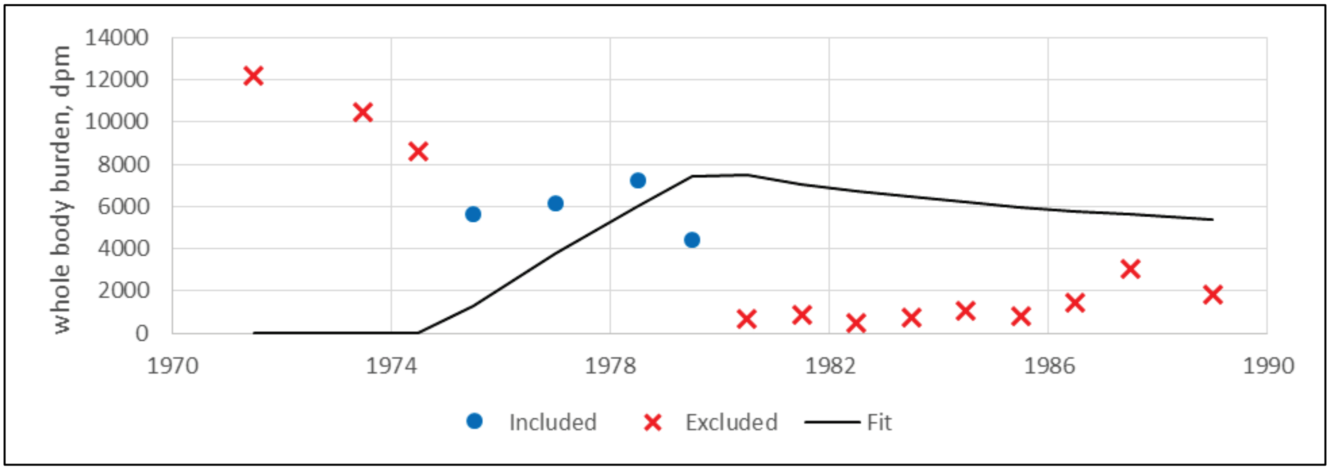

Figure E-177. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1975 to 1979, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

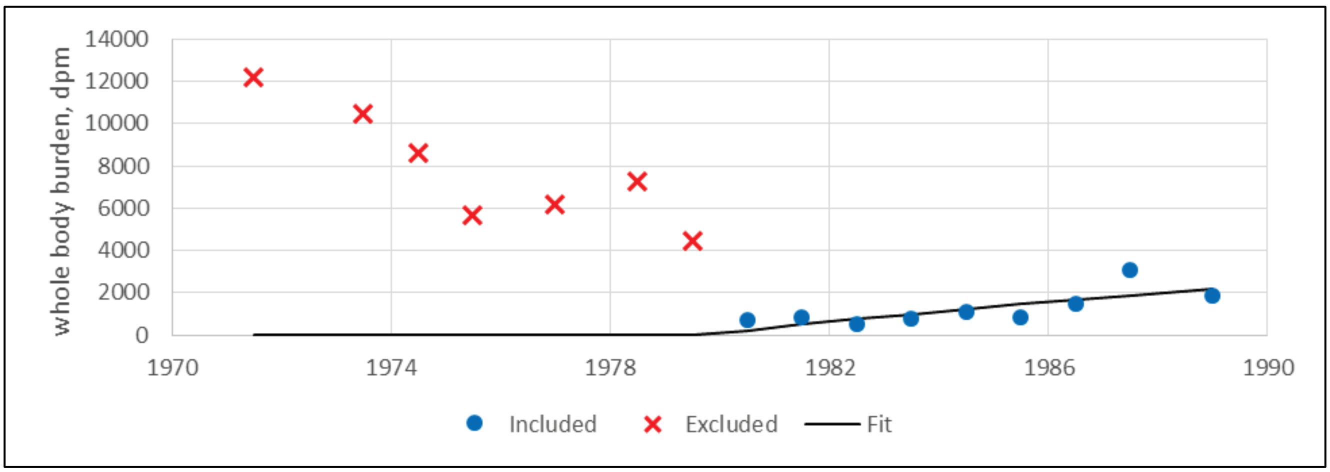

Figure E-178. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1980 to 1989, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

