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Internal Dosimetry Co-Exposure Data for the Savannah River Site

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

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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.

TABLE OF CONTENTS

LIST OF TABLES

TABLE **TITLE** **PAGE**

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

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
CPF	Californium Processing Facility
cpm	counts per minute
CTW	construction trade worker
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
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	induced activity
ID	identification (number)
IDOT	Internal Dosimetry Tool
IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
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
nCi	nanocurie
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
ORAU	Oak Ridge Associated Universities
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
S	slow (absorption type)
SCD	Separation Chemistry Division
SEC	Special Exposure Cohort
SED	Separation 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
TIB	technical information bulletin
TIOA	triisooctylamine
TRU	transuranic
TWOPOS	time-weighted one person–one statistic
USC	*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

EXECUTIVE SUMMARY

Co-exposure models are used to assign dose to workers whose personal bioassay data are missing or who were not monitored and, in retrospect, perhaps should have been. Developing co-exposure models is a complex task, involving the acquisition of large amounts of historical records, transcription and cleaning of the data, statistical analysis and modeling, and interpretation of the final models. The *Draft Criteria for the Evaluation and Use of Coworker Datasets* [National Institute for Occupational Safety and Health (NIOSH) 2015], hereafter referred to as the Guide, was issued to establish criteria that would bring some degree of consistency to the co-exposure process as applied across different radionuclides, sites, and timespans. The Guide [NIOSH 2015] specifies aspects of the data and methodology that should be critically examined to determine if a useful co-exposure model can be constructed.

The Guide covers several topics in relation to the development of a co-exposure study, including the adequacy and completeness of the data, review and analysis of the monitoring program data, and evaluation of stratification. The Savannah River Site (SRS) internal dose co-exposure study, as documented in this document, was selected as a test case for implementation of the Guide. Nine radionuclide groups were addressed: americium, tritium, uranium, plutonium, fission products (FPs), ^{137}Cs, ^{60}Co, neptunium, and thorium. Further, each dataset was stratified into two groups: construction trade workers (CTWs) and nonCTWs (all other workers).

A brief overview of how the SRS co-exposure study and subsequent documentation implemented the requirements in the Guide is presented here. Criteria specified by the Guide are presented here as section headings, followed by bulleted questions that describe the issues of concern. Next is a brief summary of how these issues are addressed, followed by a listing of the sections where this information can be found.

Adequacy of Bioassay Data for Modeling (Guide Section 2.1)

- *Are the measurement techniques capable of quantitatively measuring the exposure of interest?*

- *Were the monitored workers on the right bioassay program at the right time so that significant exposures were detected and properly assessed?*

SRS had bioassay control procedures that specified which workers should be sampled for specific radionuclides. These included instructions for requesting and collecting urine samples.

This document contains a section for each radionuclide that addresses data adequacy. Personnel monitoring programs and bioassay analytical techniques are summarized within those sections. Descriptions of the sample chemical processing techniques and counting equipment for each nuclide are given. Radiochemical recovery data are presented where appropriate. When a technique did not isolate a single element (for instance, americium counting includes californium, curium, and thorium), the assumption was made that all of the activity was from the radionuclide of interest, which is favorable to claimants.

Relevant sections: 4.1.1.1, 4.1.1.3, 4.1.2.3, 4.2.1.1, 4.2.1.3, 4.3.1.1, 4.3.1.3, 4.3.2.2, 4.4.1.1, 4.4.1.3, 4.4.2.2, 4.5.1.1, 4.5.1.3, 4.5.2.2, 4.7.1.1, 4.7.1.3, 4.7.2.2, 4.8.1.1, 4.8.1.3, 4.8.2.2, 4.9

Quality of Data (Guide Section 2.1)

- *Were results reviewed to determine if they were appropriate for use in the model?*

Data were selected that were representative of the evaluated radionuclides. Many analytical methods were specific to certain radionuclides. In some cases, several radionuclides would be included in the

analysis. A urinalysis technique that was designated as “fission products” was used to monitor a variety of nuclides. This consisted of chemical separations followed by gross beta counting, a gross gamma count, or a combination of the two. Before 1966, the gross beta analysis was used in this study to assess FP intakes assuming ^{90}Sr for the intake analysis. Beginning in 1966, the direct measurement of ^{137}Cs in the body using a whole-body counter became prevalent, while the gross beta portion of the FP analyses dropped significantly. Therefore, the ^{137}Cs body content results based on whole-body counts (WBCs) were used from 1966 on to assess FP intakes. Ratios are applied to the ^{90}Sr or ^{137}Cs intakes at the time of dose reconstruction to address the entire FP mix.

All results were reviewed for anomalies, and those that were considered unrepresentative of the population were excluded. This included results from actinide samples collected within 100 days of chelation and those collected as a result of a significant event in which few workers would have been exposed. These reviews are documented in the “Data Exclusion” section for each radionuclide. Paired measurement sample variance in the americium results was evaluated; results are presented in Attachment D.

Relevant sections: 4.1.1.4, 4.1.2.4, 4.3.2.3, 4.4.2.3, 4.5.2.3, 4.7.2.3, 4.8.2.3, Attachment D

Completeness of Data (Guide Section 2.2)

- *Do the bioassay data in the available records contain enough of all the bioassay data actually generated to allow us to make meaningful co-exposure models?*

- *Are exposure conditions of the monitored workers representative of or bound those of the unmonitored workers to whom the intakes will be applied?*

Data from the NIOSH-Division of Compensation Analysis and Support Claims Tracking System (NOCTS) were used as the best available compilation of data in a usable form. 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, *Use of Claimant Datasets for Coworker Modeling* [Oak Ridge Associated Universities (ORAU) Team (ORAUT) 2016a]. Hundreds of thousands of bioassay results were available for more than 1,500 workers in the evaluated timeframe. When there were too few monitored workers from the NOCTS dataset to develop a co-exposure model, data from the original bioassay logbooks were abstracted and used for the analysis. This was done for the Am/Cm/Cf, thorium (based on americium), and neptunium co-exposure models.

During the period of the co-exposure study, SRS had a functioning bioassay program with procedures that specified which workers were monitored for exposure to specific radionuclides. Selection for monitoring and frequency of sampling was based on work location and work activities. Attachment C contains tables of required bioassay frequencies by area and job. Those workers with higher exposure potential (operators, maintenance, etc.) were monitored more than administrative workers. Due to this differential in monitoring practices, the co-exposure models are weighted more towards the exposures indicative of workers with higher exposure potential.

Relevant sections: 3.1, 3.1.1, 3.2, Attachment A, Attachment C

Accuracy of Data (Guide Section 2.2)

- *Is the transcription of data from historic hardcopy records to computer-readable format accomplished with an acceptably low error rate?*

Data were transcribed from NOCTS and SRS laboratory logbooks. Checks of the accuracy of data transcription from these sources, including legibility of the source documents, were primarily performed in accordance with ORAUT-RPRT-0078, *Technical Basis for Sampling Plan* [ORAUT

2016b], and are described in Attachment A. Confidence intervals are provided for each test that was performed.

Two sets of acceptance criteria for data transcription were used, one for critical fields and another for all checked fields (critical and noncritical). Critical fields are those determined to have the potential to affect the accuracy of the results. Typical critical fields were the reported result, nuclide, and payroll identification number (PRID). Typical noncritical fields were the individual's name and job title. The plan for all checked fields used a 5% maximum allowable error rate, while the plan for critical fields subjected them to a stricter 1% maximum allowable error rate.

Relevant sections: 3.1.2, 3.2.3, 4.1.2.2, 4.2.2, 4.8.2.1, Attachment A

Reproducibility of Calculations (Guide Section 3.0)

- *Is the documentation of calculations used in the development of co-exposure models detailed enough to allow all numerical results and plots to be successfully reproduced at a future date?*

The statistical analysis and intake modeling efforts are discussed in the respective nuclide sections. The step-by-step data preparation and statistical analysis instructions are reproduced in Attachment E. These instructions document all operations performed on the data such that the final results can be recreated independently. Attachment E includes a list of all source files that were used for the analyses. In addition to a review as each individual assessment was performed, the entire process was stepped through upon completion. All calculations were reviewed to ensure both that the instructions were correct and that the analyses had been performed correctly.

Relevant sections: 4.1.3, 4.1.4, 4.2.3, 4.3.3, 4.3.4, 4.4.3, 4.4.4, 4.5.3, 4.5.4, 4.6.2, 4.6.3, 4.7.3, 4.7.4, 4.8.3, 4.8.4, 4.9, Attachment E

Applicability of Monitoring Data to Unmonitored Workers (Guide Section 3.1)

- *Was it established who was monitored and why?*

This document contains sections for each radionuclide on Personnel Monitoring and Applicability to Unmonitored Workers. Within those respective sections are descriptions of the monitoring programs, including information on frequency of sampling and who was monitored.

Bioassay sampling procedures dating back to 1965 document who was to be monitored for which radionuclides. Attachment C contains tables from those procedures detailing monitoring type and frequency by area and job classification. The procedures prioritized monitoring for those workers with higher exposure potential. In 1965, groups of workers with potential for intakes of tritium and/or FPs were specified. The procedure lists eight work groups across several buildings that were required to leave urine samples for FP analysis. Work groups not listed in the procedure were not considered to have potential for intakes.

By 1968, SRS designed a category system to identify and track intake potential. Monitoring frequency was based on exposure potential and categories ranged from minimum to maximum potential. Specific nuclides were location dependent, but workers with minimum potential might have been sampled for plutonium, FPs, uranium, or neptunium once every 3 years. Frequency increased with increasing potential, and the maximum potential groups were sampled as often as four times per year for plutonium and twice per year for FPs. Each category listed specific groups of workers with associated monitoring frequencies. Workers not included in any of the 23 categories were considered not to have a potential for intake and were therefore not sampled. Category definitions and work group designations were updated over time in subsequent versions of the bioassay control procedures based on missions and materials, but SRS continued to sample workers by intake potential. Because the workers with the highest exposure potential were part of the monitoring

program, any unmonitored workers would have an exposure potential that was similar to or less than that of the monitored workers.

The co-exposure models were stratified on the basis of the exposure potential characteristics as discussed in Section 3.2.

Relevant sections: 3.2, 4.1.1.1, 4.1.1.2, 4.2.1.1, 4.2.1.2, 4.3.1.1, 4.3.1.2, 4.4.1.1, 4.4.1.2, 4.5.1.1, 4.5.1.2, 4.7.1.1, 4.7.1.2, 4.8.1.1, 4.8.1.2, Attachment C

Analysis and Application of the Modeled Data (Guide Section 3.2 & 3.3)

- *Were appropriate methods used to manipulate the bioassay data and perform statistical analyses?*

The time-weighted one person–one statistic method, as described in ORAUT-RPRT-0053, *Analysis of Stratified Coworker Datasets* [ORAUT 2014a], was used for the statistical evaluations. For most analyses, time intervals of 1 year were used. No intervals greater than 3 years were used. Results are tabulated in the respective nuclide sections. Box and whisker plots are also provided to illustrate the relative range and distribution of the bioassay data. The complete set of instructions for the development of the statistical analyses is included in Attachment E.

General guidance on when to assign the geometric mean (GM) and geometric standard deviation (GSD) or the 95th percentile is provided in Section 5.0. The decision is left to the dose reconstructor based on a review of the worker's records and site information.

Relevant sections: 1.0, 4.1.3, 4.2.3, 4.3.3, 4.4.3, 4.5.3, 4.6.2, 4.7.3, 4.8.3, 5.0, Attachment E

Stratification (Guide Section 4.0)

- *Do different categories of workers warrant separate co-exposure models so as to not bias their dose low?*

The co-exposure modeling was stratified by CTW versus nonCTW. CTWs were determined using SRS payroll numbers and craft codes. A detailed discussion of these categories and how classification was accomplished is contained in the noted section and its subsections.

Some workers handled pure or relatively pure ^{60}Co during the period from 1955 to 1970. A separate co-exposure model, using the FP urinalysis results, was developed to ensure that potential intakes were not underestimated.

Relevant sections: 3.2, 4.6

Summary

A series of co-exposure models were developed for application to SRS workers whose data are lacking for the assessment of intakes of radioactive material. The *Draft Criteria for the Evaluation and Use of Coworker Datasets* [NIOSH 2015] was applied in the development of these models.

The discussion above summarizes the major points of the Guide and provides a brief discussion of how each was addressed in the development of the co-exposure models. The body of this document provides the details of this analysis. In answering the questions posed by the Guide about completeness, accuracy, and quality of the data, as well as those about the monitoring program and who was placed on it, it is demonstrated that the models are valid for the dose reconstruction of workers who were not monitored or whose monitoring data are not available.

1.0 INTRODUCTION

Technical information bulletins (TIBs) 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 sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s), such as changing scientific understanding of operations, processes, or procedures involving radioactive materials. TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

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 U.S. Department of Energy (DOE) or Atomic Weapons Employer (AWE) facility. It does not mean, nor should it be equated to, an “AWE facility” or a “DOE facility.” The terms AWE and DOE facility are defined in 42 *United States Code* (USC) 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000, respectively.

ORAUT-OTIB-0019, *Analysis of Coworker Bioassay Data for Internal Dose Assignment* [ORAUT 2005b], 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. *Draft Criteria for the Evaluation and Use of Coworker Datasets* [NIOSH 2015] provides the criteria to evaluate the adequacy and completeness of co-exposure data. In the sections below, the data and evaluations required by the guidance are provided for each evaluated radionuclide.

Bioassay data in the (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].

A statistical analysis of the data was performed according to ORAUT-OTIB-0019 [ORAUT 2005b], ORAUT-RPRT-0053, *Analysis of Stratified Coworker Datasets* [ORAUT 2014a], and ORAUT-RPRT-0096, *Multiple Imputation Applied to Bioassay Coworker Models* [ORAUT 2019]. 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.

2.0 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 co-exposures can be used to assign an internal dose to address potential intakes of radioactive material. The purpose of this TIB is to provide monitored co-exposure information for calculating and assigning occupational internal doses to employees at 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 7.0.

3.0 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 4.0.

3.1 DATA SOURCES

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.

3.1.1 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, *Use of Claimant Datasets for Coworker Modeling* [ORAUT 2016a]. This analysis demonstrated that, for three evaluated cases, claimant datasets can be considered to be random samples of the complete dataset and that the justification provided the basis 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 [ORAUT 2017c]. The first step consisted of verifying that all individuals with at least 1 day of verified employment at SRS during the timeframe 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, similar to the process used below for checking data accuracy. 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 2017c]; therefore the exact method of ORAUT-RPRT-0086 was not used. The details of the results of these evaluations are contained in Attachment A.

3.1.2 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 4.2.2. 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 representative 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 identification number (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 0.62% with a 95% confidence interval of 0.41% to 0.89% 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 2.17% with a 95% confidence interval of 1.21% to 3.37%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

3.2 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 CTWs (Maintenance and Construction) and operations workers that warrant considering them as two distinct cohorts or strata with regards 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 involve contaminated equipment (i.e., smaller quantities), but the engineered controls (e.g., gloveboxes, cabinets, fume hoods, or 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 and CTW models for SRS.

Two classifications of workers were evaluated: CTWs and nonCTWs. CTWs at SRS, also referred to as building trades workers, fit into two categories. The first consists of workers hired by the site prime contractor tending to stay in mostly permanent employment, while the second consists of workers brought in temporarily and often for short periods to perform specific tasks. Many of the workers in the second category have repeat temporary employment at either SRS or other DOE sites. From the onset of construction at SRS through 1989, workers in the first category were employed by DuPont while workers in the second category were employed by subcontractors such as B. F. Shaw Company, Miller-Dunn Electric Company, and North Brothers Company. CTWs in the first category were assigned to DuPont Roll number 2. (Roll numbers separated workers by payroll type, e.g., salaried employees, hourly employees, and contracted workers.) Workers in the second category were assigned to Roll 4 and some to Roll 5 and were assigned a two-digit craft code. For example, craft code 20 was Boilermaker [DuPont 1954]. In 1989, Bechtel Savannah River took over construction duties at SRS. Bechtel tended to use CTWs hired through subcontracted companies rather than direct hire.

3.2.1 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. These types of jobs were performed by workers in both categories. Workers from both categories 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 electrician ([redacted]) worked lengthy periods between 1958 and 1975, while another ([redacted]) worked varying periods from 1955 through 1966. 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.

Prime CTWs had similar exposure conditions to subcontractor CTWs [ORAUT 2017b], so bioassay data from prime CTWs and intakes based on that data may be used to assign intakes to unmonitored subcontractor CTWs. This is based on the conclusion that the exposure conditions and potential for intakes were similar among all CTWs. Similar jobs were performed by both prime and subcontractor CTWs. SRS Health Physics monitored jobs by prime CTWs and subcontractor CTWs for surface and airborne contamination and incidents.

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.

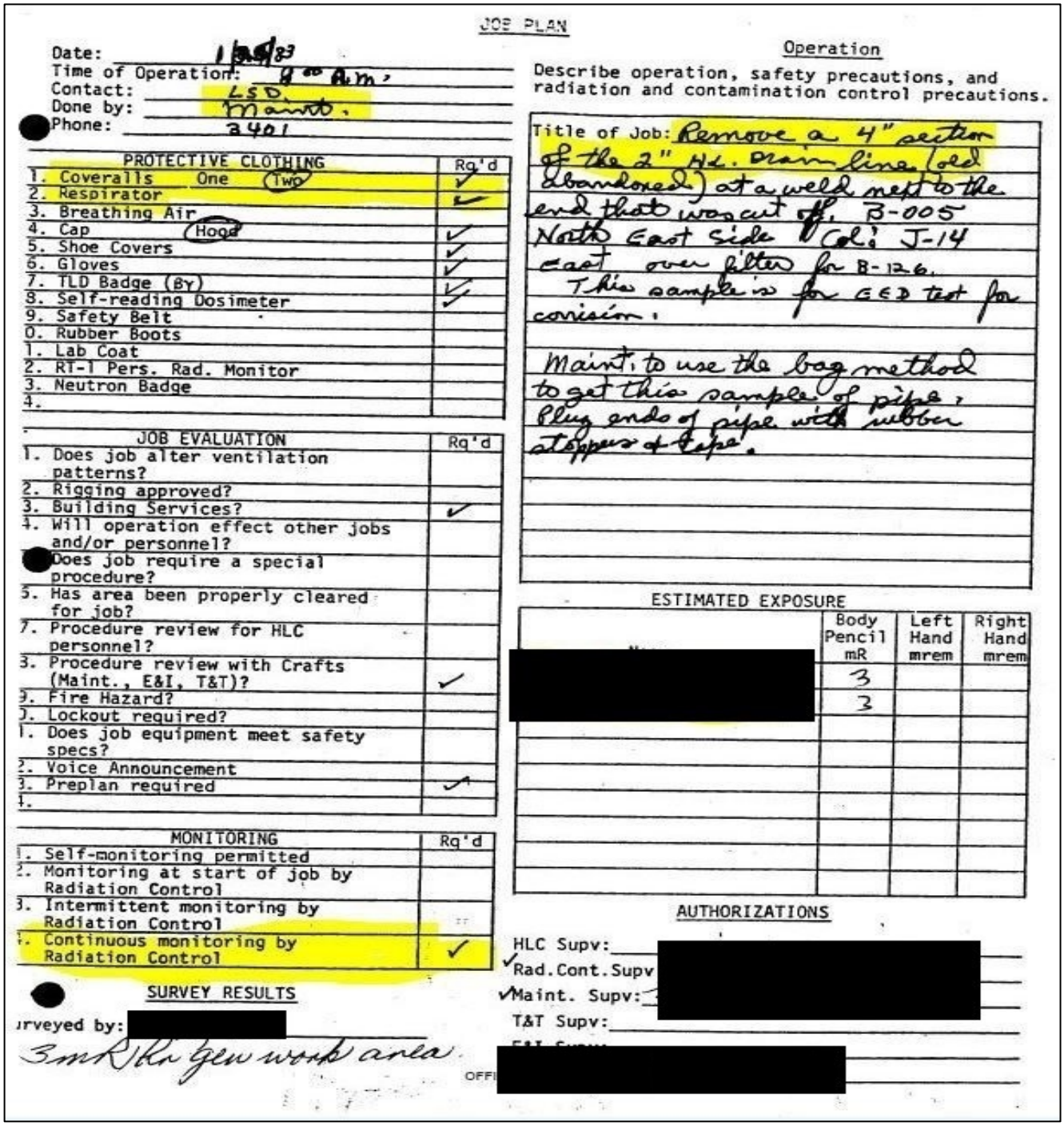
Bingham [1997] stated that the DOE stated in Congressional testimony that it is likely that the greatest risks to workers on its sites involve mainly the construction workers, including those who are involved in decommissioning, dismantling of facilities, and maintenance or repair activities. According 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 b]. 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]. These examples and others show that CTW workers in Rolls 2, 4, and 5 were subjected to similar potential paths of radiation exposure, and that they were monitored. External dose and bioassay data received from DOE for former SRS prime contractor and subcontractor CTWs support both of these conclusions (i.e., that radiation exposure and intake potential and monitoring were similar).

Subcontractor CTWs often had limited routine monitoring because their work was split between routine maintenance and renovations. In addition, they were not continuously in the same work area. The monitoring was mostly job specific and based on need and workplace indicators. Both DuPont and subcontractor CTWs were monitored when incidents occurred. From ORAUT-RPRT-0083 for the period 1980 through 1986, 67% of evaluated subcontractors had bioassay in the year they were noted as working on jobs with potential for intakes. Thirty-nine percent were on routine bioassay. Workers on short-duration jobs (less than a few days) were not likely to have been sampled unless an incident in the associated work area led to an incident bioassay. The team found bioassay results of coworkers on the same Job Plans for another 26% of the subcontractor CTWs using respiratory protection, although it is possible that the co-exposure bioassay was collected as a result of work on a different job or work location. The team identified temporary workers with bioassay [ORAUT 2017b], including one who was sampled after an incident [DuPont 1987b]. Therefore, 93% of subcontractor CTWs were either monitored or had a coworker who was monitored.

Another important note is that while there were differences in biological monitoring, ALL 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. The only possible difference between DuPont Construction work and Subcontractor Construction work appears to be scale of work that was likely governed by Davis-Bacon rules.

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-inch section from the High Level Drain Line as shown in Figure 3-1. The pipe ends were to be plugged and taped. The workers wore two pair of coveralls and respirators and had continuous coverage by Health Physics 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 3-2. 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). Health Physics also covered this job, continuously monitoring for contamination. This example also illustrates off-normal work that was similar in type and with similar exposure potentials being conducted by both DuPont construction (Maintenance) and subcontractor pipefitters on the highly contaminated drain lines from cells in radiological areas. The workplace protective clothing requirements and workplace monitoring were similar. NIOSH believes these two groups of workers (prime and subcontractor CTWs) should be in the same co-exposure model.



JOB PLAN

Date: 1/26/83
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	
0. Rubber Boots	
1. Lab Coat	
2. RT-1 Pers. Rad. Monitor	
3. Neutron Badge	
4.	

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?	
Does job require a special procedure?	
5. Has area been properly cleared for job?	
7. Procedure review for HLC personnel?	
3. Procedure review with Crafts (Maint., E&I, T&T)?	✓
9. Fire Hazard?	
0. Lockout required?	
1. Does job equipment meet safety specs?	
2. Voice Announcement	
3. Preplan required	✓
4.	

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 glow 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 GED 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

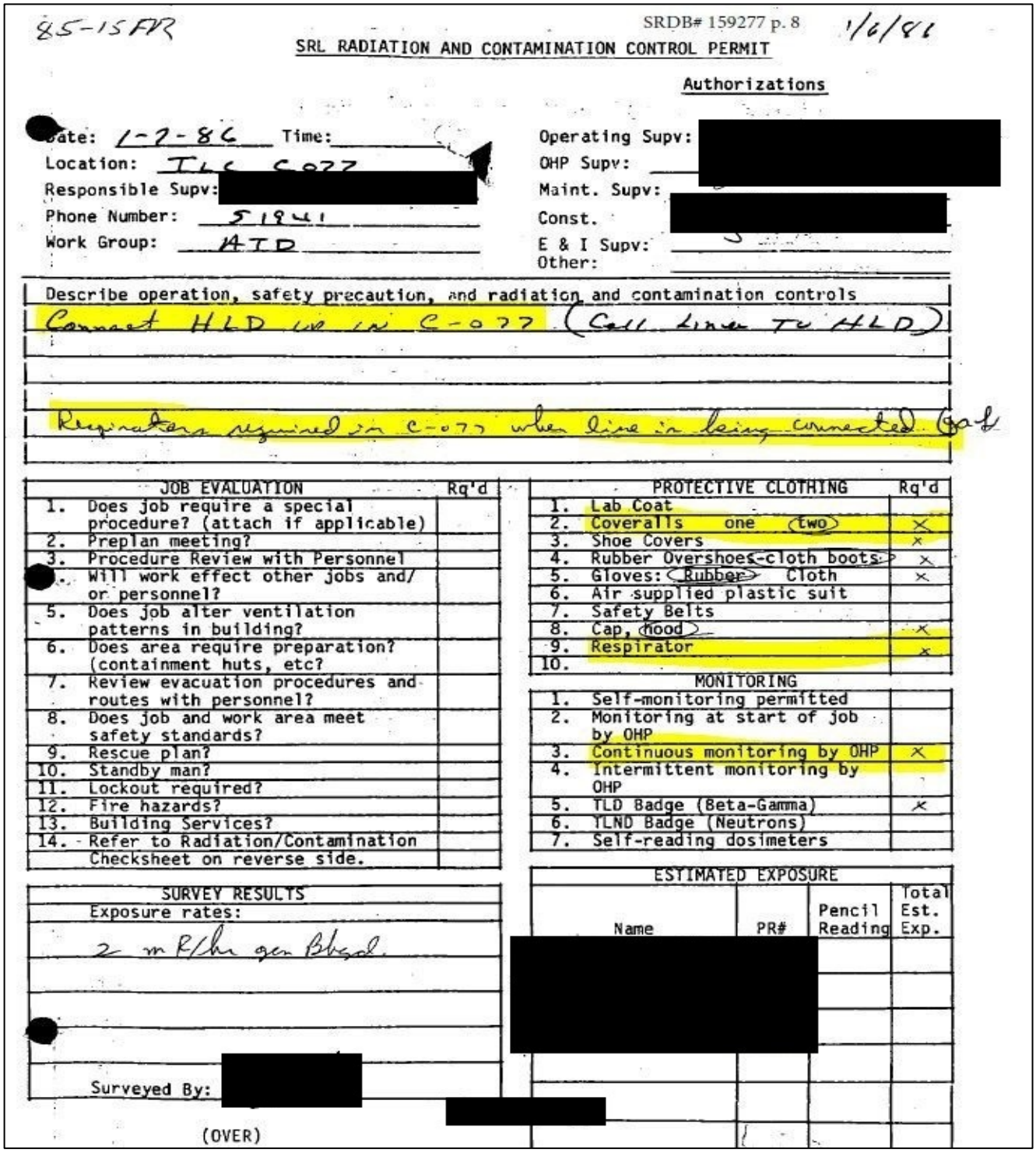
	Body Pencil mR	Left Hand mrem	Right Hand mrem
[redacted]	3		
	3		

AUTHORIZATIONS

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

Figure 3-1. 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 3-3. 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. Health Physics coverage was intermittent during this operation depending on the repairs being conducted. In general, very few construction operations mention the MSMs. One job noted removal of the MSM covers, which exposed the



85-15 FR

SRDB# 159277 p. 8

1/6/86

SRL RADIATION AND CONTAMINATION CONTROL PERMIT

Authorizations

Date: 1-2-86 Time:

Location: TLC C-077

Responsible Supv: [redacted]

Phone Number: 51841

Work Group: ATD

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 (Coil Liner TO HLD)

Respirators required in C-077 when line is being connected to HLD

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 Blvd.

Surveyed By: [redacted]

(OVER)

ESTIMATED EXPOSURE

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

Figure 3-2. Construction work on the High Level Drain Line [DuPont 1986].

workers to the cell as shown in Figure 3-4. 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, Health Physics provided monitoring throughout the job. Stratification by CTW type in this example is not appropriate because all of the workers had the same exposure potential. Due to similarity of jobs and exposures, NIOSH believes all crafts should be

ORIGINAL

SRDB# 157063 p. 80

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 (Rγ)	x
8. Self-reading Dosimeter	
9. Safety Belt	
10. Rubber Boots	
11. Lab Coat	
12. RT-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/hr Rx gen workarea

Surveyed by: [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]

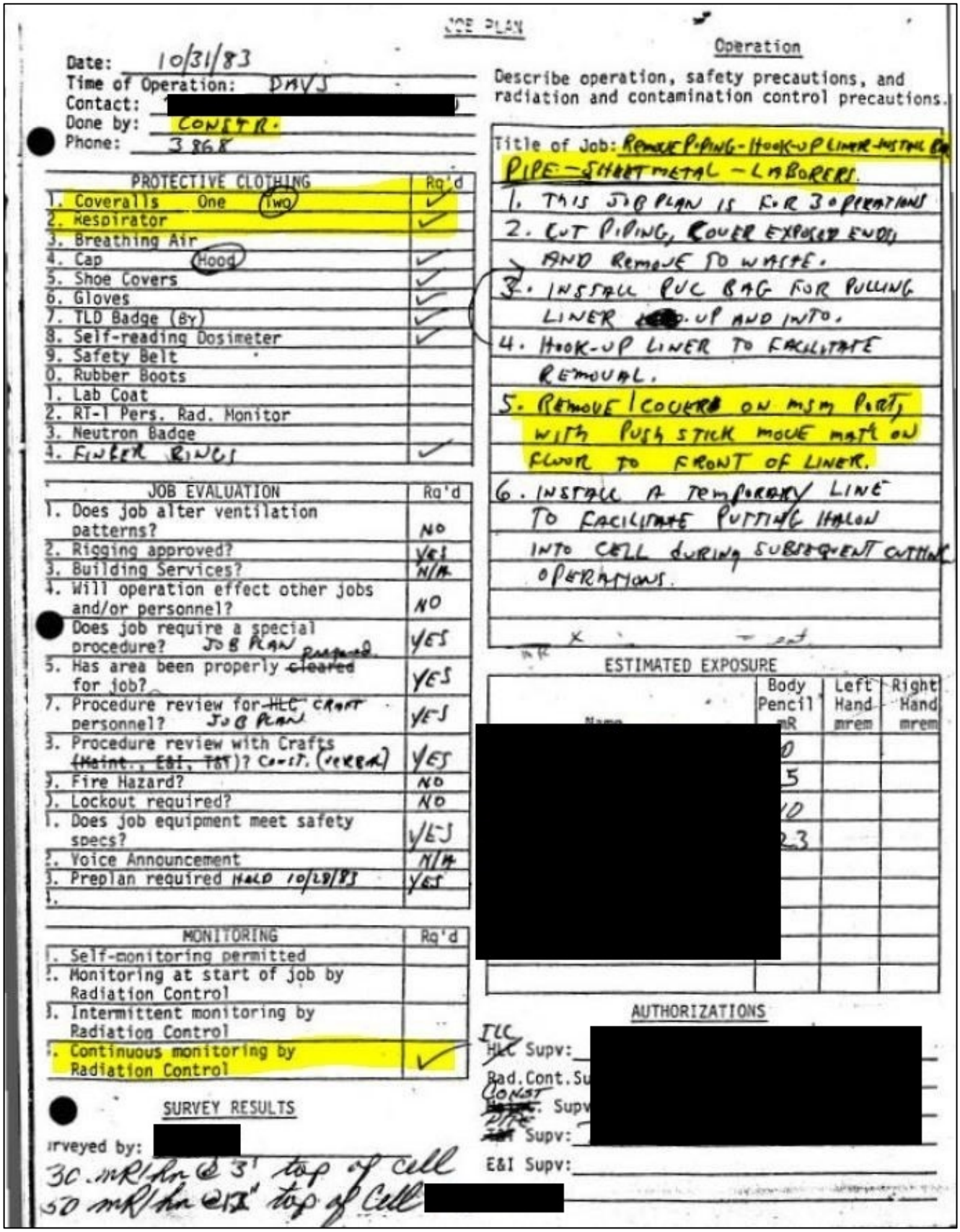
Rad.Cont.Supv: [redacted]

Maint. Supv: [redacted]

T&T Supv:

E&I Supv:

Figure 3-3. 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
Does job require a special procedure? JOB PLAN prepared.	YES
5. 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. (HERE)	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 HOLD 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 @ 2" top of Cell [redacted]

Operation

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

Title of Job: REMOVE PIPING - HOOK-UP LINER - INSTALL [redacted] 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 [redacted] UP AND INTO.
4. HOOK-UP LINER TO FACILITATE REMOVAL.
5. REMOVE COVERS ON MSM PORT, WITH PUSH STICK MOVE MAT 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]	0		
	5		
	10		
	23		

AUTHORIZATIONS

~~HLC~~ I&C Supv: [redacted]
Rad.Cont.Su
CONST. Supv
~~T&T~~ Supv:
E&I Supv:

Figure 3-4. Construction removing MSM covers [DuPont 1983b, p. 161].

included in a single co-exposure model. The workplace monitoring at SRS varied depending on the magnitude of the exposure potential and associated risk. Health Physics monitoring and personnel protective equipment changed depending on this exposure potential and is quite similar to radiological monitoring conducted today.

Many, but not all, workers including subcontractor CTW as shown in ORAUT-RPRT-0083 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 (DuPont versus subcontractor or by 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.

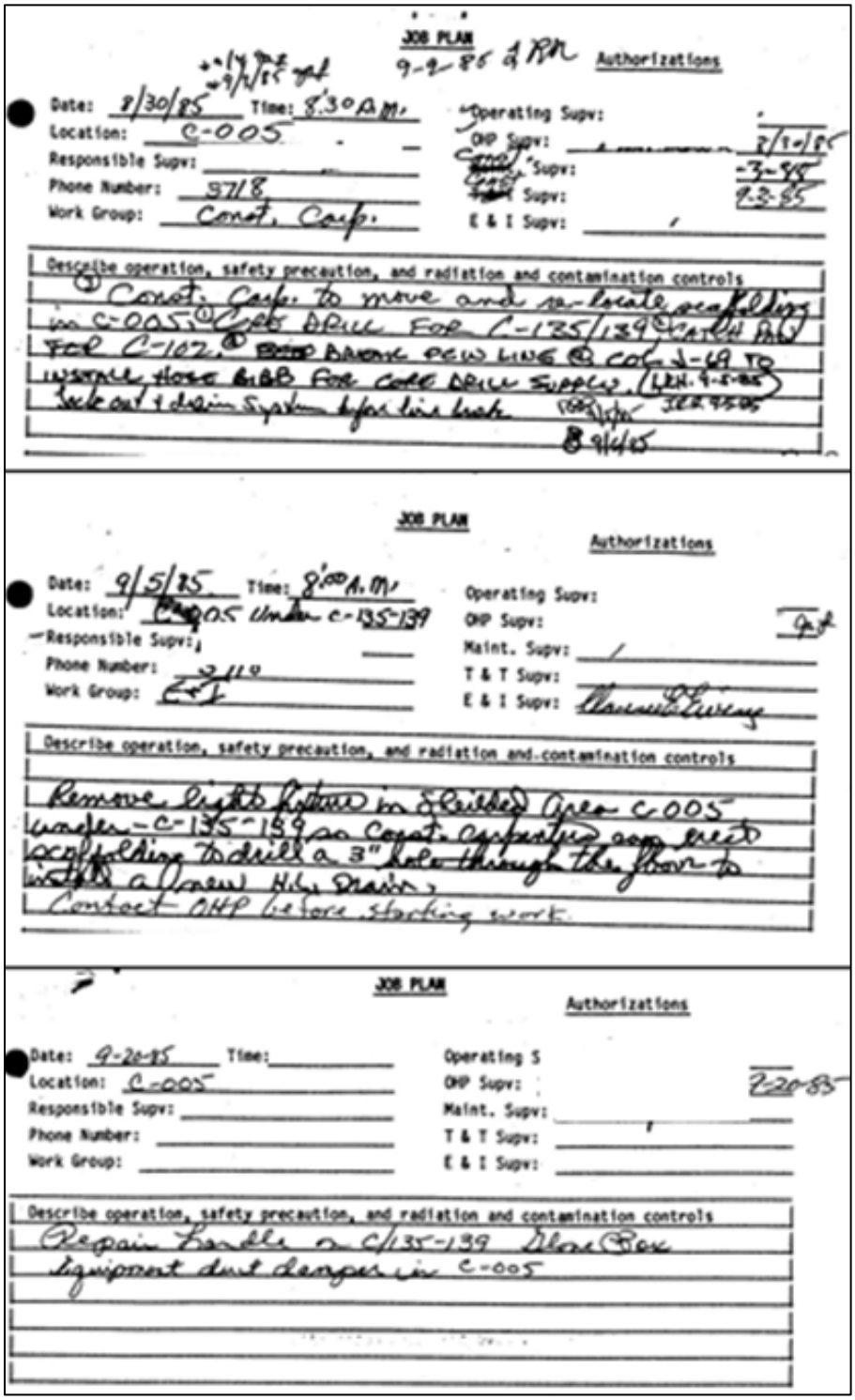
Therefore, permanent workers in Roll 2 who performed maintenance or decontamination tasks should be included in the same cohort as workers from Roll 4 or 5 who performed similar tasks. Including both groups is supported by work previously done within the DOE complex. In *Surveillance of Former Construction Workers at Oak Ridge Reservation*, the authors identified two categories of CTWs very similar to the two categories at SRS, but they included workers from both categories in one CTW population for surveillance and evaluation [Bingham 1997]. In *Savannah River Building Trades Medical Screening Program: A Needs Assessment*, the authors' intended population was "building and CTWs who have been employed mainly by subcontractors at DOE sites" but included workers that had mostly permanent employment with the construction subcontractors. While that definition does not specifically include building trade workers employed by DuPont Construction, those workers performing building and construction trades should be included because the report's goal was those "mainly" employed by subcontractors. Lastly, the website for the DOE-funded Building Trades National Screening Program states this as the criteria for being included as a CTW [CPWR 2016]:

> *You performed construction work (for either the prime contractor or subcontractors) at any time in the past at any of the following: Atomic Energy Commission (AEC) or Department of Energy (DOE) sites associated with the research or production of nuclear weapons.*

The population of CTWs at SRS includes people that worked for the prime and subcontracted construction contractors. A previous SRS employee of DuPont made the following statement in a worker outreach meeting in 2008 [NIOSH 2008, p. 13]:

> *[Redacted] stated that although the site profile accounts for missed dose, he believes that NIOSH cannot account for the missed dose for unmonitored workers who were in and out of the "hot" areas all the time. [Redacted] explained that the E&I mechanics were like the construction workers named in the proposed SEC* [Special Exposure Cohort] *class in that they did not work in a specific area like the production workers did.*

While the occupation Electrical and Instrumentation (E&I) Mechanic was cited by the former worker, other prime contractor craftspeople worked across the site performing maintenance type tasks. Portions of three Job Plans for a set of connected work in Building 773-A Rooms C-135/C-139 are shown in Figure 3-5. Work was performed by construction Carpenters, E&I Mechanics, and Maintenance Mechanics, which supports the premise that both DuPont and subcontracted CTWs performed similar work for short periods across SRS. Additional examples are shown in Attachment B.



JOB PLAN

Authorizations

Date: 8/30/85 Time: 8:30 A.M.
Location: C-005
Responsible Supv:
Phone Number: 3718
Work Group: Const. Carp.

Operating Supv:
OHP Supv: 8/30/85
Maint. Supv: 9-3-85
T & T Supv: 9-3-85
E & I Supv:

Describe operation, safety precaution, and radiation and contamination controls
Const. Carp. to move and re-locate scaffolding in C-005. Core DRILL FOR C-135/139 CATCH BASIN FOR C-102. BREAK NEW LINE @ col J-69 TO INSTALL HOSE BIBB FOR CORE DRILL SUPPLY. Lock out & drain System before line break
8/30/85

JOB PLAN

Authorizations

Date: 9/5/85 Time: 8:00 A.M.
Location: C-005 Under C-135-139
Responsible Supv:
Phone Number: 3119
Work Group: E&I

Operating Supv:
OHP Supv:
Maint. Supv:
T & T Supv:
E & I Supv:

Describe operation, safety precaution, and radiation and contamination controls
Remove light fixtures in effected area C-005 under C-135-139 so Const. Carpenters can erect scaffolding to drill a 3" hole through the floor to install a new Hilo Drain.
Contact OHP before starting work.

JOB PLAN

Authorizations

Date: 9-20-85 Time:
Location: C-005
Responsible Supv:
Phone Number:
Work Group:

Operating S
OHP Supv: 9-20-85
Maint. Supv:
T & T Supv:
E & I Supv:

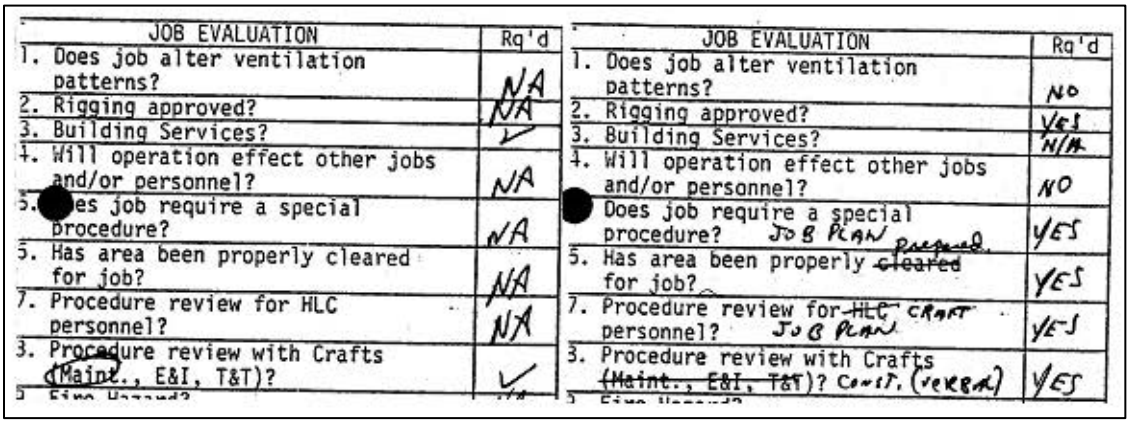
Describe operation, safety precaution, and radiation and contamination controls
Repair handle on C/135-139 Blow Box
Equipment duct damper in C-005

Figure 3-5. Job Plans.

SRS HP treated construction and DuPont Roll 2 crafts the same by procedure for job evaluation as shown in Figure 3-6. 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.



JOB EVALUATION	Rq'd
1. Does job alter ventilation patterns?	NA
2. Rigging approved?	NA
3. Building Services?	✓
4. Will operation effect other jobs and/or personnel?	NA
5. Does job require a special procedure?	NA
6. Has area been properly cleared for job?	NA
7. Procedure review for HLC personnel?	NA
8. Procedure review with Crafts (Maint., E&I, T&T)?	✓

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. (REVIEW)	YES

Figure 3-6. Procedure review with crafts, DuPont, and construction.

For SRS, the Center to Protect Workers' Rights compiled the list in Table 3-1 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 3-1 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 and craft code [DuPont 1954] are included.

3.2.2 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

Table 3-1. 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
Sheetmetal Worker	Roll 2, 4, craft code 21

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 3-2. If no Roll code is available, the person is assumed to be Roll 2 and the designation is made based on the occupation title.

Table 3-2. 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
Sheetmetal 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

There are two applications of this methodology:

1. Self-contained dataset. 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 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,
     - NOCTS WBC data, and
     - ORAUT-RPRT-0058 [ORAUT 2012b] 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 2012b]. 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 2012a] have no future use.

3.2.3 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 2012b] 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 3-3. The details of the results of the evaluation are contained in Attachment A.

Table 3-3. Master Occupation Table data source QA check results.

Data source	1% check results (95% confidence interval)	5% check results (95% confidence interval)
Americium logbook data	0.42% (0.26%–0.66%)	0.92% (0.40%–1.80%)
Neptunium logbook data	0.67% (0.45%–0.96%)	0.86% (0.38%–1.67%)
NOCTS WBC data	0.62% (0.41%–0.89%)	2.17% (1.31%–3.37%)
ORAUT-RPRT-0058 MFP gamma in vitro data	0.43% (0.27%–0.67%)	0.12% (0.0042%–0.65%)

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 3-4. The details of the results of the evaluation are contained in Attachment A.

Table 3-4. CTW determination QA check results.

Data source	Check results (95% confidence interval)
NOCTS in vivo data	2.95% (1.93%–4.30%)
NOCTS in vitro data	1.83% (1.05%–2.95%)
NOCTS tritium data	0.69% (0.25%–1.49%)
Neptunium logbook data	1.13% (0.55%–2.10%)
Americium logbook data	0.95% (0.42%–1.84%)

3.3 EVALUATION OF MISSED DOSE

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-0053 [ORAUT 2014a] 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.

4.0 RADIONUCLIDE ANALYSES

4.1 AMERICIUM

4.1.1 Data Adequacy

4.1.1.1 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 1968b]. 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 C. 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 C.

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.

4.1.1.2 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 4-1. (Additional discussion of other results in Table 4-1 is provided in Section 4.1.2.1.) The sampling frequency decreased during this same period as detailed in Tables C-2 through C-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.