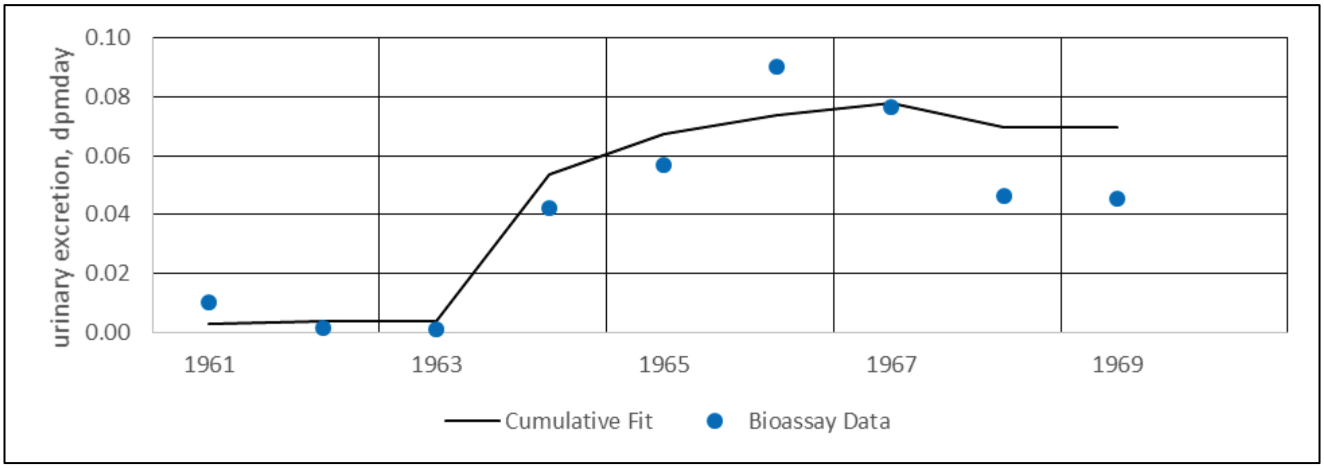

Figure E-179. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, urinalysis results, type M.

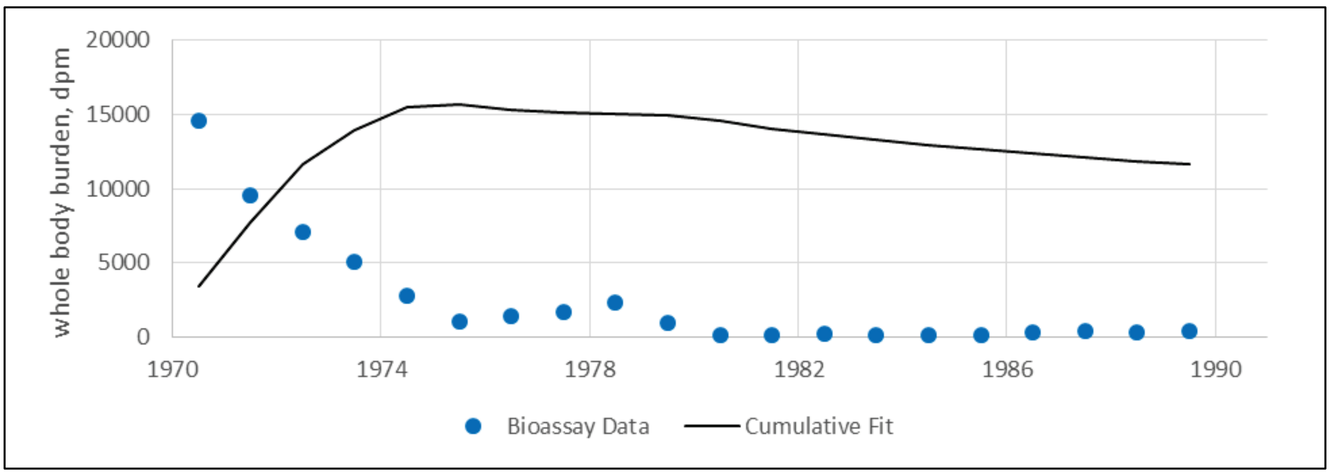

Figure E-180. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, WBCs, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