DuPont workers, which included Roll 2 CTWs, were part of the routine monitoring program in the bioassay control procedures detailed in Section 4.1.1.1. 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

Table 4-1. 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	75	104
1965	173	201	116
1966	295	283	96
1967	253	298	118
1968	480	770	160
1969	1,194	918	77
1970	2,730	2,623	96
1971	2,016	2,121	105
1972	1,820	1,858	102
1973	1,332	1,342	101
1974	1,274	1,356	106
1975	891	881	99
1976	761	795	104
1977	593	570	96
1978	446	483	108
1979	664	589	89
1980	387	270	70
1981	344	356	103
1982	466	343	74
1983	413	376	91
1984	334	413	124
1985	244	435	178
1986	540	532	99
1987	420	386	92

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, then it was assumed that there was no intake for all the workers in the workgroup. If an intake (positive bioassay result) was confirmed, then 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.

4.1.1.3 Bioassay Analysis Techniques

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. 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.

4.1.1.4 Paired Measurements Sample Variance

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 results significantly greater than the MDA (i.e., greater than 1 dpm/d) 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 D. The conclusion of the evaluation is that the occurrence of samples with significant intra-count variation is limited and that inclusion of these samples has an insignificant effect on the overall results.

Data from HPRED does not contain the level of detail necessary to evaluate paired measurements or even to determine if there are paired measurements.

4.1.2 Data Validation

4.1.2.1 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, 1968a, 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 4-1. 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.

4.1.2.2 Data Quality

The 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 0.42% with a 95% confidence interval of 0.26% to 0.66%. All fields were evaluated with a maximum 5% allowable error rate. The QA check resulted in a point estimate error rate of 0.92% with a 95% confidence interval of 0.40% to 1.80%. Therefore, the dataset passed the QA check. The details of the results of the evaluation are contained in Attachment A.

4.1.2.3 Data Interpretation

A single americium urine sample was commonly counted multiple times, usually twice, but as many as 10 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/1.5 L (this information was used). Further, a reported value for each sample, also in units of dpm/1.5 L, was usually provided. The result in dpm/1.5 L 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/1.5 L data that were less than zero were reported as zero.

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.

4.1.2.4 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 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 C-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. All results for [redacted] individuals were excluded for an entire year 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 E.

4.1.3 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 2019]. The data were analyzed on an annual basis except for 1963 to 1964 and 1988 to 1989 for the nonCTW data and for 1965 to 1967, 1983 to 1984, 1985 to 1986, and 1987 to 1989 for the CTW data. These years were merged due to the small amount of data available for them. Table 4-2 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-1 and 4-2. The box and whisker plots are overlaid with the cumulative excretion results predicted by the intake modeling as discussed further below.

4.1.4 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 F; 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 4-2.

The solid lines in Figures F-1 to F-18 in Attachment F show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials for nonCTWs and CTWs. Figures F-19 to F-22 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes for nonCTWs and CTWs. Tables F-1 and F-2 list the 50th- and 84th-percentile intake rates with the associated GSDs from the americium urinalysis for nonCTWs and CTWs, respectively.

Table 4-2. Calculated 50th- and 84th-percentile urinary excretion rates of americium based on a lognormal fit to the TWOPOS data, 1963 to 1989 (dpm/d).

Year[a]	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1963	0.295	0.901	3.05	41	N/A	N/A	N/A	N/A
1964								
1965	0.273	0.998	3.66	123	0.401	1.444	3.60	52
1966	0.457	1.365	2.99	144				
1967	0.389	1.159	2.98	182				
1968	0.215	0.620	2.89	280	0.230	0.665	2.89	88
1969	0.164	0.461	2.80	277	0.176	0.526	3.00	93
1970	0.127	0.290	2.28	448	0.117	0.255	2.19	120
1971	0.132	0.236	1.79	530	0.132	0.243	1.84	100
1972	0.074	0.178	2.40	538	0.071	0.152	2.16	108
1973	0.013	0.066	5.22	518	0.015	0.072	4.68	107
1974	0.027	0.097	3.65	367	0.027	0.093	3.47	85
1975	0.012	0.081	6.87	361	0.014	0.091	6.64	96
1976	0.026	0.083	3.24	352	0.027	0.083	3.10	90
1977	0.025	0.096	3.82	316	0.028	0.090	3.21	69
1978	0.064	0.189	2.97	164	0.059	0.168	2.86	52
1979	0.038	0.132	3.50	253	0.034	0.106	3.12	60
1980	0.042	0.106	2.50	184	0.038	0.094	2.44	40
1981	0.017	0.075	4.30	242	0.025	0.150	5.93	40
1982	0.021	0.147	7.06	315	0.027	0.193	7.23	45
1983	0.109	0.189	1.74	266	0.108	0.234	2.16	64
1984	0.028	0.105	3.71	259				
1985	0.039	0.086	2.22	237	0.054	0.138	2.58	35
1986	0.046	0.138	2.98	244				
1987	0.123	0.168	1.37	283	0.134	0.210	1.57	26
1988	0.136	0.232	1.70	279				
1989								

a. Where multiple years are noted for a single line of excretion rates, the data for these years were combined for the statistical analysis.

Figures 4-1 and 4-2 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 GMs of the excretion rates are favorable to claimants in comparison with the GMs of the TWOPOS data.

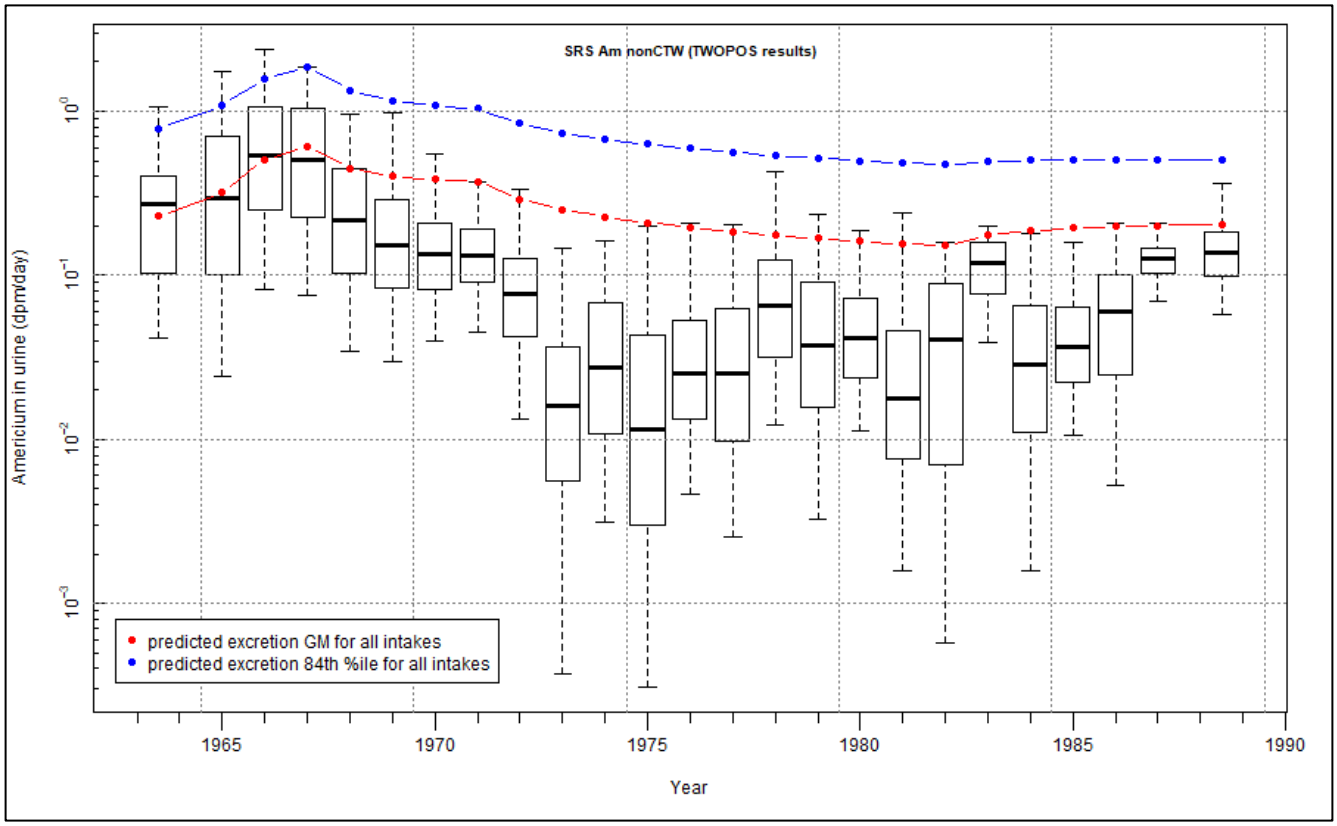


Figure 4-1. Americium nonCTW TWOPOS data box and whisker plot.

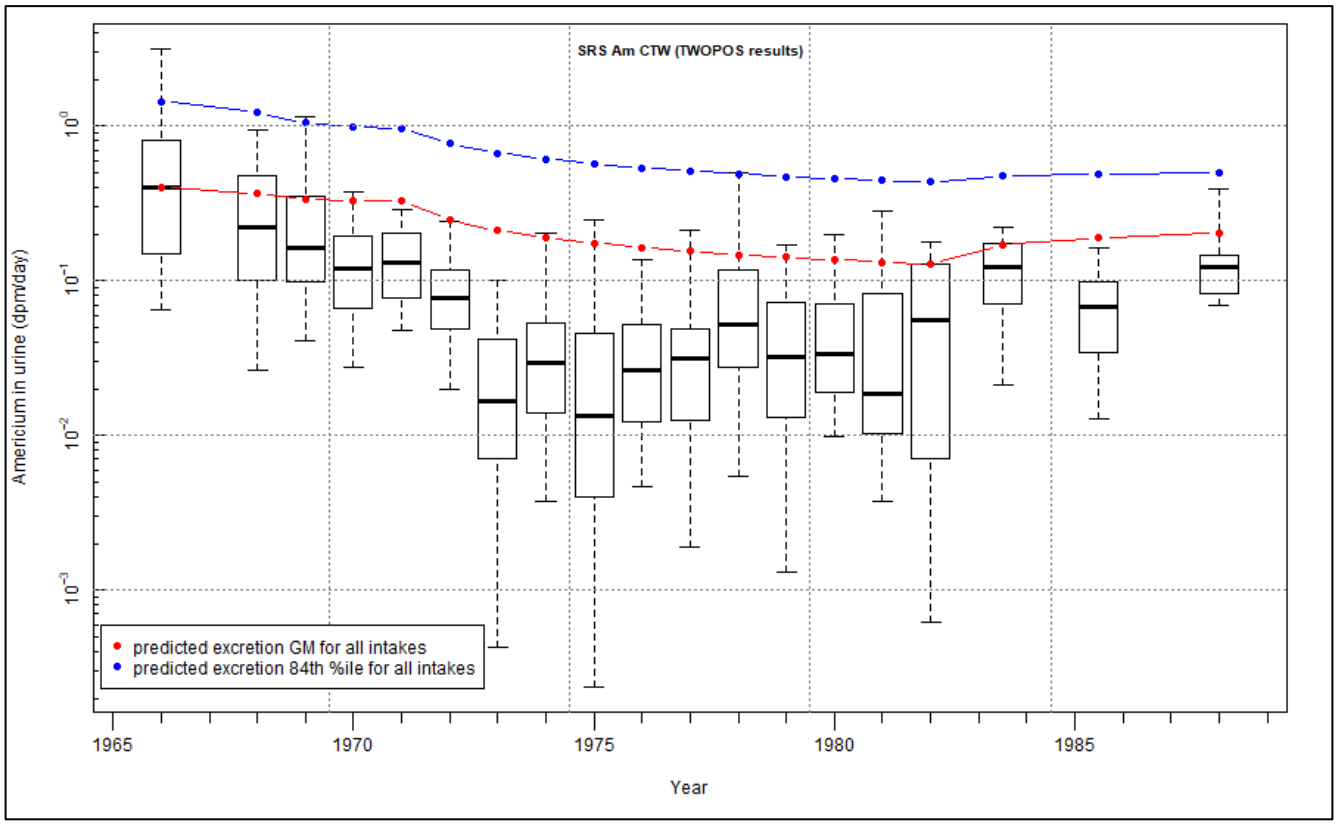


Figure 4-2. Americium CTW TWOPOS data box and whisker plot.

4.2 TRITIUM

4.2.1 Data Adequacy

4.2.1.1 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 1968], 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; DuPont 1959–1971, p. 355; DuPont 1976, no date a].

Bioassay control remained unchanged from 1978 through 1985 [DuPont 1985, 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 100,000 bioassay results from individuals who submitted more than one sample for tritium analysis on more than one occasion. One third of these samples were collected either daily or weekly, and two-thirds were collected within 7 days. This is illustrated in Figure 4-3.

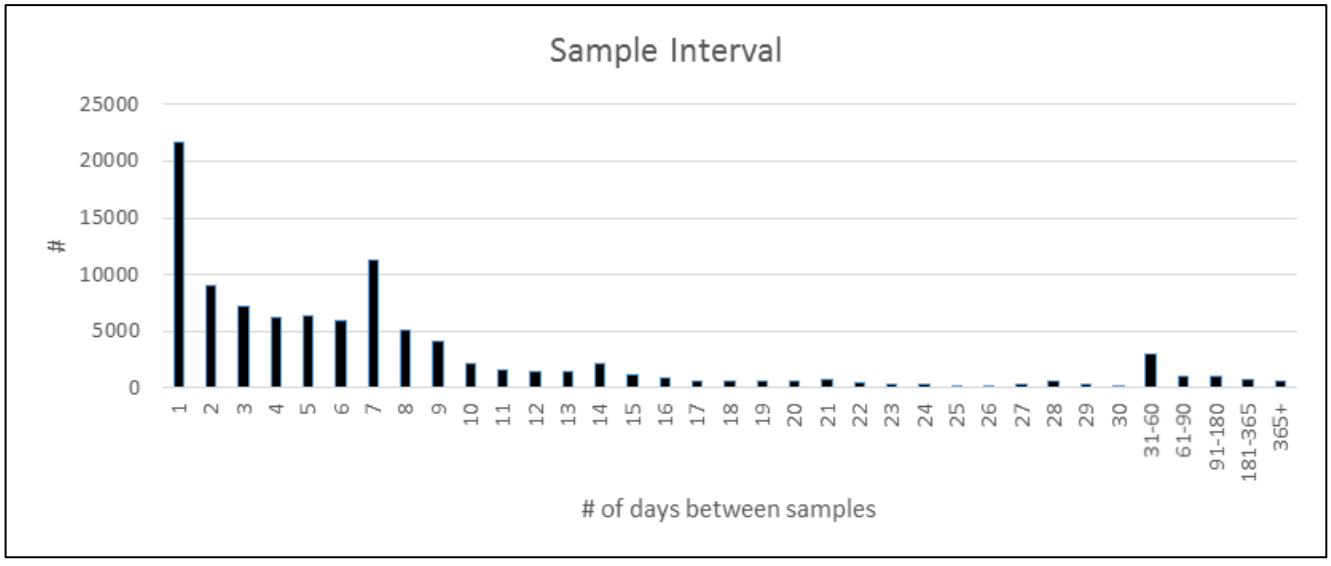


Figure 4-3. Tritium bioassay sample frequency.

4.2.1.2 Applicability to Unmonitored Workers

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.

4.2.1.3 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.)

4.2.2 Data Validation

Tritium data are from NOCTS bioassay data as discussed in Section 3.0. 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.

4.2.3 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]. Doses for 1991 to 1995 were calculated

from the HPRED dataset, which is considered a complete dataset. Table 4-3 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 4-4 and 4-5 for nonCTWs and CTWs, respectively. Figure 4-6 further separates the CTWs into those that worked for the prime contractor and those that did not. As can be seen, the subcontractor CTWs generally had lower doses than the prime contractor CTWs although there is substantial overlap in the distributions, justifying the consideration of all CTWs collectively as one population.

Table 4-3. Tritium annual doses (rem) and GSDs.

Year	nonCTW # of individuals	nonCTW 50th percentile	nonCTW GSD	CTW # of individuals	CTW 50th percentile	CTW GSD
1954	89	0.012	1.83	33	0.012	1.89
1955	103	0.013	1.99	57	0.015	2.16
1956	83	0.019	2.67	53	0.016	2.52
1957	166	0.025	2.76	114	0.025	2.56
1958	243	0.035	2.45	157	0.031	2.36
1959	219	0.034	3.04	112	0.038	2.78
1960	231	0.046	3.12	151	0.042	3.07
1961	227	0.050	2.88	142	0.039	3.37
1962	247	0.051	2.84	186	0.041	2.81
1963	239	0.048	2.49	186	0.040	2.74
1964	218	0.060	3.02	158	0.054	2.84
1965	188	0.055	3.38	113	0.043	2.88
1966	182	0.046	2.89	97	0.031	3.13
1967	174	0.049	2.46	79	0.034	3.00
1968	162	0.051	2.77	91	0.030	2.97
1969	160	0.052	2.43	75	0.031	3.24
1970	156	0.042	2.63	68	0.023	3.50
1971	163	0.051	2.30	63	0.028	3.32
1972	214	0.047	2.83	80	0.033	3.33
1973	227	0.045	2.77	83	0.027	3.39
1974	205	0.048	2.65	74	0.031	3.34
1975	188	0.048	2.68	69	0.032	2.97
1976	176	0.047	2.68	69	0.030	3.27
1977	168	0.053	2.40	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	2.21	68	0.024	2.79
1981	166	0.031	2.40	98	0.016	2.74
1982	188	0.027	2.40	99	0.015	2.72
1983	189	0.022	2.41	104	0.016	2.38
1984	183	0.023	2.48	93	0.015	2.75
1985	150	0.025	2.18	63	0.016	2.43
1986	144	0.008	3.33	66	0.006	3.19
1987	132	0.008	3.11	57	0.007	3.13
1988	117	0.008	2.72	47	0.006	3.53
1989	138	0.006	2.81	70	0.004	3.07
1990	136	0.006	2.78	94	0.006	2.58

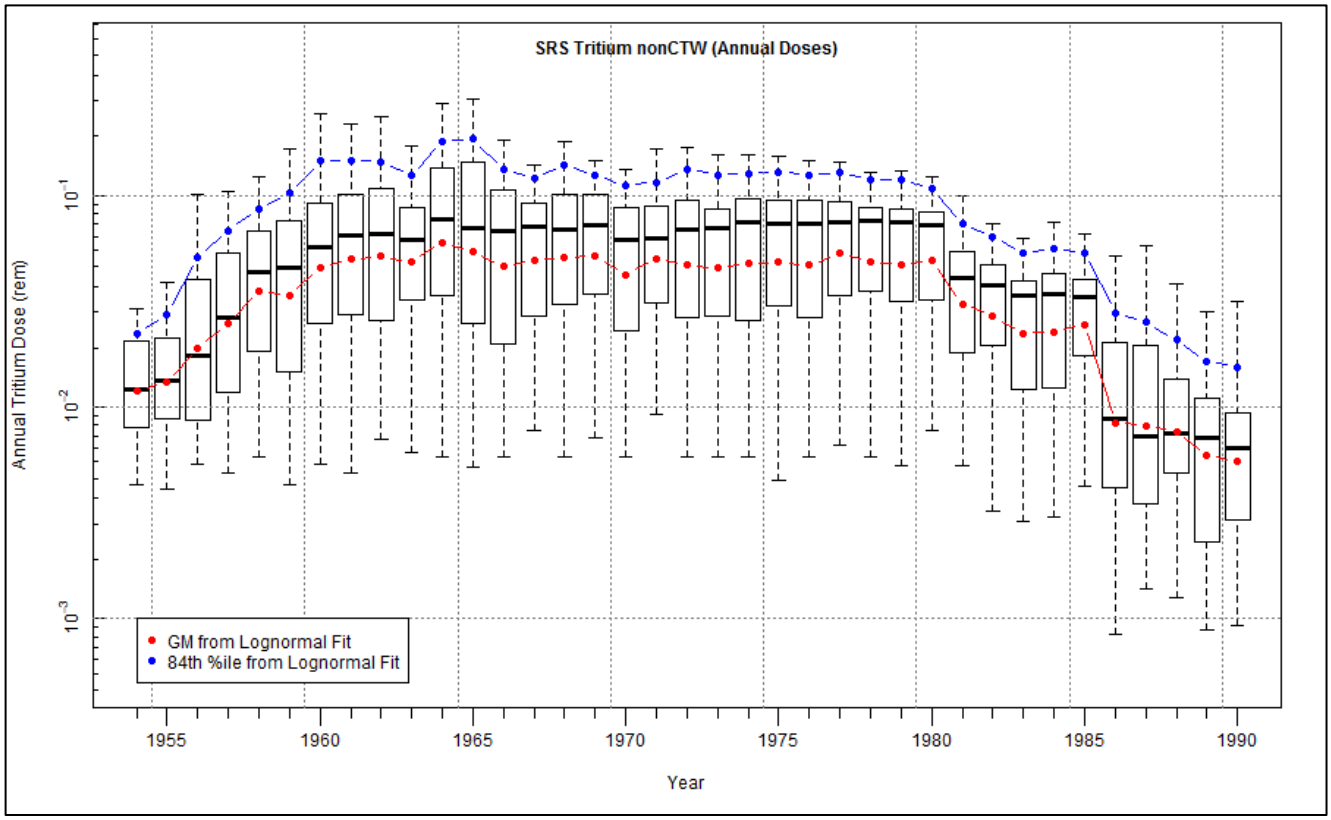


Figure 4-4. Tritium nonCTW individual dose data box and whisker plot.

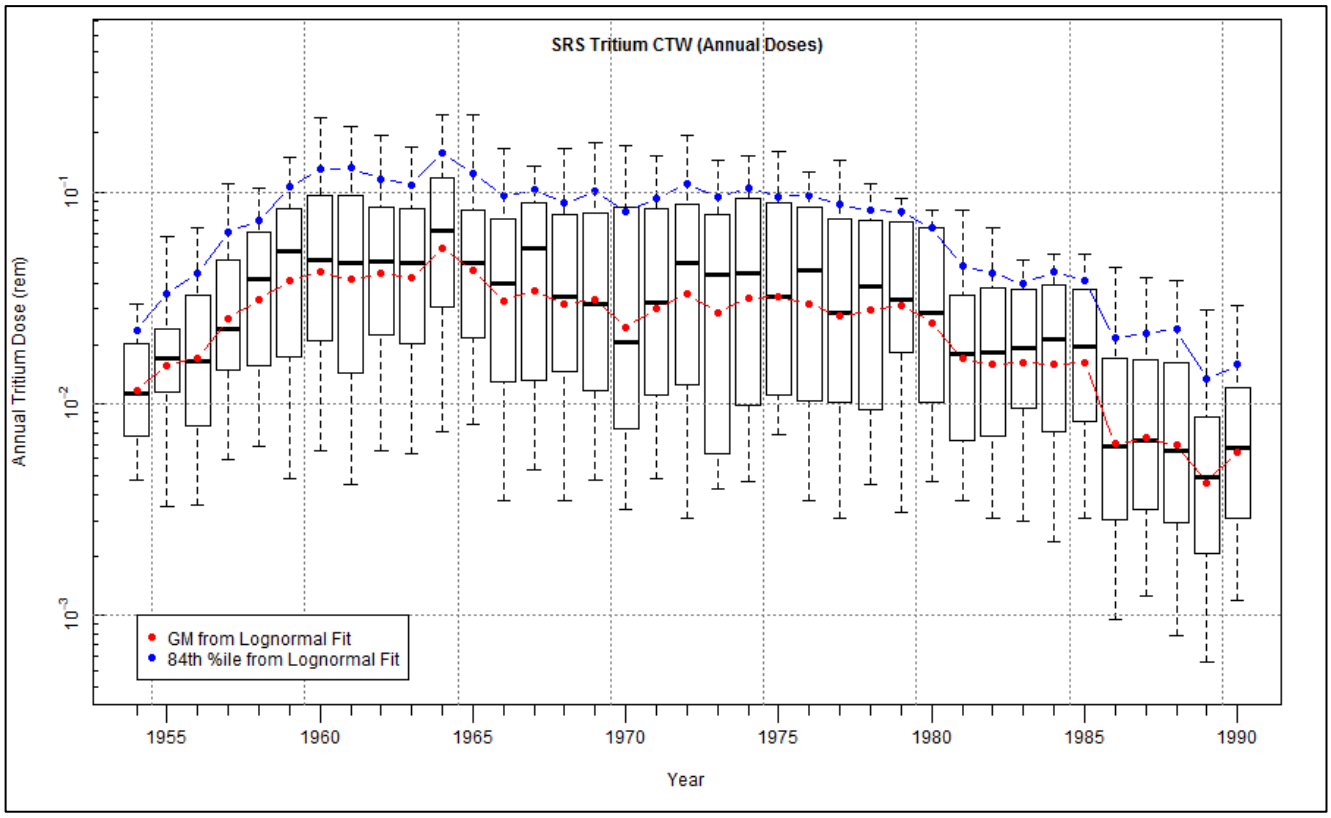


Figure 4-5. Tritium CTW individual dose data box and whisker plot.

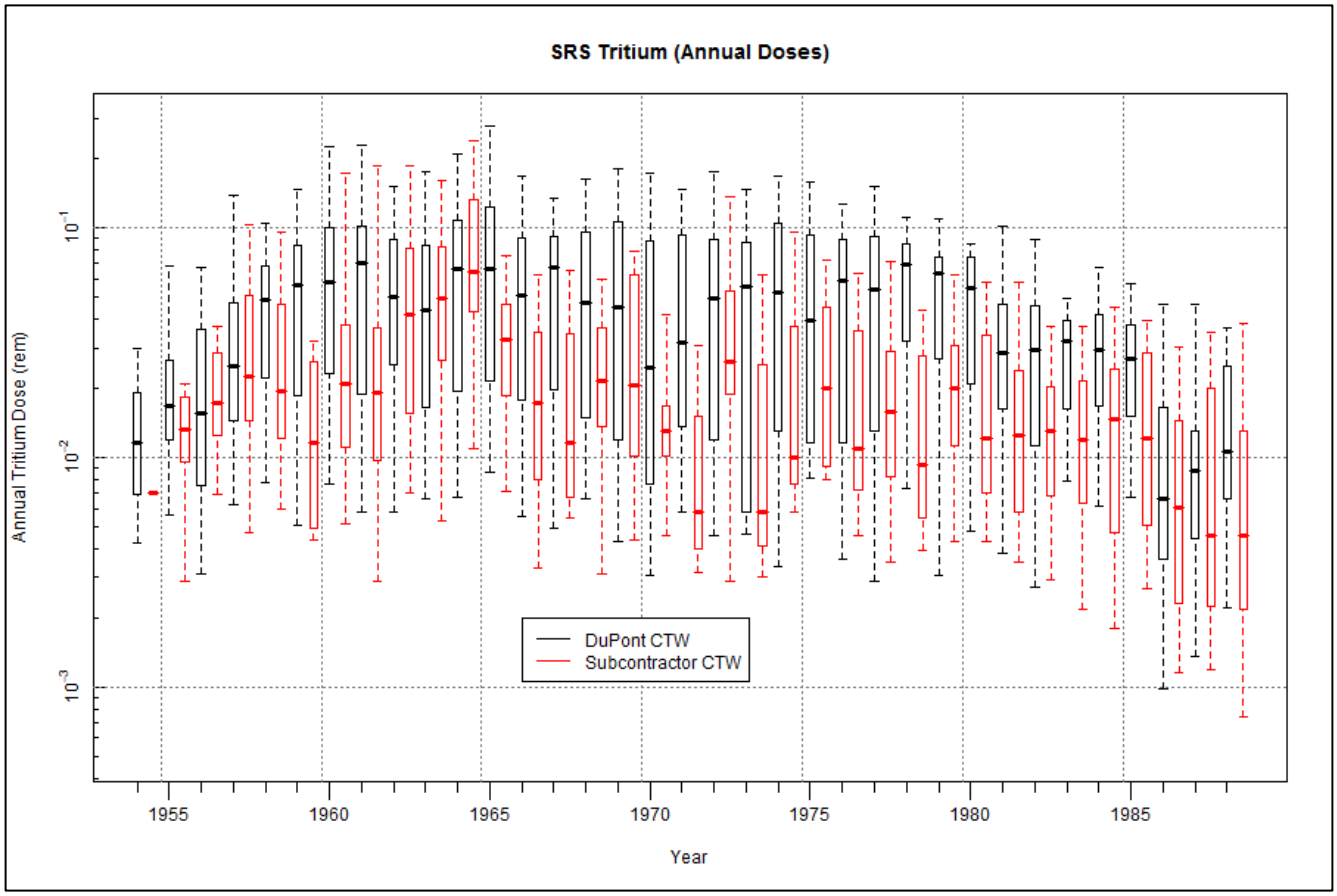


Figure 4-6. Tritium prime and subcontractor stratified CTW individual dose data box and whisker plot.

4.3 PLUTONIUM

4.3.1 Data Adequacy

4.3.1.1 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 1968b]. 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 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 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 C. 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 C.

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].

4.3.1.2 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.

4.3.1.3 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 and transuranic (TRU) 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].

4.3.2 Data Validation

4.3.2.1 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 3.1 above.

4.3.2.2 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.

4.3.2.3 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 C-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 worker 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 E.

4.3.3 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 2019]. The data were analyzed on an annual basis. Table 4-4 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-7 through 4-18. 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.

4.3.4 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).

Table 4-4. Calculated 50th- and 84th-percentile urinary excretion rates of plutonium based on a lognormal fit to the TWOPOS data, 1955 to 1990 (dpm/d).

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

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 1989 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 F; 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 4-4.

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

Figures 4-7 through 4-18 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 exceeds the actual TWOPOS results for years after 1960; the predicted excretion for 1955 to 1960 agrees well with the TWOPOS results.

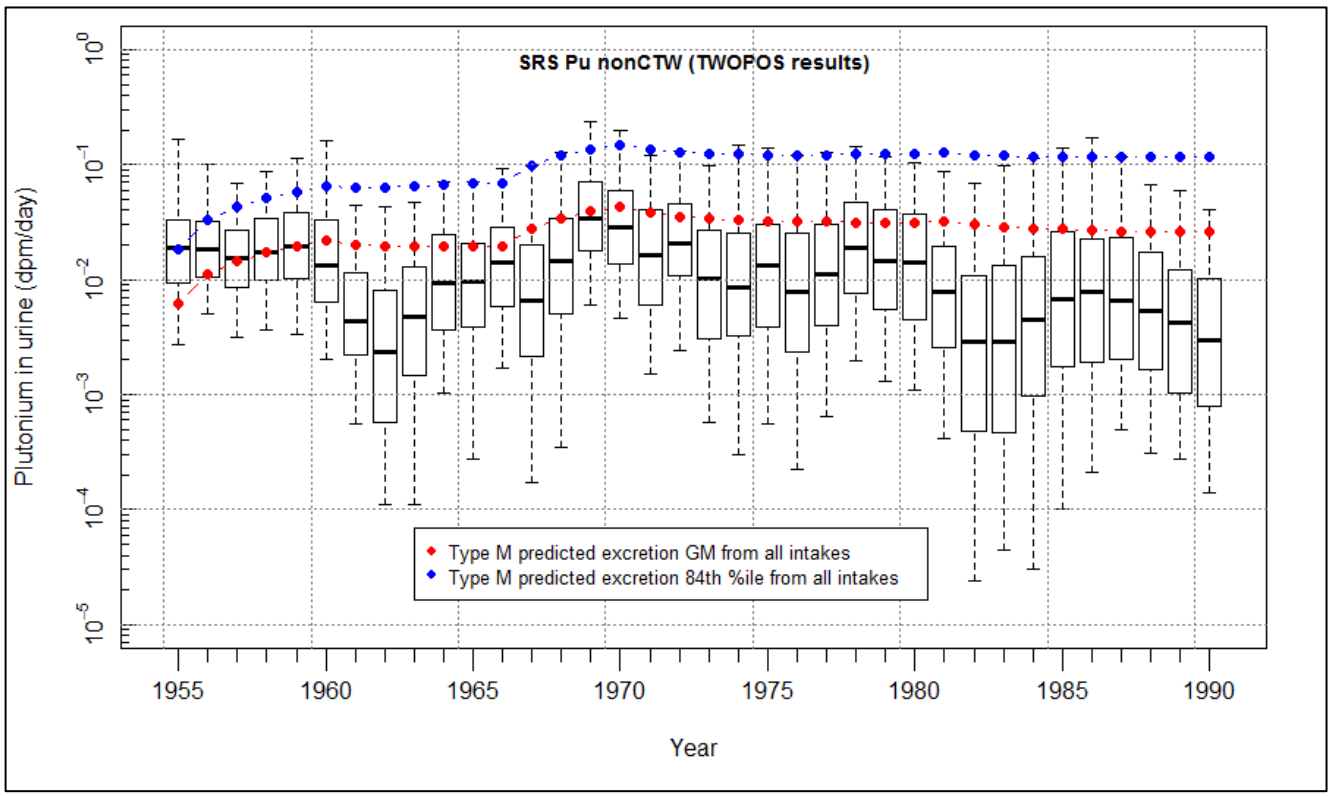


Figure 4-7. Plutonium type M nonCTW TWOPOS data box and whisker plot beginning in 1955.

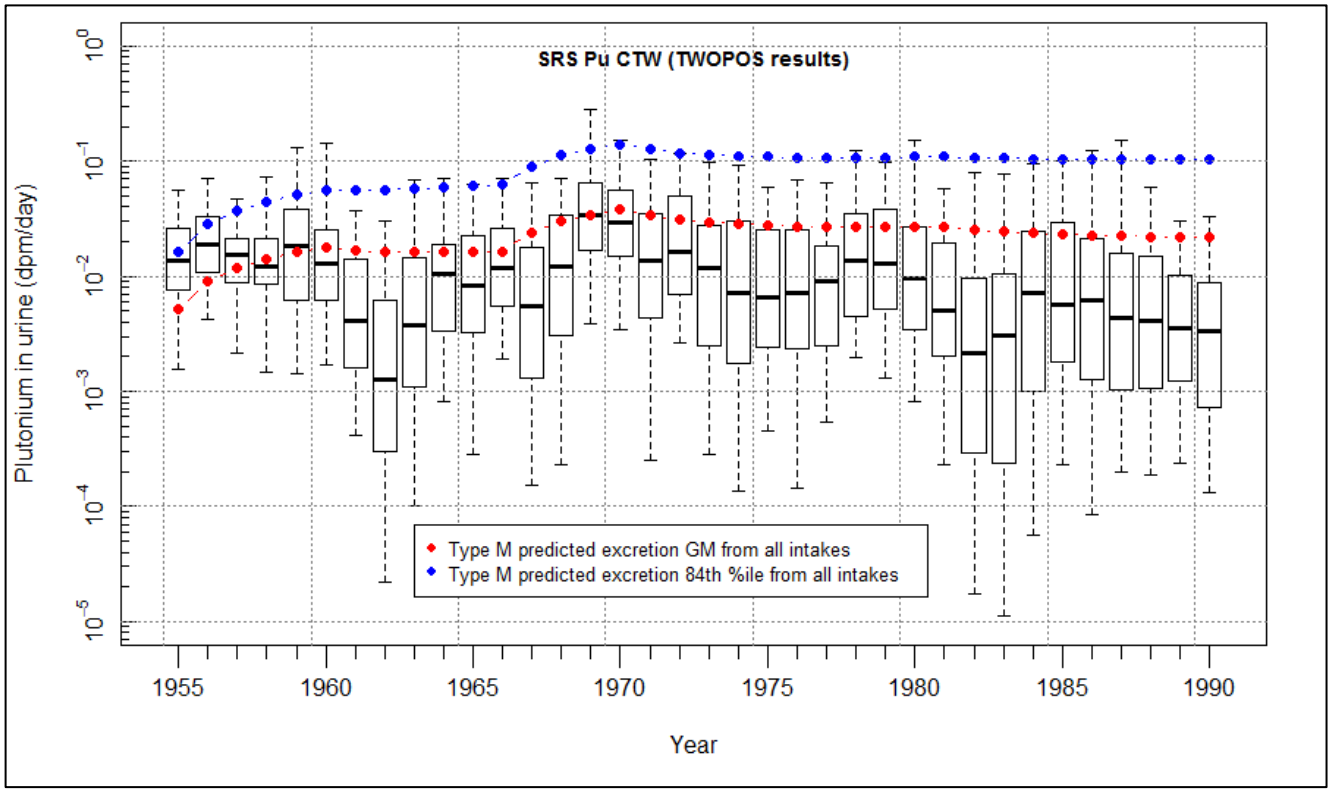


Figure 4-8. Plutonium type M CTW TWOPOS data box and whisker plot beginning in 1955.

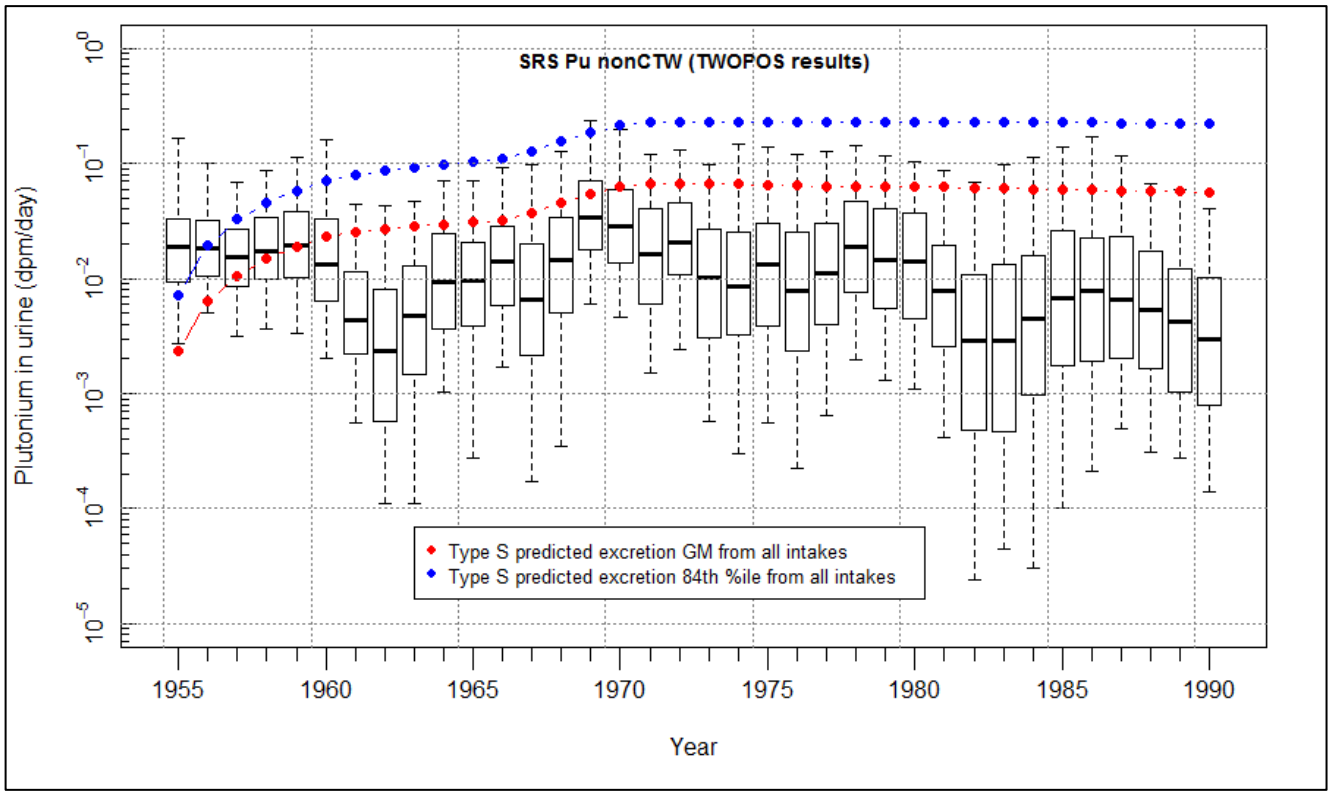


Figure 4-9. Plutonium type S nonCTW TWOPOS data box and whisker plot beginning in 1955.

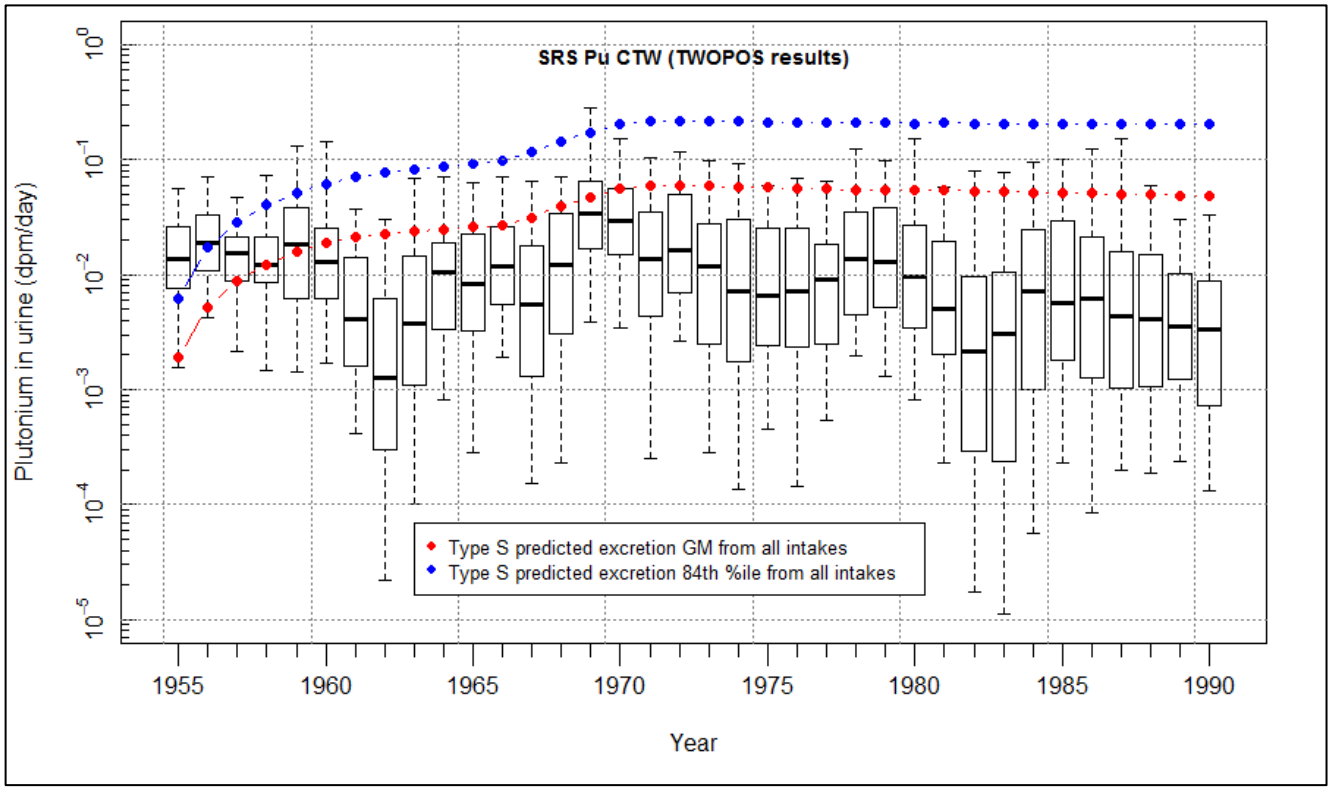


Figure 4-10. Plutonium type S CTW TWOPOS data box and whisker plot beginning in 1955.

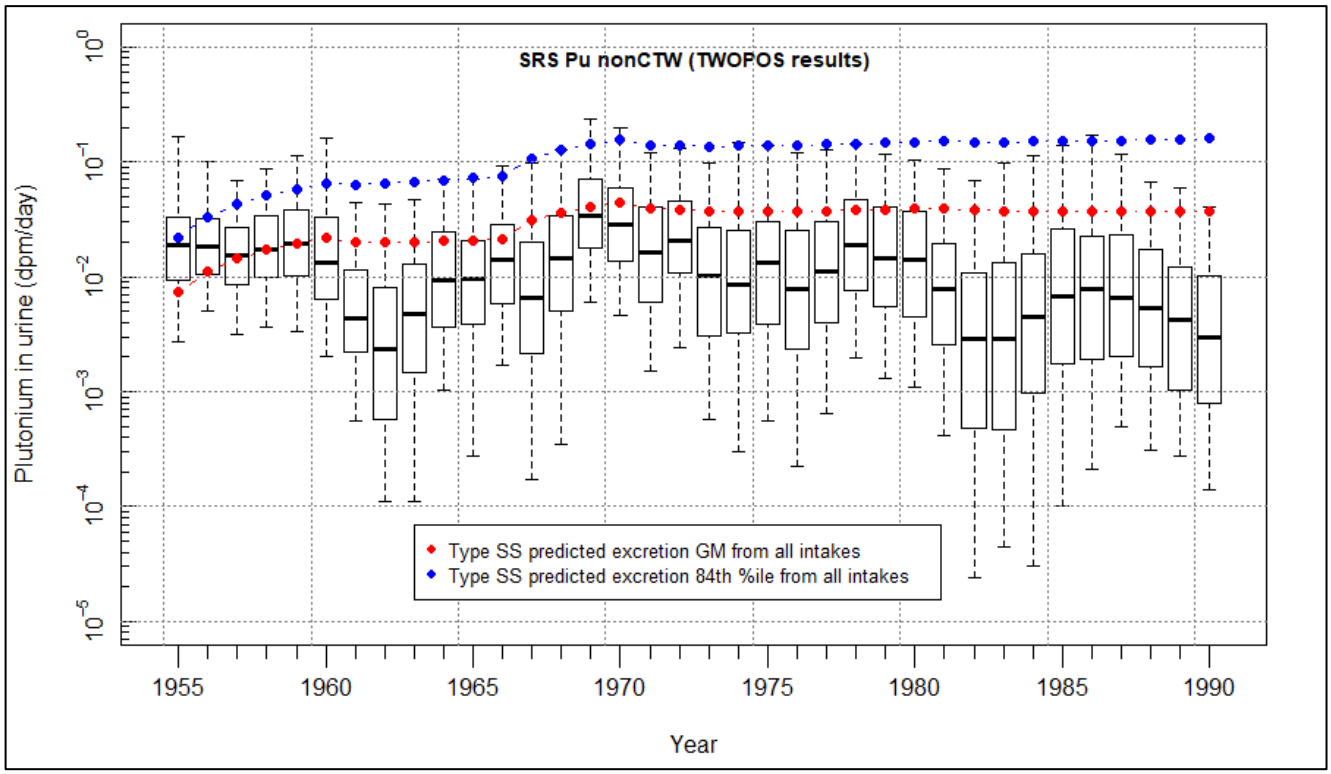


Figure 4-11. Plutonium type SS nonCTW TWOPOS data box and whisker plot beginning in 1955.

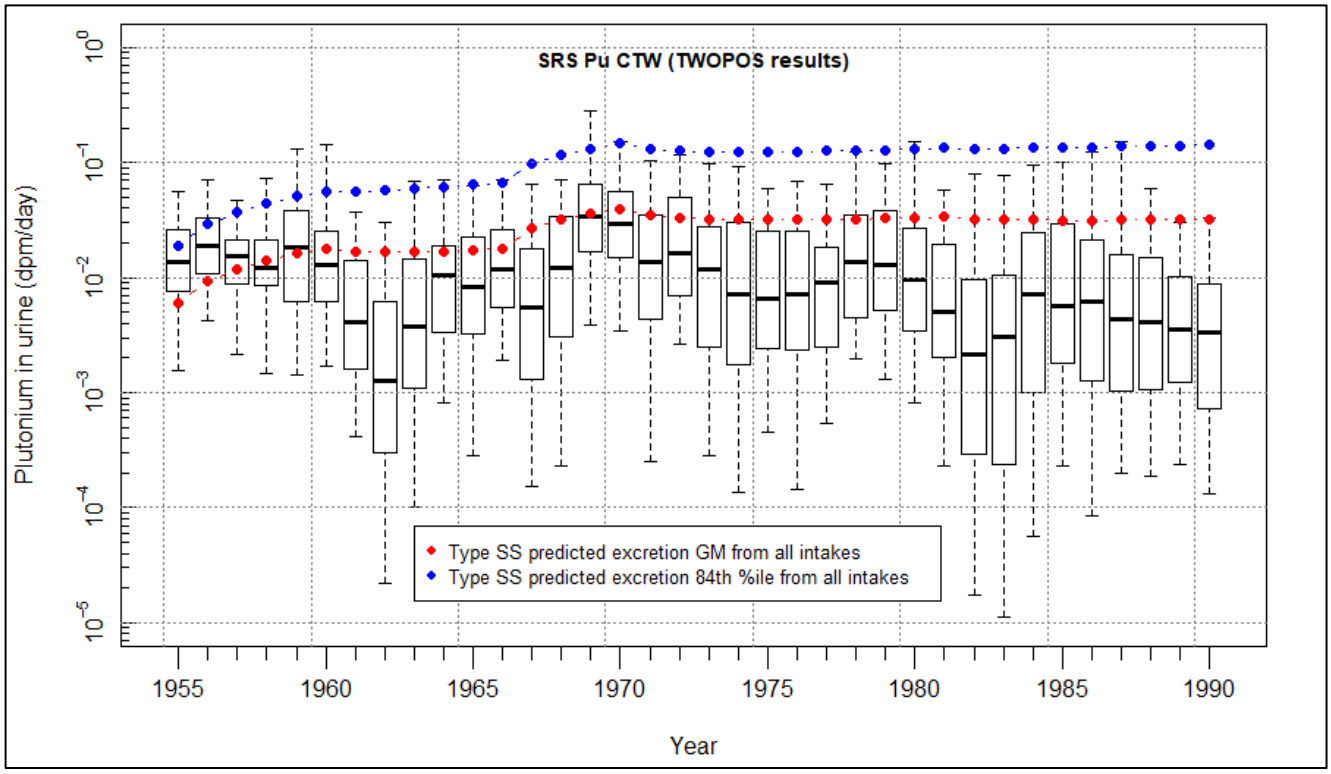


Figure 4-12. Plutonium type SS CTW TWOPOS data box and whisker plot beginning in 1955.

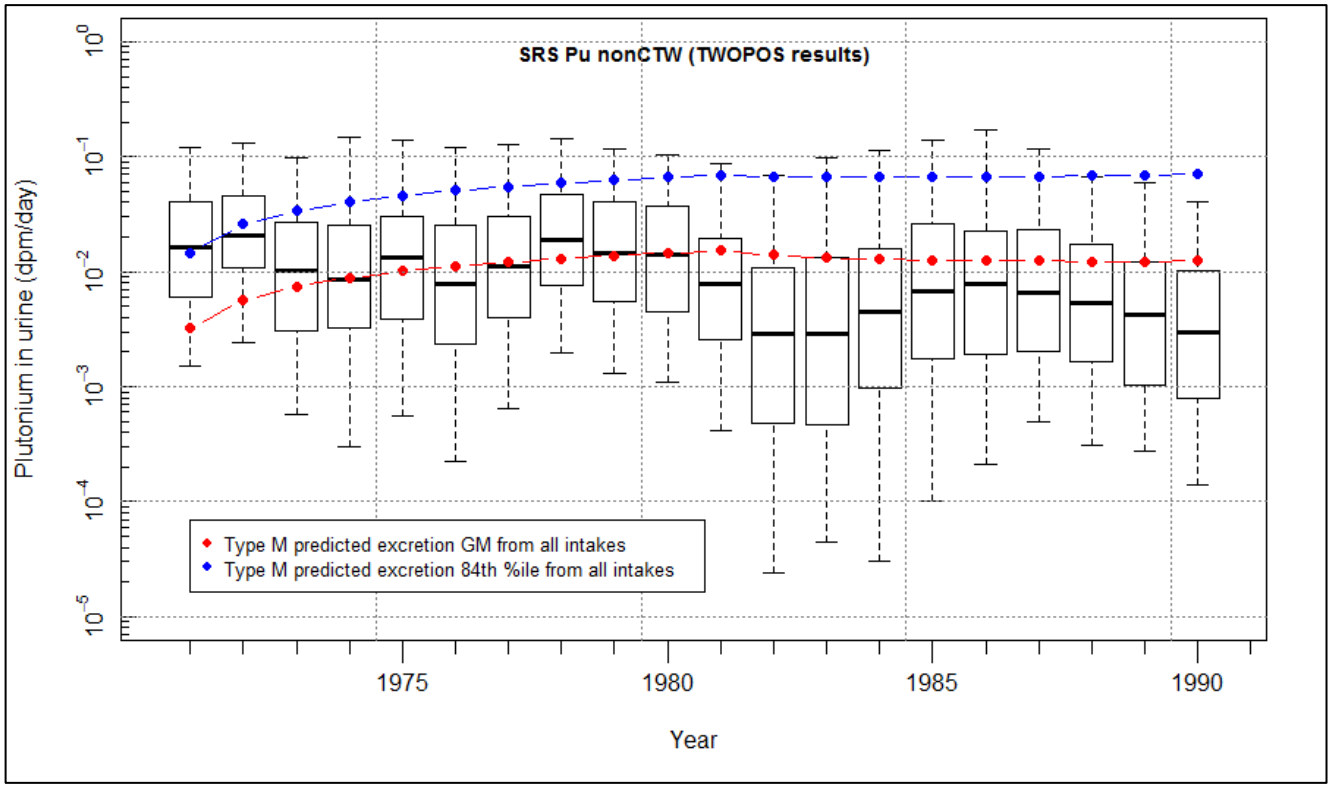


Figure 4-13. Plutonium type M nonCTW TWOPOS data box and whisker plot beginning in 1971.

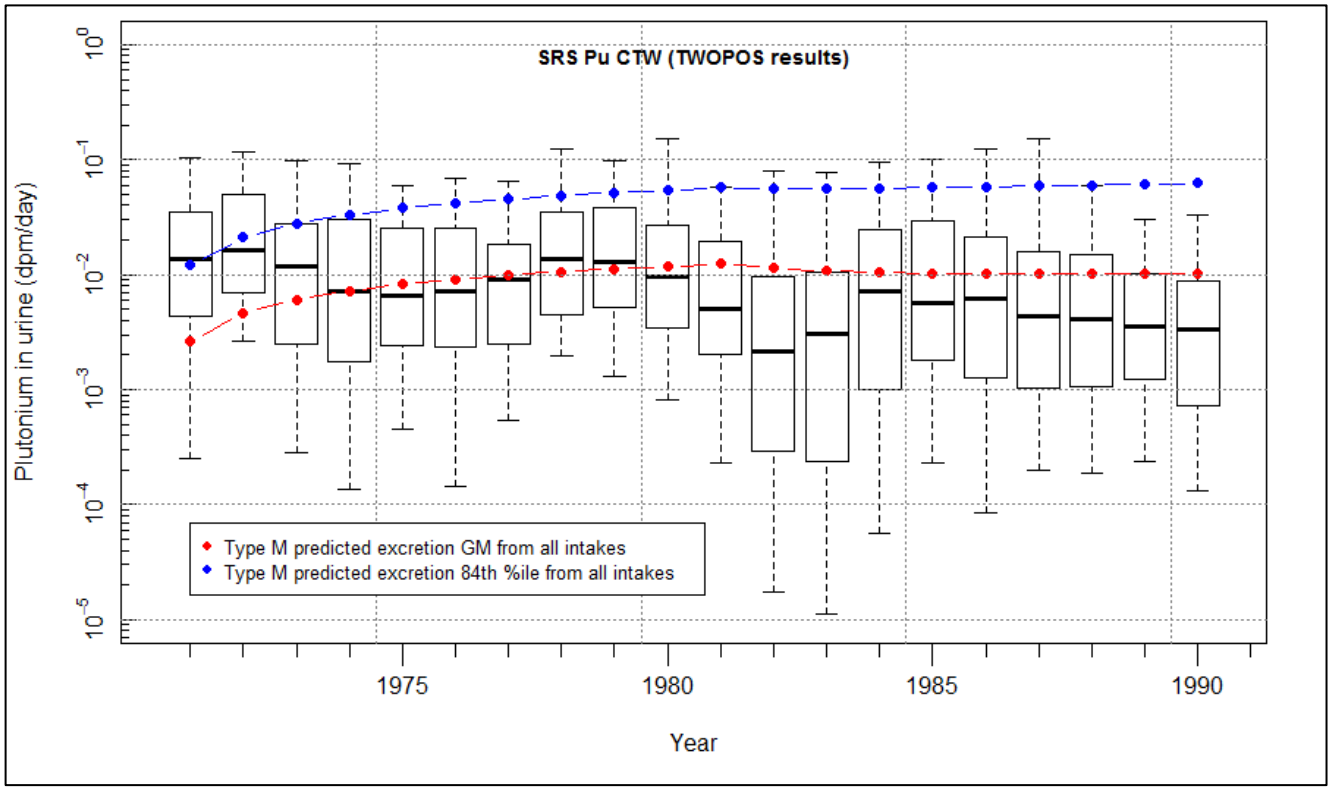


Figure 4-14. Plutonium type M CTW TWOPOS data box and whisker plot beginning in 1971.

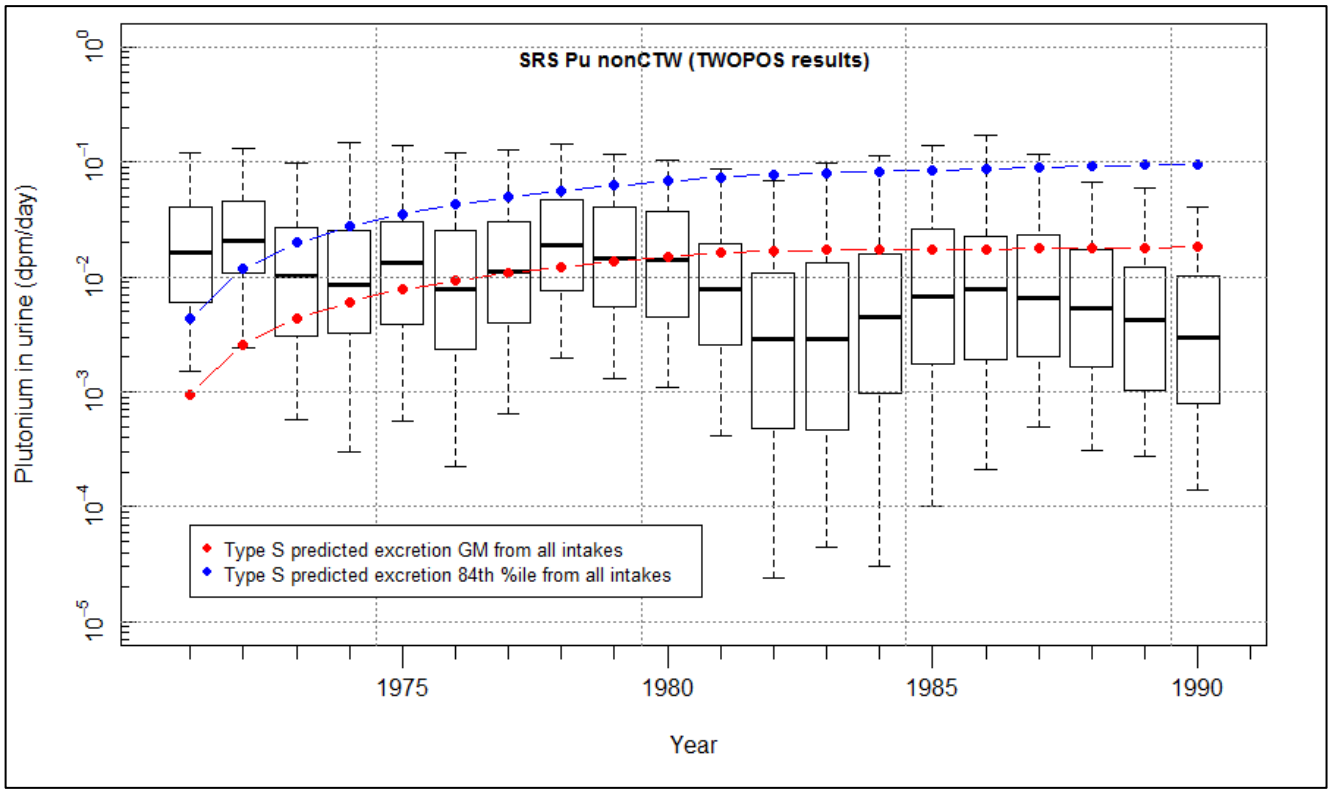


Figure 4-15. Plutonium type S nonCTW TWOPOS data box and whisker plot beginning in 1971.

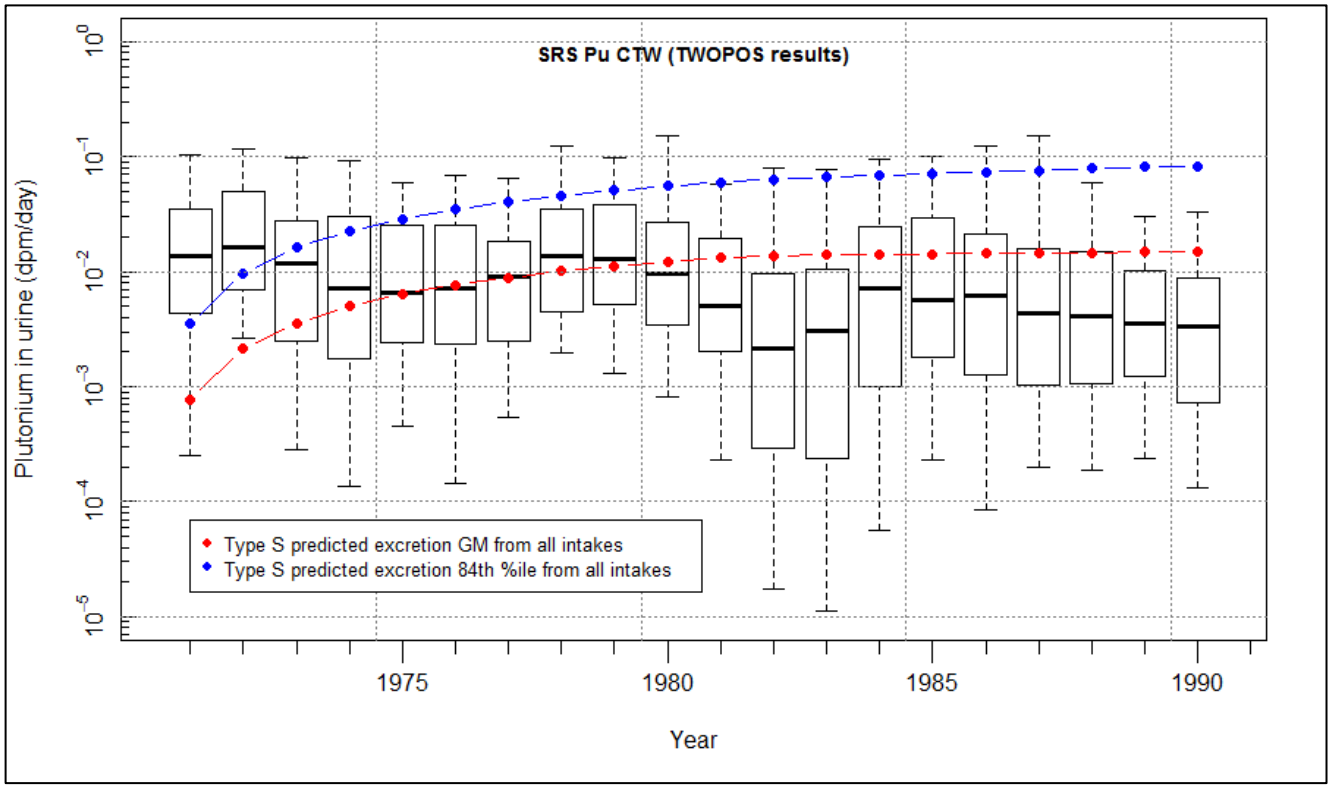


Figure 4-16. Plutonium type S CTW TWOPOS data box and whisker plot beginning in 1971.

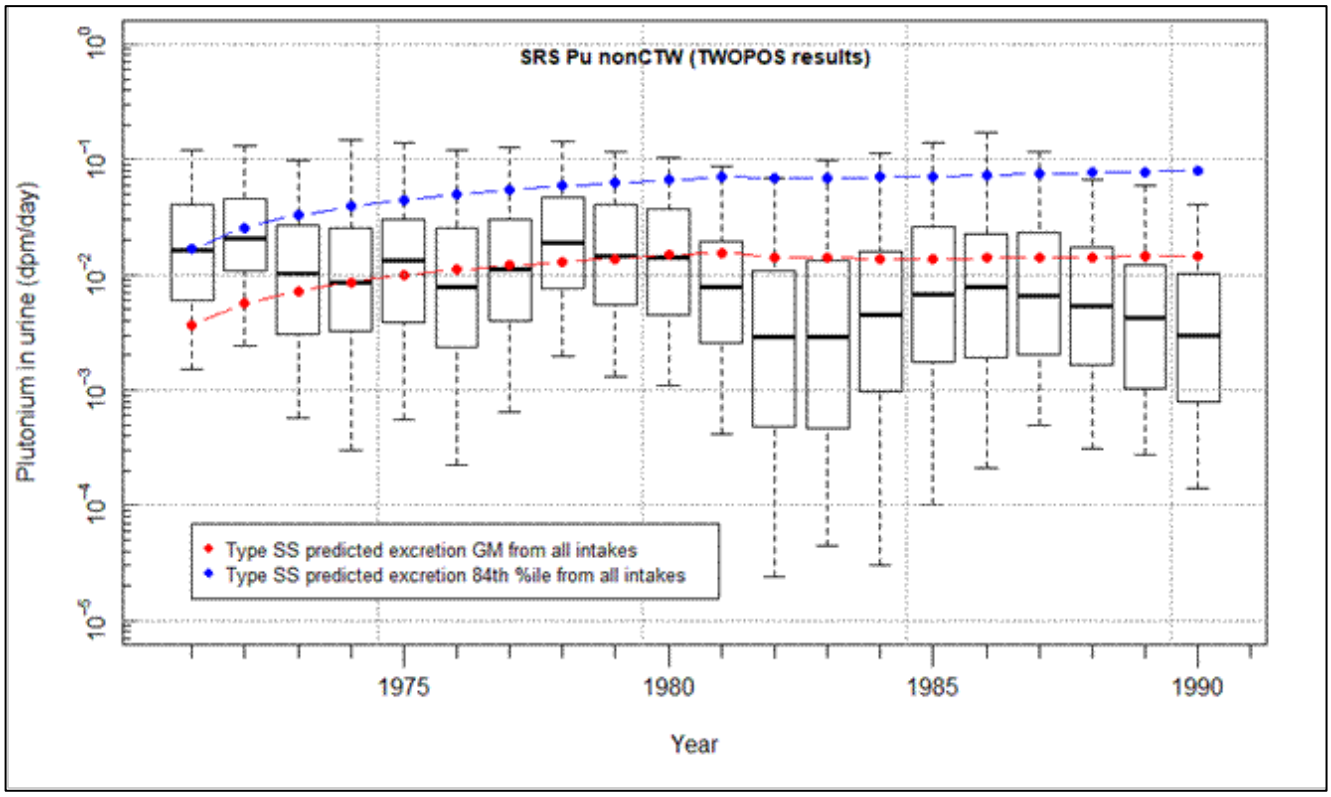


Figure 4-17. Plutonium type SS nonCTW TWOPOS data box and whisker plot beginning in 1971.

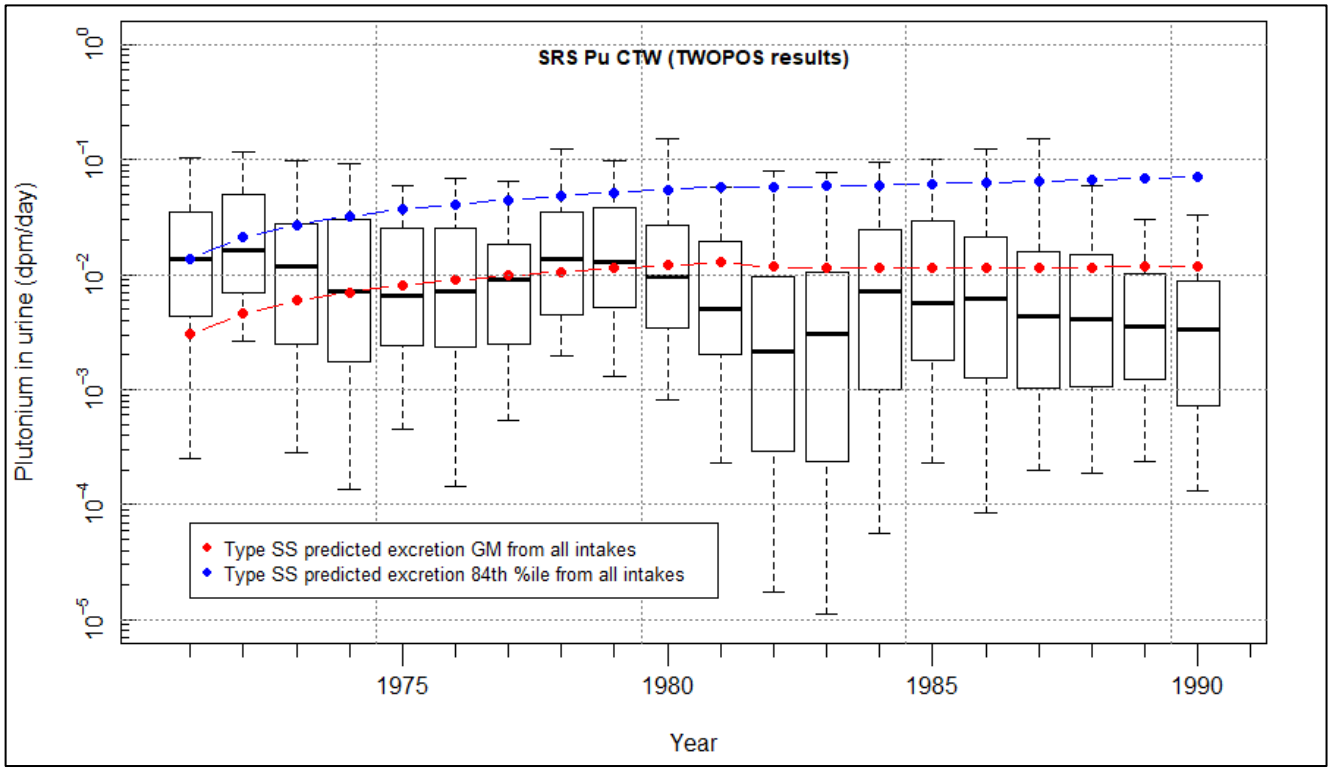


Figure 4-18. Plutonium type SS CTW TWOPOS data box and whisker plot beginning in 1971.

4.4 URANIUM

4.4.1 Data Adequacy

4.4.1.1 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 1968b]. 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 C. 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].

4.4.1.2 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.

4.4.1.3 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 4-5 [ORAUT 2005a].

Table 4-5. 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	EU	0.4 pCi/L (MDA)	Batch alpha counting
1994–present (EU) (DU)	DU RU HEU U-234 U-235 U-238	Use U-238[b] Use U-238[b] Use U-235[b] 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. Use the applicable isotopic ratios from the Hanford Internal Dosimetry Technical Basis Document in accordance with the SRS site profile [ORAUT 2005a].

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 2005a]. 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 emulsion. 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 enriched uranium analyses. This method had an MDA of about 1 dpm/1.5 L, which was considered adequate at the time.

Analyses for depleted uranium 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 enriched and depleted uranium 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 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 enriched uranium and the Jarrell-Ash method for depleted uranium. KPA for depleted uranium was used from 1986 through 1994 [WSRC 2001].

4.4.2 Data Validation

4.4.2.1 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 3.1.1 above.

4.4.2.2 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 natural uranium (NU; 1.52 dpm/µg) through 1967 and depleted uranium (DU; 0.826 dpm/µg) thereafter [WSRC 2000].

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

4.4.2.3 Data Exclusion

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

4.4.3 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 2019]. 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 data available in those years. Table 4-6 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-19 through 4-24. The box and whisker plots are overlaid with the excretion results predicted by the intake modeling as discussed further below.

Table 4-6. Calculated 50th- and 84th-percentile urinary excretion rates of uranium based on a lognormal fit to the TWOPOS data, 1953 to 1990 (dpm/d).

Year[a]	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	N/A	N/A	N/A	N/A
1954	3.9499	6.064	1.54	139	N/A	N/A	N/A	N/A
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.

4.4.4 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.

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 F; 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 4-6. The solid lines in Figures F-95 to F-102 in Attachment F 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 F-103 to F-126 in Attachment F show the individual fits to the 50th- and 84th-percentile excretion rates for type S materials for nonCTWs and CTWs. Figures F-127 to F-130 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type S intakes for nonCTWs and CTWs. Tables F-9 to F-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.

Figures 4-19 through 4-24 overlay the urinary excretion rates (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data.

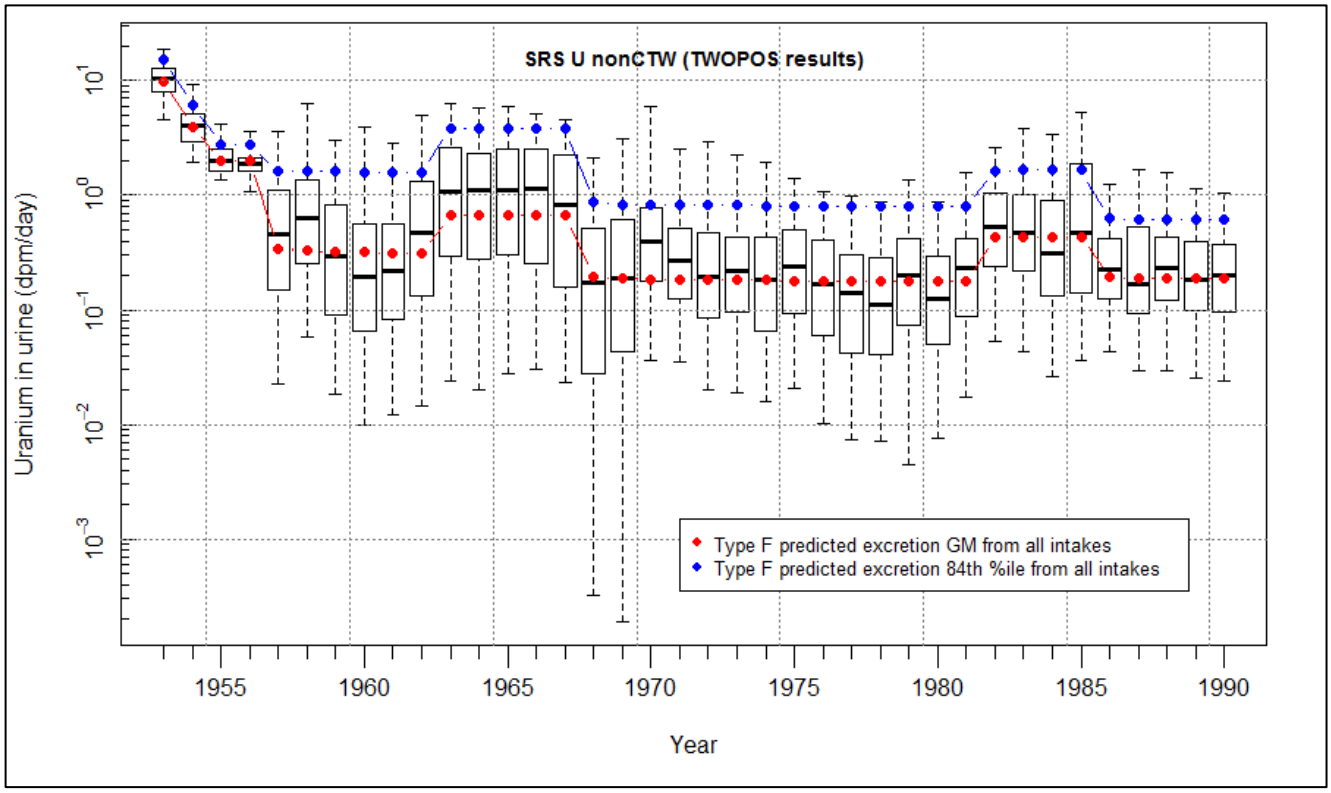


Figure 4-19. Uranium type F nonCTW TWOPOS data box and whisker plot.

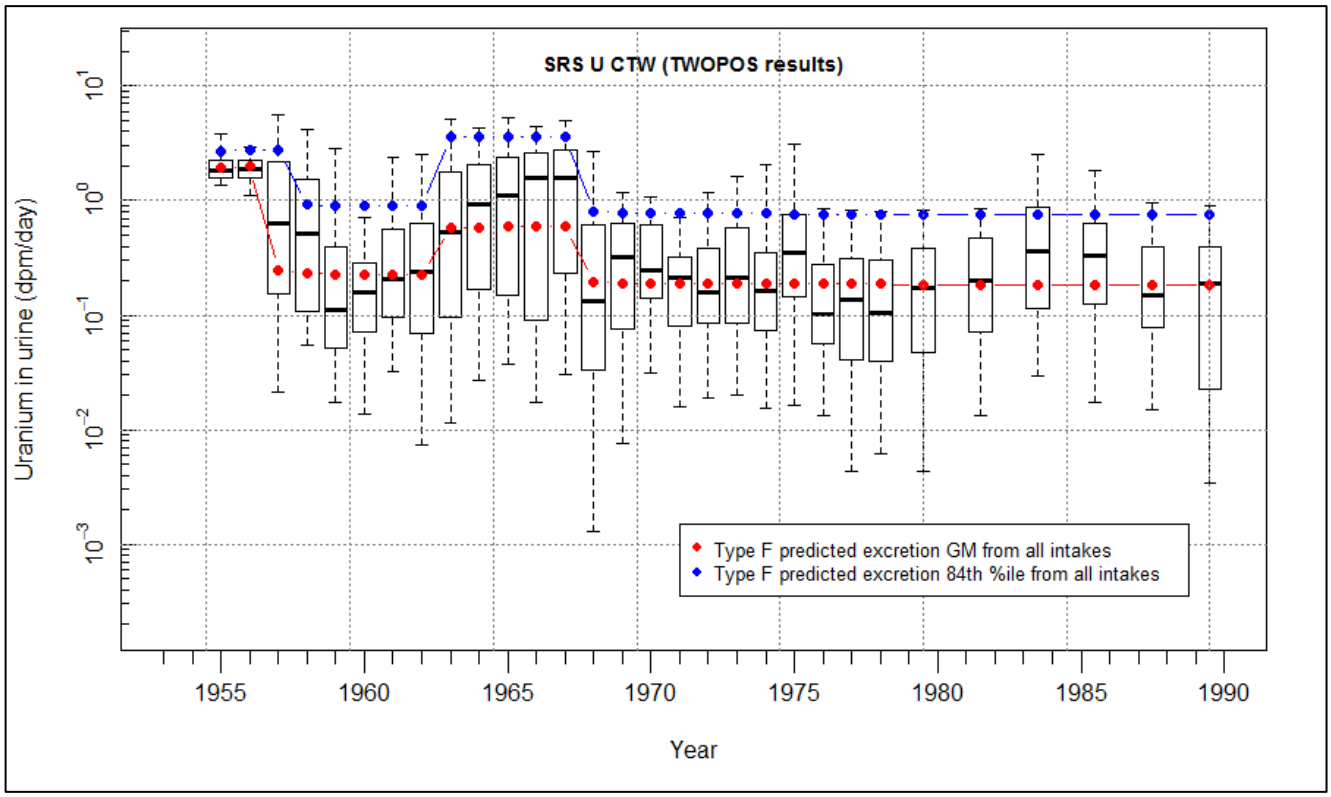


Figure 4-20. Uranium type F CTW TWOPOS data box and whisker plot.

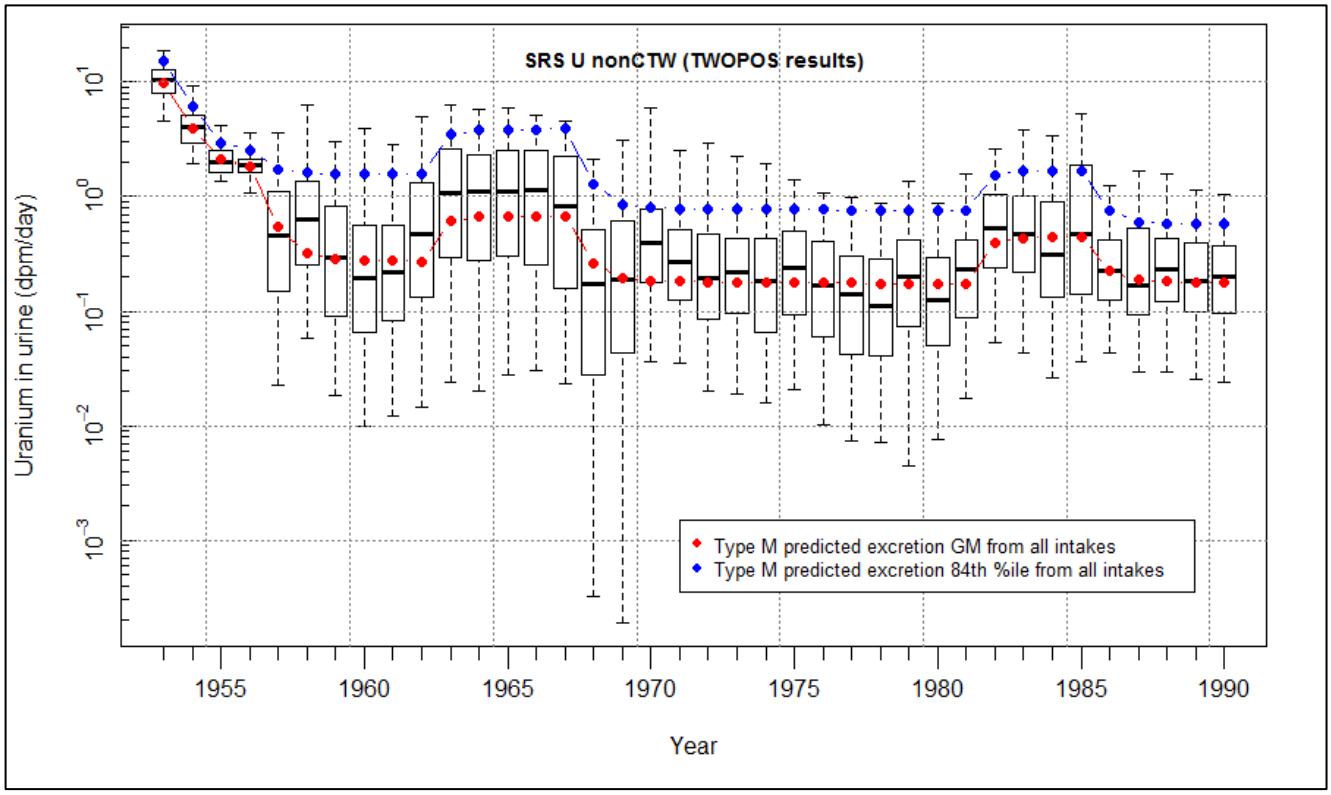


Figure 4-21. Uranium type M nonCTW TWOPOS data box and whisker plot.

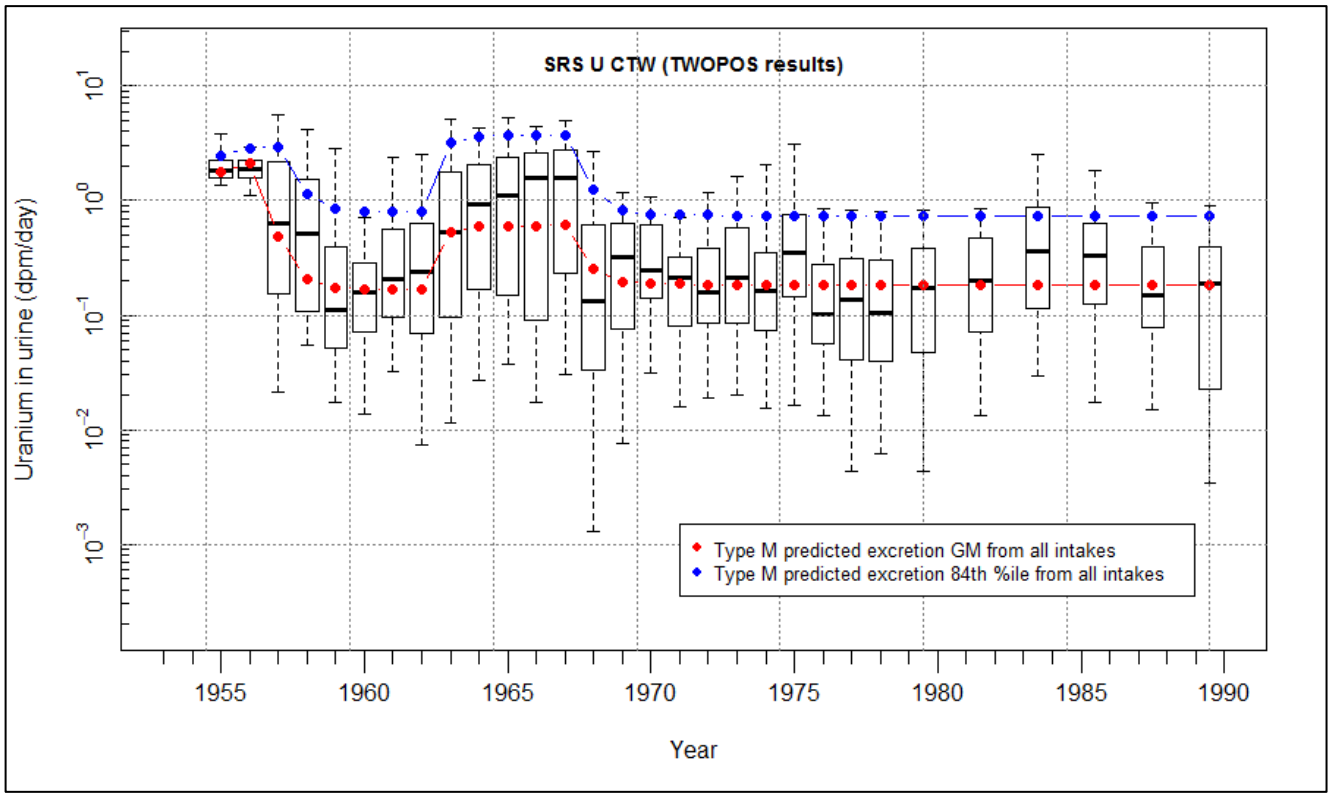


Figure 4-22. Uranium type M CTW TWOPOS data box and whisker plot.

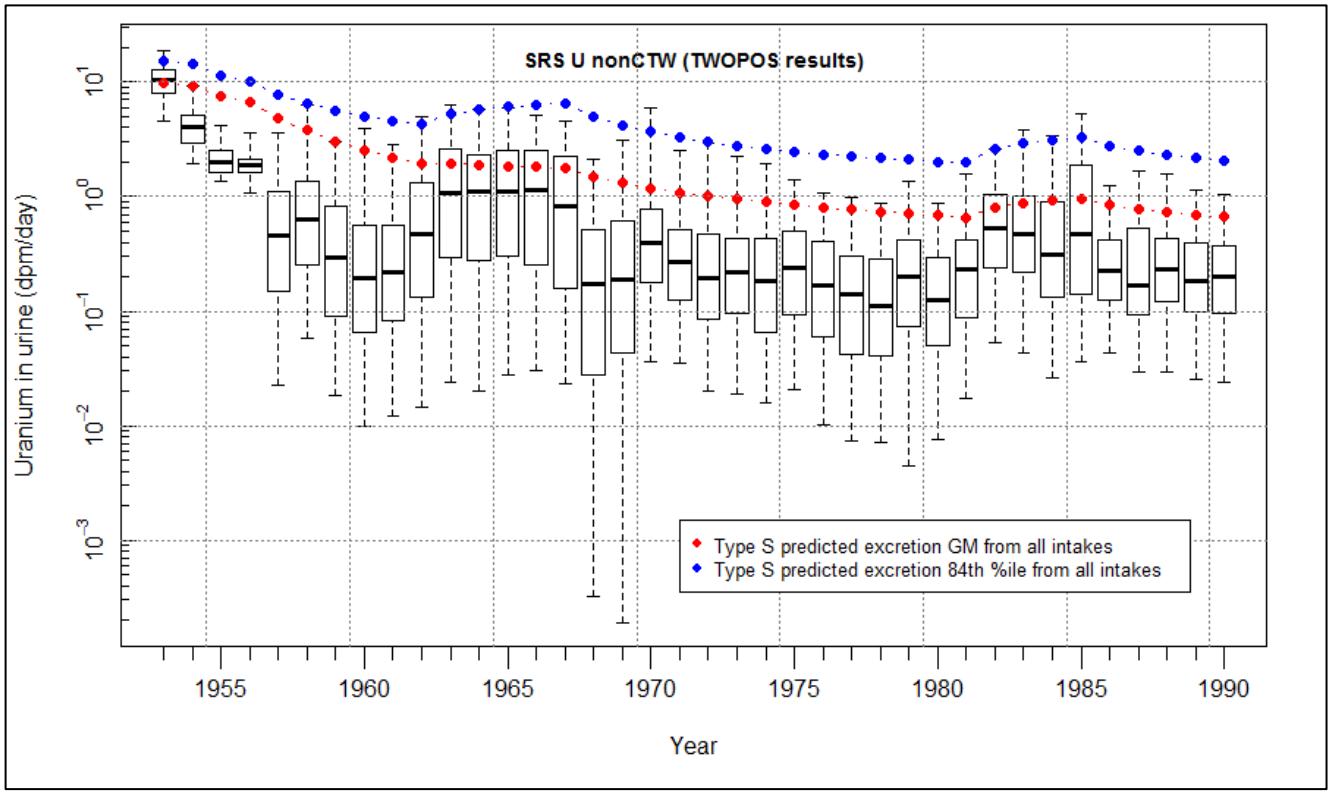


Figure 4-23. Uranium type S nonCTW TWOPOS data box and whisker plot.