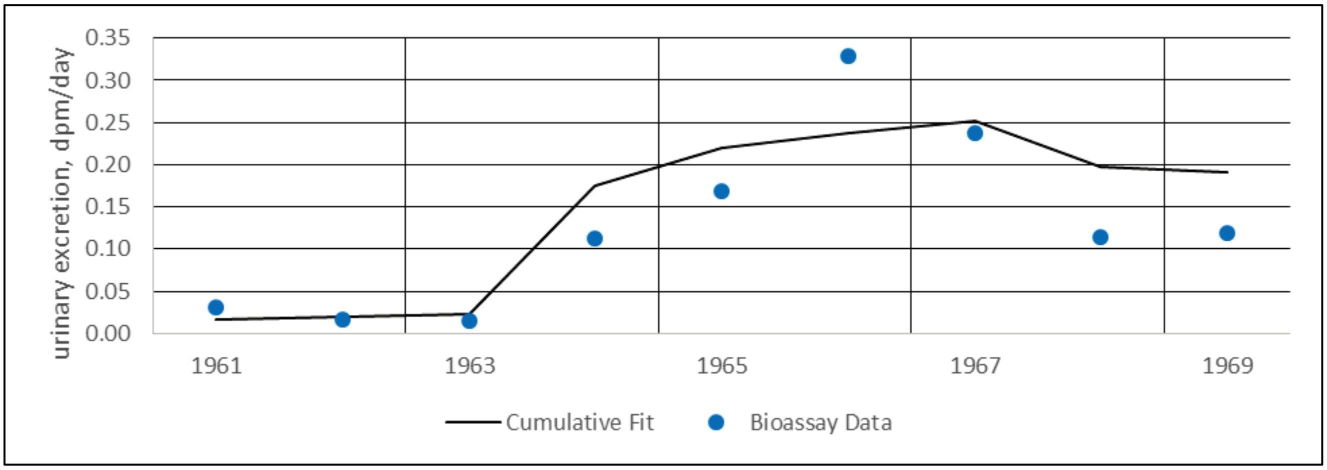

Figure E-181. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, urinalysis results, type M.

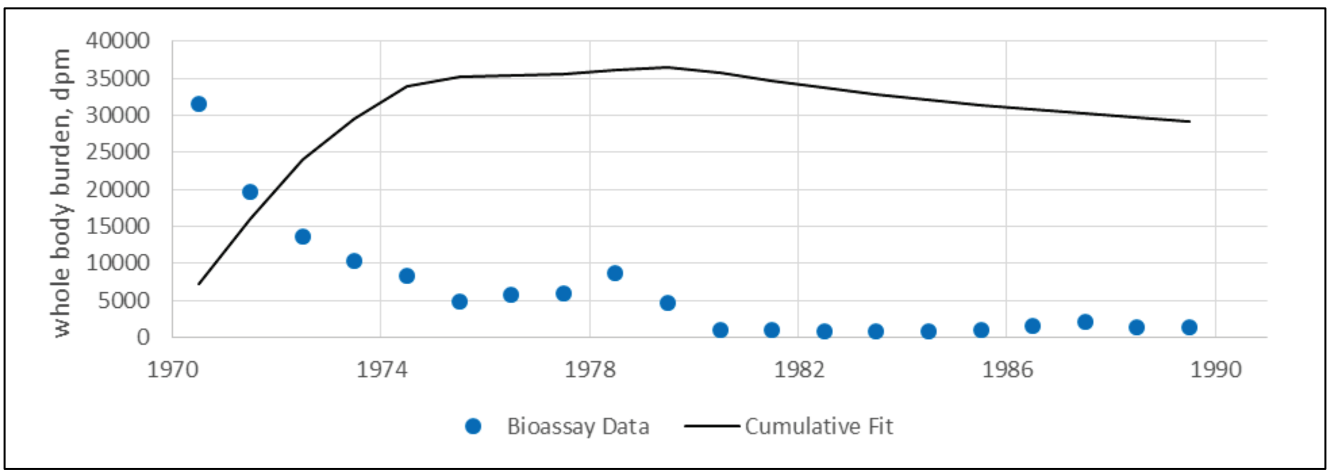

Figure E-182. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, WBCs, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

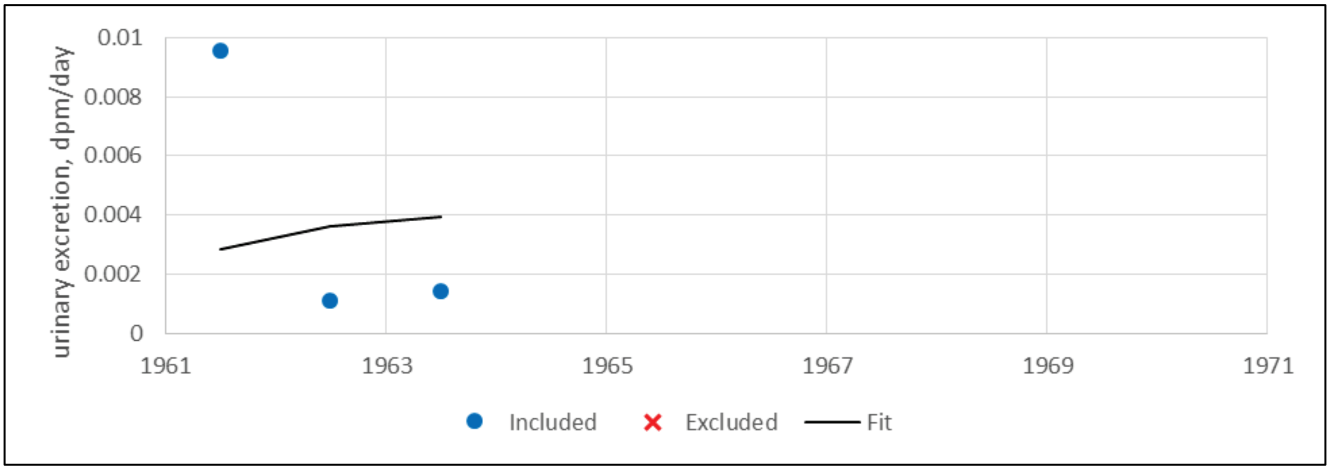

Figure E-183. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, urinalysis results, type M.