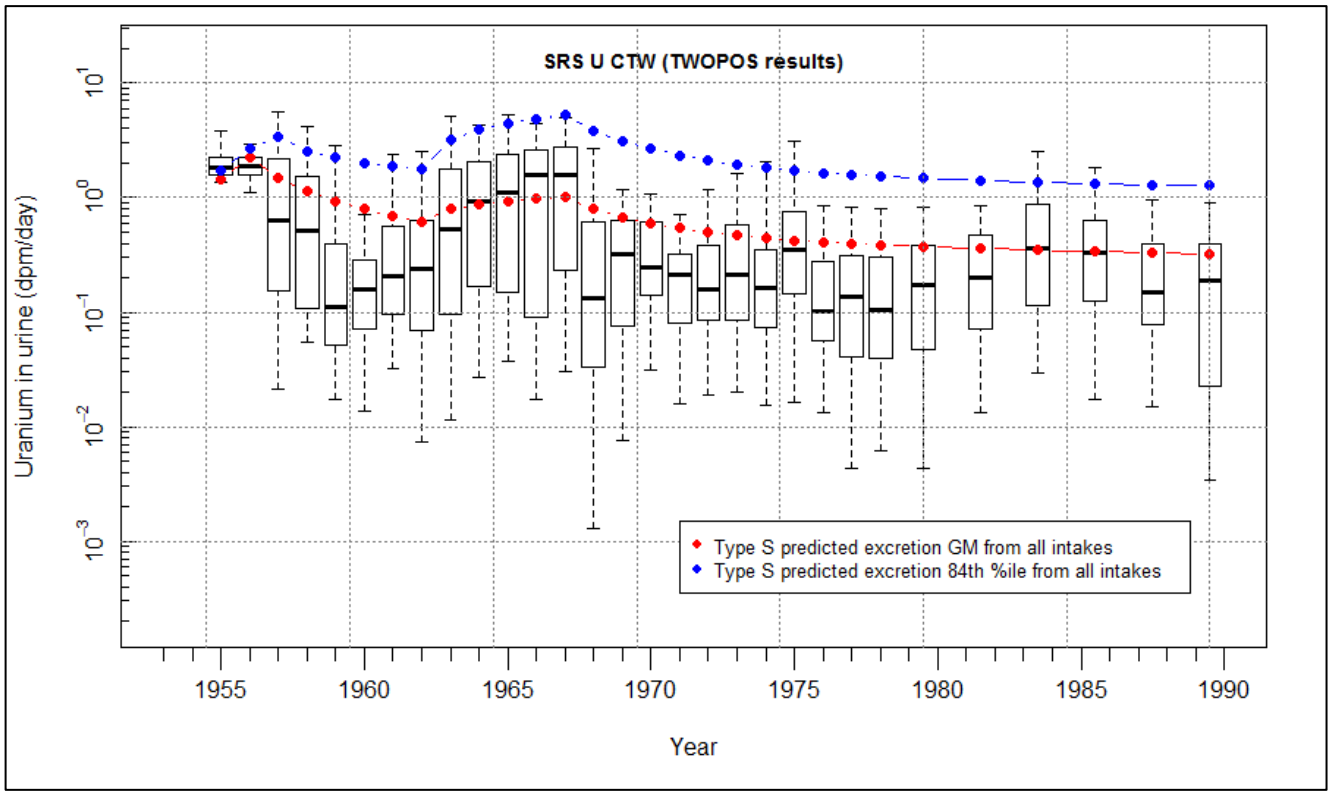


Figure 4-24. Uranium type S CTW TWOPOS data box and whisker plot.

4.5 FISSION PRODUCTS

4.5.1 Data Adequacy

4.5.1.1 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 1968b]. 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.

4.5.1.2 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.

4.5.1.3 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.

4.5.2 Data Validation

4.5.2.1 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 3.1.

4.5.2.2 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].

4.5.2.3 Data Exclusion

Samples marked as LIP, IA (insufficient amount), gross gamma results, and those that lacked sufficient identifying information (e.g., sample date or worker 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 E.

4.5.3 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 2019]. The data were analyzed on an annual basis. Table 4-7 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-25 and 4-26. The box and whisker plots are overlaid with the excretion results predicted by the intake modeling as discussed further below.

Table 4-7. Calculated 50th- and 84th-percentile urinary excretion rates of FPs based on a lognormal fit to the TWOPOS data, 1955 to 1965 (dpm/d).

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

4.5.4 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 4-7.

The solid lines in Figures F-131 to F-134 in Attachment F show the fits to the 50th- and 84th-percentile excretion rates for type F ^{90}Sr for nonCTWs and CTWs, respectively. Tables F-15 and F-16 list the 50th- and 84th-percentile intake rates with the associated GSDs from the FP urinalysis for nonCTWs and CTWs.

Figures 4-25 and 4-26 overlay the urinary excretion rates (lines) from the intake modeling on the box and whisker plots of the TWOPOS data.

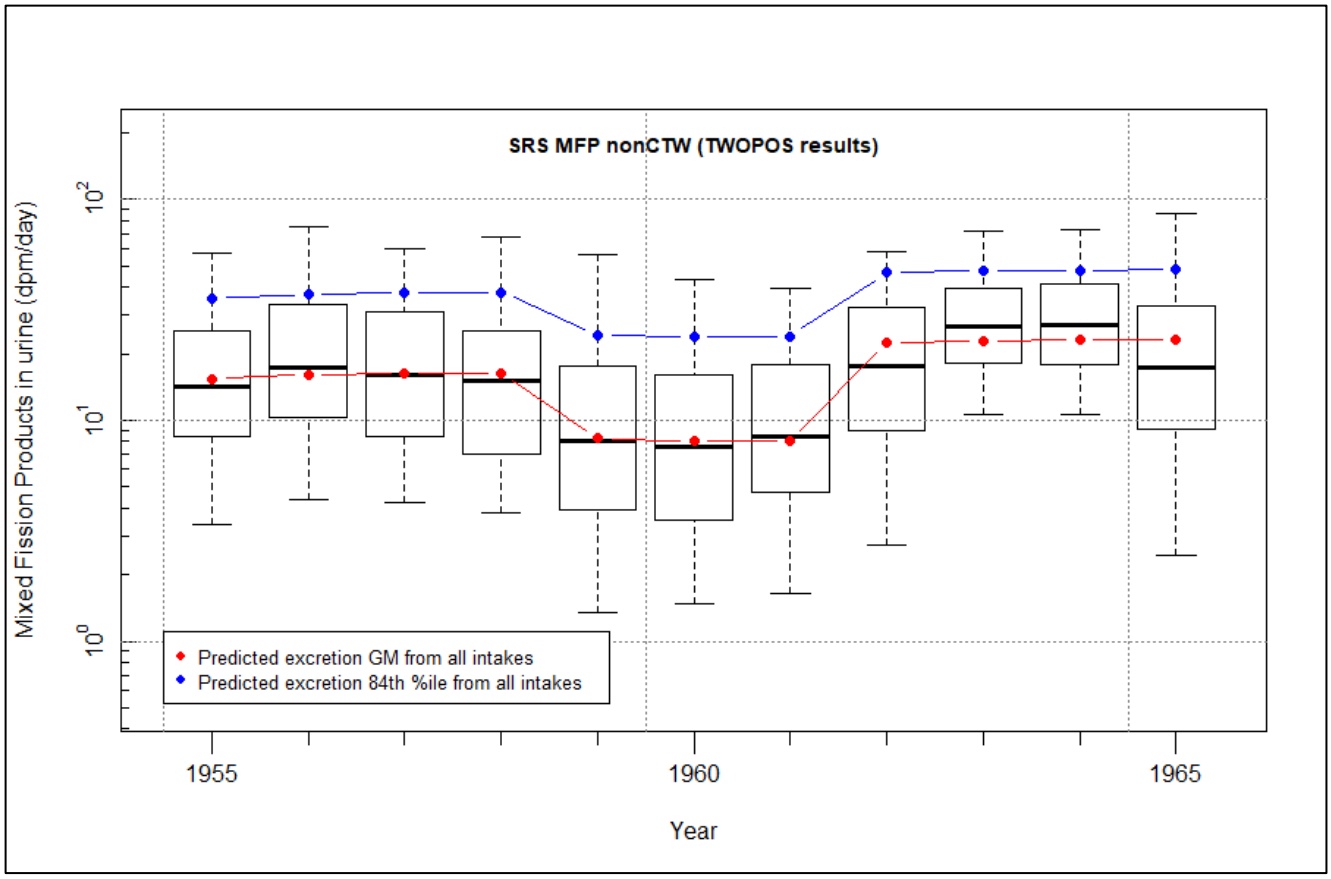


Figure 4-25. FP nonCTW TWOPOS data box and whisker plot.

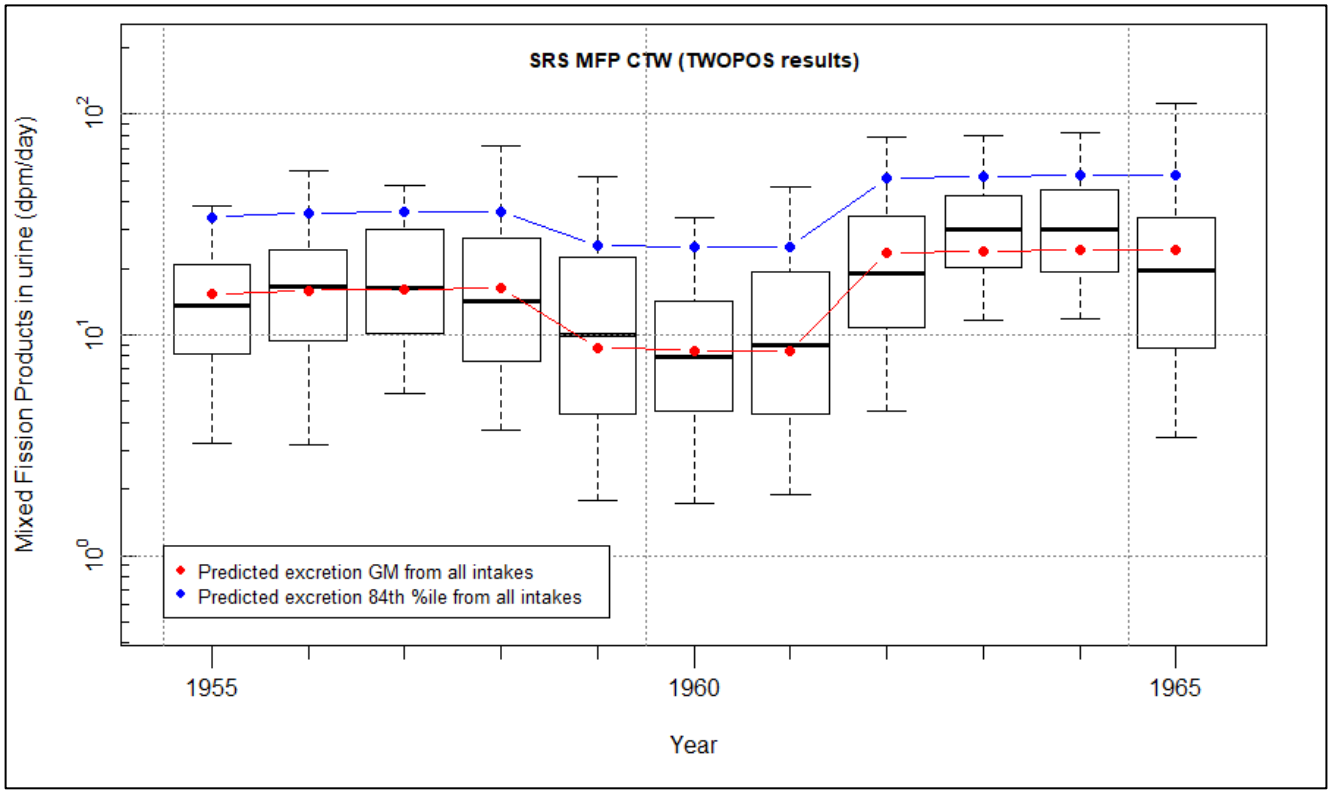


Figure 4-26. FP CTW TWOPOS data box and whisker plot.

4.6 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].

4.6.1 Bioassay Data

The FP bioassay data discussed in Section 4.5 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 E.

4.6.2 Statistical Analysis

Statistical analysis of the FP bioassay data was performed in accordance with the current version of ORAUT-RPRT-0053 [ORAUT 2014b] using the TWOPOS method from that document and the multiple imputation method from ORAUT-RPRT-0096 [ORAUT 2019]. The data were analyzed on an annual basis. Table 4-8 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-27 through 4-30. The box and whisker plots are overlaid with the urinary excretion predicted by the intake modeling as discussed further below.

Table 4-8. Calculated 50th- and 84th-percentile urinary excretions rates of ^{60}Co based on a lognormal fit to the TWOPOS data, 1955 to 1970 (pCi/d).

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

4.6.3 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 F-135 to F-142 in Attachment F show the fits to the 50th- and 84th-percentile excretion rates for types M and S materials for nonCTWs and CTWs. Tables F-17 through F-20 list the 50th- and 84th-percentile intake rates with the associated GSDs from the ^{60}Co urinalysis.

Figures 4-27 through 4-30 overlay the urinary excretion rates (lines) from the intake modeling on the box and whisker plots of the TWOPOS data.

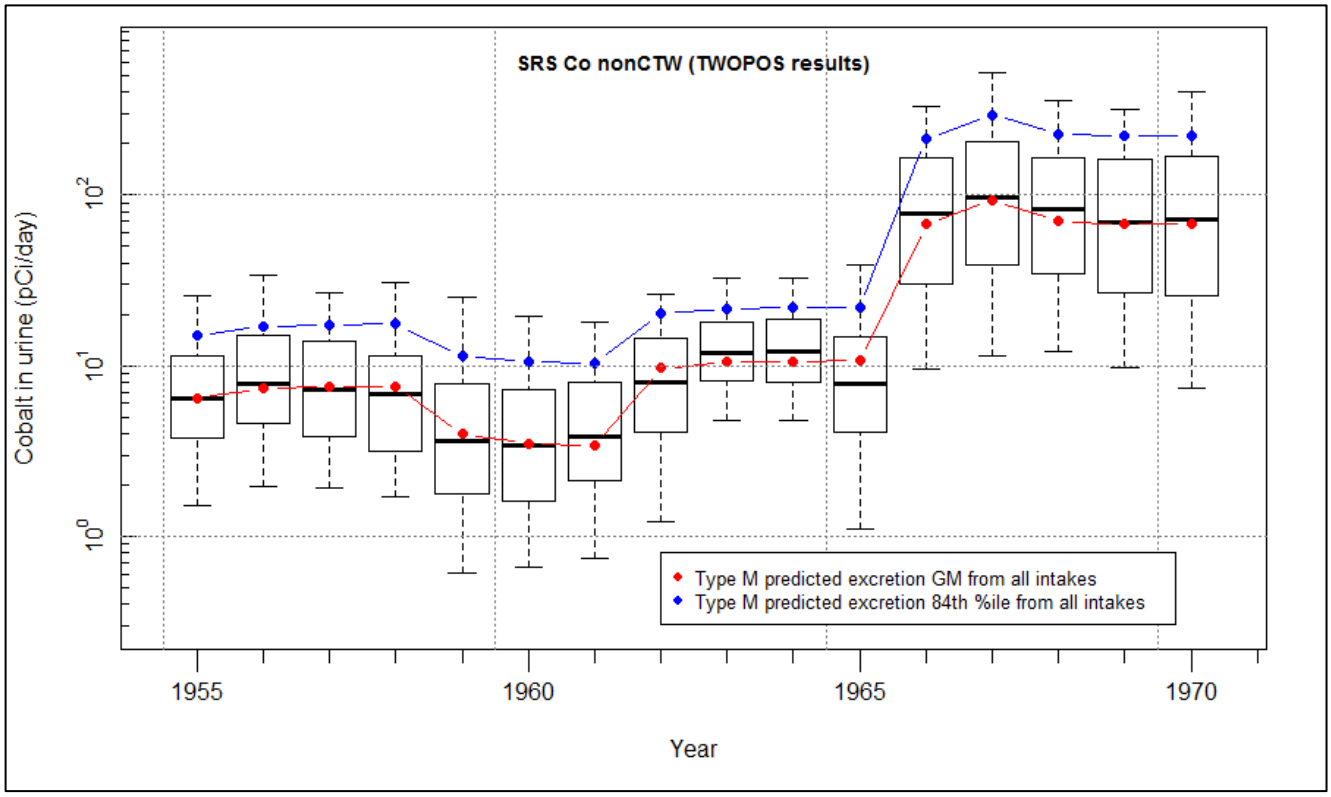


Figure 4-27. Cobalt-60 nonCTW TWOPOS data box and whisker plot, Type M.

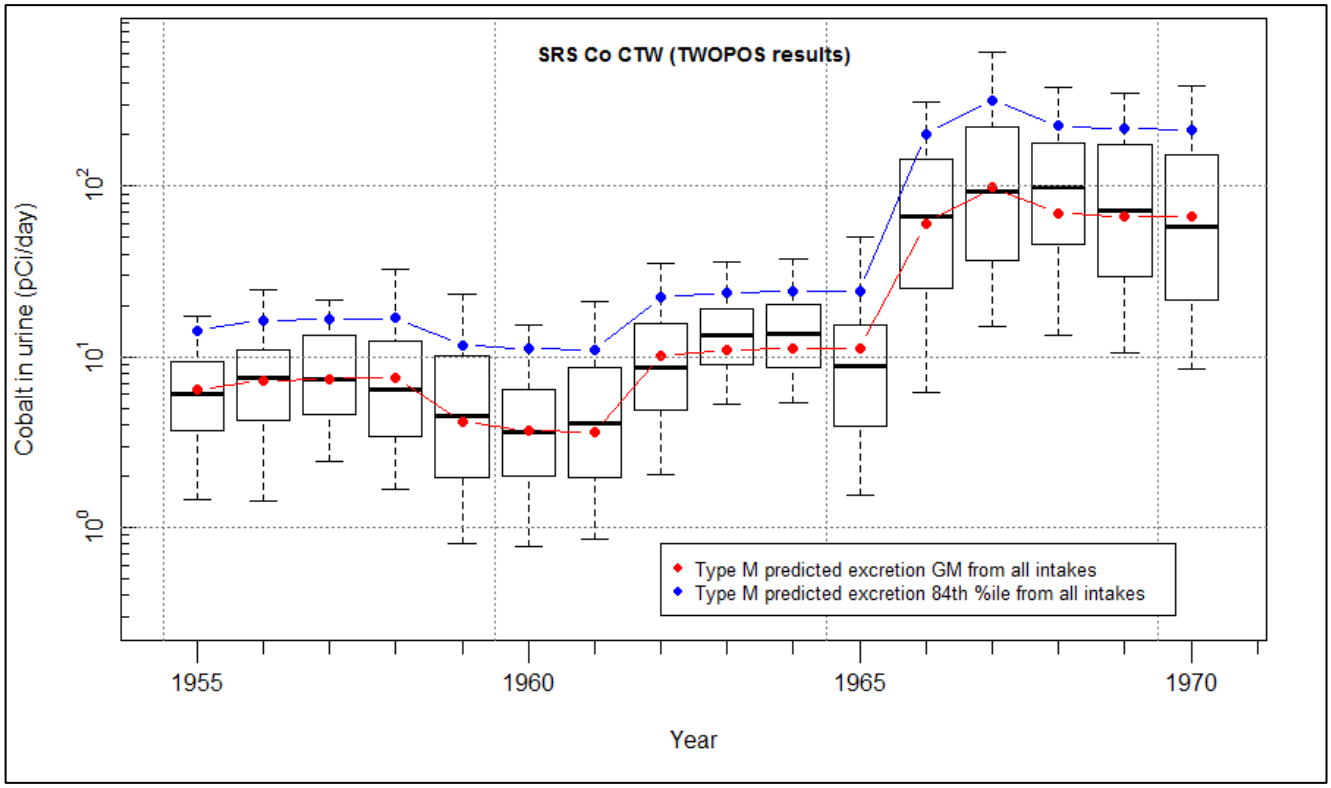


Figure 4-28. Cobalt-60 CTW TWOPOS data box and whisker plot, Type M.

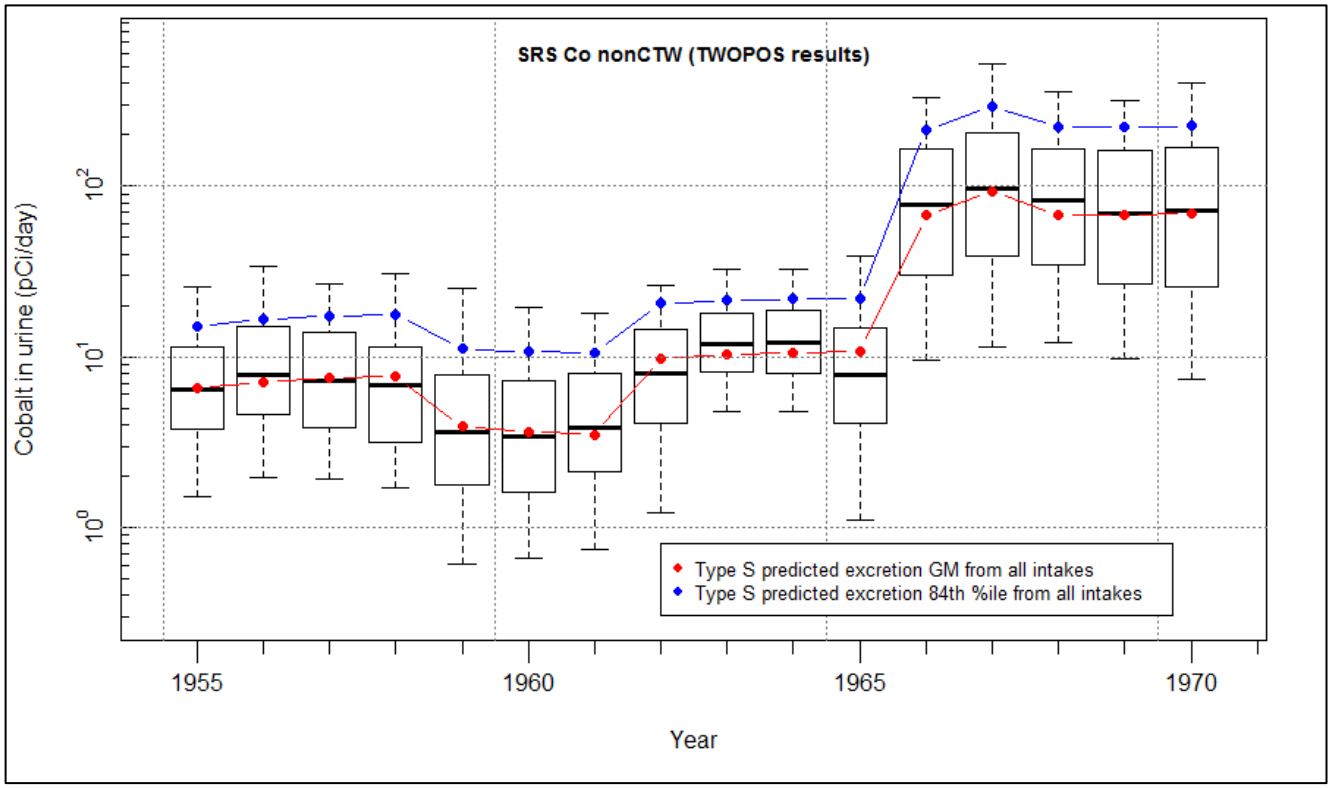


Figure 4-29. Cobalt-60 nonCTW TWOPOS data box and whisker plot, Type S.

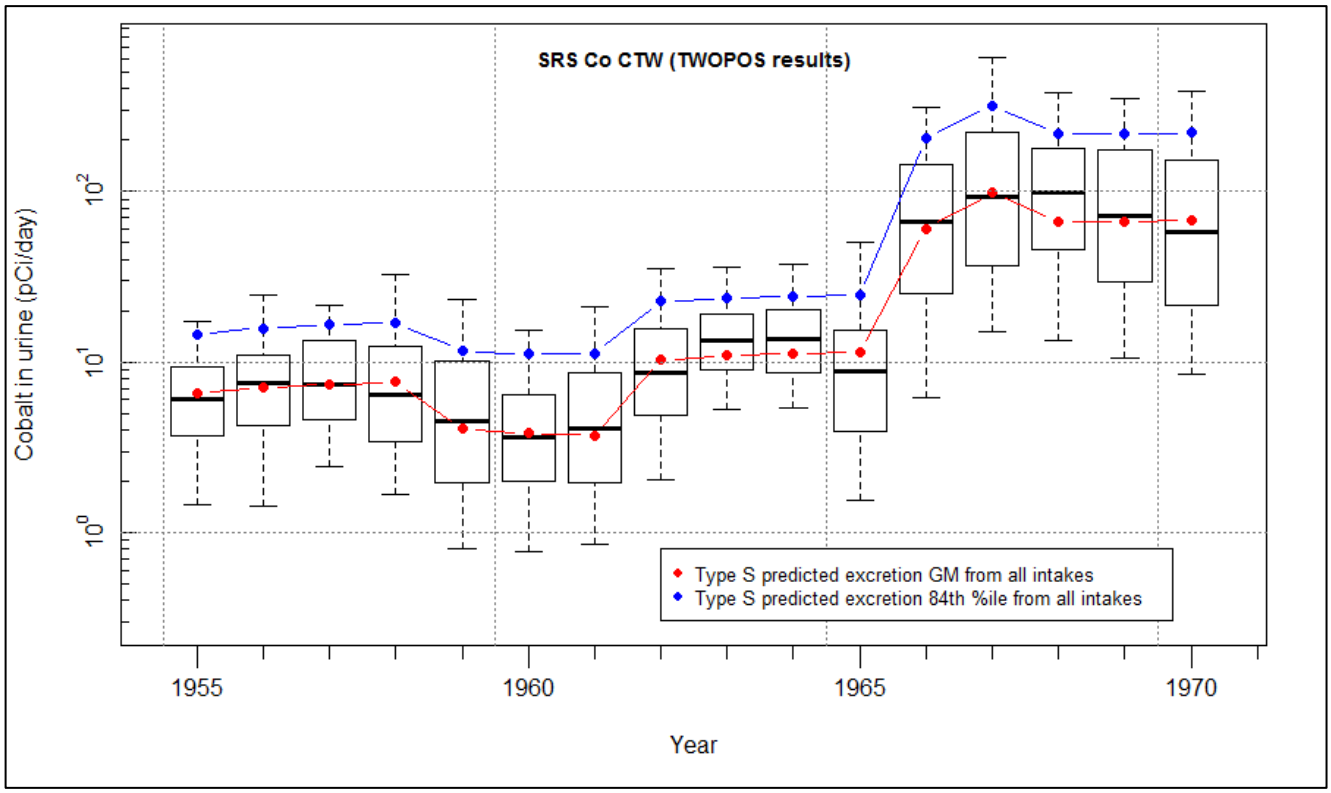


Figure 4-30. Cobalt-60 CTW TWOPOS data box and whisker plot, Type S.

4.7 CESIUM-137

4.7.1 Data Adequacy

4.7.1.1 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].

4.7.1.2 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].

4.7.1.3 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 1995].

During the early 1970s, the 40-cm arc geometry was replaced with a bed geometry using four 4- by 4-inch 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 1995].

4.7.2 Data Validation

4.7.2.1 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 3.1.

4.7.2.2 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).

4.7.2.3 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 worker 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 E.

4.7.3 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 2019]. The data were analyzed on an annual basis except for the years indicated in Table 4-9, which were merged due to the small amount of data available in those years. No analysis was performed for CTWs for 1960 because there was not enough CTW data in that year for evaluation. Table 4-9 provides the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-31 and 4-32. The box and whisker plots are overlaid with the whole-body content predicted by the intake modeling as discussed further below.

4.7.4 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 4-9.

Table 4-9. Calculated 50th- and 84th-percentile ^{137}Cs whole-body content based on a lognormal fit to the TWOPOS data, 1960 to 1989 (pCi).

Year[a]	nonCTW 50th percentile	nonCTW 84th percentile	nonCTW GSD	nonCTW # of individuals	CTW 50th percentile	CTW 84th percentile	CTW GSD	CTW # of individuals
1960	4,954	6,926	1.40	200	N/A	N/A	N/A	N/A
1961					4,472	5,884	1.32	34
1962	5,780	8,696	1.50	215	5,996	8,067	1.35	57
1963	8,762	12,464	1.42	151	9,634	13,846	1.44	66
1964	14,745	22,345	1.52	70	13,765	21,442	1.56	33
1965	8,588	14,187	1.65	46				
1966								
1967	2,014	5,667	2.81	50	4,751	11,273	2.37	35
1968	5,034	8,422	1.67	73				
1969	1,242	5,052	4.07	79	1,997	6,309	3.16	28
1970	1,242	5,052	4.07	79				
1971	1,441	4,165	2.89	59				
1972	2,887	5,702	1.98	144	2,881	4,951	1.72	54
1973	2,384	4,581	1.92	201				
1974	2,041	4,384	2.15	327	2,187	4,379	2.00	70
1975	2,047	4,769	2.33	395	2,118	4,323	2.04	88
1976	1,900	3,704	1.95	221	1,645	3,272	1.99	62
1977	1,839	4,073	2.21	327	1,338	3,137	2.34	95
1978	1,329	3,668	2.76	338	1,095	2,660	2.43	91
1979	963	2,578	2.68	308	736	2,524	3.43	66
1980	755	2,230	2.95	323	688	2,169	3.15	81
1981	654	2,176	3.33	361	646	2,003	3.10	91
1982	553	1,652	2.99	348	458	1,482	3.23	85
1983	457	1,487	3.26	292	389	1,234	3.17	92
1984	364	1,234	3.39	271	442	1,273	2.88	69
1985	669	2,015	3.01	219	545	1,877	3.44	55
1986	2,017	4,152	2.06	311	1,336	3,964	2.97	62
1987	403	1,622	4.03	371	310	996	3.21	180
1988	398	1,313	3.30	370	290	738	2.55	240
1989	349	1,044	2.99	467	300	898	2.99	240
1990	200	771	3.86	653	202	767	3.79	388

a. 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.

Excluded results are shown as an “X” in the figures in Attachment F; included results are shown as dots. The solid lines in Figures F-143 through F-150 in Attachment F show the fits individual to the 50th- and 84th-percentile body burdens for type F ^{137}Cs for nonCTWs and CTWs. Figures F-151 to F-154 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type F ^{137}Cs intakes for nonCTWs and CTWs. Tables F-21 and F-22 list the 50th- and 84th-percentile intake rates with the associated GSDs from the ^{137}Cs WBCs.

Figures 4-31 and 4-32 overlay the WBCs from the intake modeling (lines) on the box and whisker plots of the TWOPOS data.

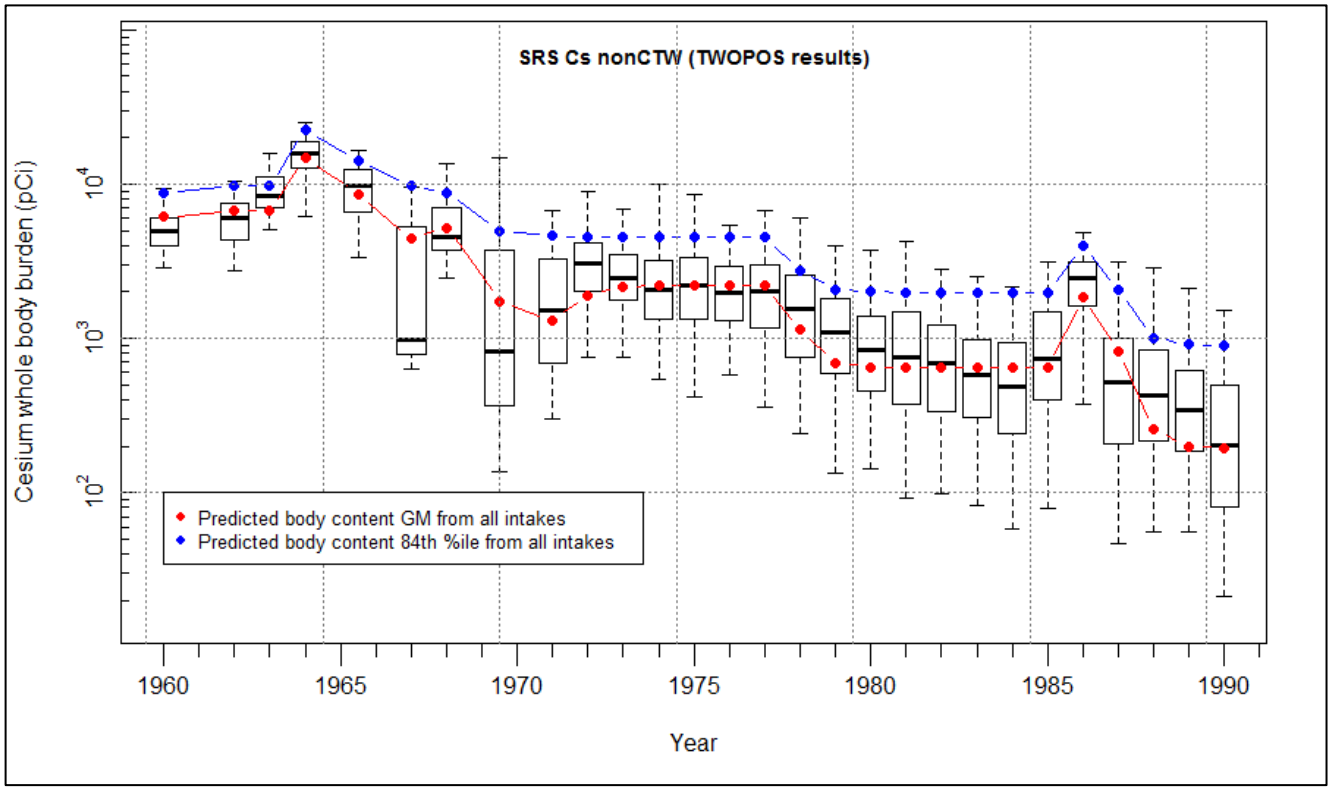


Figure 4-31. Cesium-137 body burden nonCTW TWOPOS data box and whisker plot.

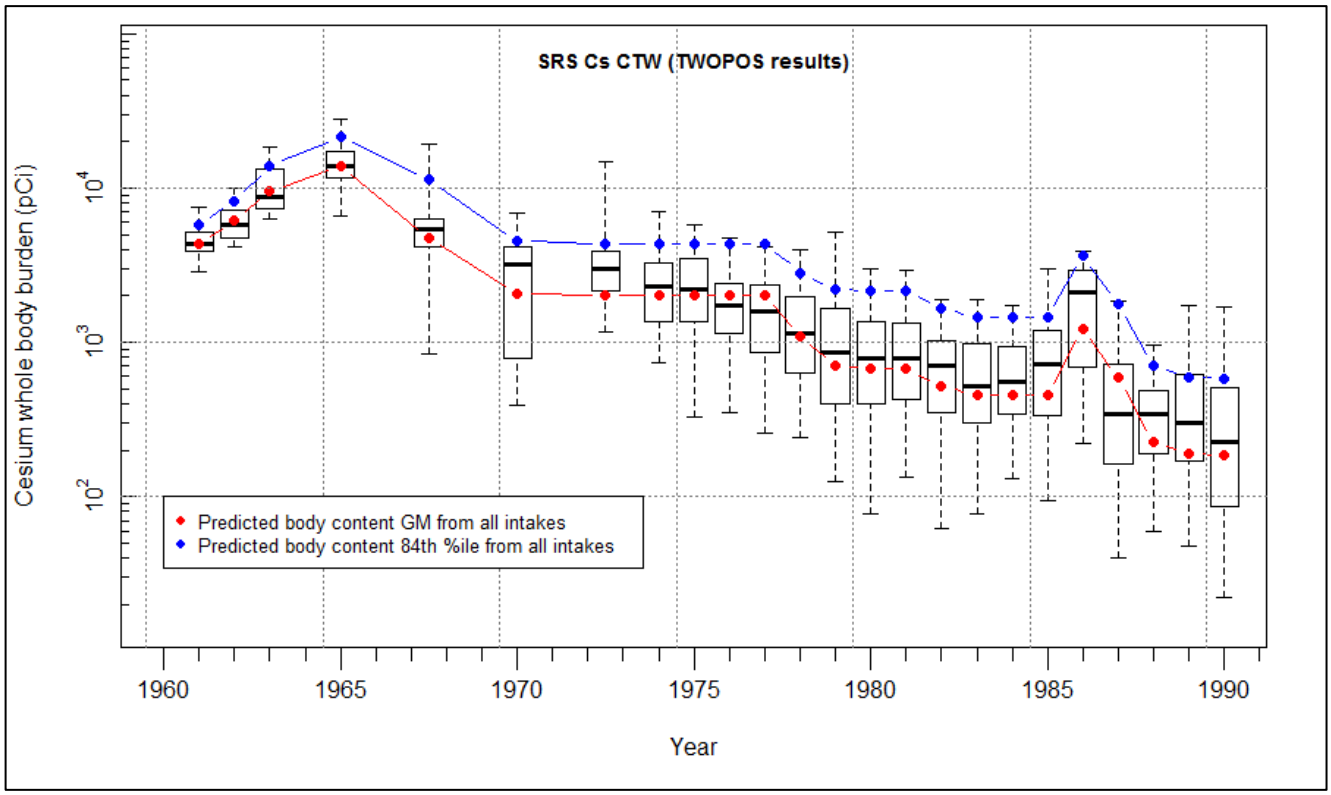


Figure 4-32. Cesium-137 body burden CTW TWOPOS data box and whisker plot.

4.8 NEPTUNIUM

4.8.1 Data Adequacy

4.8.1.1 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 1968b]. 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 plutonium 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].

4.8.1.2 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 are usable 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.

4.8.1.3 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 (gamma ray energy range) that was associated with neptunium, however, the gamma-ray yield in this region of interest is relatively low. The gamma ray yield of neptunium and neptunium decay products in other regions of interest is higher. Section 4.8.2.2 details how data from the other regions of interest are used to infer potential neptunium whole-body contents.

4.8.2 Data Validation

4.8.2.1 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, 1968a, 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 4-10. 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 4-10. Logbook data completeness estimate.[a]

Year	Bioassay summary # of Np samples	Logbook # of Np samples	% in logbook
1961	N/A	618	N/A
1962	N/A	1,539	N/A
1963	898	544	61
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 3.1.

4.8.2.2 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 a region of interest (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:

$$nCi\ {}^{237}Np = 0.243 \times \left[\left({}^{131}I\ net\ cpm \right) - 0.389 \times \left({}^{40}K\ net\ cpm \right) \right] \quad (4\text{-}1)$$

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:

$$nCi\ {}^{237}Np = 0.243 \times \left(DIFF\ counts\ for\ 300\text{-}to\text{-}400\text{-}keV\ ROI\right) \quad (4\text{-}2)$$

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:

$$nCi\ {}^{237}Np = 0.0125 \times \left(DIFF\ counts\ for\ 300\text{-}to\text{-}400\text{-}keV\ ROI\right) \quad (4\text{-}3)$$

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 region of interest. Therefore, the ^{237}Np body burden can be calculated as:

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

4.8.2.3 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 C-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 worker ID number) were excluded.

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

4.8.3 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 2019]. The data were analyzed on an annual basis except for the years indicated in Tables 4-11 and 4-12. Tables 4-11 and 4-12 provide the results of the statistical analysis. Box and whisker plots of the TWOPOS data are shown in Figures 4-33 through 4-36. 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 4-37 and 4-38 overlaid with the box and whisker plots of the available urinalysis data.

Table 4-11. 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]

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.

Table 4-12. Calculated 50th- and 84th-percentile whole body burdens of neptunium based on a lognormal fit to the TWOPOS data, 1970 to 1989 (dpm).

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

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

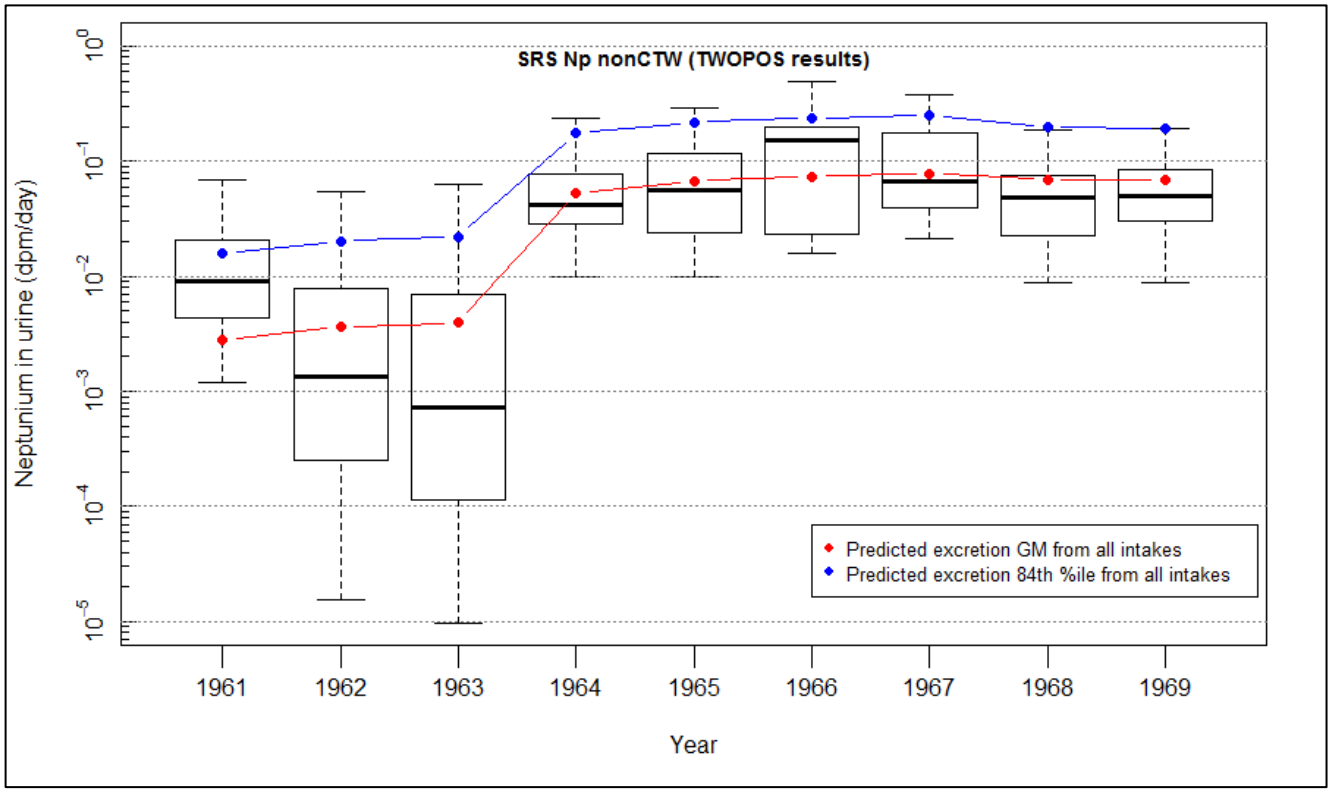


Figure 4-33. Neptunium urinalysis nonCTW TWOPOS data box and whisker plot.

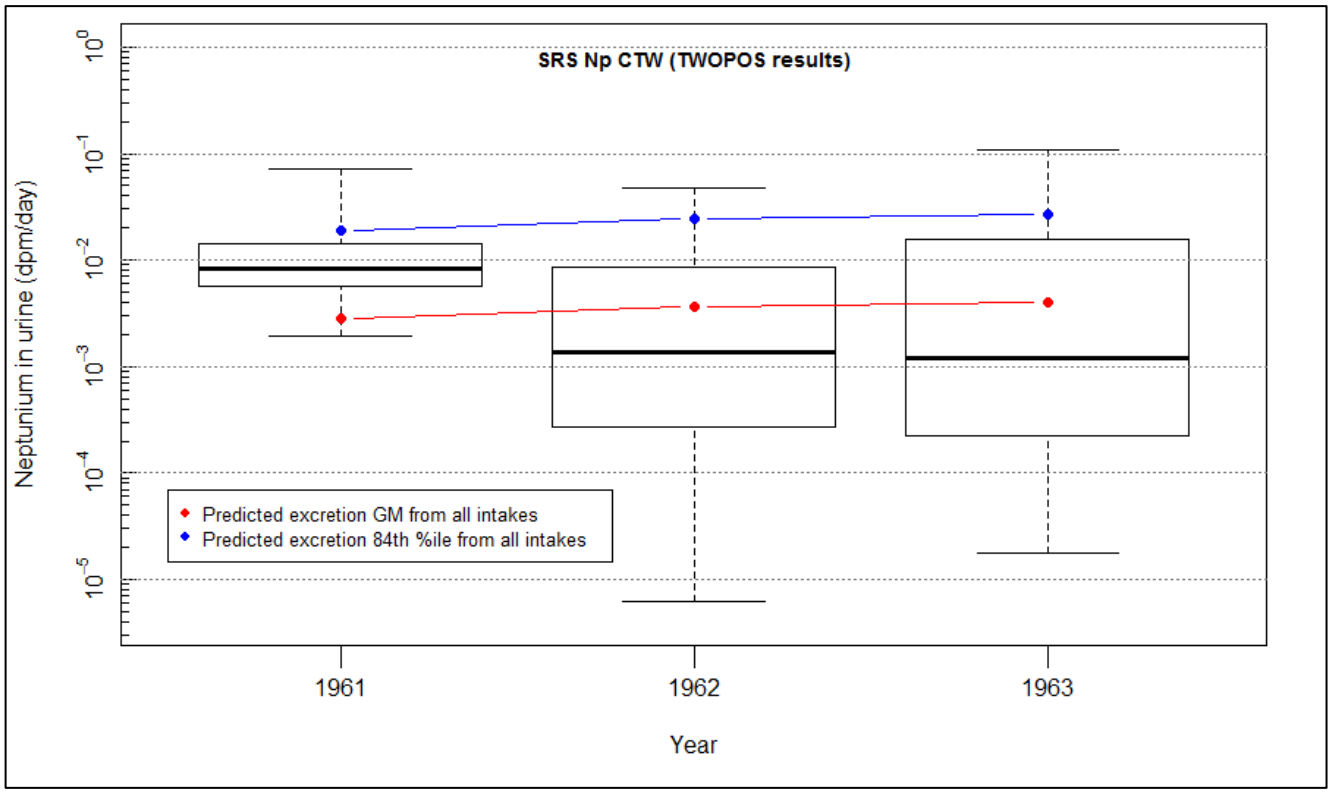


Figure 4-34. Neptunium urinalysis CTW TWOPOS data box and whisker plot.