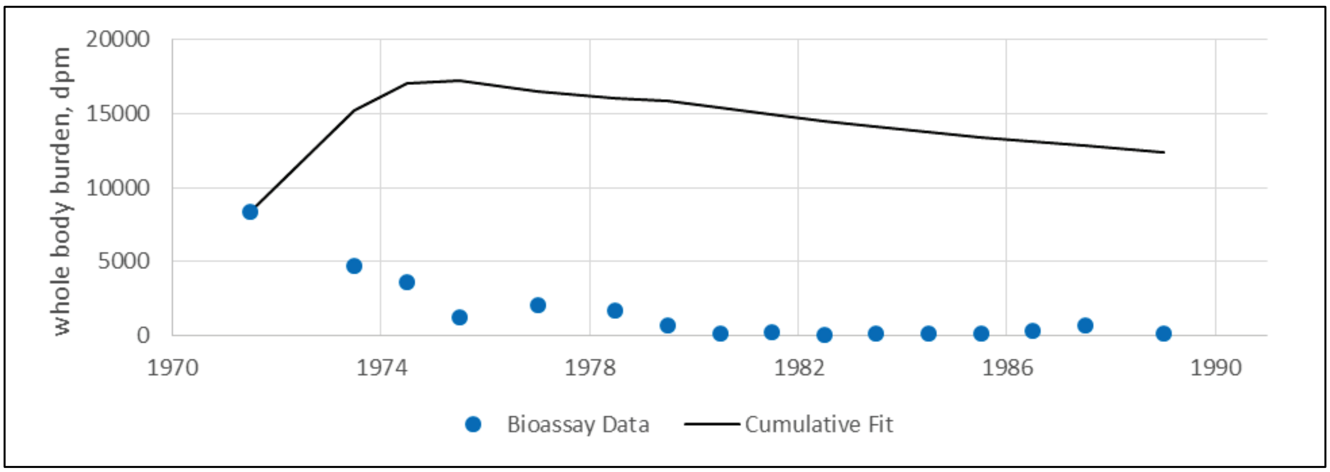

Figure E-184. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, WBCs, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

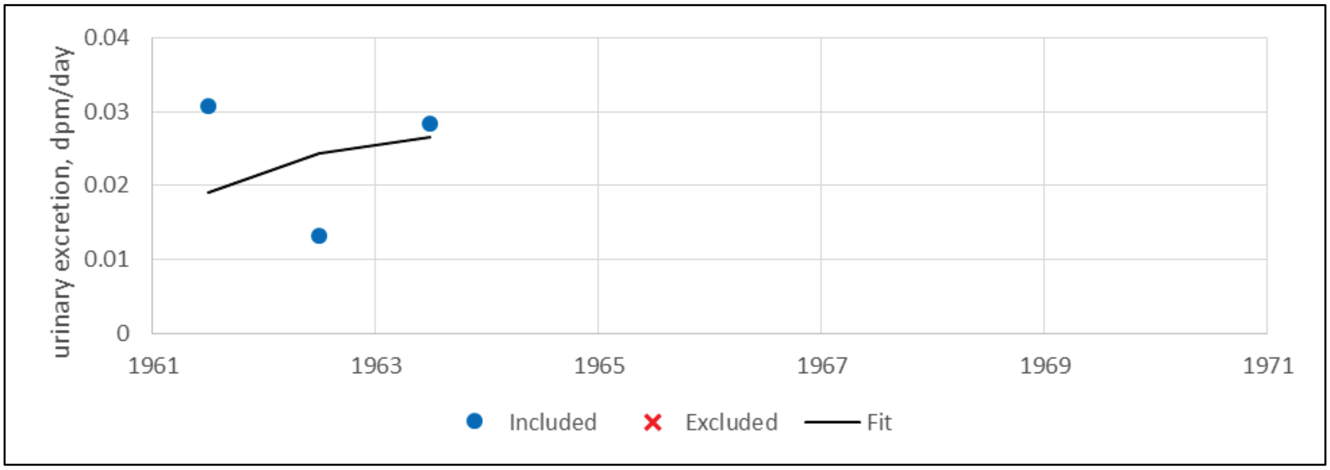

Figure E-185. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, urinalysis results, type M.

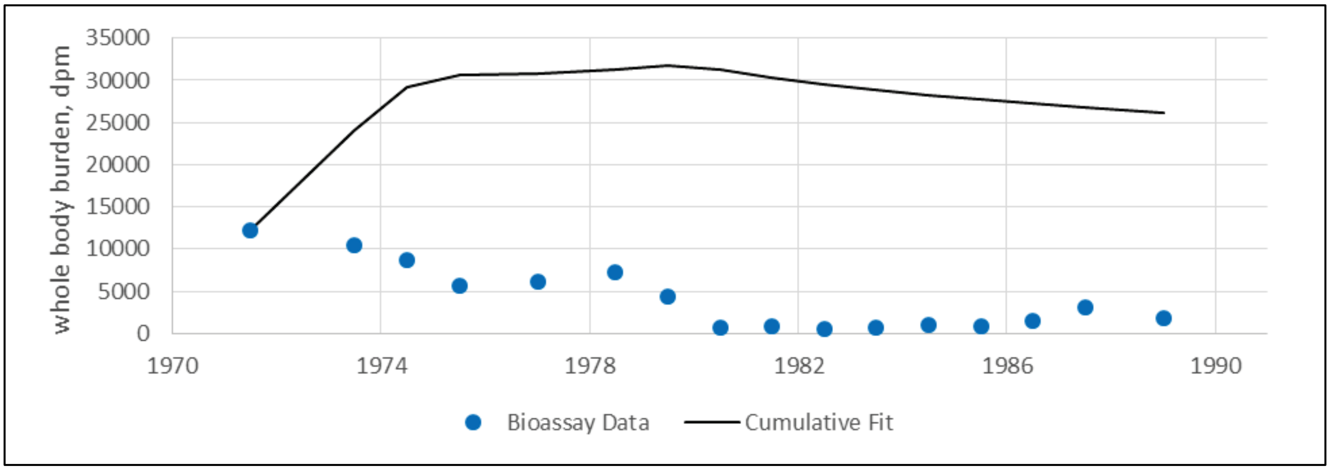

Figure E-186. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, WBCs, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-23. Summary of ^{237}Np nonCTW intake rates (dpm/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1961	12/31/1963	0.1541	0.8663	5.62	5.62	2.638
01/01/1964	12/31/1967	2.844	9.146	3.22	3.22	19.43
01/01/1968	12/31/1969	2.16	5.499	2.55	3.00	13.16
01/01/1970	12/31/1972	297.7	605.5	2.03	3.00	1,814
01/01/1973	12/31/1974	163.6	422.5	2.58	3.00	996.9
01/01/1975	12/31/1979	32.76	130.5	3.98	3.98	318.3
01/01/1980	12/31/1989	3.183	15.54	4.88	4.88	43.21

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

Table E-24. Summary of ^{237}Np CTW intake rates (dpm/d) and dates.[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1961	12/31/1963	0.1545	1.036	6.71	6.71	3.535
01/01/1970	12/31/1972	328.2	481.2	1.47	3.00	2,000
01/01/1973	12/31/1974	186.8	435.4	2.33	3.00	1,138
01/01/1975	12/31/1979	26.36	117.7	4.47	4.47	309
01/01/1980	12/31/1989	3.119	19.47	6.24	6.24	63.44

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

E.8 THORIUM INTAKE MODELING RESULTS

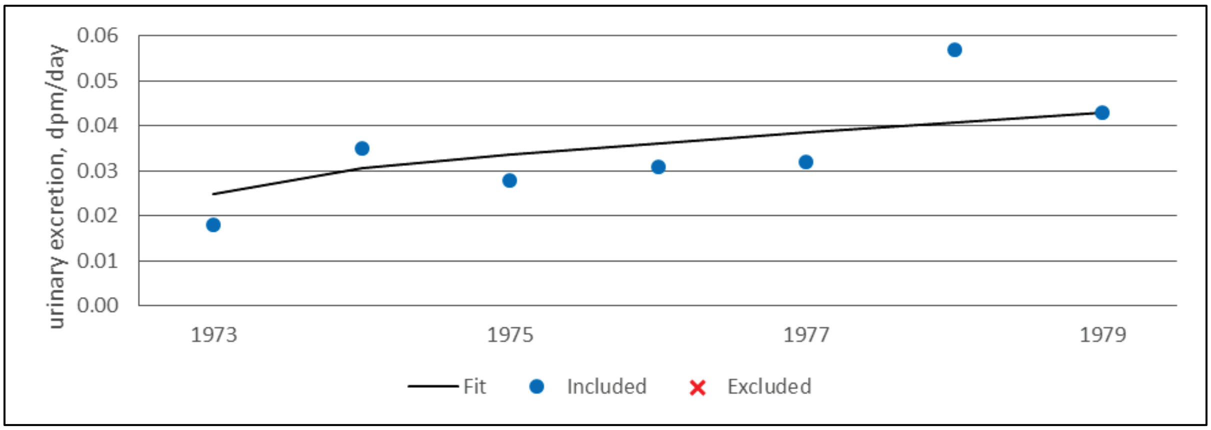

Figure E-187. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 11/01/1972 to 05/31/1980, type M.