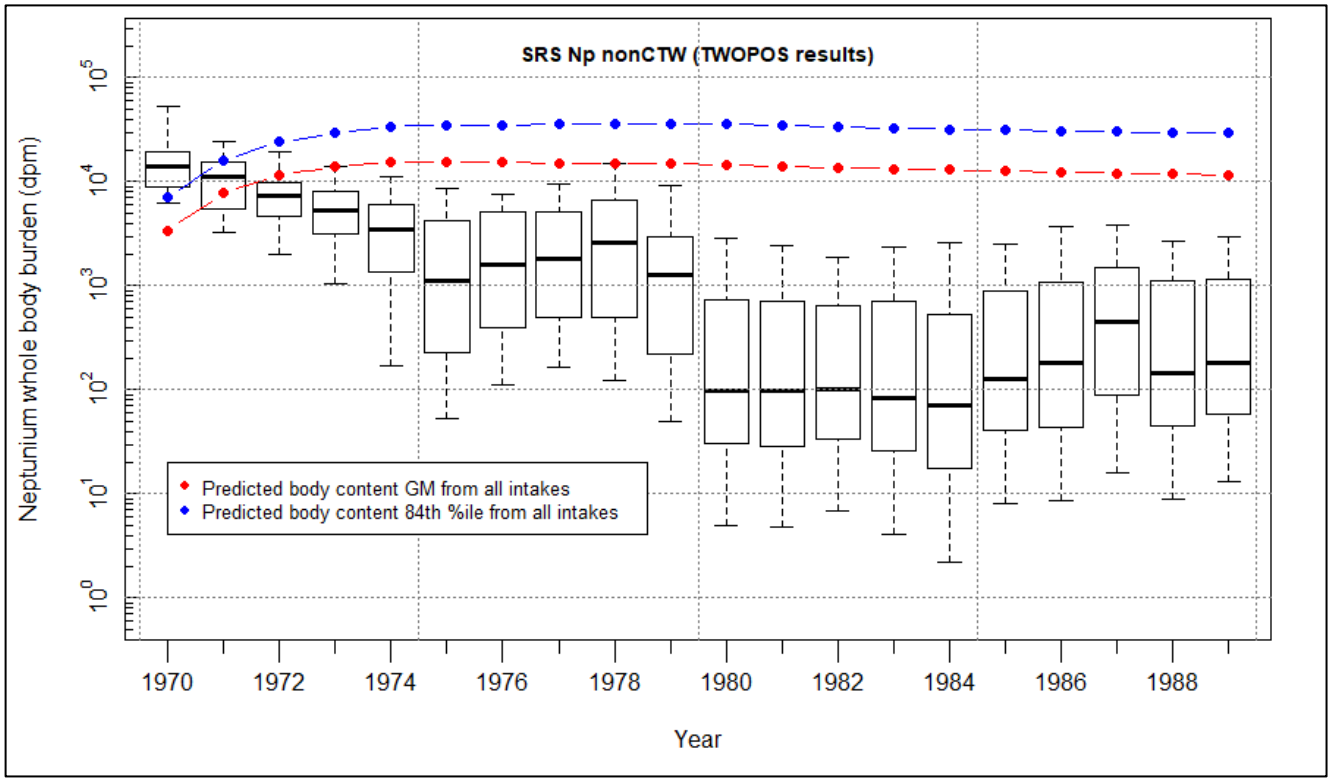


Figure 4-35. Neptunium whole-body burden nonCTW TWOPOS data box and whisker plot.

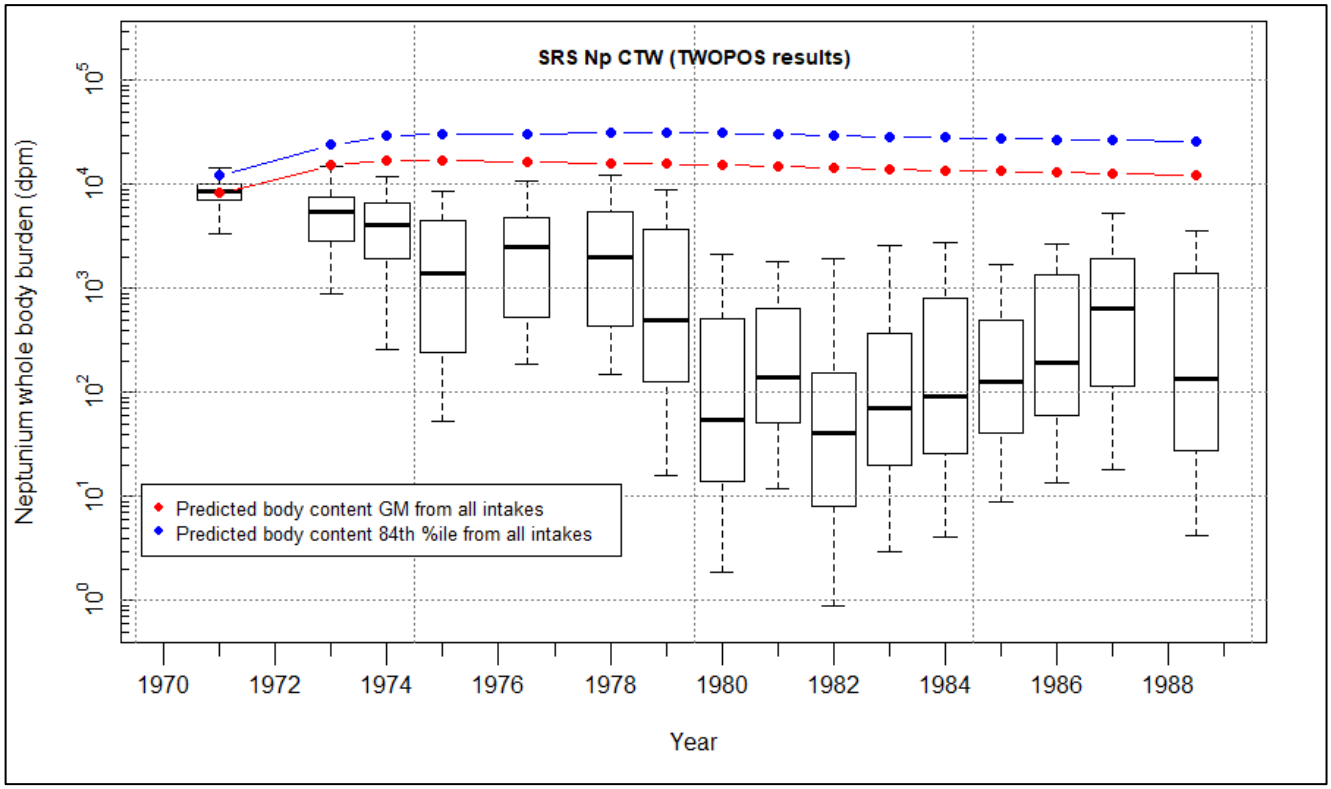


Figure 4-36. Neptunium whole-body burden CTW TWOPOS data box and whisker plot.

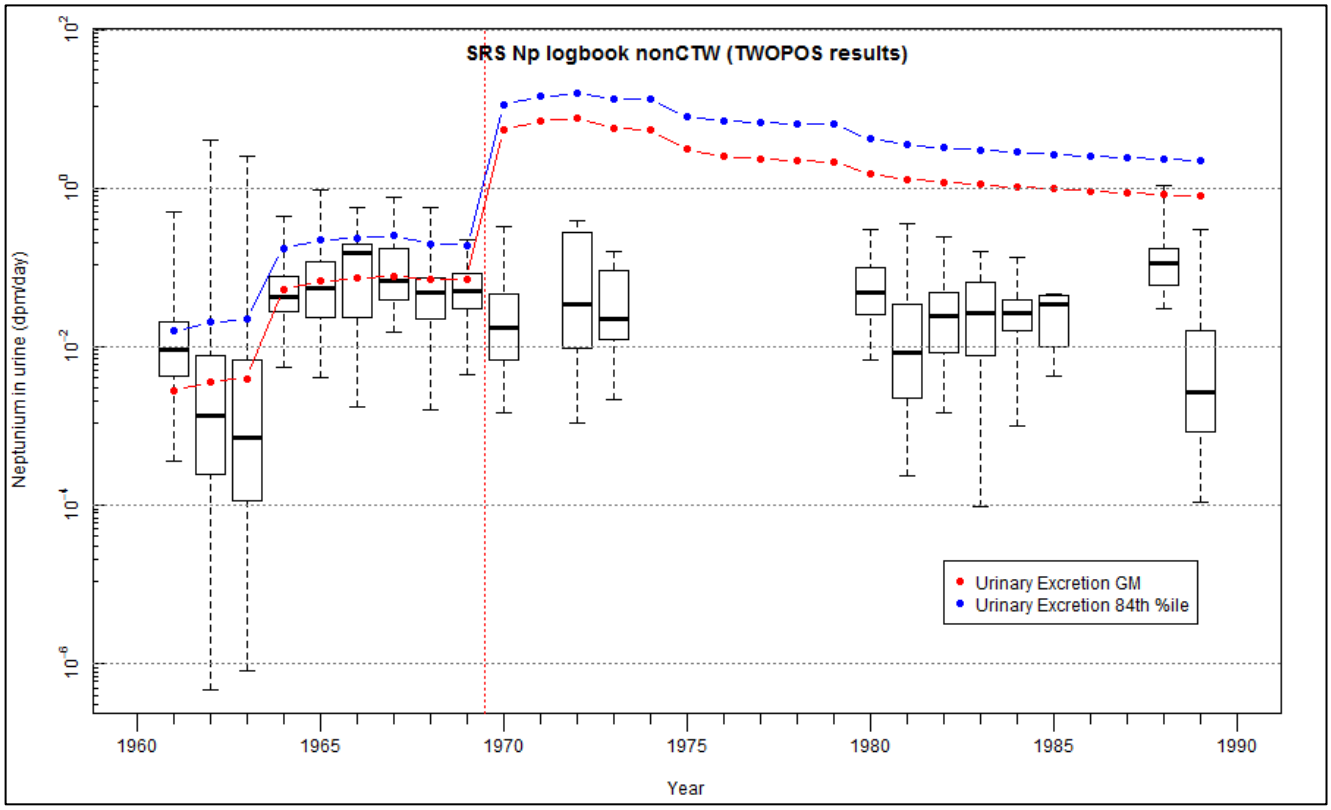


Figure 4-37. Neptunium urinalysis nonCTW TWOPOS data box and whisker plot, 1970 to 1989.

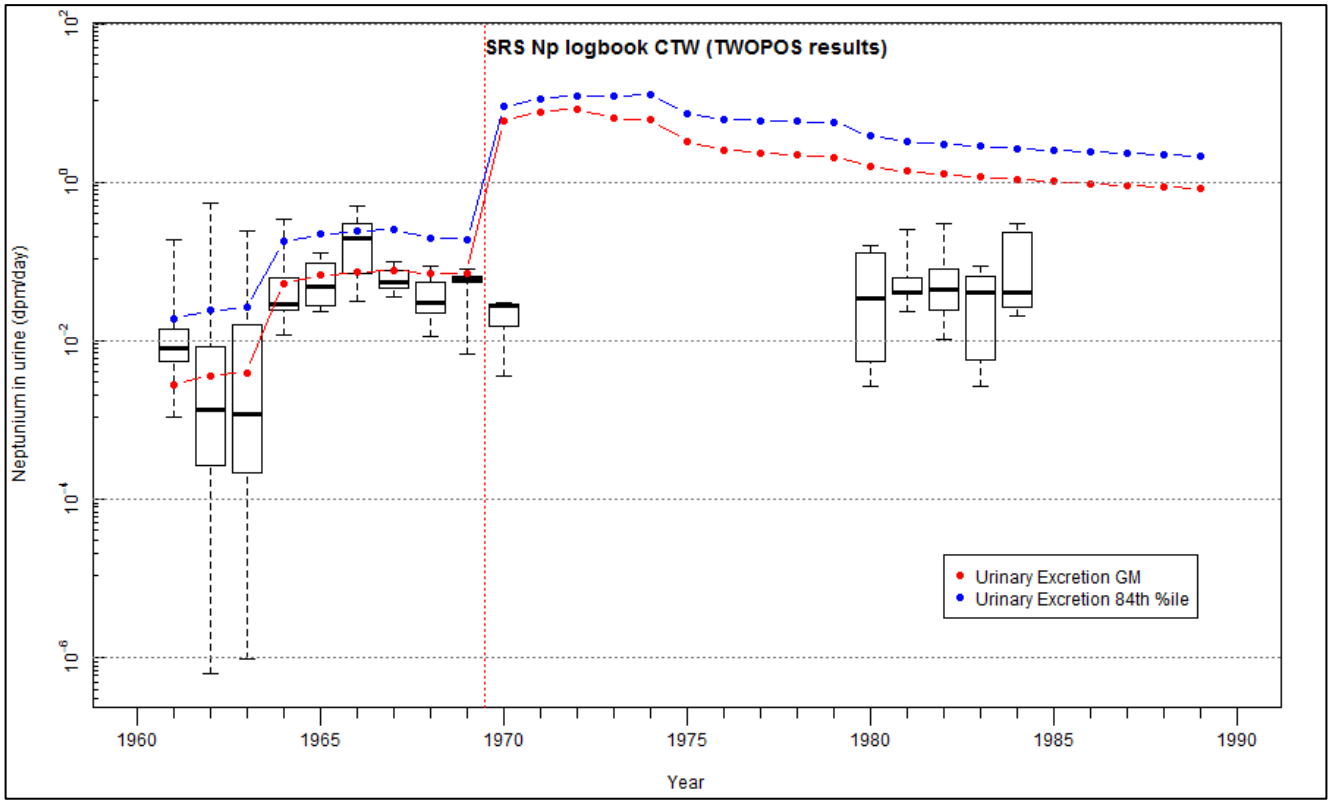


Figure 4-38. Neptunium urinalysis CTW TWOPOS data box and whisker plot, 1970 to 1989.

4.8.4 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 F; 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 4-11 and 4-12.

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

Figures 4-33 and 4-34 overlay the urinary excretion rates (lines) predicted by the intake modeling on the box and whisker plots of the TWOPOS data. Figures 4-35 and 4-36 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 4-37 and 4-38 depict the nonCTW-data based predicted urinary excretion rates in comparison to the limited CTW available.

4.9 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 4-13. For practical use at SRS, the plutonium, uranium, and neptunium would be stripped first to permit separation of the americium, californium, and curium.

Table 4-13. 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 4-39 and 4-40). 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 4-39. Thorium was also noted as being included in the americium, curium, and californium determination in 1987 [DuPont 1987b, p. 60] as shown in Figure 4-40. 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.

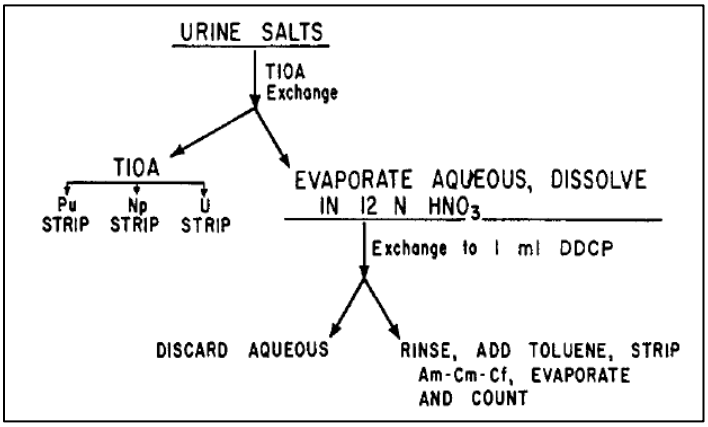


Figure 4-39. TIOA-DDCP sequential stripping process [Butler and Hall 1970].

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Revision 1
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Page 1 of 6

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 4-40. Sample analysis procedure for extracting americium, curium, californium, plutonium, neptunium, and EU [DuPont 1987b].

Therefore, the americium bioassay data discussed in Section 4.1 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 F-187 to F-194 in Attachment F show the fits to the 50th- and 84th-percentile excretion rates for Type M and S for nonCTWs and CTWs. Tables F-25 and F-26 list the 50th- and 84th-percentile intake rates with the associated GSDs from the neptunium urinalysis for nonCTWs and CTWs.

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

5.0 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 F 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. 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 5-1 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.

If the work location is unknown, the radionuclides listed for "not identifiable or unknown" (the last line in Table 5-1) 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.

5.1 AMERICIUM

Tables 5-2 and 5-3 list the ^{241}Am intakes and associated GSDs to be used for each year of potential americium exposure for nonCTWs and CTWs respectively.

5.2 TRITIUM

Table 5-4 lists the tritium doses and GSDs to be used for each year of potential tritium exposure.

5.3 PLUTONIUM

Tables 5-5 through 5-7 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 4.1.1-3 of the SRS site profile [ORAUT 2005a].

5.4 URANIUM

Tables 5-8 to 5-13 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. 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 5-14 through 5-19 [2].

5.5 FISSION PRODUCTS

Table 5-20 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 5-21 and 5-22 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].

Table 5-1. Radionuclides of concern potentially present at SRS facilities.

Building or facility	Dosimeter codes[a] 1961–1972	Dosimeter codes[a] 1973–1990	Dosimeter codes[a] 1991–2003	Dosimeter codes[a] 2004–present	Radionuclides of concern
Reactors (R, P, L, K, C)	7A, 8A, 9A, 10A, 11A,	1C through 6C, 1K, 1P, 1L, 1R	C01, C02, C03, K01, L01, P01	LLL, NMM, SDD[b]	^{3}H, FP
F-Area unknown facility	1A	1F through 5F, 7F through 9F	F, F01 through F05, F07 through F09	235, CLB, FBL, FCA	Pu, U, Am, Np, FP
F-Area A-Line	1A	See F canyon	See F canyon	FCA	U
221-F B-Line (FB- and JB-Lines)	1A	1F through 5F, 7F through 9F	F, F01 through F05, F07 through F09	FBL	Pu, Am (with Pu only)
221-F Canyon	1A	1F through 5F, 7F through 9F	F, F01 through F05, F07 through F09	FBL, FCA,	Pu, U, FP, Th through 1966, Am (MPPF only)
F-Area Outside Facilities	1B	9F	F09	FCA	Pu, U, FP
$^{238}PuO_2$ Fuel Form Facility and $^{238}PuO_2$ Experimental Facility (235-F)	1A	5F, 8F	F05, F08	235	Pu, Am, Np, Th (1975–1981)
235-F Vaults	1A	2F, 5F, 8F	2F, F05, F08	235	Pu, U, Np, Am, Cm, Th
772-F and 772-1F Laboratories	1A	1A[c]	A01	CLB	Pu, U, FP, Am, ^{3}H, Np
F/H Tank Farms, Effluent Treatment Facility, Cooling Water and Retention Basins	None	5F, 5H	F05, H05	ETP, FTF	Pu, U, FP
H-Area unknown facility	2A	1H through 6H	H01 through H06	299, HBL, HCA	^{3}H, Pu, U, Am, FP, Np
Old HB-Line Facility (through 1989)	2A	6H	H06	HBL	Pu, FP, Am, Np, U[e]
New HB-Line Facility	None	None	H06	HBL	Pu, Np
H-Canyon and A-Line	2A	1H, 2H, 5H, 6H	H, H01, H02, H05, H06	HCA	Pu, U, FP, Np
221-H Area Outside Facilities	2A	9H	H09	HCA	^{3}H, Pu, U, FP, Np
232-H, H Area New Manufacturing Facility, H Area Old Manufacturing Facility, Tritium complex	None	6F, 4H	F06, H04, T	TEF, TRI	^{3}H
300 M-Area, M Area unknown facility	3A	3M	M03	SDD[b]	U, Th, Pu, Np, Am 1964–1965 only, Cm 1964–1965 only
704-U, 704-B	None	1U, 6E, 7G	U, U01, E06, G07	No active codes	FP
723-A, 773-A	5A, 6N	1A, 5A	A01, A02, A05,	SRTC	Pu, Am, Cm, Cf, Th October 1972 and after, U, Np, FP, ^{3}H
735-A and 735-11A	6F	5D	A02, A03, A09, A16, B01	SRTC (apply 773-A intakes)	Environmental radionuclides, Np 1962

Building or facility	Dosimeter codes[a] 1961–1972	Dosimeter codes[a] 1973–1990	Dosimeter codes[a] 1991–2003	Dosimeter codes[a] 2004–present	Radionuclides of concern
776-A	None	1A, 15A	A01, A15	SRTC (apply 773-A intakes)	Pu, Am, Cm, Cf, Th, U Np 1961–1988, FP, ^{3}H
777-M	5B	5B	A33	No active codes	U, FP, Np through 1984
CMX and TNX (Semi-works facilities)	5C	5C	T01	No active codes	U
Central Shops and Maintenance, Pittsburgh Testing Laboratory	6C, 6H, 6I, 6M, 6N, 6R, 12D, 12E, 12I	5J, 5W, 6B,6W, 7A, 7B, 7G, 7I, 7J, 7K, 7L, 7M, 7N, 7R, 7Q, 7W, 8A through 8C, 8H, through 8M, 8P, 8S, 8T, 1N	A12, A24, A25, A26, A27, A29, A34, J01, through J08, J12 through 41	No active codes	Pu (with Pu only), U, FP, ^{3}H, Am, Cm, Np, Th
D-Area	4A	1D, 4D	D, D01, D04	SDD	^{3}H
E-Area Solid Waste Disposal Facility	12A	12B, 4F, 3G, 8G	B12, G03, F04	SSS	^{3}H, Pu, FP, Np
New Special Recovery and Plutonium Storage Facility	None	See H-Area unknown facility	See H-Area unknown facility	MPF	Pu, Am, U
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, Am, ^{3}H
S-Area Defense Waste Processing Facility	None	1S, 2S, 1W, 2W	S01, S02	SWM	Pu, FP, U
Waste Certification Facility	None	3G	G03	SSS	^{3}H, Pu, FP
Z-Area	None	2Z	Z02	ZZZ	^{3}H, FP, Pu,
Not identifiable or unknown[d]	None	7Y, 8D, 8E, 000, missing	R01, Y01, missing	Blank, any code not already listed	Pu, U, FP, ^{3}H, Am, Cm, Cf, Np, Th

a. Any code with an "X" should not be included. These indicate offsite assignment.
b. 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.
c. Code 1A was used for both 772 and 773 before 1991. If no other information about work location is available, the applicable radionuclides for both locations should be assigned.
d. Unknown facility radionuclides should only be assigned if no information is available from any source about the worker's work location.
e. Uranium-232/233 should only be assigned for the HB-Line for January 1, 1964, through September 30, 1972.

Table 5-2. 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	32.11	3.39	239
01/01/1966	12/31/1967	57.9	3.00	353
01/01/1968	12/31/1971	16.3	3.00	99.3
01/01/1972	12/31/1982	2.327	3.62	19.3
01/01/1983	12/31/1989	7.694	3.00	46.9

Table 5-3. CTW type M ^{241}Am intake rates (dpm/d).

Start	End	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile
01/01/1965	12/31/1967	48.46	3.60	399
01/01/1968	12/31/1971	16.56	3.00	101
01/01/1972	12/31/1982	2.387	3.76	21.1
01/01/1983	12/31/1989	8.891	3.00	54.2

Table 5-4. Tritium annual doses (rem) and GSDs.

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

Year	nonCTW 50th percentile	nonCTW GSD	nonCTW 95th percentile	CTW 50th percentile	CTW GSD	CTW 95th percentile
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

Table 5-5. Type M plutonium gross alpha intake rates (dpm/d).

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

Table 5-6. Type S plutonium gross alpha intake rates (dpm/d).

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

Table 5-7. Type SS plutonium gross alpha intake rates (dpm/d).

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

Table 5-8. 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 5-9. 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 5-10. 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 5-11. CTW type F ^{234}U intake rates (dpm/d).

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

Table 5-12. CTW type M ^{234}U intake rates (dpm/d).

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

Table 5-13. CTW type S ^{234}U intake rates (dpm/d).

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

Table 5-14. 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	09/30/1972	0.0103	0.595	4.59	0.126	7.30

Table 5-15. 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	09/30/1972	0.041	2.385	4.44	0.48	27.65

Table 5-16. 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	09/30/1972	0.62	35.71	4.20	6.55	378.6

Table 5-17. Type F ^{233}U CTW 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	0.7962	0.0135	4.06	0.14	7.84
01/01/1963	12/31/1967	2.124	0.0361	6.18	0.722	41.74
01/01/1968	09/30/1972	0.6529	0.011	4.08	0.11	6.47

Table 5-18. Type M ^{233}U CTW 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	0.040	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	09/30/1972	0.045	2.58	3.98	0.43	25.0

Table 5-19. Type S ^{233}U CTW 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	0.912	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	09/30/1972	0.607	35.1	3.97	5.86	339

Table 5-20. Type F FP (^{90}Sr) intake rates (dpm/d).

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

Table 5-21. 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 5-22. Type F ^{137}Cs CTW intake rates (pCi/d).

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	54.81	3.00	334.0
01/01/1969	12/31/1977	29.31	3.00	178.6
01/01/1978	12/31/1981	9.71	3.21	66.00
01/01/1982	12/31/1985	6.557	3.19	44.14
01/01/1986	12/31/1986	22.95	3.00	139.9
01/01/1987	12/31/1990	2.697	3.14	17.74

5.6 COBALT-60

Tables 5-23 and 5-24 list the FP (^{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 for whom there is reason to believe they handled purified ^{60}Co.

Table 5-23. Type M ^{60}Co intake rates (pCi/d).

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

Table 5-24. Type S ^{60}Co intake rates (pCi/d).

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

5.7 NEPTUNIUM

Table 5-25 lists the neptunium intakes and associated GSDs to be used for each year of potential neptunium exposure for nonCTWs and CTWs.

Table 5-25. Neptunium intake rates (pCi/d).

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	1138
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

5.8 THORIUM

Tables 5-26 and 5-27 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.

Table 5-26. Type M ^{232}Th intake rates (dpm/d).

nonCTW

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	4.203	3.56	34.0
06/01/1980	12/31/1989	Inhalation	4.87	Constant	-
06/01/1980	12/31/1989	Ingestion	0.1	Constant	-

CTW

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	4.145	3.37	30.6
06/01/1980	12/31/1989	Inhalation	4.87	Constant	-
06/01/1980	12/31/1989	Ingestion	0.1	Constant	-

Table 5-27. Type S ^{232}Th intake rates (dpm/d).

nonCTW

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	81.49	3.47	631
06/01/1980	12/31/1989	Inhalation	4.87	Constant	-
06/01/1980	12/31/1989	Ingestion	0.1	Constant	-

CTW

Start	End	Pathway	50th percentile	GSD	95th percentile
11/01/1972	05/31/1980	Inhalation	79.41	3.26	556
06/01/1980	12/31/1989	Inhalation	4.87	Constant	-
06/01/1980	12/31/1989	Ingestion	0.1	Constant	-

6.0 CONCLUSIONS

The NIOSH guidance for evaluation and use of co-exposure datasets requires that data adequacy, completeness, and applicability be determined [NIOSH 2015]. This requires determination 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 5.0 may be assigned to unmonitored workers to evaluate potential unmonitored internal dose.

7.0 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. Mr. 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 Mr. LaBone, those materials are fully attributed to the source. Mr. 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 1955–1971, pp. 458–460, 355, 1984a, 1984b]. Use of 8 ppm is a conservative estimate of ^{232}U content.

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ATTACHMENT A
QUALITY ASSURANCE SUMMARY

LIST OF FIGURES

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Savannah River Site Internal Co-Exposure In Vitro Completeness Check
May 5, 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 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 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 2017c], 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.

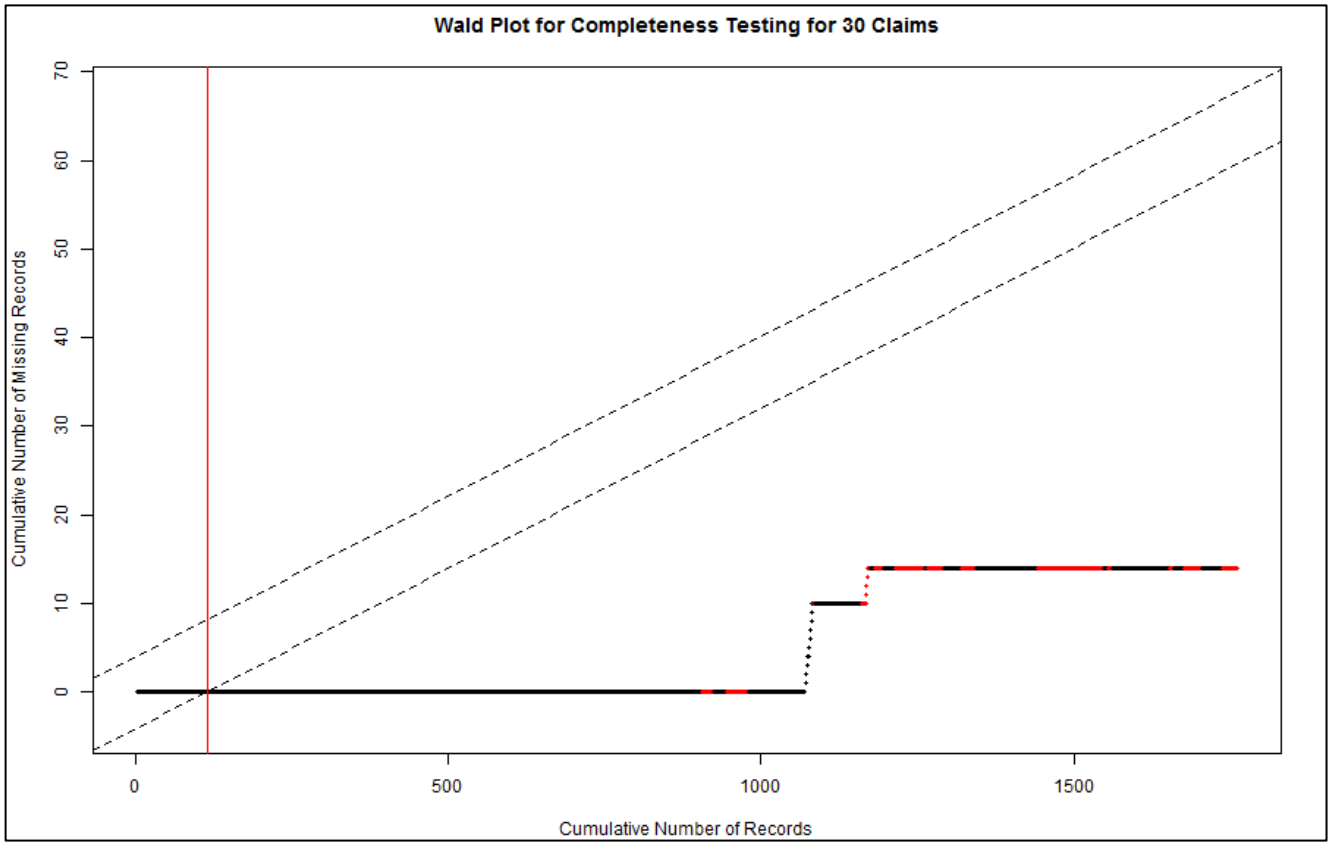


Figure A-1. Wald plot for 30 individuals. The color of the dots is alternated from red to black going from one person to the next.

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 were 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 2017c], 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. The plots below summarize this information.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

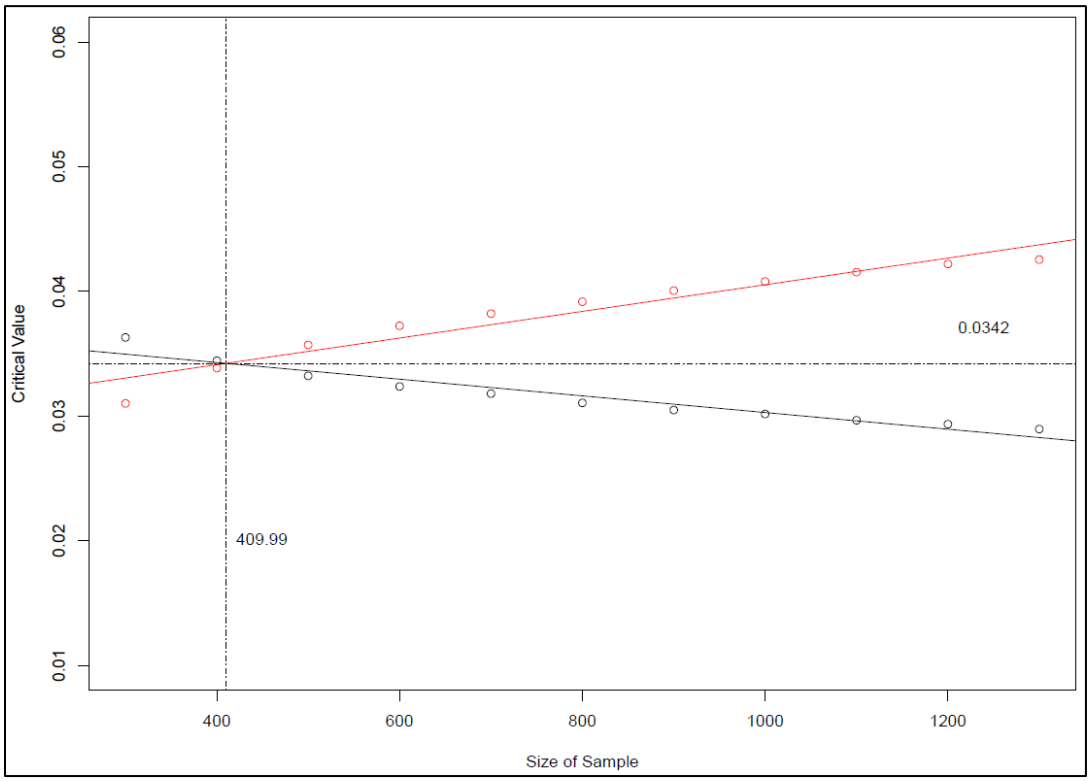


Figure A-2. Plot to determine the minimum number of claims to be sampled.

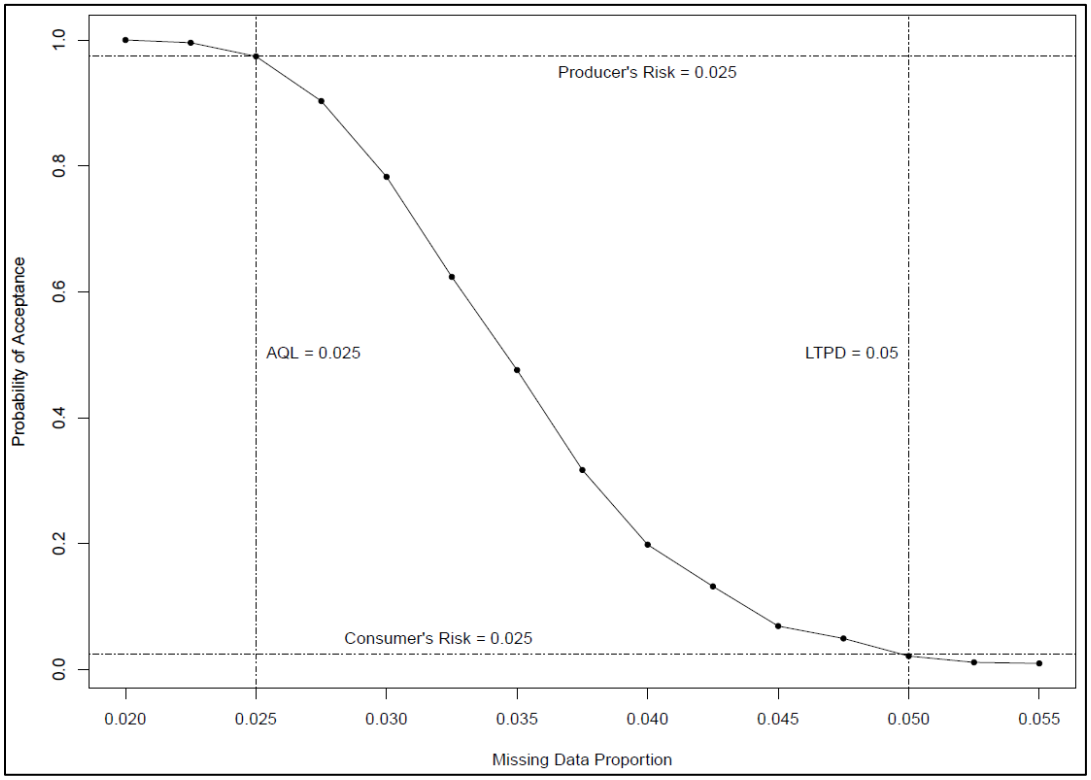


Figure A-3. OC curve for 410 individuals.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

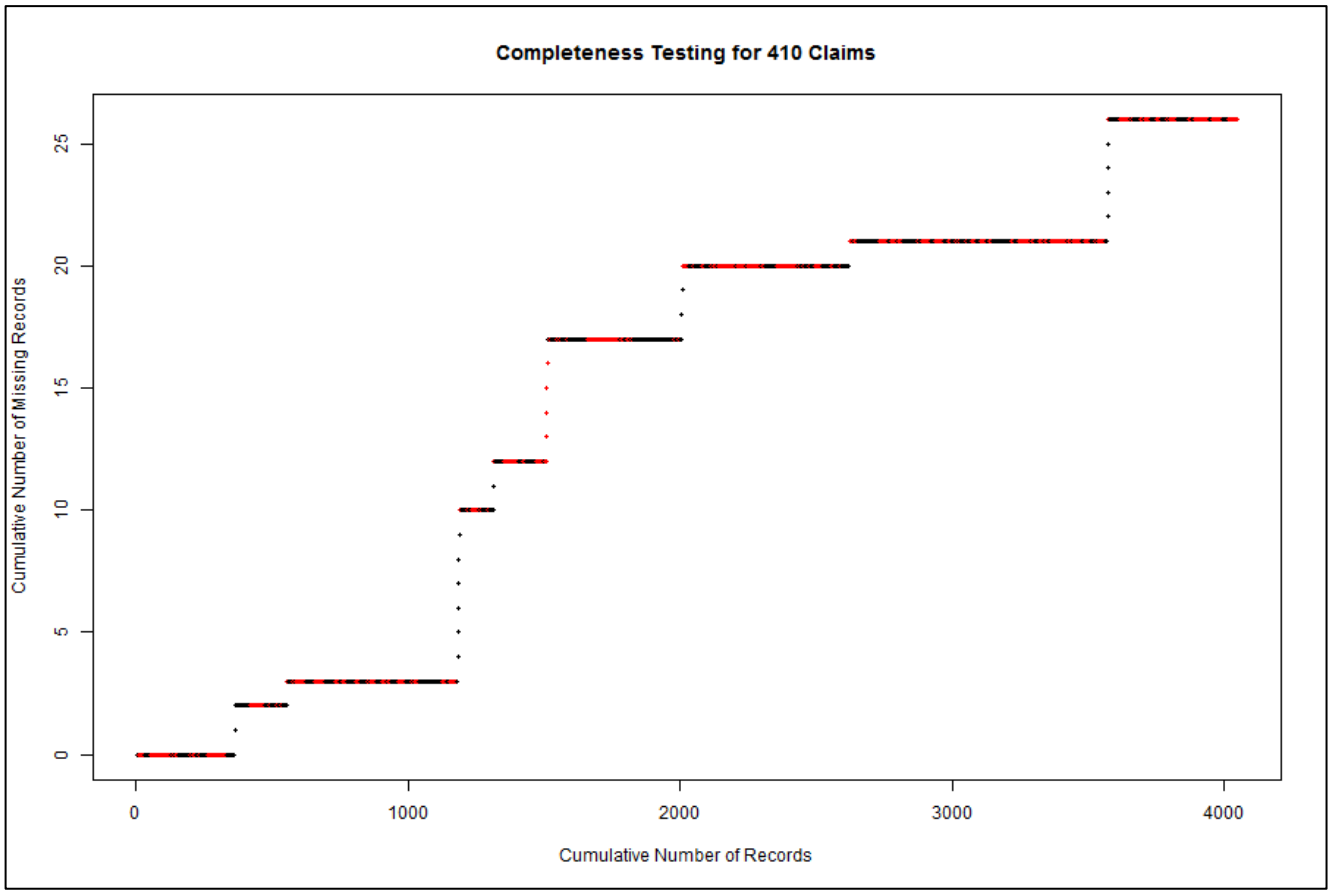


Figure A-4. Sequential plot of missing records plot for 410 individuals. The color of the dots is alternated from red to black going from one person to the next.

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). The attached plot shows the error checking for the 382 claims in question.

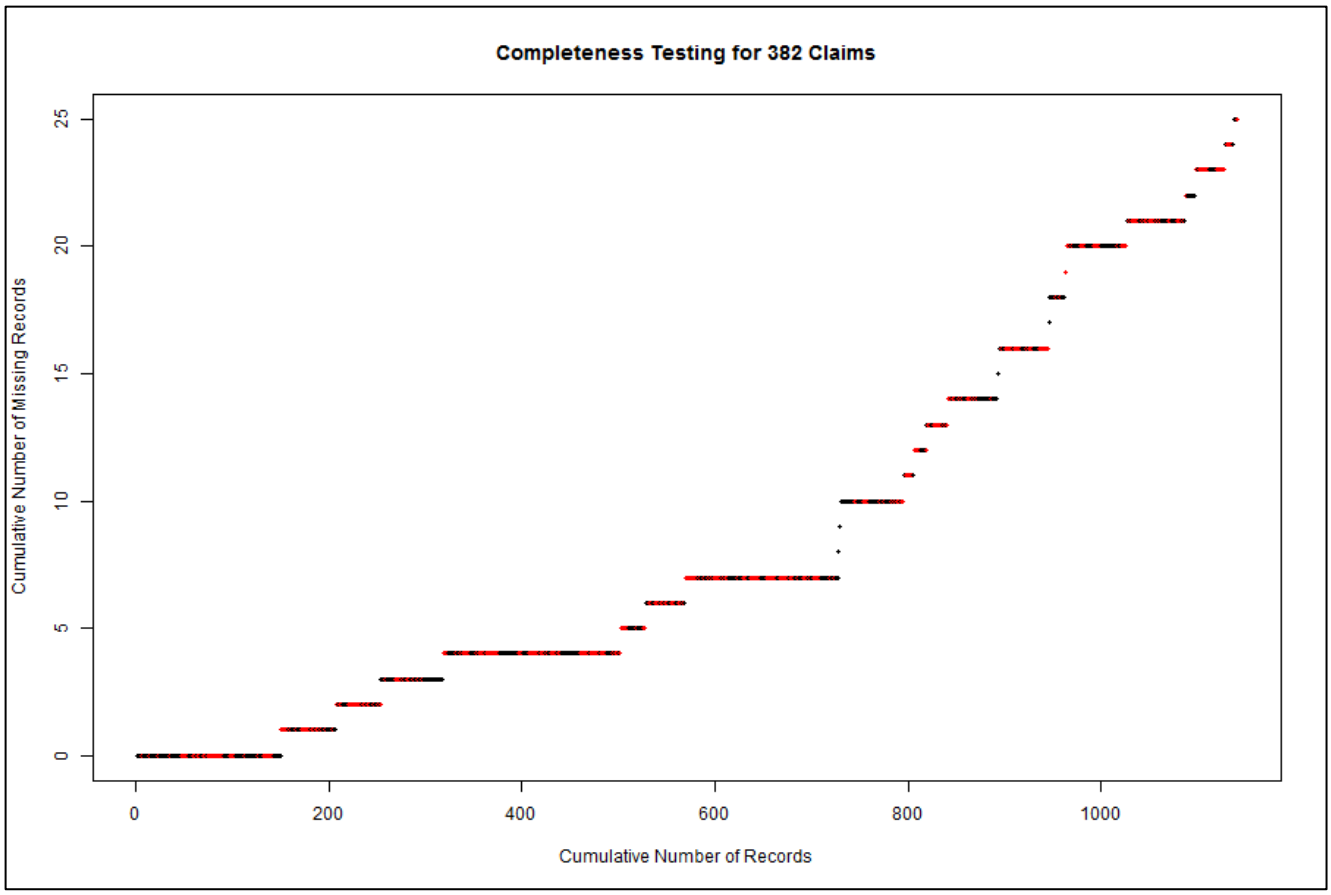


Figure A-5. Sequential plot of missing records plot for 382 individuals. The color of the dots alternates from red to black going from one person to the next.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Savannah River Site Internal Co-Exposure In Vitro Completeness Check – Americium (Am)
May 6, 2020

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 original dataset was transcribed before the development and approval of ORAUT-RPRT-0086, *Internal Dosimetry Co-Exposure Data Completeness Test*. Considering that the intake modeling for americium will be performed under Revision 05 of this document, 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 given individual 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. While investigating discrepancies between the Master List and the americium dataset, it was discovered that SRDB Ref ID 53284 was not entered during the original data entry effort, so it was entered before proceeding with this test. As a result of this review, 484 claims were noted as containing americium results in both the transcribed logbook dataset and NOCTS claim data. These 484 claims are subject to Part 2 completeness testing.