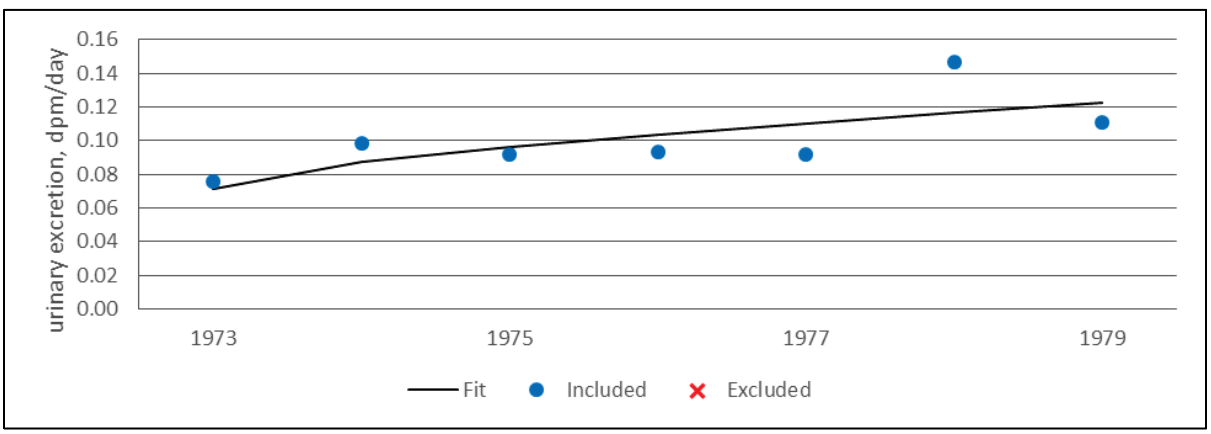

Figure E-188. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 11/01/1972 to 05/31/1980, type M.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

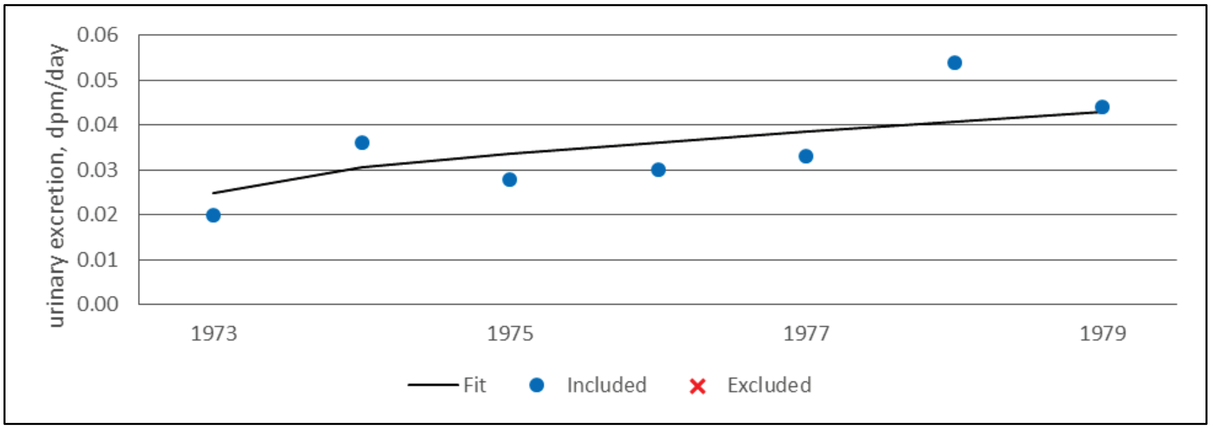

Figure E-189. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 11/01/1972 to 05/31/1980, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

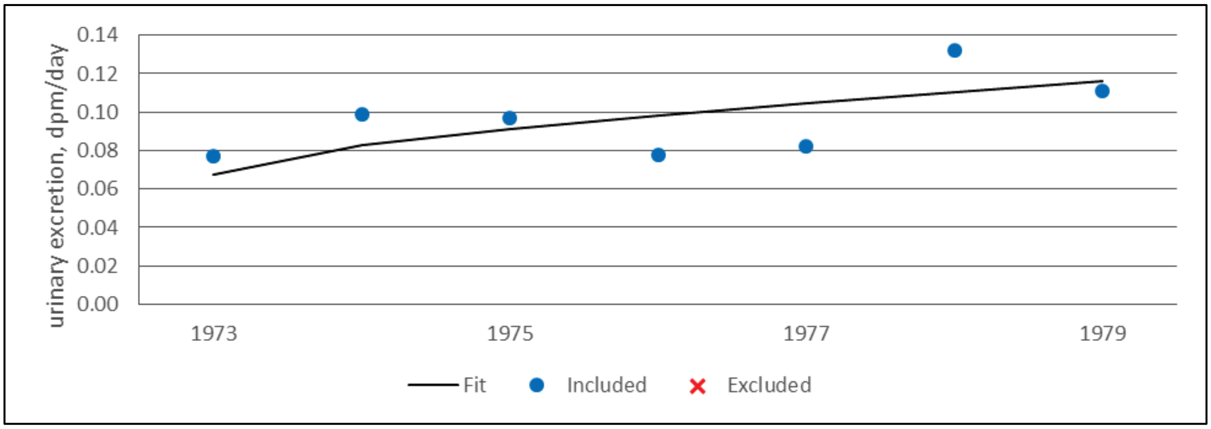

Figure E-190. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 11/01/1972 to 05/31/1980, type M. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

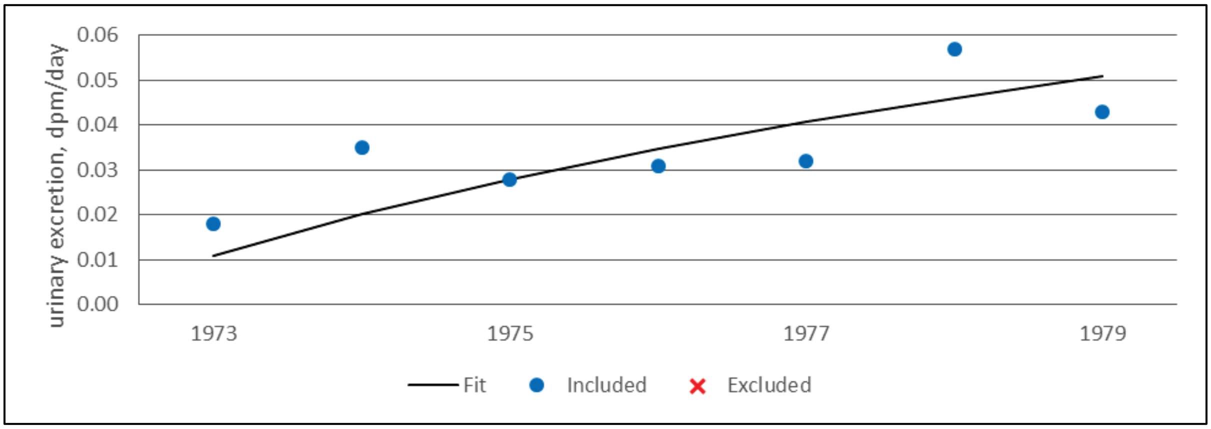

Figure E-191. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 11/01/1972 to 05/31/1980, type S.

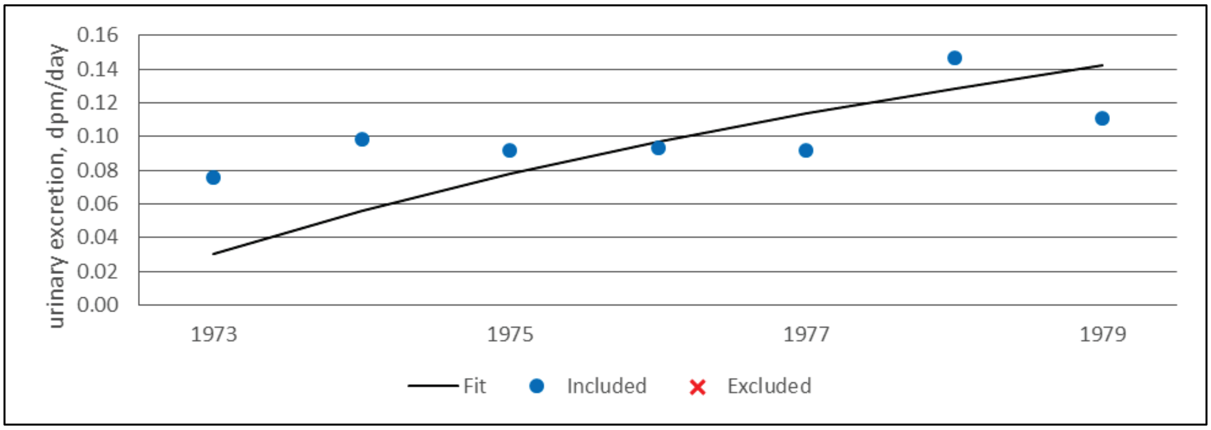

Figure E-192. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 11/01/1972 to 05/31/1980, type S.