Part 2 (Result-Level) Completeness Check Results
Limiting the Part 2 claim pool to 484 claimants from the claim-level test, the ORAU Team developed a testing plan for this dataset. A list of 107 claims were randomly chosen from the original set of 484 claims. The claim files for these 107 claims were checked. The plots below summarize this information.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

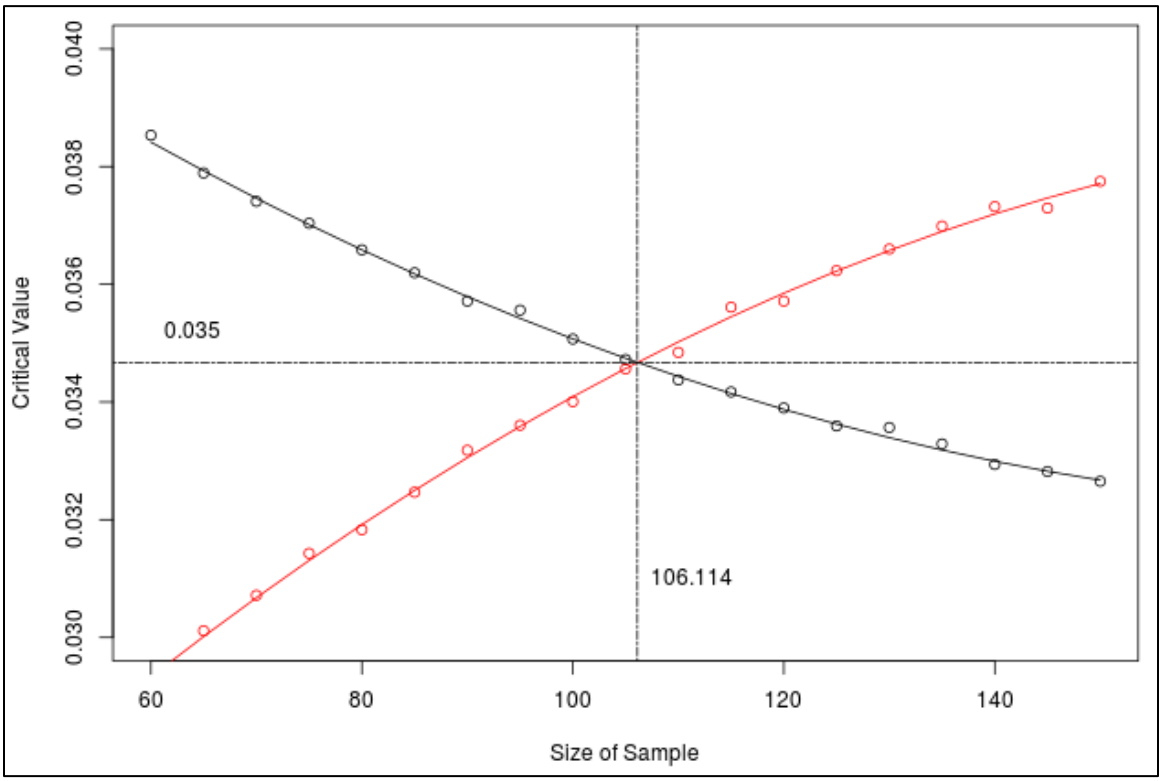


Figure A-6. Plot to determine the minimum number of claims to be sampled.

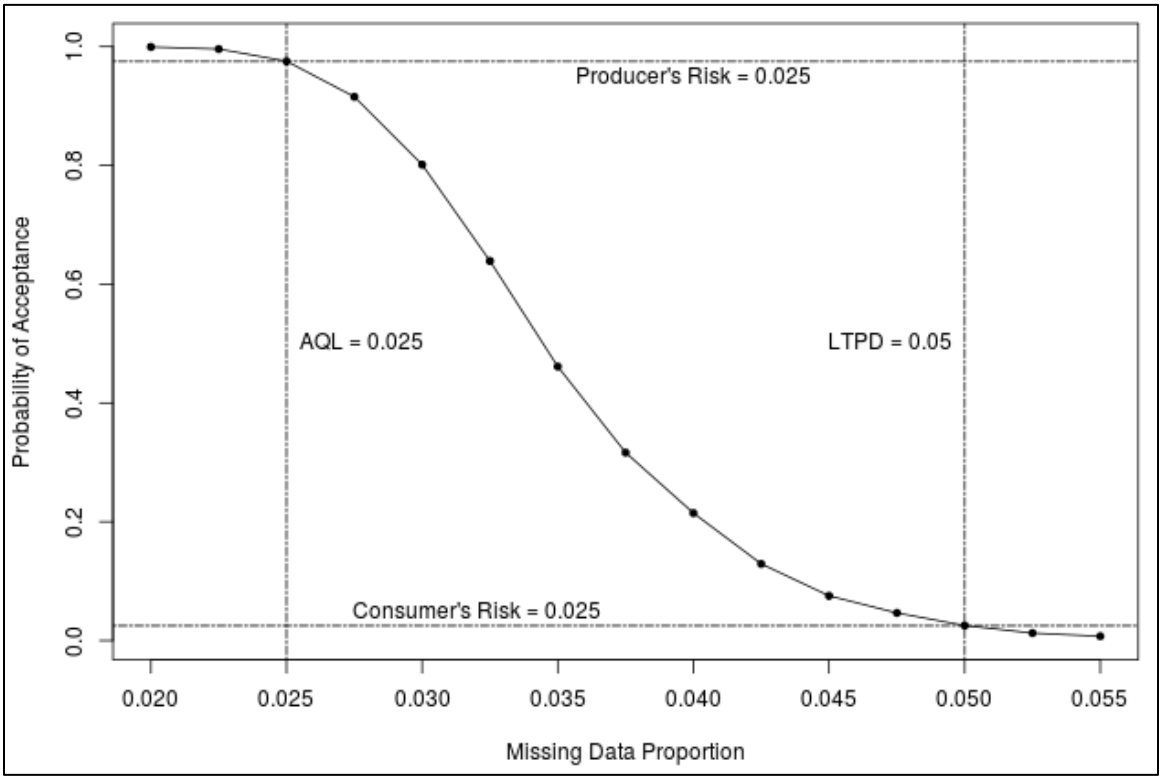


Figure A-7. OC curve for 107 individuals.

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

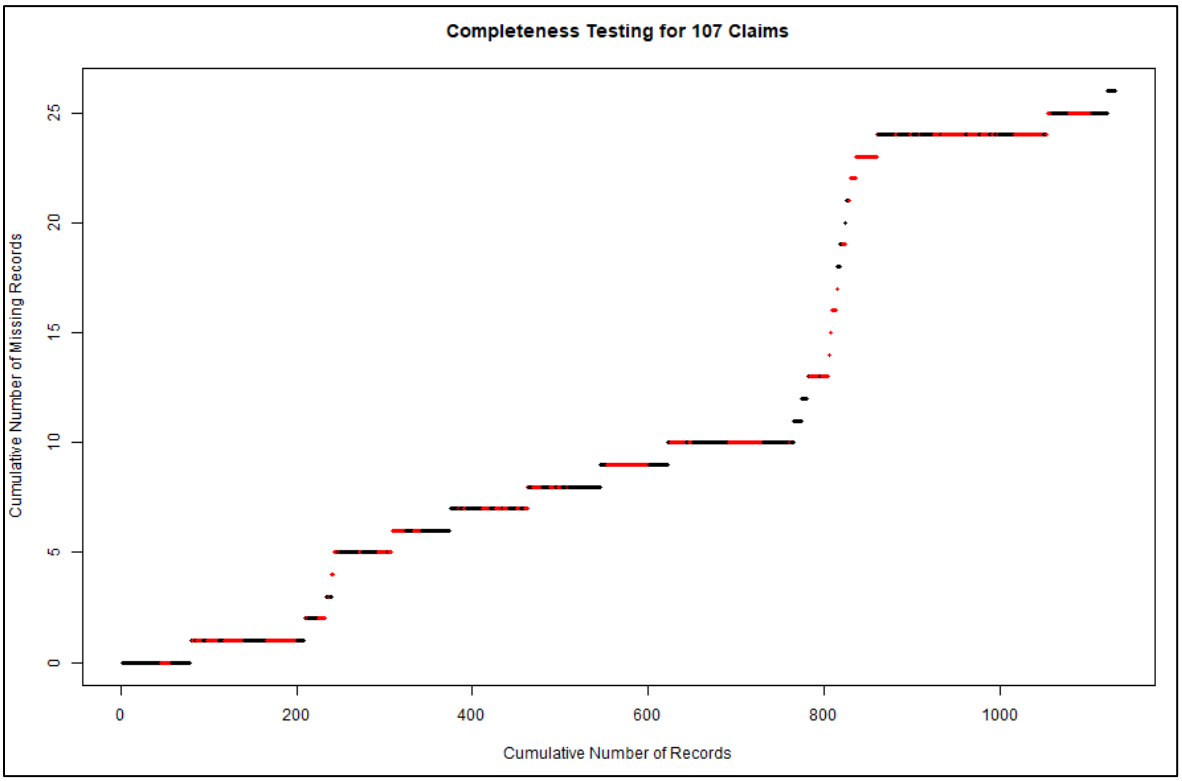
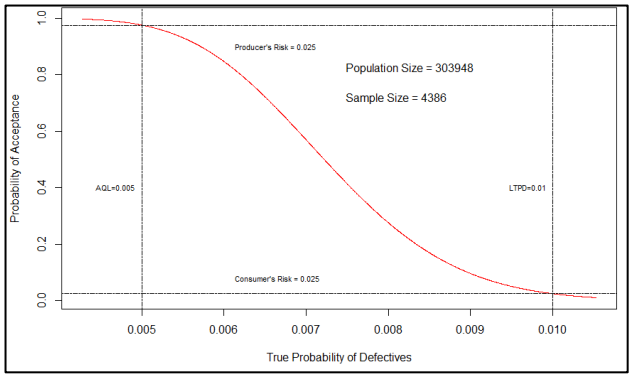
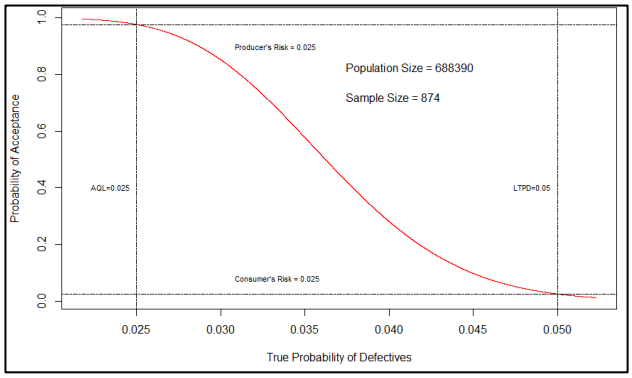


Figure A-8. Sequential plot of missing records for 107 individuals. The color of the dots is alternated from black to red going from one person to the next.

Results
26 missing / 1,132 opportunities = 2.30%
We are 95% confident that the missing record rate is between 1.34% and 3.65%.

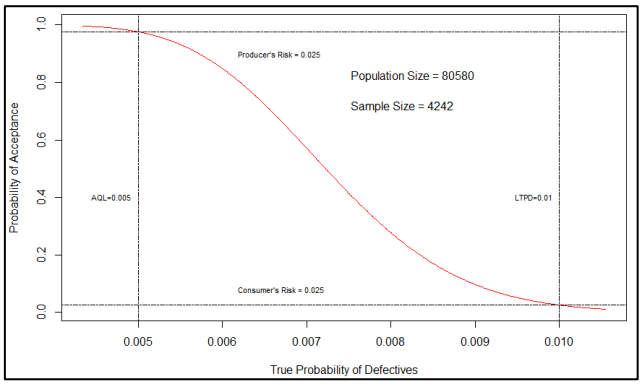
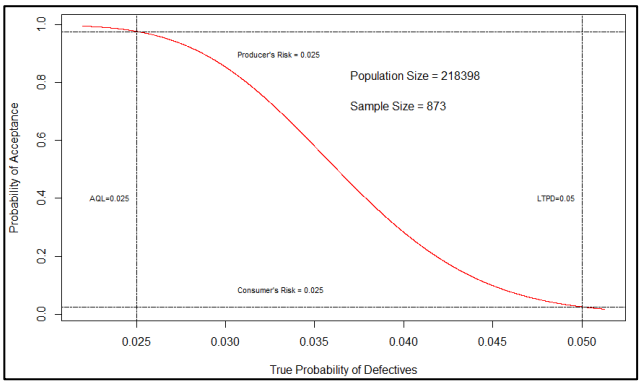
ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

SRS NOCTS In Vitro Data QA Summary
May 9, 2017

Critical Fields Plan	All Fields Plan
Fields Isotope < Result	Fields Critical Fields Last Name (nonblank First Name (nonblank) Middle Name (nonblank) PR (nonblank) Date Units (nonblank) Area (nonblank)
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	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 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%.	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 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.	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 Am QA Summary
May 11, 2020

Critical Fields Plan	All Fields Plan
Fields Payroll ID# Pu dpm/1.5L (12 columns) (nonblank) Pu Report (nonblank) EU dpm/1.5L (10 columns) (nonblank) EU Report (nonblank) Am dpm/1.5L (10 columns) (nonblank) Am Report (nonblank) Np dpm/1.5L (10 columns) (nonblank) Np Report (nonblank)	Fields Critical Fields Employee Last Name Employee First Initial Employee Middle Initial Volume Area Type Bottle Date Remarks (nonblank)
Sampling Plan N = 80,580 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 = 4,242	Sampling Plan N = 218,398 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 45 errors / 4,242 checked = 1.06% Ignoring payroll prefix issues: 18 errors / 4,242 checked = 0.42% We are at least 95% confident that the critical fields transcription error rate is between 0.26% and 0.66%.	Results 9 errors / 873 checked = 1.03% Ignoring payroll prefix issues: 8 errors / 4,242 checked = 0.92% We are at least 95% confident that the all fields transcription error rate is between 0.40% and 1.80%.
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.	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 Np Logbooks QA Summary
February 26, 2018

<table>
<tr><th colspan="2">Critical Fields Plan</th><th colspan="2">All Fields Plan</th></tr>
<tr><td colspan="2">Fields</td><td colspan="2">Fields</td></tr>
<tr><td>Data 1

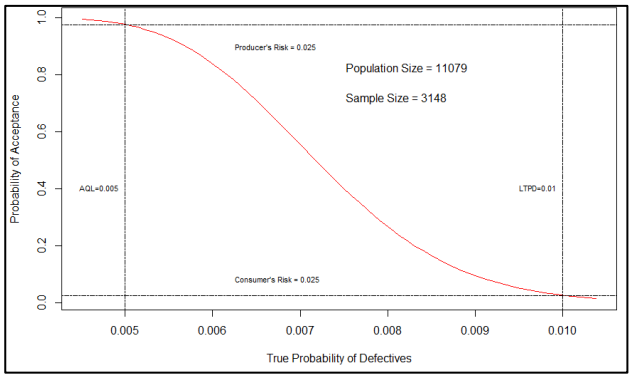
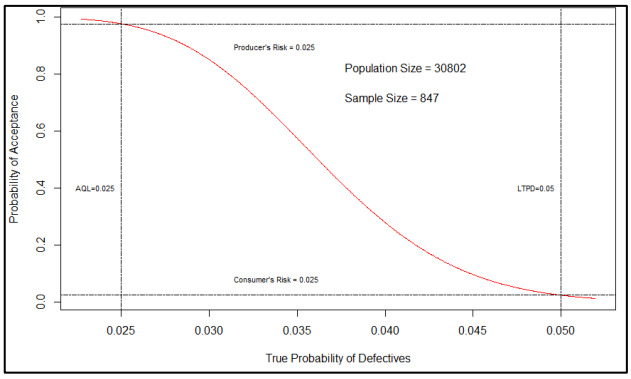
Payroll ID #
Pu results (nonblank)
Pu units (nonblank)
Np results (nonblank)
Np units (nonblank)</td><td>Data 2

Payroll ID #
dpm/1.5L (10 columns) (nonblank)
Report (nonblank)</td><td>Data 1

Critical fields
Area
Employee Last Name
Employee First Initial
Employee Middle Initial
Bottle Date (nonblank)
Rec’d Date (nonblank)
Comment (nonblank)</td><td>Data 2

Critical fields
Employee Last Name
Employee First Initial
Employee Middle Initial
Volume
Area
Bottle Date
Type
Remarks (nonblank)</td></tr>
<tr><td colspan="2">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</td><td colspan="2">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</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td colspan="2">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%.</td><td colspan="2">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%.

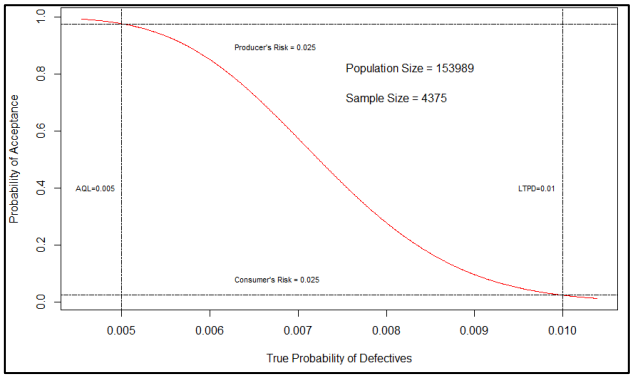
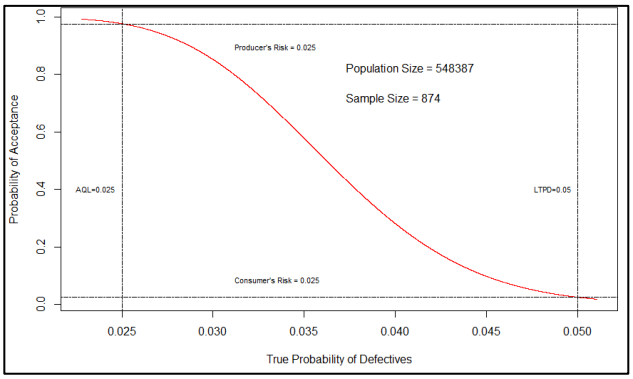
* The sampling plan requires 847 fields to be checked. The other 85 fields were checked because of a coding error in the sampling plan. The additional 85 fields help to narrow the confidence interval.</td></tr>
</table>

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 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. 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 NOCTS WBC QA Summary
June 3, 2016

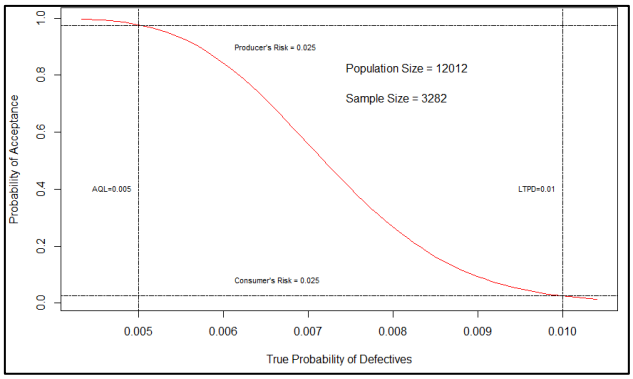
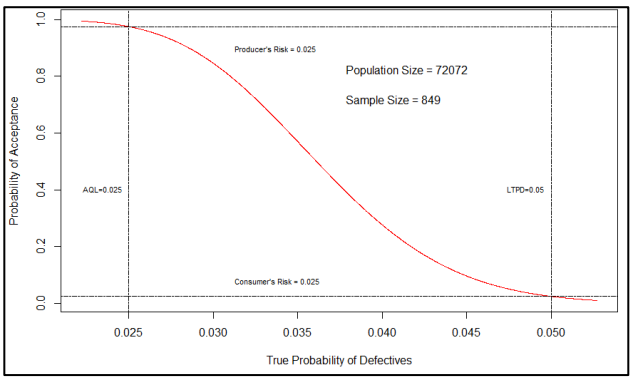
Critical Fields Plan	All Fields Plan
Fields PR Form Type (nonblank) Nuclide gross counts (nonblank) bkg counts (nonblank) net counts (nonblank) NET c/m (nonblank) DIFF counts (nonblank) Result (nCi) (nonblank) MDA @95%CL (counts) (nonblank) MDA @95%CL (nCi) (nonblank) Lung Burden (nCi) (nonblank) Sampling 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%)	Fields Critical Fields Last name Fist 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%)

ATTACHMENT A
QUALITY ASSURANCE SUMMARY (continued)

Critical Fields Plan	All 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 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	All 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%)	Fields PR Date Last name Fist 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	All 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 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 In Vivo CTW QA Summary
October 5, 2017

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	Sampling Plan
Rev4CTW	N = 28,026 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

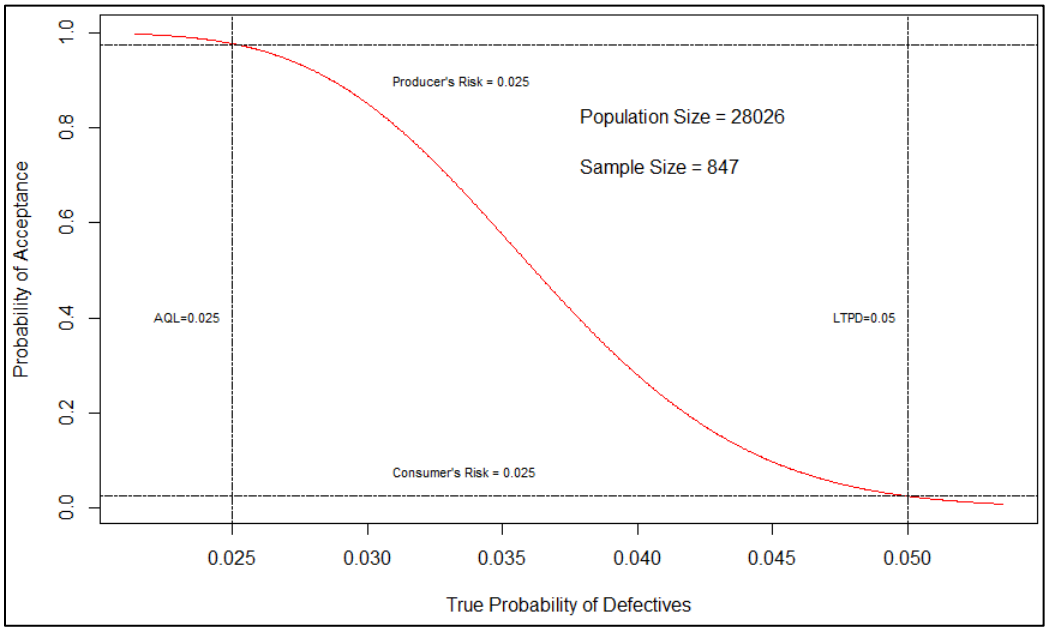


Figure A-9. True probability of defectives versus the probability of acceptance (October 5, 2017).

Results
25 errors / 847 checked = 2.95%

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 1.93% and 4.30%.

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 In Vitro CTW QA Summary
June 1, 2017

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	Sampling Plan
Rev4CTW	N = 100,952 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

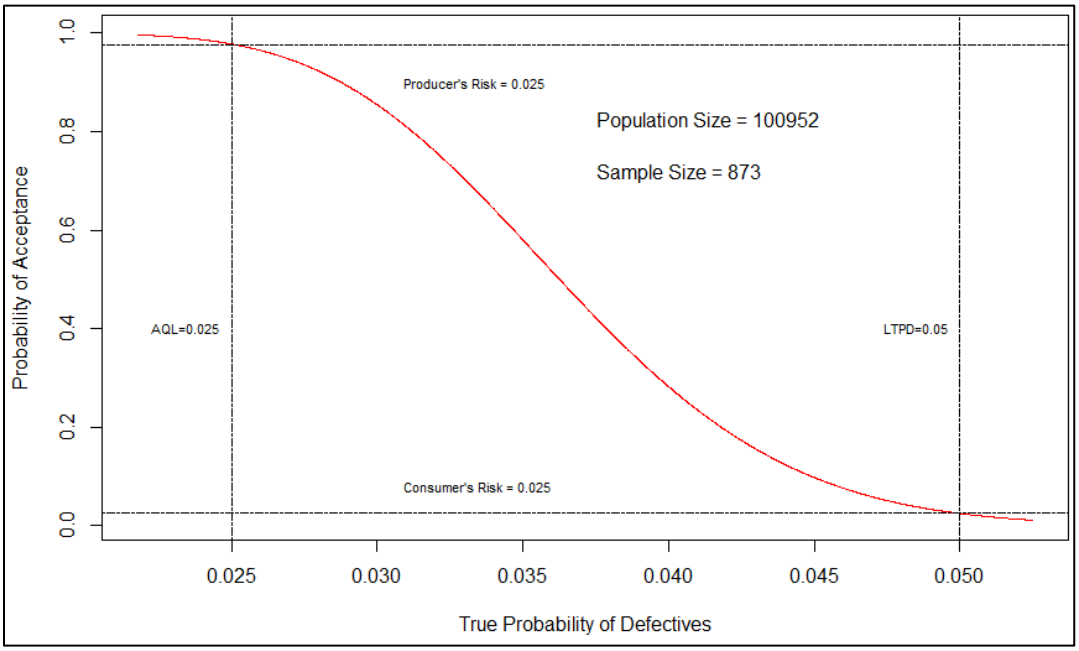


Figure A-10. True probability of defectives versus the probability of acceptance (June 1, 2017).

Results
16 errors / 873 checked = 1.83%

We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 1.05% and 2.95%.

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 Np Logbook CTW QA Summary
March 6, 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	Sampling Plan
Rev4CTW	N = 3,620 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

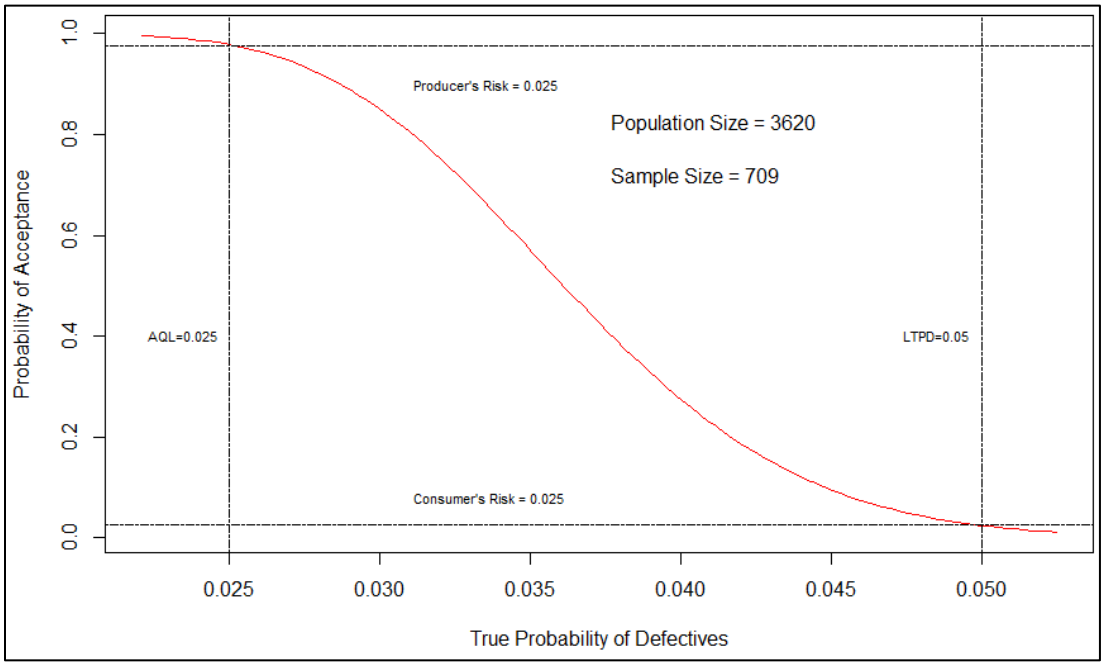


Figure A-11. True probability of defectives versus the probability of acceptance (March 6, 2017).

Results
8 errors / 709 checked = 1.13%

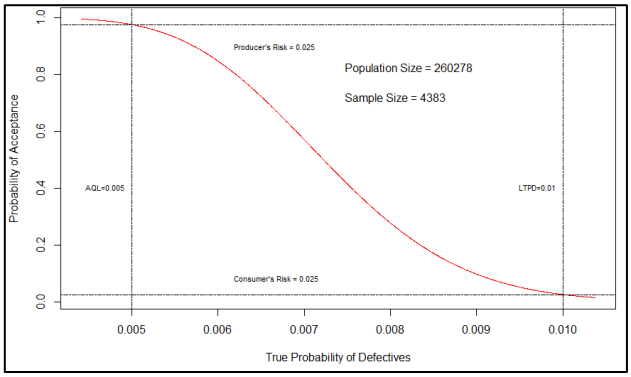
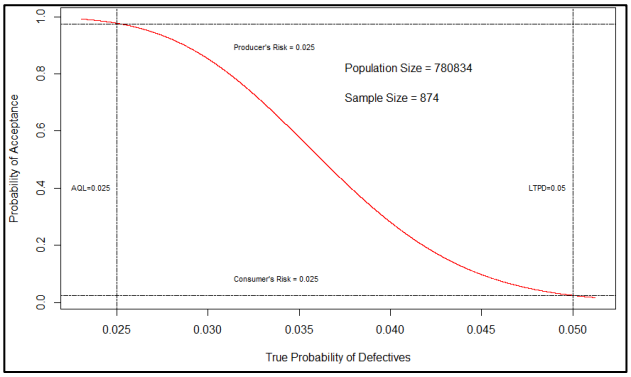
We are at least 95% confident that the classification error rate between CTW determination and the worker history cards is between 0.55% and 2.10%.

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 Tritium QA Summary
May 16, 2016

Critical Fields Plan	All Fields Plan
Fields Result	Fields Result Date Area
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	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 14 errors / 4,383 checked = 0.32% We are 96.32% confident that the critical field transcription error rate is between 0.18% and 0.53%.	Results 2 errors / 874 checked = 0.23% We are 97.31% 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 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).

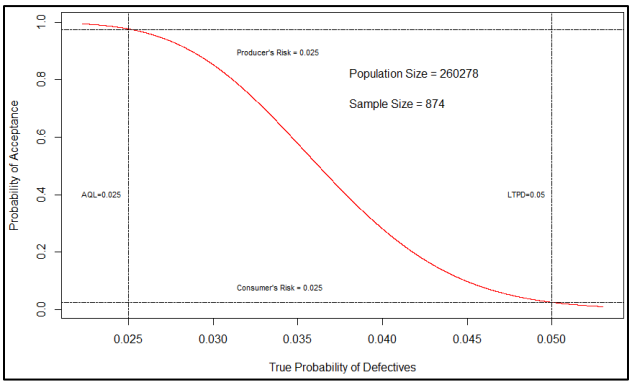
All Fields Plan

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

There is a 95% confidence 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 Am Logbook CTW QA Report
May 12, 2020

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).

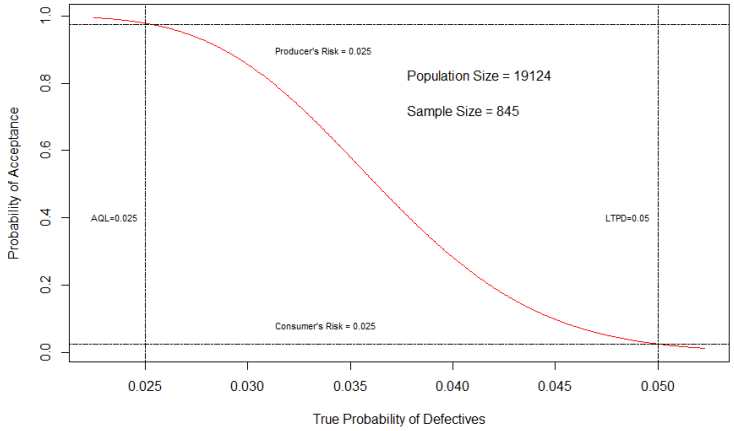
All Fields Plan

Fields

Rev4CTW

Sampling Plan

N = 19,124
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

8 errors / 845 checked = 0.95%

There is at least 95% confidence that the classification error rate between CTW determination and the worker history cards is between 0.42% and 1.84%.

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 B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES

LIST OF FIGURES

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

Work tasks performed on the installation of the Alpha Decontamination and Decommissioning (D&D) facility on November 18 and 19, 1981, by Construction and Maintenance are shown in Figure B-1.

Work tasks performed with the modification of Cells 10 and 11 from late January 1982 through early February 1982 by Construction and Maintenance are shown in Figure B-2. Both groups poured cement in performance of respective tasks.

A Job Plan describing work performed by Maintenance to prepare for work to be done by Construction is shown in Figure B-3.

Work tasks performed with the modification of the Californium Processing Facility (CPF) in April 1984 Construction, Maintenance, and E&I are shown in Figure B-4.

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

OSR 14-8(Rev. 9-61)

SPECIAL WORK PERMIT

TIME: 8:00 AM / 4:30 PM | BLDG.: 773-A | DATE: 11-18-81 / 11-25-81 | SWP NO.:

LOCATION: Bldg. 773-A F-Wing

DEPARTMENT(S):

JOB DESCRIPTION: Project 2183. Install Alpha D&D Facility, Install HVAC, pipe & Electrical service. Remove trench Covers

SPECIAL INSTRUCTIONS – MONITORING: ☐ AT START OF JOB ☒ INTERMITTENT ☐ CONTINUOUS

INSTRUCTIONS

WHEN MORE THAN ONE RATE IS LISTED ON SWP, STATE WHICH RATE WAS USED.

ENTER TIME IN RDZ ON TIME SHEET.

HEALTH PHYSICS SHALL BE PRESENT FOR LINE BREAKS.

PERSONAL SURVEY IS REQUIRED WHEN LEAVING RADIATION DANGER ZONE.

☒ NO PERSONAL OUTER CLOTHING

☒ SPECIAL PROTECTION REQUIRED FOR CUTS OR ABRASIONS.

☐ TAPE GLOVES-CANVAS BOOTS TO COVER-ALLS.

☐ PROVIDE TIMEKEEPER.

☐ PRE-PLAN MEETING REQUIRED.

☒ CONTACT HEALTH PHYSICS FOR A SURVEY BEFORE STARTING WORK IN A NEW LOCATION.

☐ PROVIDE ASSISTANCE FOR THE REMOVAL OF PROTECTIVE CLOTHING.

☐ GIVE BIO-ASSAY SAMPLE BEFORE LEAVING BUILDING.

PROTECTIVE CLOTHING

HEAD	CAP	X
	HOOD	
FEET	SHOE COVERS	X
	RUBBERS	
	CANVAS BOOTS	
HANDS	CANVAS GLOVES / Leather	X
	RUBBERIZED CANVAS	
	SURGEONS - SHORT RUBBER	
	RUBBER GAUNTLET	
BODY	COVERALLS - 1 PAIR / 2 PAIR	X
	LAB COAT	
	SUIT ☐ RUBBER ☐ PLASTIC	
RESP.	☐ AIR PAK ☐ AIR LINE MASK	
	ASSAULT MASK	
MET.	FILM BADGE	X
	PENCILS	X
	TLD (neutron)	

EXPOSURE

	RATE	UNITS	DISTANCE	TIME FOR 50 mrem OR 250 μc H³	BODY OR HANDS	SURVEYED BY	TIME
A	2	mrem/hr	N+8	8 hr	BODY	F.B.S.	AM PM
B					BODY HANDS		AM PM
C					BODY HANDS		AM PM
D					BODY HANDS		AM PM

APPROVALS

DIVISION	8:00 TO 4:30 SHIFT	TO	SHIFT	TO	SHIFT
HEALTH PHYSICS	[redacted]				
OPERATIONS					
MAINTENANCE					
Const.					

Figure B-1a. Work tasks performed on the installation of the Alpha D&D facility on November 18 and 19, 1981 [DuPont 1981].

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

JOB PLAN

Date: 11/19/81
Time of Operation:
Contact: [redacted]
Done by: MAINT., E&I, H.P.
Phone:

PROTECTIVE CLOTHING	Rq'd
1. Coveralls (One) (Two)	yes
2. Respirator	yes ~~no~~
3. Breathing Air	no
4. Cap (Hood)	yes ~~no~~
5. Shoe Covers Or Building Shoes	yes
6. Gloves	yes
7. TLD Badge (βγ)	yes
8. Self-reading Dosimeter	no
9. Safety Belt	no
0. Rubber Boots	no
1. Lab Coat or coveralls	~~yes~~ no
2. RT-1 Pers. Rad. Monitor	no
3. Neutron Badge	yes
4.	

JOB EVALUATION	Rq'd

Operation

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

Title of Job:

① INSTALL NEW WALL IN F-062, PANEL FAB. (MAINT)
② E&I TO LOCK OUT PANELS AND REMOVE ELECTRICAL LINES, BOXES, AND CONDUIT.
③ REMOVE WALL UP TO APPROX. 9' HIGH BETWEEN F-055 & F-062 TO INCLUDE DOOR. (MAINT)
④ E&I TO INSTALL WIRING, SWITCHES, & CONDUIT FOR POWER TO OUTLETS AND LIGHTING IN THE NEW WALL. (ITEM #1 ABOVE)

Figure B-1b. Work tasks performed on the installation of the Alpha D&D facility on November 18 and 19, 1981, continued [DuPont 1981].

JOB PLAN

Date: 1-29-82
Time of Operation: 9 1 Pm.
Contact: [redacted]
Done by:
Phone: 873J

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

Operation

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

Title of Job:

Pour Concrete into old Cell 10 & 11 Sumps.

Figure B-2a. Work tasks performed with the modification of Cells 10 and 11 from late January 1982 through early February 1982 [DuPont 1982].

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

JOB PLAN

Date: 2-2-82
Time of Operation: 0900
Contact: [redacted]
Done by: DLC & Maint.
Phone: 2735

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

Operation

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

Title of Job:

Fill old Cells 10 & 11 ~~with~~ exhaust ducts with Concrete.

Fresh air required to work on Roof.

Figure B-2b. Work tasks performed with the modification of Cells 10 and 11 from late January 1982 through early February 1982, continued [DuPont 1982].

JOB PLAN

Date: 2/4/82
Time of Operation: 0800
Contact: [redacted]
Done by: Construction
Phone: 2735

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

Operation

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

Title of Job:

(Lead)
Install band in Bottom of Windows 10 - 11 & 12.

Remove rubber Shoe Covers, Gloves and Coveralls before leaving Tent.

Figure B-2c. Work tasks performed with the modification of Cells 10 and 11 from late January 1982 through early February 1982, continued [DuPont 1982].

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

JOB PL

Date: 2/10/82
Time of Operation: 8 — 4
Contact: [redacted]
Done by: Construction
Phone: 2735

Operation

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

Title of Job:

Pour Concrete around Window
frame in Cells 10-11 + 12

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

Figure B-2d. Work tasks performed with the modification of Cells 10 and 11 from late January 1982 through early February 1982, continued [DuPont 1982].

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

167

JOB PLAN

Date: 4/21/83
Time of Operation: 9 am
Contact: [redacted]
Done by: Wheatley
Phone: 2156

PROTECTIVE CLOTHING	Rq'd
1. Coveralls (One) Two	X
2. Respirator	X
3. Breathing Air	
4. Cap (Hood)	X
5. Shoe Covers	X
6. Gloves	X
7. TLD Badge (βγ)	X
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?	NO
2. Rigging approved?	—
3. Building Services?	YES
4. Will operation effect other jobs and/or personnel?	NO
5. Does job require a special procedure?	NO

Operation

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

Title of Job:

Disconnect spool piece and U loop from spare (locked out) low level drain line in B002 and C002-773A. Install blind flanges on open ends. (4/21)
Disconnect spare, locked out low level drain U loop at 735-A + install blind flanges. (4/22, 4-12 shift)
Replace 735 U loop 4/23.
Replace 773 U loops week of 4/25.
Purpose of job is for construction to cut out pipe samples from 776-A.
A.O. will prepare areas prior to any disconnects.

Figure B-3. Job plan describing work performed by Maintenance to prepare for work to be done by Construction [DuPont 1983a].

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

JOB PLAN

Date: 4-11-84
Time of Operation: PM
Contact: [redacted]
Done by: [illegible]
Phone:

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

Operation

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

Title of Job:

Screws on brass on the pneumatic valve over glove boxes, CPF

Figure B-4a. Work tasks performed with the modification of the CPF in April 1984 [DuPont 1984].

Date: 4-13-84
Time of Operation: 9 AM
Contact: [redacted]
Done by: [illegible]
Phone: 3035

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

JOB EVALUATION	Rq'd
15. Does job alter ventilation patterns?	NA
16. Rigging approved?	

Operation

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

(CPF — Rear cell 1+2)

Title of Job:

(1) Remove and replace the cell inflatable seal line.

(2) Remove the 2 cell vac lines.
Between glove box 1 + 2
(a) as each pipe is unscrewed place tape over the opening and place the flexable line in place

(b) South of glove box 1 same as (a)

Figure B-4b. Work tasks performed with the modification of the CPF in April 1984, continued [DuPont 1984].

ATTACHMENT B
HIGH-LEVEL CAVE JOB PLAN EXAMPLES (continued)

JOB PLAN

Date: 4-15-84
Time of Operation: 8-4
Contact: [redacted]
Done by: Maint
Phone: 2319

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

Operation

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

Title of Job: Adjust cams in exhaust filter housing in CPF

Figure B-4c. Work tasks performed with the modification of the CPF in April 1984, continued [DuPont 1984].

ATTACHMENT C
BIOASSAY DATA TYPES AND FREQUENCIES

LIST OF TABLES

ATTACHMENT C
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table C-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	–[a]
71972	72131	72200	72248	72325	72394	72828	73031	–[a]
71973	72134	72202	72249	72328	72406	72831	73035	–[a]
71974	72137	72205	72252	72330	72408	72833	73036	–[a]
71975	72138	72206	72253	72331	72413	72838	73039	–[a]
71976	72144	72209	72255	72332	72417	72839	73041	–[a]

a. None.

Table C-2. 1968 bioassay frequencies (samples per year by analysis type) [DuPont 1968b].[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 C
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table C-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.

Table C-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 C
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 C
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table C-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 C
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.

Table C-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 C
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 = Separations Engineering Division; SCD = Separations 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 C
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

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

ATTACHMENT C
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Personnel work assignment	Pu samples	EU samples	NU samples	FP/IA samples	Am/ Cm/ Cf samples	Np samples	Sr samples	In vivo counts[c]
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 C
BIOASSAY DATA TYPES AND FREQUENCIES (continued)

Table C-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 D
EVALUATION OF HIGH-VARIABILITY AMERICIUM DATA

LIST OF TABLES

LIST OF FIGURES

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

An SC&A memorandum of February 24, 2014, to the SRS Work Group contains an examination of raw trivalent actinide (americium, curium, and californium) urinalysis data that were used to calculate thorium intakes for the SRS internal dose co-exposure study [SC&A 2014]. The examination focused on results greater than the MDA that exhibited a large variability between multiple counts of the same sample, or where the reported result was inconsistent with the individual sample counts. Individual urine samples might be counted anywhere from 1 to 10 times, with 2 or 4 times being common. Large variability occurs when the results of these repeat counts of the same sample are widely different. An inconsistent reported result occurs when the reported result does not match the average of the individual counts of the sample. The examination consisted of the compilation of >MDA results, highlighting of results with inconsistency or large variability, and identification of workers who were chelated. This attachment provides further evaluation of those results to determine the potential significance of the highlighted results as well as evaluation of the removal of chelated individuals. For the highlighted results, only the inconsistent and high-variability results greater than 1 dpm/d were evaluated further.

During the preparation of the response to SC&A's findings, ORAUT-RPRT-0053 was revised to alter the one person–one sample analysis method to the TWOPOS method [ORAUT 2014a]. An additional change with the TWOPOS method is to consider all negative (in the numeric sense of being less than zero rather than less than the MDA) sample results as "<0" censored results. The impact of the high-variability and inconsistent results and removal of the chelated individuals were evaluated using the TWOPOS method.[1]

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

Results Greater than 3 dpm/1.5L

SC&A found 220 results greater than 3 dpm/1.5L. These 220 samples were from 35 different individuals. Twenty-one of those individuals had received DTPA. Of these 220 results, 28 results had high variability between the dpm/1.5L values. An additional 20 results had inconsistent results between the reported and dpm/1.5L values.

Of the 28 results with high variability, 17 were from one person who had already been excluded from the co-exposure study; therefore, the variability in those data is not relevant. Urinalysis results influenced by administration of DTPA have been removed from this revision of the co-exposure study. Therefore, the data from any other individuals whose urinalysis results were influenced by administration of DTPA do not need any further evaluation because they are excluded.

After exclusion of urinalysis results influenced by administration of DTPA, 21 samples greater than 3 dpm/1.5L remained. Of these, only five individuals not receiving DTPA had highlighted results. Two individuals had one sample each exhibiting high variability, two individuals had one sample each with an inconsistent result, and one individual had two samples with inconsistent results, one of which was a typographical error. These individuals had a total of 21 results >3 dpm/1.5L.

[1] This evaluation was conducted before stratification of the coworker data into CTW and nonCTW strata.

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

A broad-scale view of the trends in variability of all the trivalent actinide bioassay data without chelation can be seen in Figure D-1. This figure plots the coefficient of variation in the count-specific results for each sample as a function of sample result. Figure D-2 is a smaller scale view of the same data focusing on results less than 5 dpm/d. The trend line is the 95th percentile of the coefficient of variation, meaning only 5% of the sample results are above this line. The trend line behaves as expected, with higher values for very small results and decreasing as a function of increasing sample results. There are a few results that can be perceived to be high outliers, but most of these results have straightforward reasons for the high variability and will most likely be excluded in the next revision of the co-exposure study.