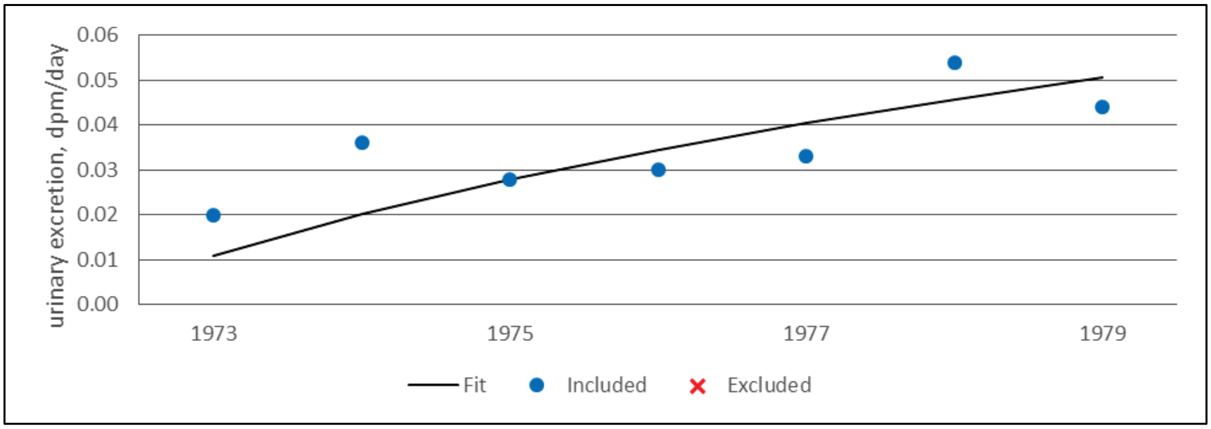

Figure E-193. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 11/01/1972 to 05/31/1980, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

ATTACHMENT E
CO-EXPOSURE DATA FIGURES (continued)

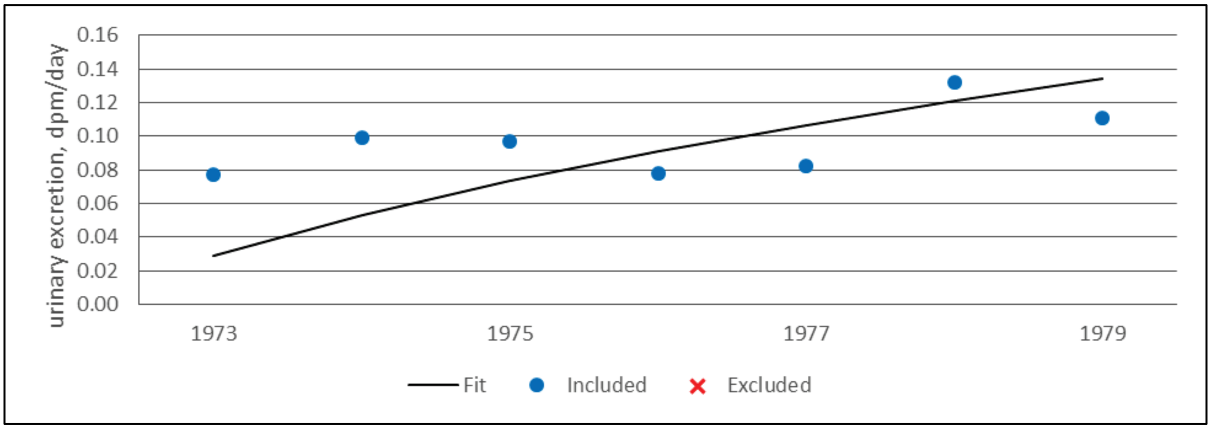

Figure E-194. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 11/01/1972 to 05/31/1980, type S. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-25. Summary of type M ^{232}Th intake rates (dpm/d) and dates.

nonCTW

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
11/01/1972	05/31/1980	4.91	14.0	2.86	3.00	29.9

CTW[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
11/01/1972	05/31/1980	4.91	13.3	2.71	3.00	29.9

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.

Table E-26. Summary of type S ^{232}Th intake rates (dpm/d) and dates.

nonCTW

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
11/01/1972	05/31/1980	92.5	258	2.79	3.00	564

CTW[a]

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
11/01/1972	05/31/1980	92.1	243	2.64	3.00	561

a. These values do not apply to subcontractor CTWs between October 1, 1972 and December 31, 1990.