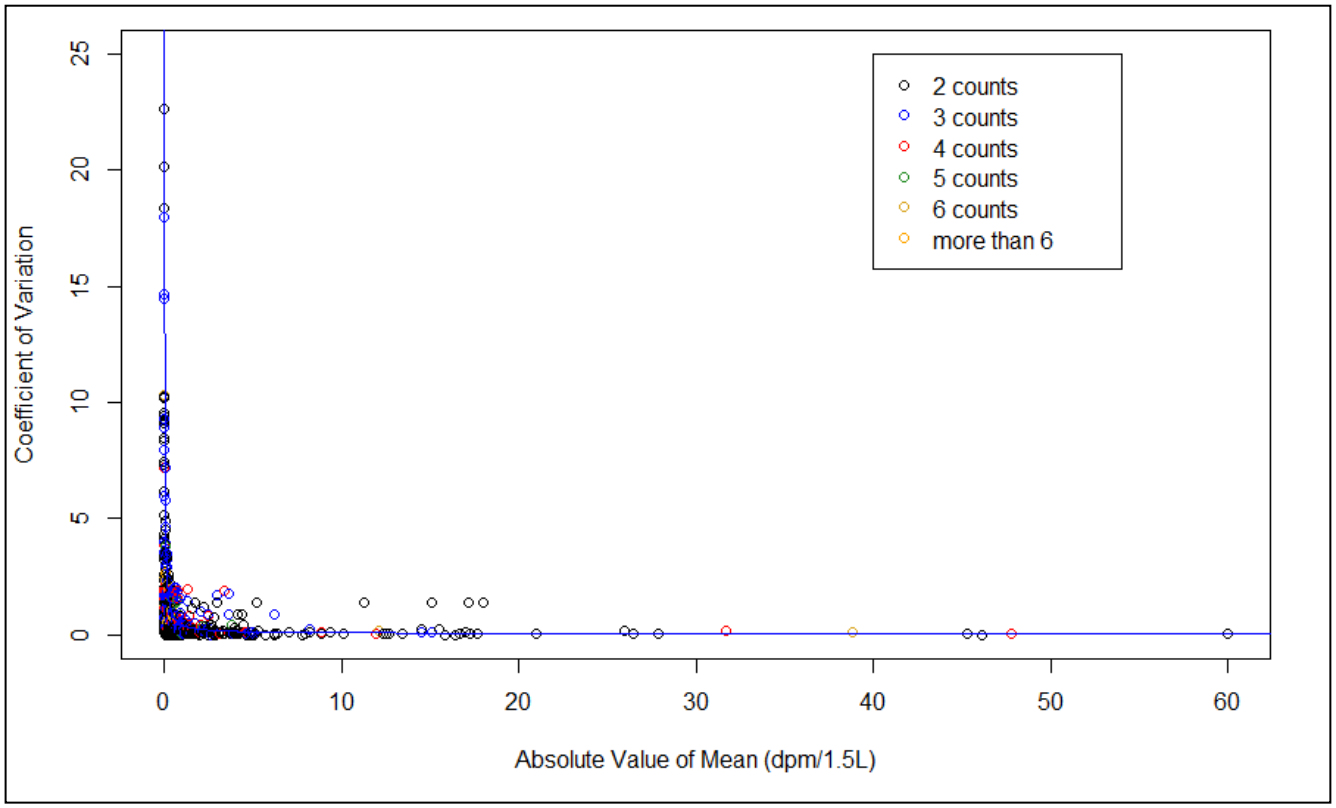


Figure D-1. Coefficient of variation of count-specific results.

Results Between 1 and 3 dpm/1.5L

SC&A found 116 results between 1 and 3 dpm/1.5L from 49 different individuals. Twenty-one of the individuals received DTPA. Of the 116 results, 29 had high variability between the dpm/1.5L values. An additional five results had inconsistent results between the reported and dpm/1.5L values.

Of the 29 results with high variability, 14 were from [redacted] who had already been excluded from the co-exposure study because the high americium results were from [redacted], so the variability in those data is not relevant. Urinalysis results influenced by administration of DTPA have been removed from this revision of the co-exposure study. Therefore, the data from any other individuals whose urinalysis results were influenced by administration of DTPA do not need any further evaluation because they are excluded.

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

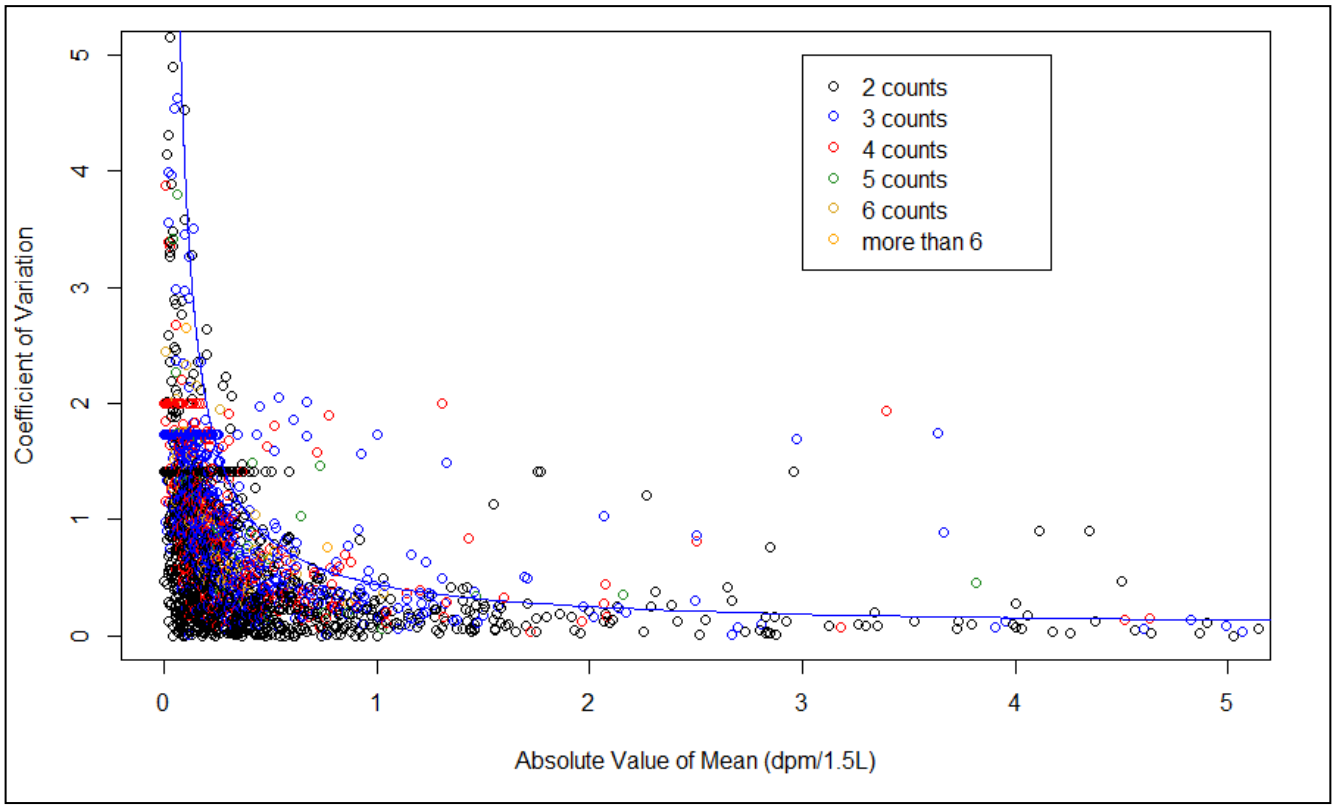


Figure D-2. Coefficient of variation of count-specific results, small scale.

After exclusion of urinalysis results influenced by administration of DTPA, 31 sample results between 1 and 3 dpm/1.5L remained. Of these, only three individuals not receiving DTPA had highlighted results.

All three individuals had one result with high variability. These individuals had a total of four results between 1 and 3 dpm/1.5L. Only one had a result greater than 3 dpm/1.5L, and that result was not highlighted.

Conclusions

Table D-1 summarizes the data SC&A reviewed that was greater than 1 dpm/d and the portion that had high variability. Only 4 of 52 samples >1 dpm/d unaffected by chelation had high variability. Two of those were characterized as highly variable due to issues with data entry rather than with the site's bioassay program. This means that, of the samples used in the co-exposure study, less than 4% had high variability as defined by SC&A due to potential issues with the site's bioassay program. This low percentage of individual disc variability and uncertainty is subsumed under the statistical analysis of all the samples collectively. All of the uncertainties discussed by SC&A are much less than the minimum GSD of 3.0 used for co-exposure study intakes. Therefore, the conclusion is that aliquot variability has an insignificant effect on the overall results and the data can be used as is.

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

Table D-1. Summary of data >1 dpm/d.

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

a. Excluding high variability due to data entry issues.
b. 14 of these 29 samples are from one person.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018

TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

E.1 SOURCE DATA AND DATA PREPARATION INSTRUCTIONS

SOURCE DATA
All files in this section are at "O:\\Coworker Data\Master Sites Repository\SRS\OTIB-0081 Rev 04\stat instructions source data". 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

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
- **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
- **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
- **MOT Corrections 5:** MOT corrections 2018-10-02.xlsx

Other Files:
- **Chelation Data:** SRS Chelation Data_Payroll ID's added_082514.xlsx
- **SRS NOCTS Names:** NioshClaims_With_Names.csv
- **SRS NOCTS SSNs:** SRS SSNs.csv
- In-vitro nuclide list.xlsx

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

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 and place them in O:\Coworker Data\Master Sites Repository\SRS\OTIB-0081 Rev 04\SRS Files Ready for Cleanup and Stat Analysis.

Renamed files, to be used with the individual nuclide sections below, are as follows:

- **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
- **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.
- 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.

E.2 MASTER OCCUPATION TABLE INSTRUCTIONS

1. Merge the following files into one master occupation table **(CTW Master)**.

- Np data
- WBC data
- MFPG WHC data

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- Am data
- CTW Master Update Part 1, 2, 3, and 4

Table E-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.

Table E-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)	Fist 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 (WkHxFile Name)
WkHxPage	Page[b]	Page[c]	Page[d]	Page[e]	Page[f]	OccPage	WkHxFile Page[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.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

g. Only if the WkHxFile source is the WkHxFileName column, otherwise leave blank.

1. Remove duplicate lines.

2. 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.

3. 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.

4. 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.

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

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

   a. Set CTW = ‘Y’.
   b. Otherwise, set CTW = ‘N’.

Table E-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.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

Table E-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
Health Physics	Supervisor
Human Resources	Technician
Instructor	

a. Ignore capitalization differences.

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

2. 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] 7, 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.
   n. Claim [redacted], PRID [redacted], nonCTW after 11/02/1975.

E.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.

   a. Match the person based on the following fields given in preference order:

      i. NIOSH ID.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

ii. PRID.
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.
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.

E.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.”

E.4.1 All Nuclides

Correct illegible dates (illegible fields are indicated with Xs):

- 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.

E.4.2 Mixed Fission Products (MFPBeta/strontium)

New corrections file: *stat corrections 2018-12-05.xlsx* in O:\Coworker Data\Master Sites Repository\SRS\OTIB-0081 Rev 04\stat instructions source data.

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.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- 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.
  - With X. = "<" and Result =
    - 300.
    - 500.

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

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
    - If X. is blank: dpm/1.5L.
- Incident corrections:
  - Claim [redacted]: incident on 04/21/1962. Infer a result of <60 dpm/1.5L on 04/20/1962.

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).

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

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
  – 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.

E.4.3 Plutonium

New corrections file: *In-vitro stat corrections 2018-11-15.xlsx* in O:\Coworker Data\Working Files\SRS\Coworker Study\OTIB-0081 Rev 04\source data.

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:

    o "LIP" or "IA."

    o 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 puncture wound incurred at this time so results are not representative of coworkers (co-exposure intake model assumes inhalation intakes).

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

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.
  - 0.1 for 05/02/1962 and after.
- 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.
  - 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 06/08/1960. Infer a result of <0.05 dpm/day on 06/07/1960.
  - Claim [redacted]: Incident on 01/24/1968. Infer a result of 0.1 dpm/day on 01/23/1968.
  - Claim [redacted]: Incident on 01/13/1975. Infer a result of <0.1 dpm/day on 01/12/1975.
  - Claim [redacted]: Incident on 03/14/1973. Infer a result of <0.1 dpm/day on 03/13/1973.
  - Claim [redacted]: Incident on 07/12/1974. Infer a result of <0.1 dpm/day on 07/11/1974.
  - Claim [redacted]: Incident on 07/22/1965. Infer a result of <0.1 dpm/day on 07/21/1965.
  - Claim [redacted]: Incident on 07/05/1973. Infer a result of <0.1 dpm/day on 07/04/1973.
  - Claim [redacted]: Incident on 05/20/1973. Infer a result of <0.1 dpm/day on 05/19/1973.
  - Claim [redacted]: Incident on 12/02/1975. Infer a result of <0.1 dpm/day on 12/01/1975.
  - Claim [redacted]: Incident on 08/19/1971. Infer a result of <0.1 dpm/day on 08/18/1971.
  - Claim [redacted]: Incident on 03/11/1985. Infer a result of <0.18 dpm/day on 03/10/1985.

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 E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- 1954–1959
- 1960–05/01/1962
- 05/02/1962–1965
- 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.

E.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:

  – 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

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

  - 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 07/13/1969. Infer a result of <1 dpm/1.5L on 07/12/1969.
  – Claim [redacted]: Incident on 10/31/1972. Infer a result of <5 ug/L on 10/30/1972.

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 1.5 L.

  – 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. 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
    - 1986–1990

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

  - 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
    - 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 depleted uranium).

- 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
    - 1987–1988
    - 1989–1990

E.4.5 Cesium-137

New corrections file: *In-vivo stat corrections 2018-12-11.xlsx* in O:\Coworker Data\Master Sites Repository\SRS\OTIB-0081 Rev 04\stat instructions source data.

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”
    - “New Employee”

  - If Date is blank or nonsensical.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

  - 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:

  - 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 Jan. 1974.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- **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**
  - 11/1989 through 12/1990: **ABACOS**

- Perform the statistical analysis in accordance with the TWOPOS method in the latest version RPRT-0053:
  - 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
      - 1972–1973
    - For nonCTW, combine the years:
      - 1960–1961
      - 1965–1966
      - 1969–1970

E.4.6 Cobalt-60 (Mixed Fission Products Gamma)

New corrections file: *In-vitro stat corrections 2018-12-05.xlsx* in O:\Coworker Data\Master Sites Repository\SRS\OTIB-0081 Rev 04\stat instructions source data.

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

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

  - FP/IA
  - IA
  - IA-G
  - IA GAMMA

- 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*).
  - 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.

E.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 E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (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.

  - Form.Type = "BB" and Nuclide = "I-131"
  - 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 = 09/15/1983 (*analyzer malfunction*).
  - With Claim = [redacted] and Date = 09/20/1983 (*analyzer malfunction*).
  - With Claim = [redacted] and Date = 11/30/1983 (*analyzer malfunction*).
  - With Claim = [redacted] and Date = 04/01/1986 (*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 x (I-131 "DIFF counts")
  - If Form.Type = "BB" and Date > 12/31/1974:
    nCi Np-237 = 0.0125 x (I-131 "DIFF counts")
  - If Form.Type = "IVCR":
    nCi Np-237 = 0.211 × Cr-51 "MDA @95%CL (nCi)" × $\frac{\text{Cr-51 } \textit{DIFF counts}}{\text{Cr-51 } \textit{MDA @ 95\%CL (counts)}}$

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.*
  - 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.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- For CTW, combine:
  - 1970–1972
  - 1976–1977
  - 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.
  - 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”.
- 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.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

– 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".
  – 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.

E.4.8 Tritium

NOCTS H3 Data:

- MDA values:

  – Use the result "<X" values where available if "X" is >0,
  – Otherwise use generic MDAs of:

    o 1 µCi/l through 1980,
    o 0.5 µCi/l for 1981 through 1985, and
    o 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.

- 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"
  – Exclude all data from Claim # [redacted] (not an SRS worker)

- For each sample date, determine the individual's CTW designation as described above.

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

  - 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.

E.4.9 Americium

Am logbook data:

- Dataset rows will be identified by their Unique ID # (Unique.ID).
- Unique ID # [[redacted]] has a "dpm/1.5L" value of "<". Change that to "<0.3".
- Do not use records:

  - With "LIP" in the "report" field
  - With the following anywhere in the "remarks" field

    - "LIP"
    - "Am do not report"
    - "DTPA"
    - "Am DNR"
    - "Do not report"
    - "DO NOT USE"
    - "Lost"
    - 0.383; Am LIP; Probable Contamination
    - Am – LIP

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- Am DNR
- Am DNR (Note that there is an extra space after the R in the spreadsheet)
- Am LIP
- Am LIP low recovery-Hi Am Blank
- Am LIP low recovery-Hi Am Blank ,Am=.460
- Am LIP low recovery-Hi Am Blank, Am=.200
- Am LIP low recovery-Hi Am Blank, Am=.255
- Am LIP low recovery-Hi Am Blank, Am=.285
- Am LIP low recovery-Hi Am Blank, Am=.310
- Am LIP low recovery-Hi Am Blank, Am=.315
- Am LIP low recovery-Hi Am Blank, Am=.370
- Am LIP low recovery-Hi Am Blank, Am=.388
- Am LIP low recovery-Hi Am Blank, Am=.395
- Am LIP low recovery-Hi Am Blank, Am=.420
- Am LIP low recovery-Hi Am Blank, Am=.493
- Am LIP low recovery-Hi Am Blank, Am=.527
- Am LIP low recovery-Hi Am Blank, Am=.903
- Am LIP low recovery-Hi Am Blank, Am=1.440
- Broken flask sample LIP
- Do not report
- Do not report #6 until rerun and found valid
- Do Not Report Am
- DO NOT USE, Spike
- DO NOT USE, Spike -.-010
- DTPA Program
- Flask broken - sample lost
- LIP for Am and Pu
- LIP for Am; Pu ok
- LIP. Do Not Report note at bottom of page 23.
- Lost in Process
- Not used
- Pu LIP low recovery; Am LIP
- Pu OK, Re-run AM DO NOT USE for Am
- Pu OK, Re-run AM DO NOT USE for Am, .150
- Pu ok; Am LIP see note at bottom of page and note low recoveries.
- Rerun #7 (Am) lost

– For Remarks Column comment “1st dpm/disc LIP ; flash broke” which is Unique ID [redacted], don’t use the blank dpm/1.5L (1) result; but use the results in the dpm/1.5L (2) and dpm/1.5L (3) column.

– For Remarks Column comment “Am #1 lost; 2nd rinse onto planchet” which is Unique ID # [redacted], don’t use the dpm/1.5L (1) result; but use the dpm/1.5L (2) result.

– Except for the following, which are still used:

- “Pu LIP” (unless “Am LIP” is also in the remarks)
- “Pu report data LIP”
- “EU LIP”

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- "LIP (EU)"
- "Unique ID # [redacted] dpm/1.5L (1) even though there is a comment stating 2nd rerun lost.

- Individual "dpm/1.5L" values with a value of "LIP" (other "dpm/1.5L" values for that record are still used).

- If the "report" and all "dpm/1.5L" fields are blank,

  – Data exclusions:

    - Changed Payroll ID [redacted], incident on March 9, 1970, exclude all results for 1970.
    - Changed Payroll ID [redacted], exclude result on May 1, 1981, false positive.
    - Changed Payroll ID [redacted], exclude result on April 27, 1966, false positive.
    - Changed Payroll ID [redacted], exclude result on October 19, 1976, false positive.
    - Changed Payroll ID [redacted], ingestion intake on March 16, 1972, exclude all results for 1972.
    - Changed Payroll ID [redacted], Pu wound intake on May 8, 1986, exclude all results for 1986.
    - With a type of "DTPA" or similar.
    - With no bottle date.
    - With no Employee ID.
    - Within 100 days after receiving chelation as indicated in the Chelation Data spreadsheet. Disregard PRID prefixes for matching bioassay results to the Chelation Data spreadsheet. If the Changed Payroll ID field is blank, use the Payroll ID field instead.
    - With a value given as a percentage in any of the report or individual dpm/1.5L values.
    - Average all reported "dpm/1.5L" values to determine the result to use
      - If all "dpm/1.5L" values are blank, use the "report" value.
    - 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
      - 1969–1989: 0.3 dpm/1.5L

ATTACHMENT E
SRS CO-EXPOSURE STUDY STATISTICAL ANALYSIS INSTRUCTIONS FOR ORAUT-OTIB-0081, REVISION 4 FINAL, DECEMBER 13, 2018 (continued)

- 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
  - 1969–1989
- 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 1965–1967, 1983–1984, 1985–1986, and 1987–1989. For nonCTW, evaluate individual years except 1963–1964 and 1988–1989. Merge grouped years.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES

TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

LIST OF FIGURES

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

F.1 AMERICIUM INTAKE MODELING RESULTS

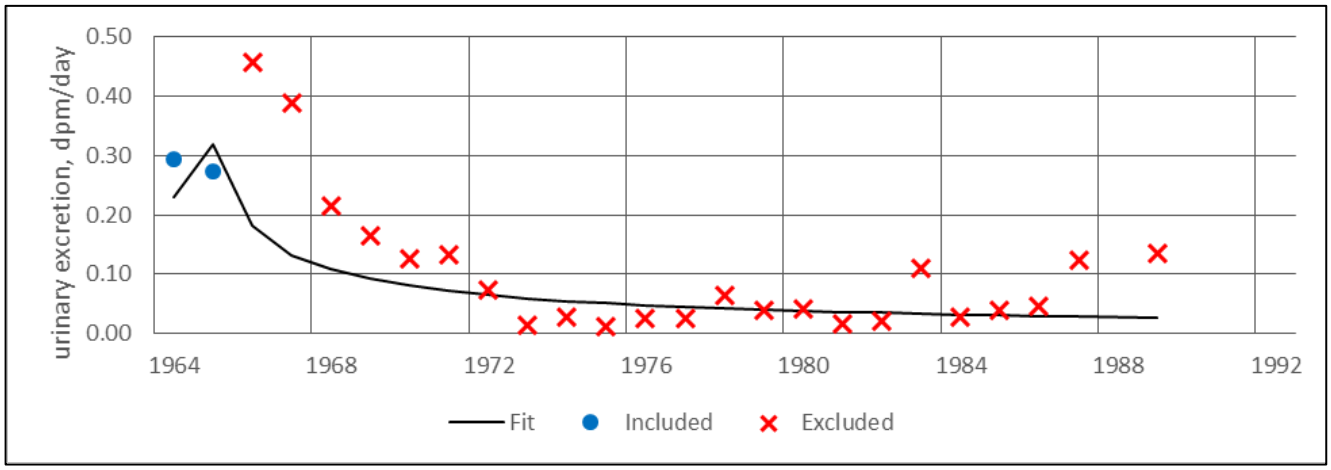


Figure F-1. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1963 to 1965, type M.

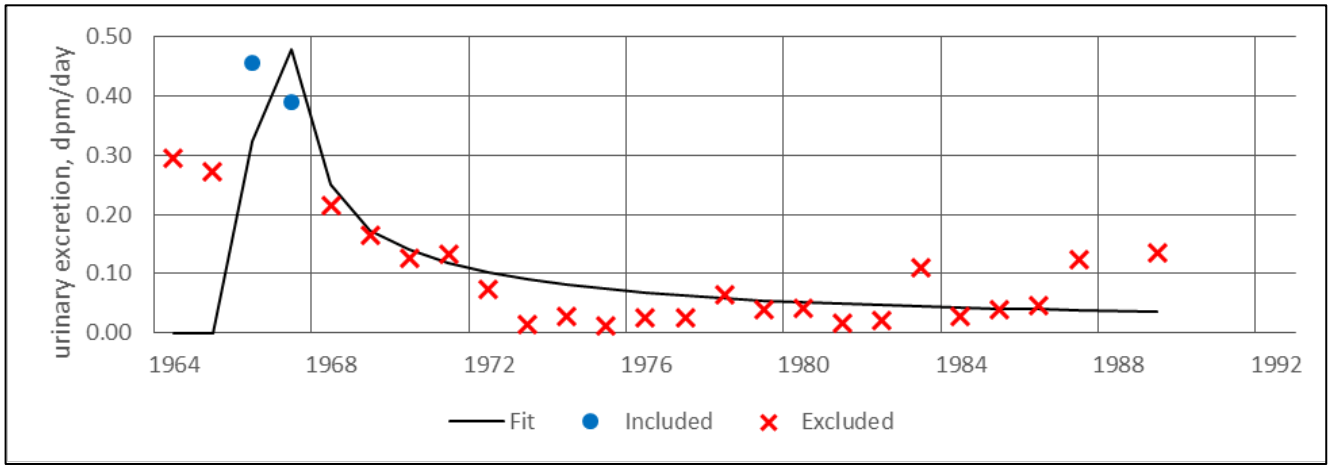


Figure F-2. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1966 to 1967, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

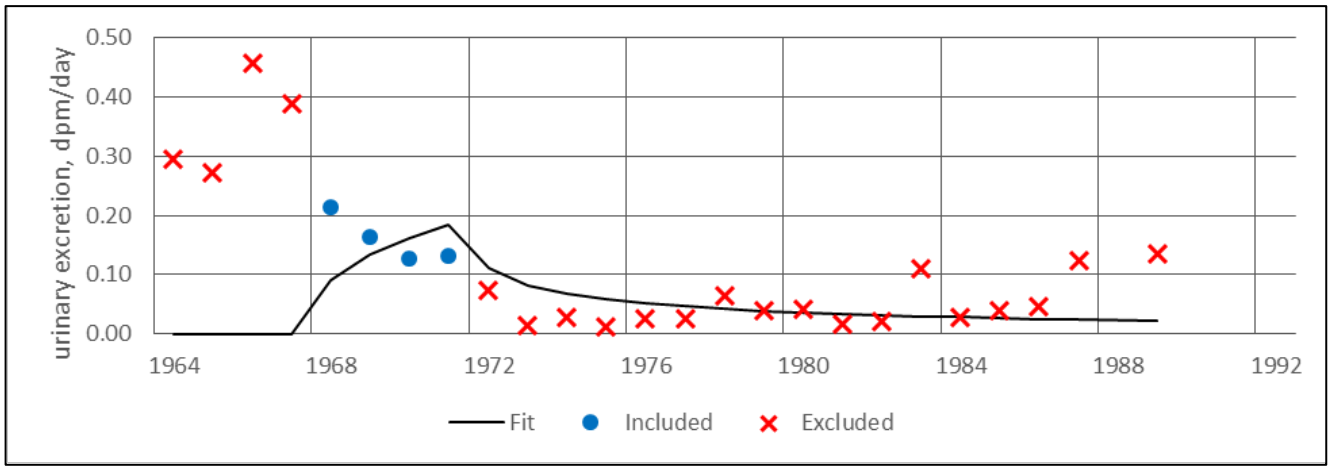


Figure F-3. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1968 to 1971, type M.

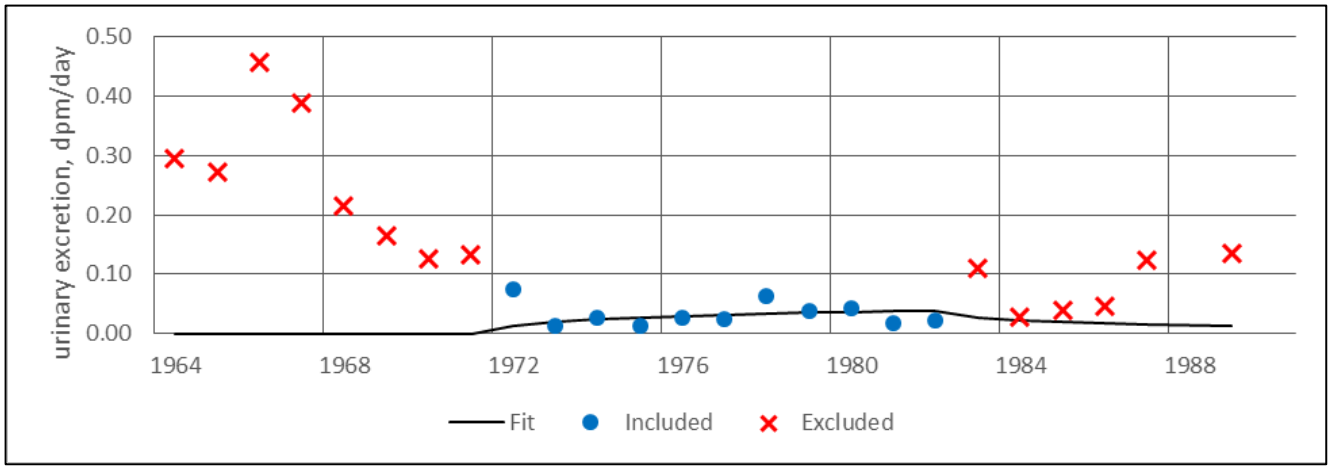


Figure F-4. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1972 to 1982, type M.

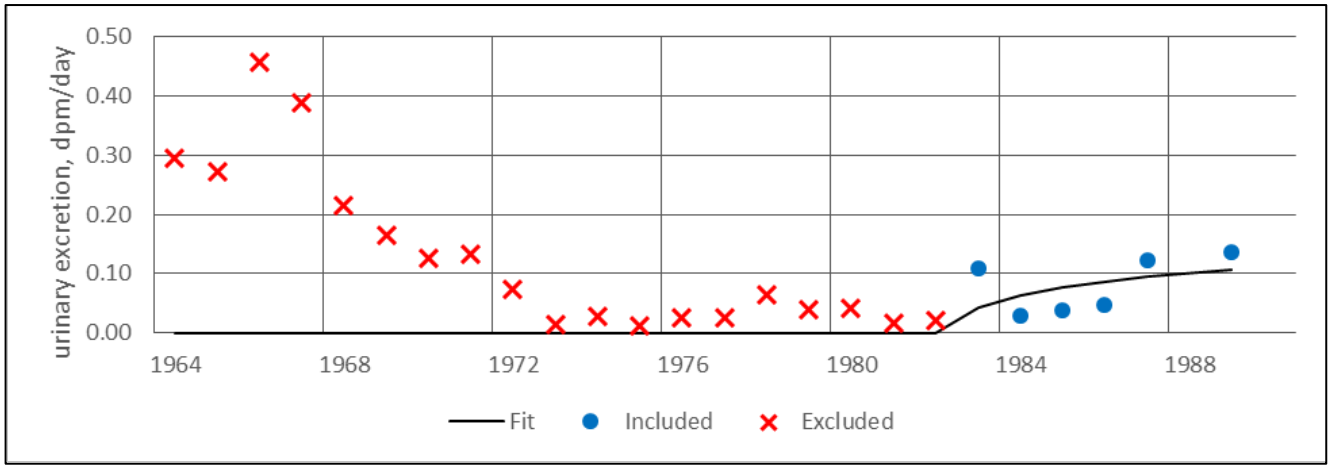


Figure F-5. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, 1983 to 1989, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

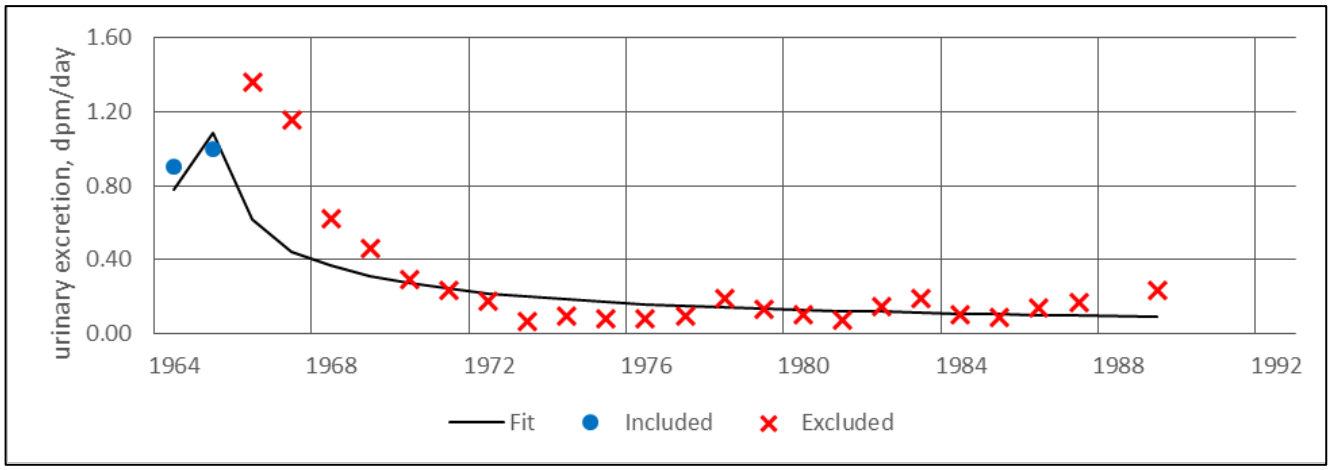


Figure F-6. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1963 to 1965, type M.

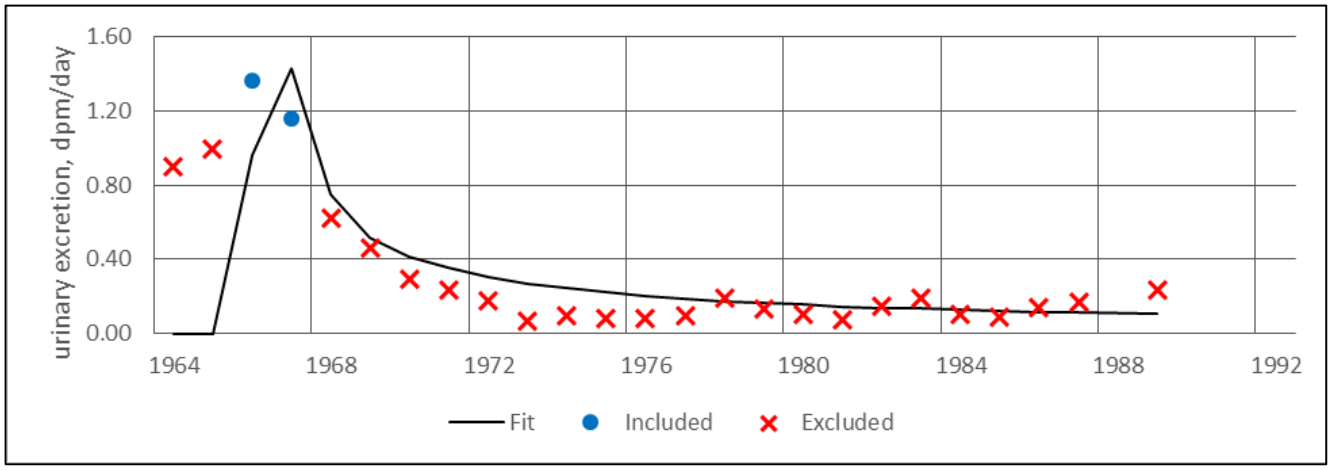


Figure F-7. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1966 to 1967, type M.

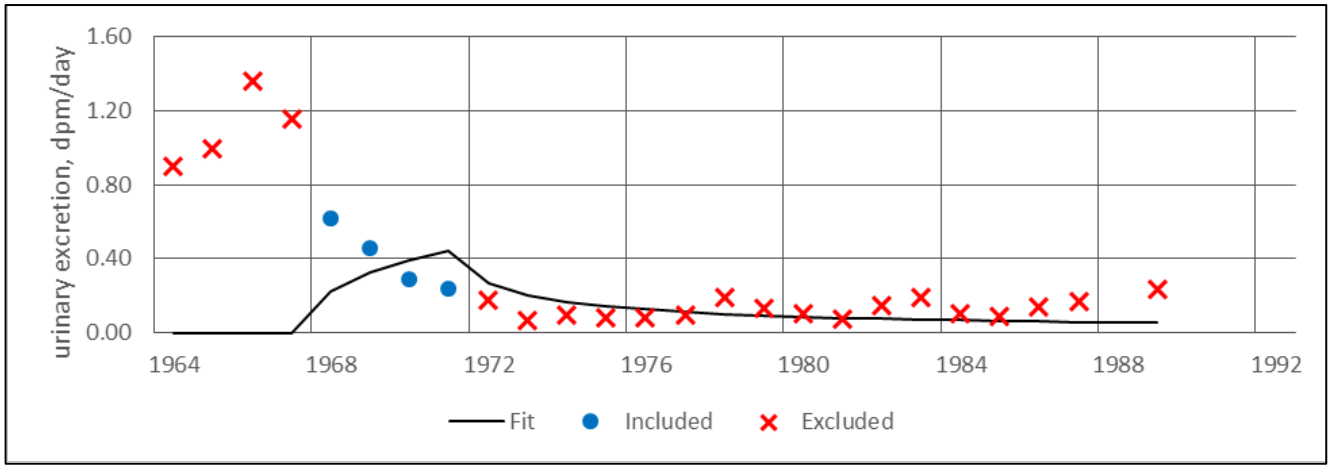


Figure F-8. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1968 to 1971, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

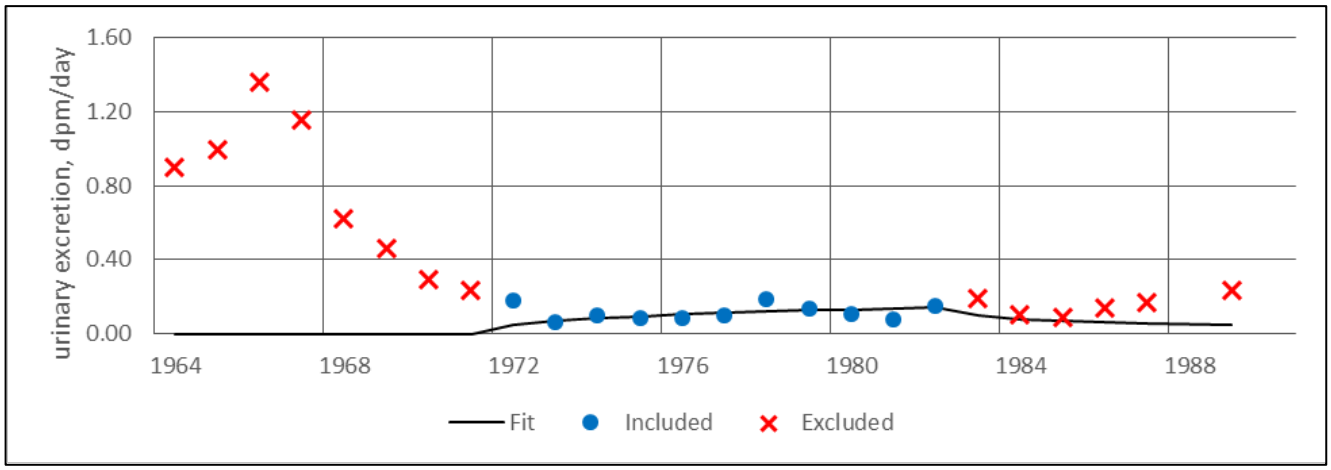


Figure F-9. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1972 to 1982, type M.

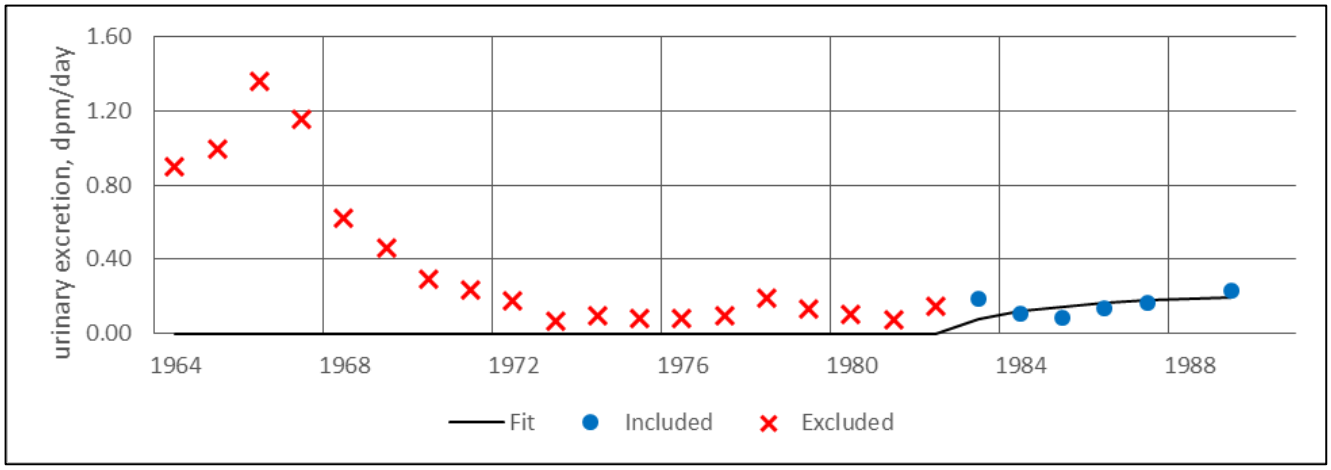


Figure F-10. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, 1983 to 1989, type M.

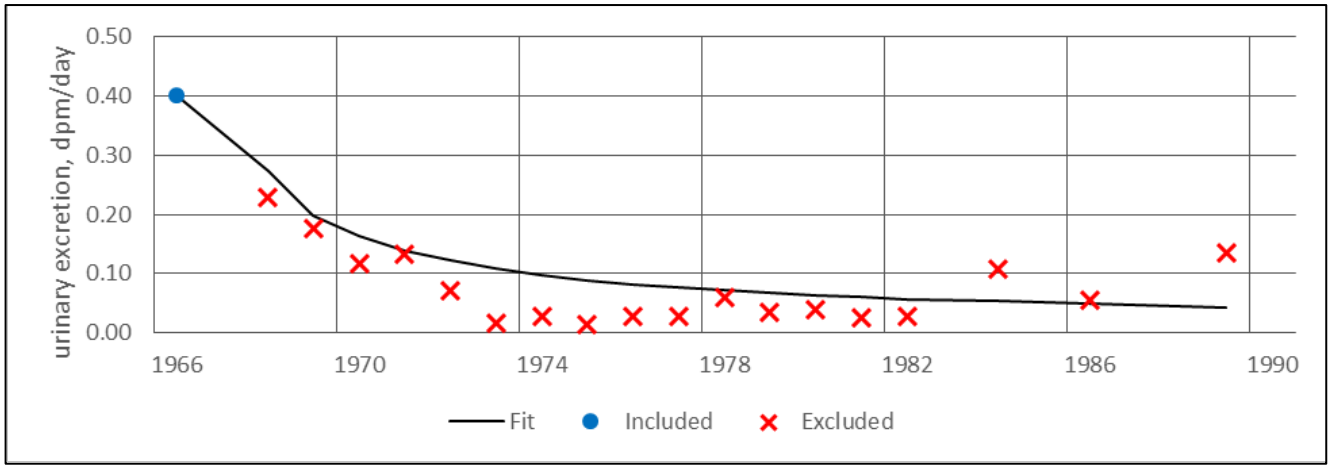


Figure F-11. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1965 to 1967, type M

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

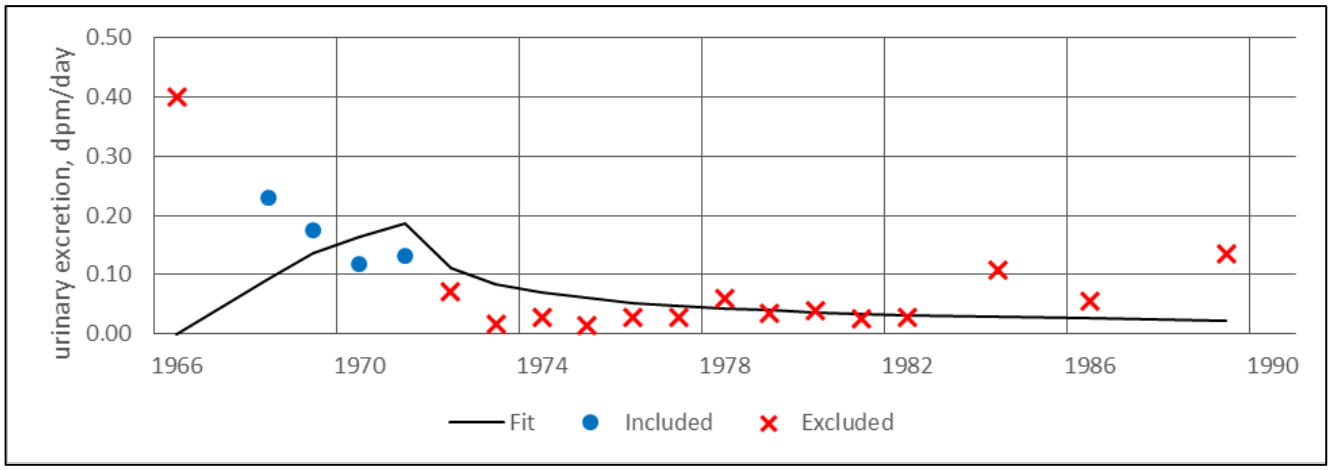


Figure F-12. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1968 to 1971, type M.

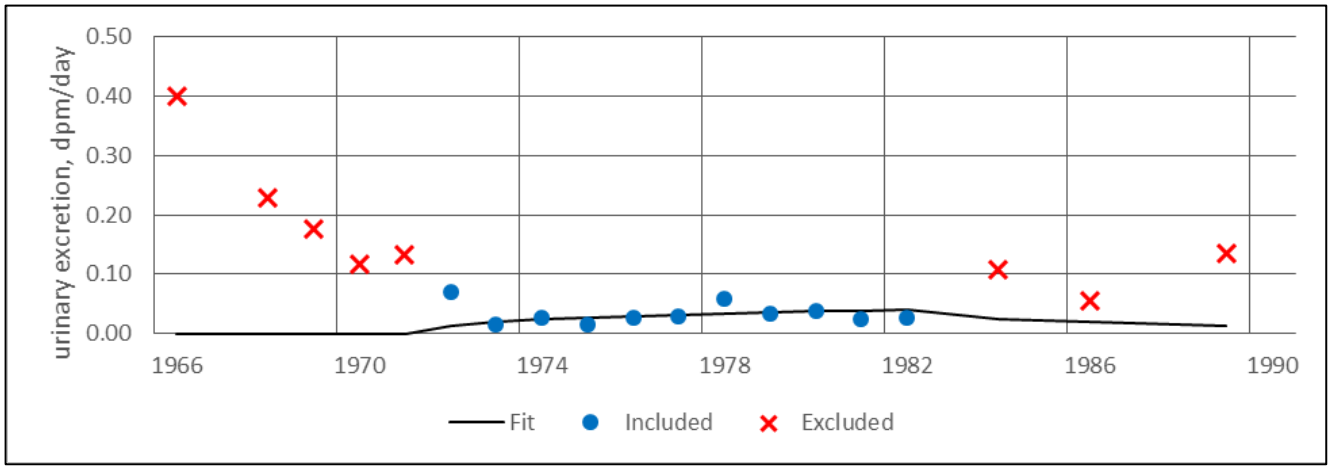


Figure F-13. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1972 to 1982, type M.

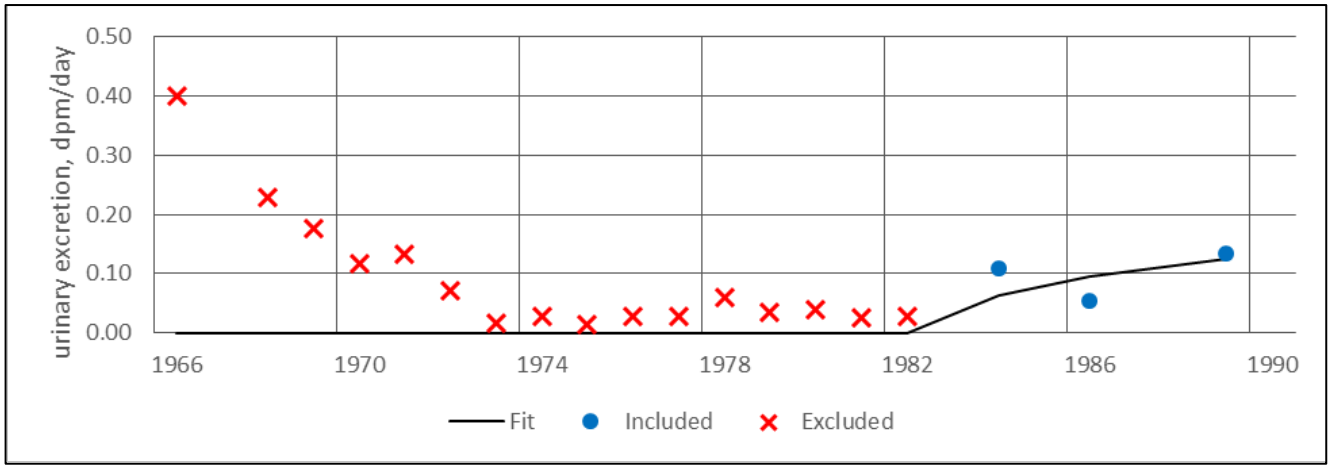


Figure F-14. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, 1983 to 1989, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

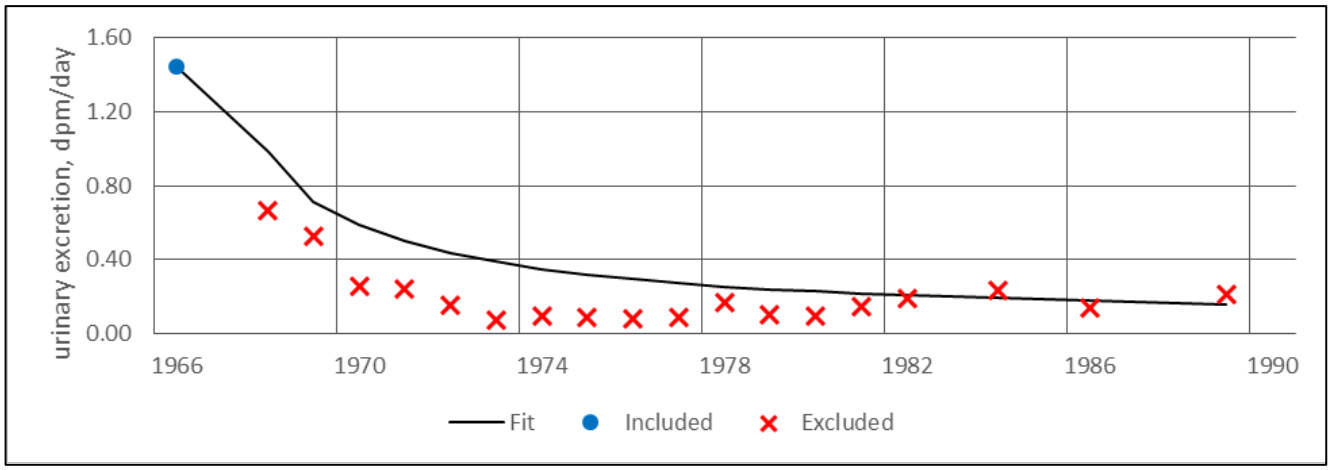


Figure F-15. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1965 to 1967, type M.

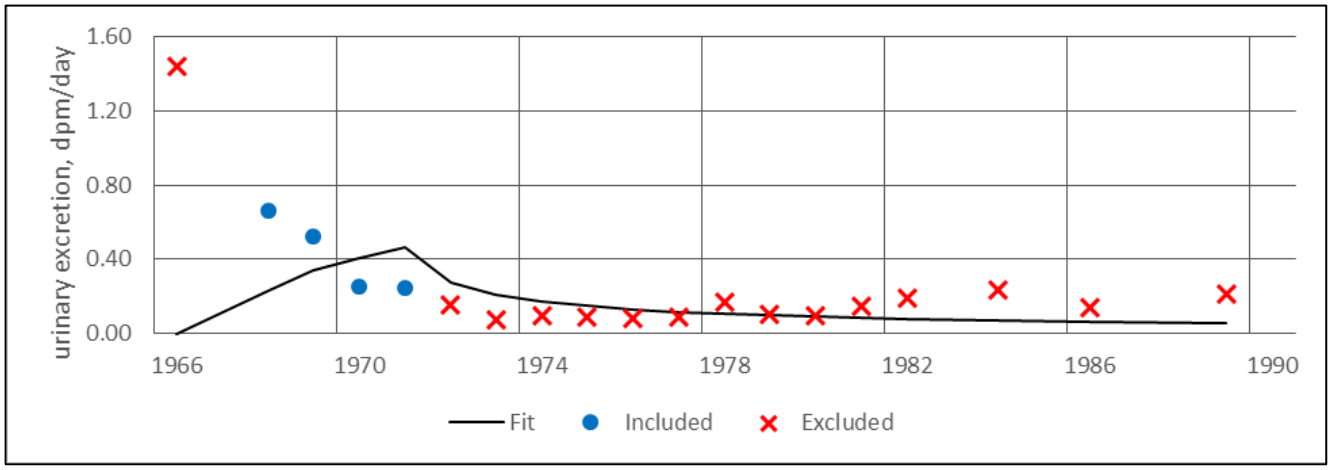


Figure F-16. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1968 to 1971, type M.

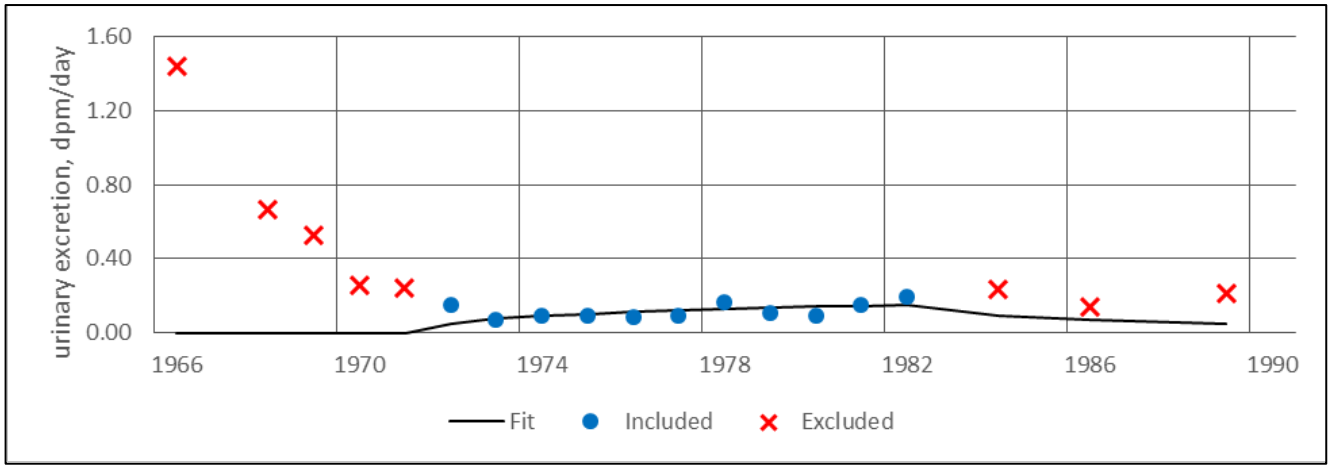


Figure F-17. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1972 to 1982, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

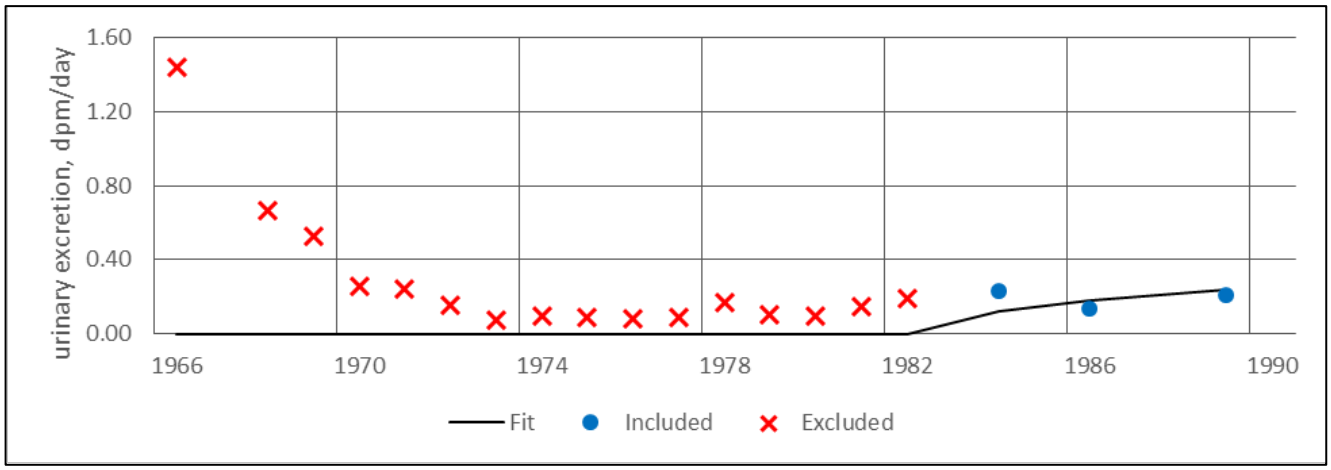


Figure F-18. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, 1983 to 1989, type M.

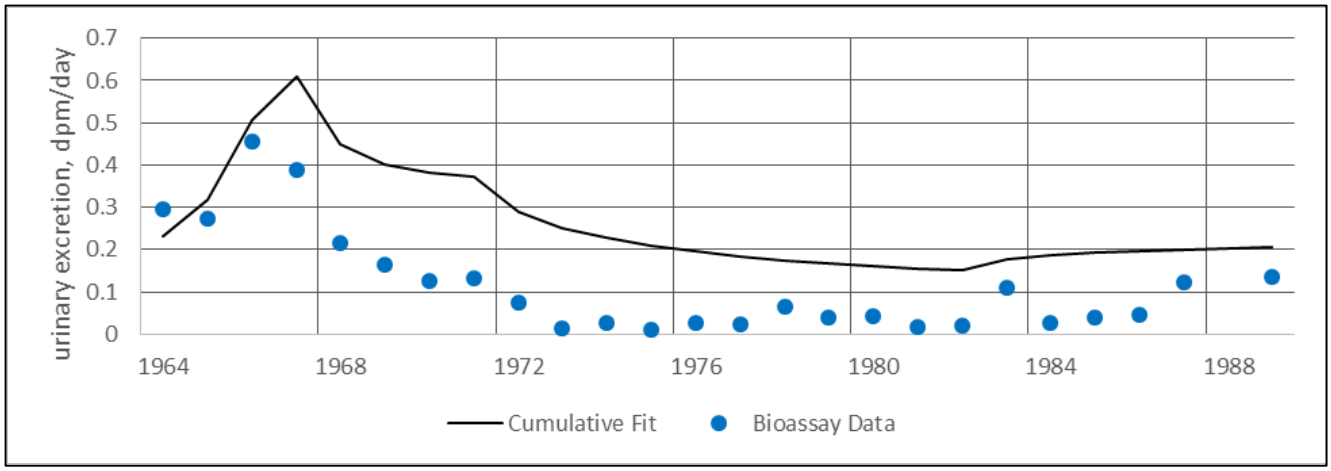


Figure F-19. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type M.

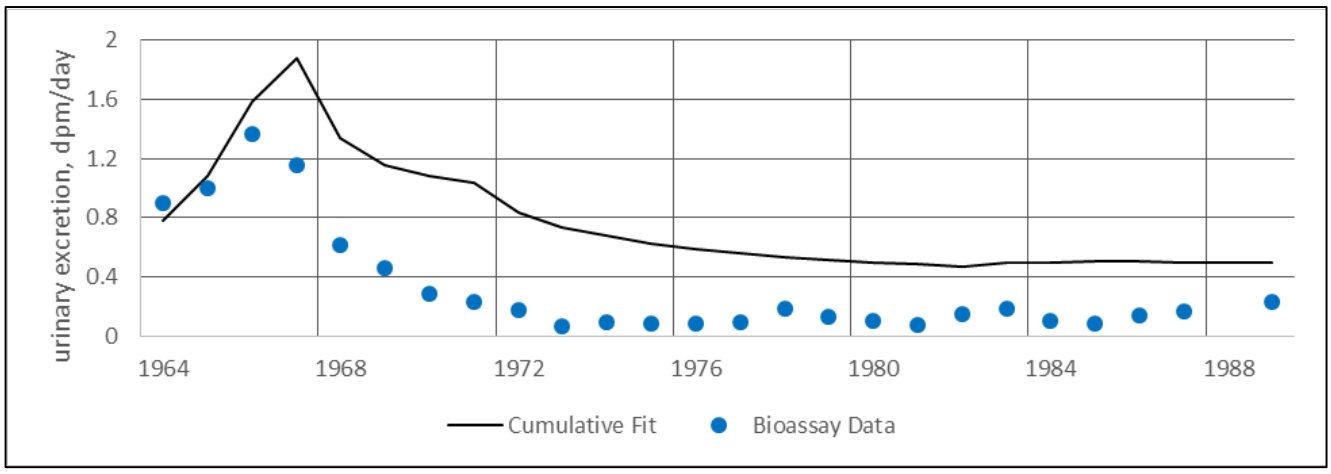


Figure F-20. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

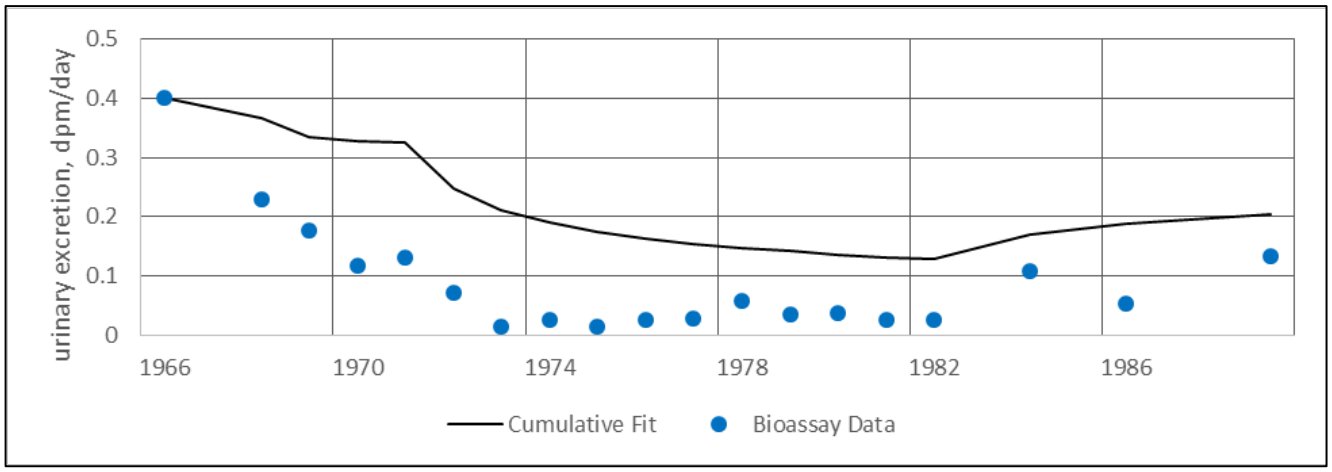


Figure F-21. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type M.

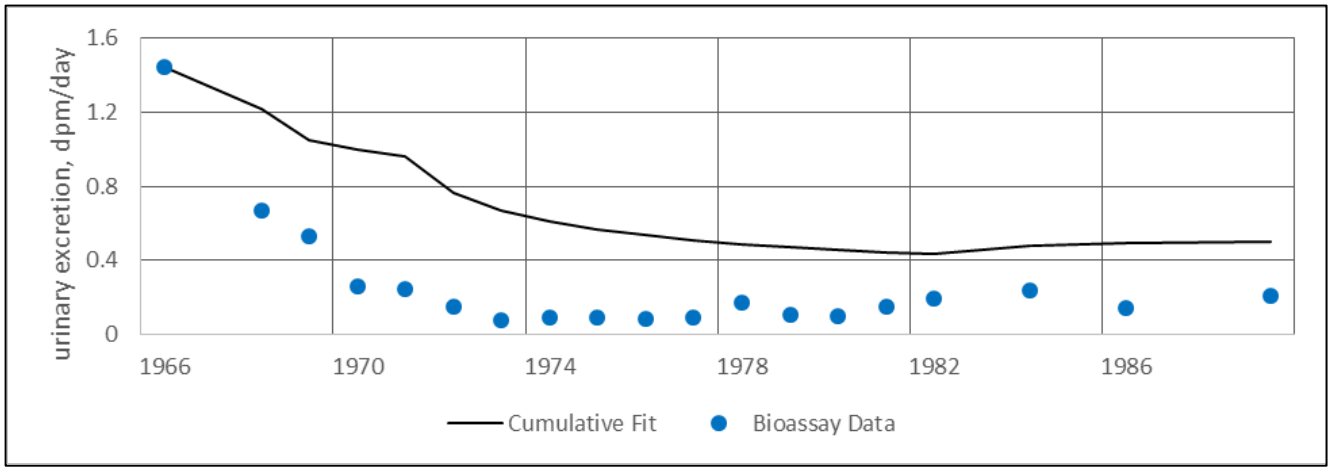


Figure F-22. Predicted ^{241}Am bioassay results calculated using IMBA-derived ^{241}Am intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type M.

Table F-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	32.11	108.9	3.39	3.39	239
01/01/1966	12/31/1967	57.9	172.7	2.98	3.00	353
01/01/1968	12/31/1971	16.3	39.37	2.42	3.00	99.3
01/01/1972	12/31/1982	2.327	8.426	3.62	3.62	19.3
01/01/1983	12/31/1989	7.694	14.38	1.87	3.00	46.9

Table F-2. Summary of ^{241}Am CTW intake rates (dpm/d) and dates.

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1965	12/31/1967	48.46	174.5	3.60	3.60	399
01/01/1968	12/31/1971	16.56	40.97	2.47	3.00	101
01/01/1972	12/31/1982	2.387	8.968	3.76	3.76	21.1
01/01/1983	12/31/1989	8.891	16.76	1.89	3.00	54.2

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

F.2 PLUTONIUM INTAKE MODELING RESULTS

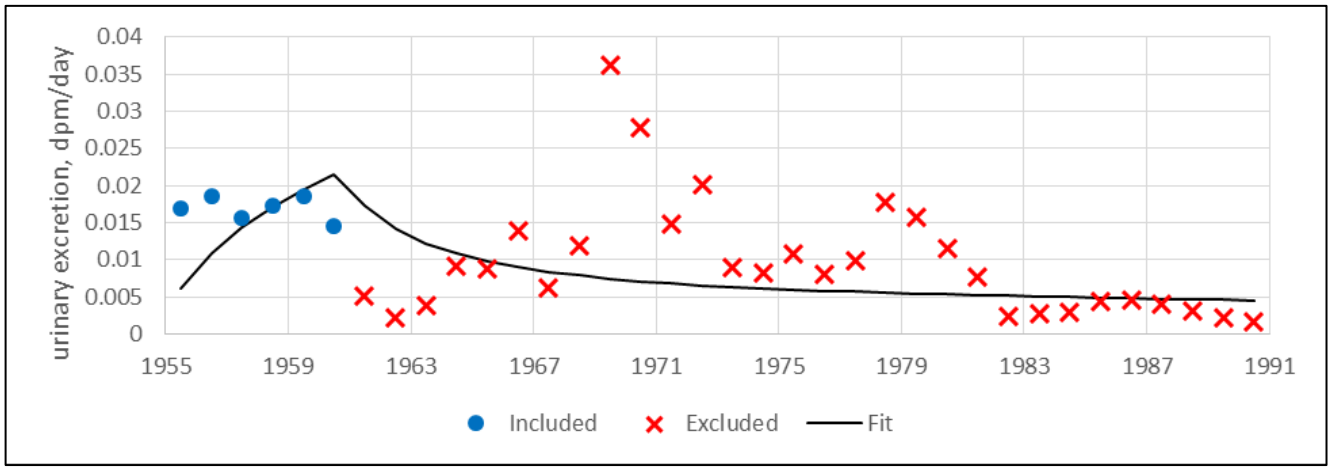


Figure F-23. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1960, type M.

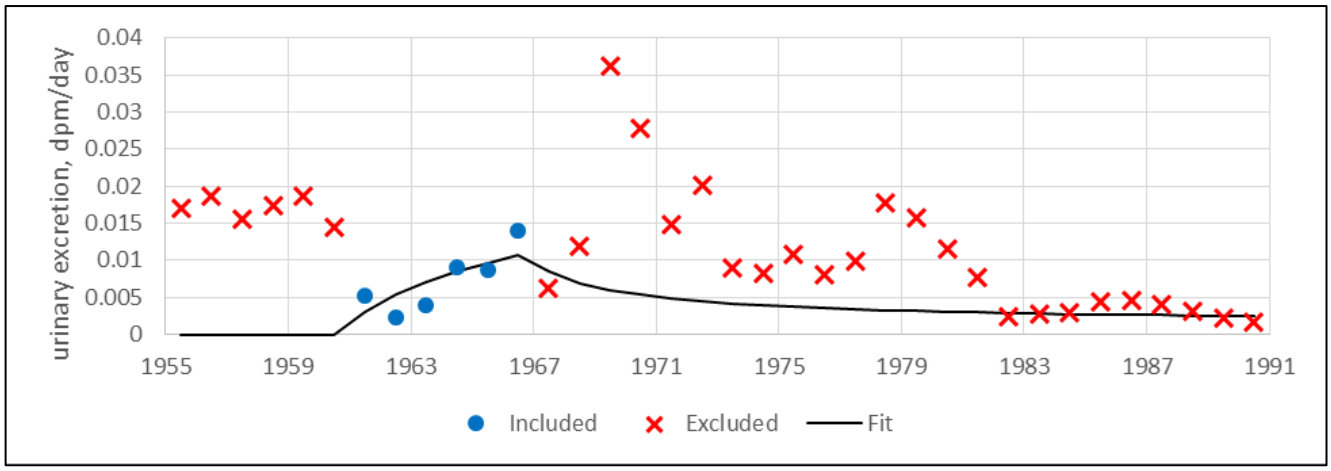


Figure F-24. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1966, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

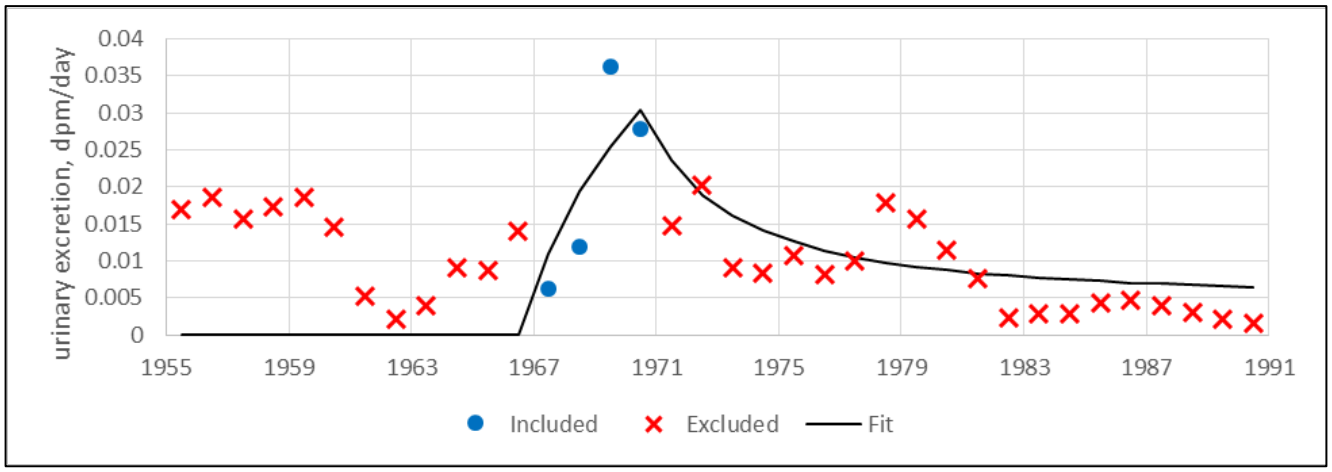


Figure F-25. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1970, type M.

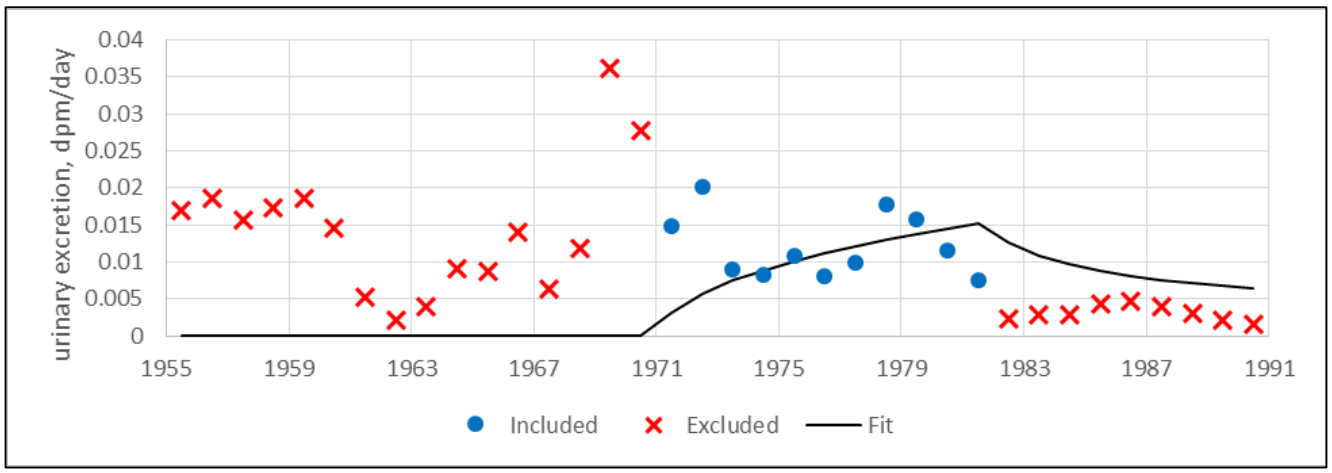


Figure F-26. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1971 to 1981, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

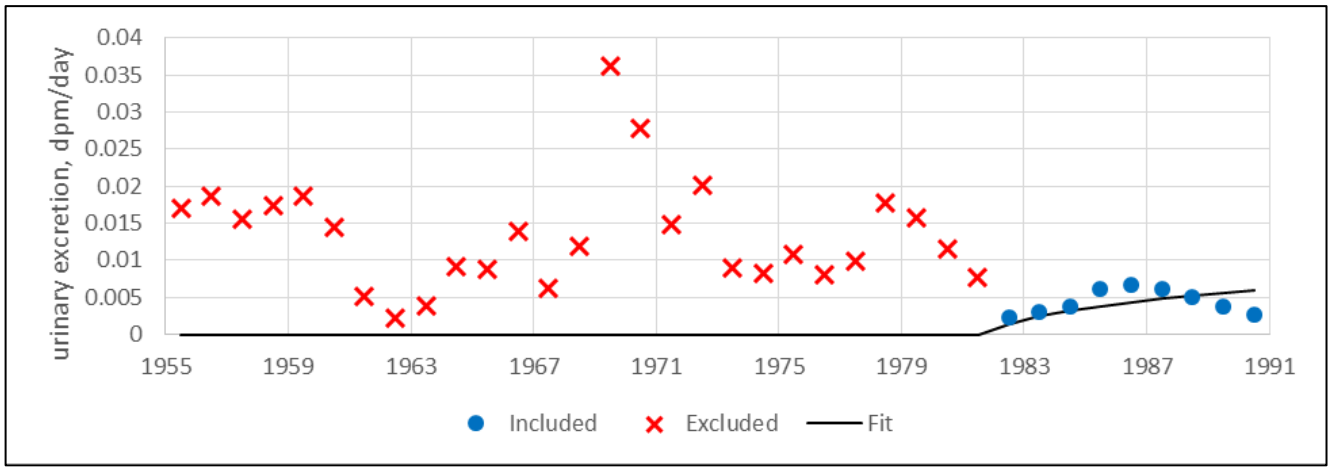


Figure F-27. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1990, type M.

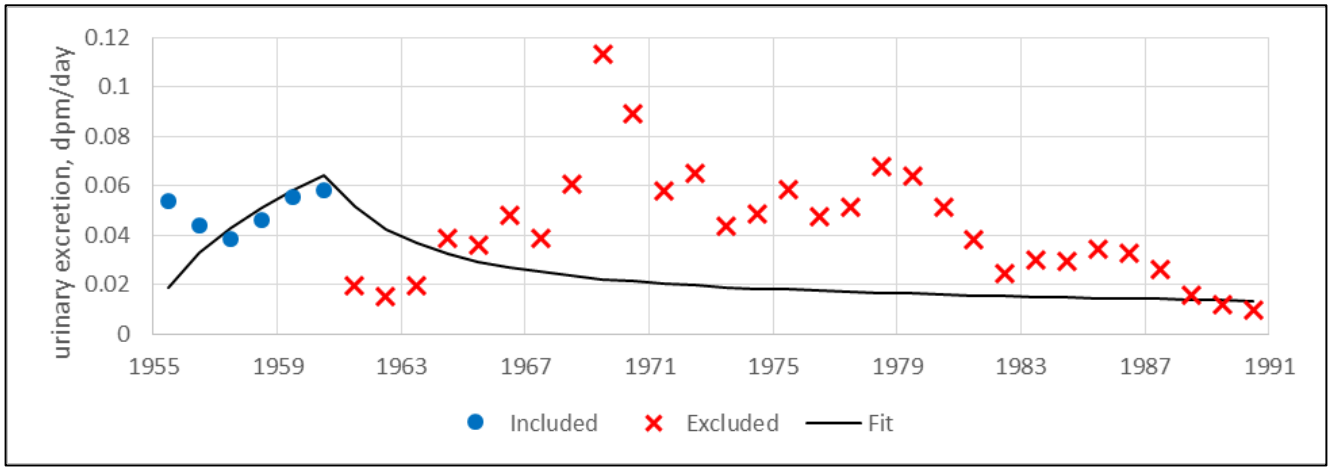


Figure F-28. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1960, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

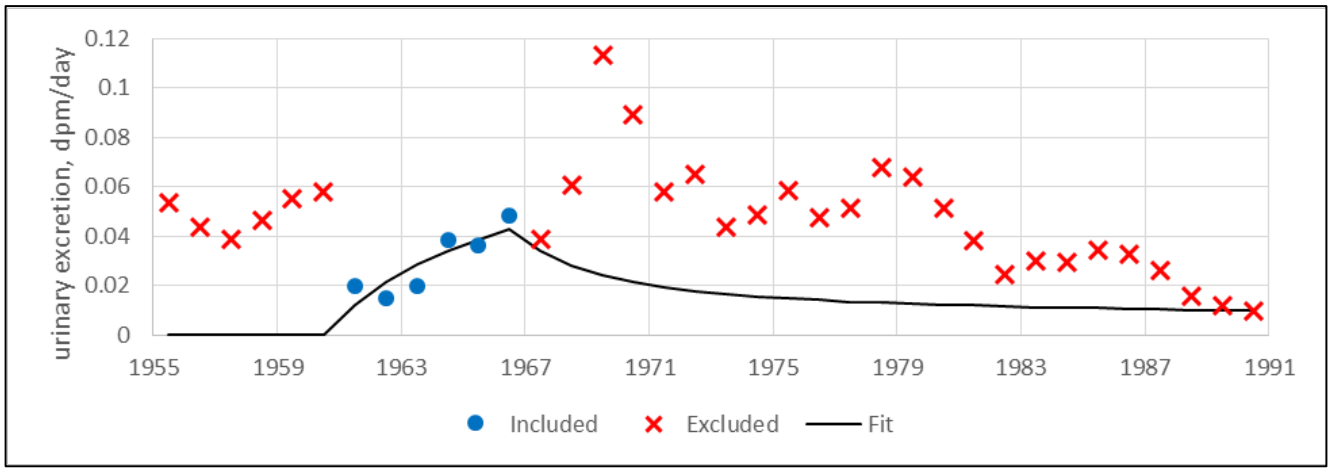


Figure F-29. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1966, type M.

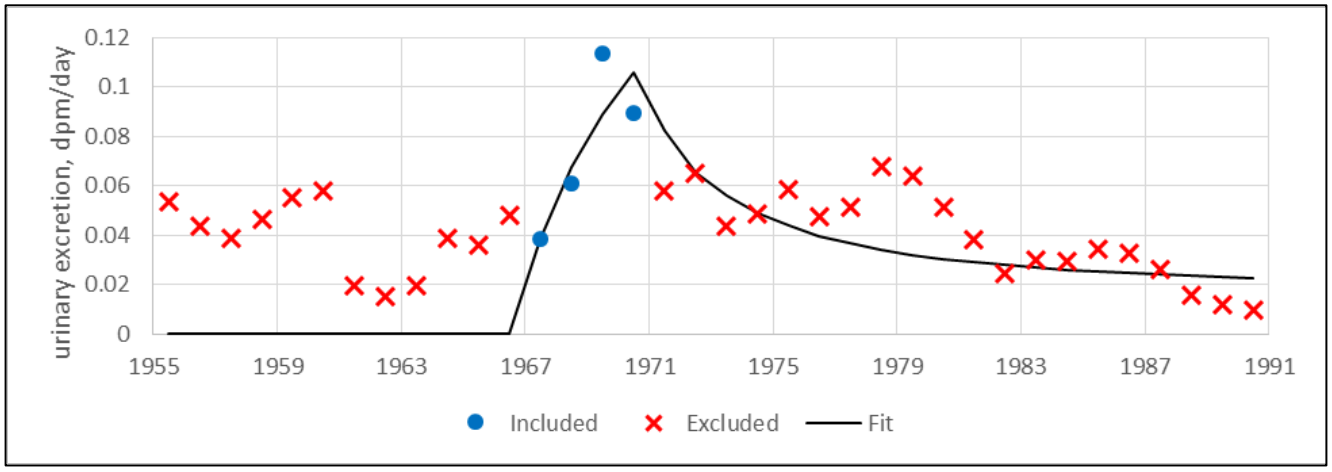


Figure F-30. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1970, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

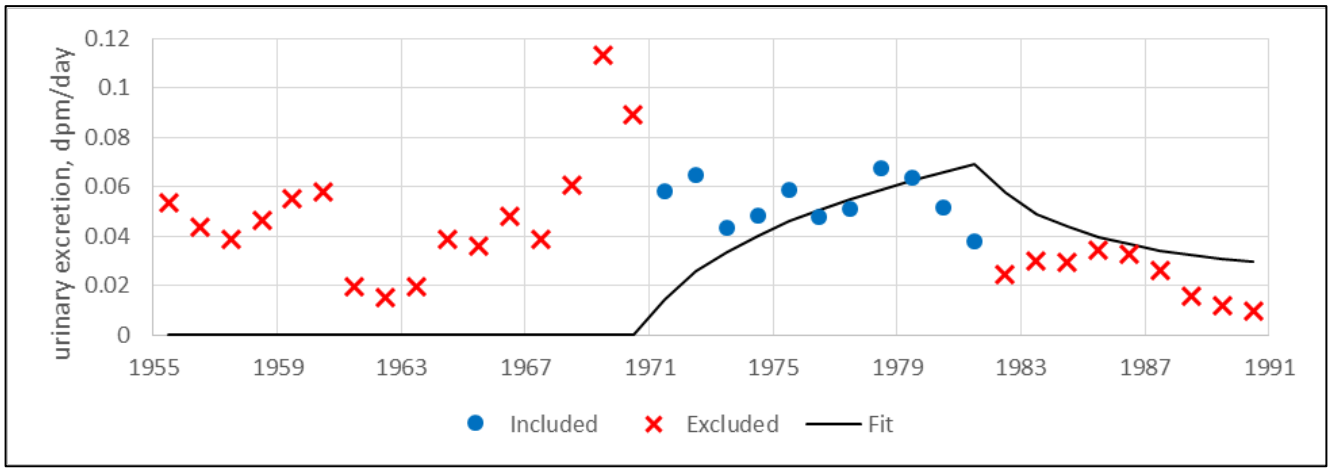


Figure F-31. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1971 to 1981, type M.

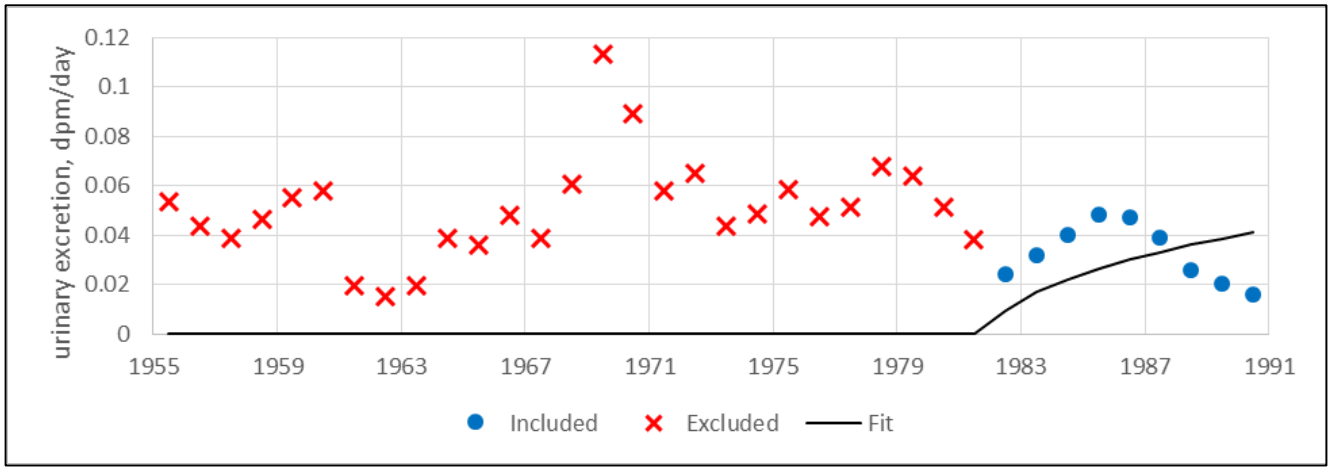


Figure F-32. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1990, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

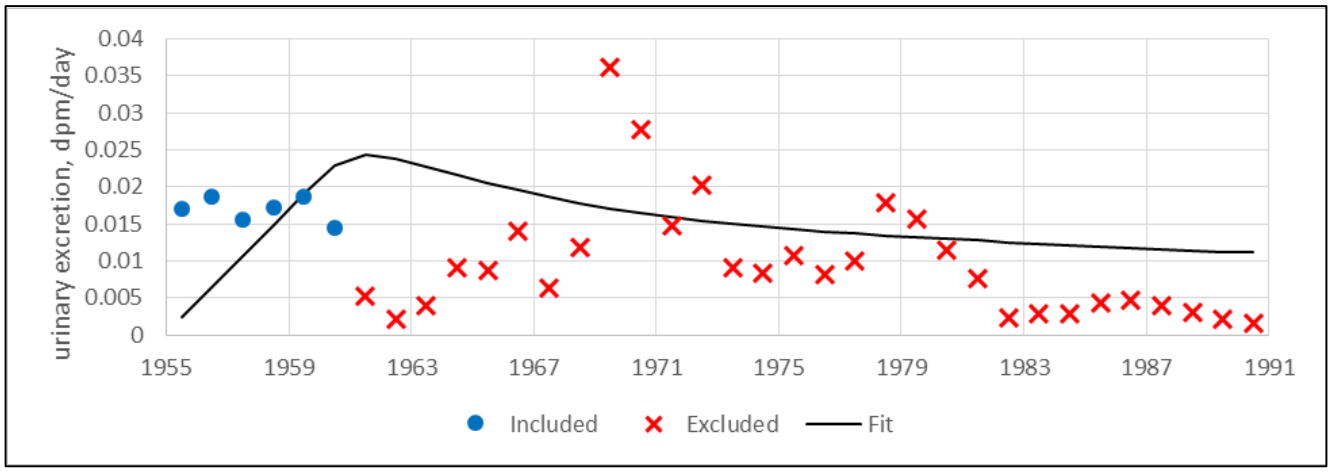


Figure F-33. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1960, type S.

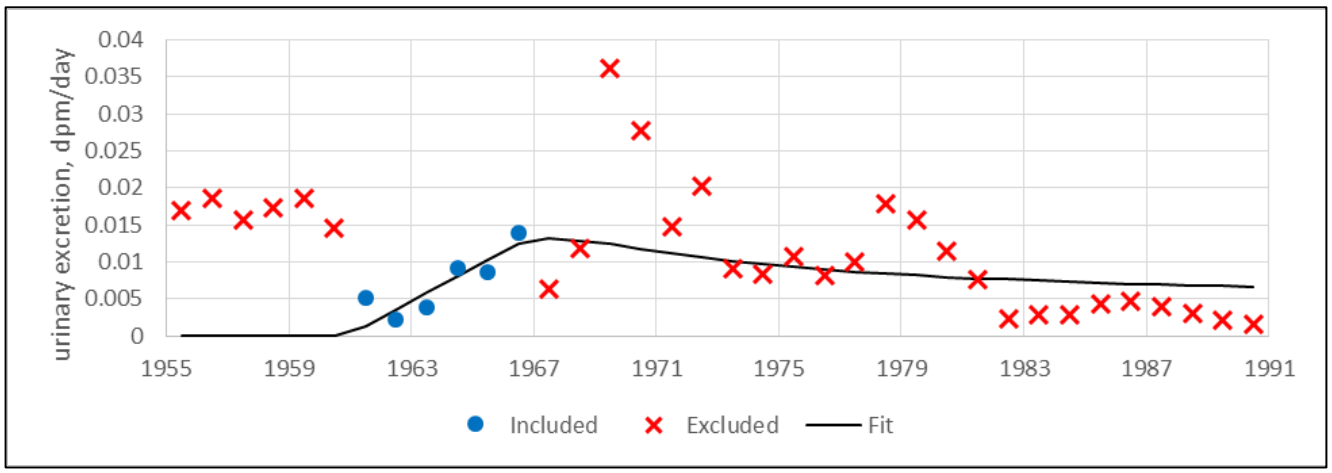


Figure F-34. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1966, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

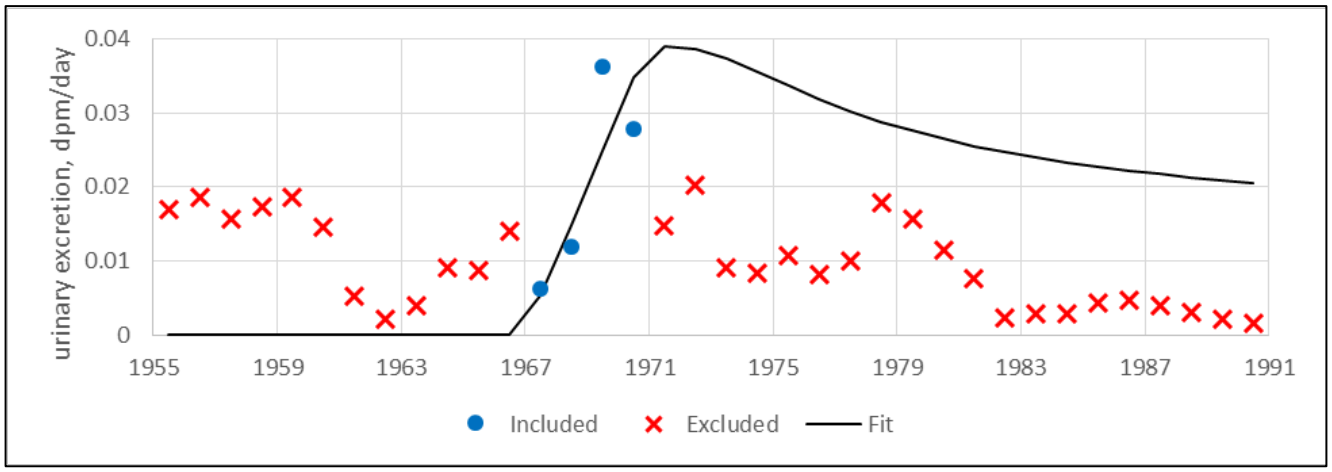


Figure F-35. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1970, type S.

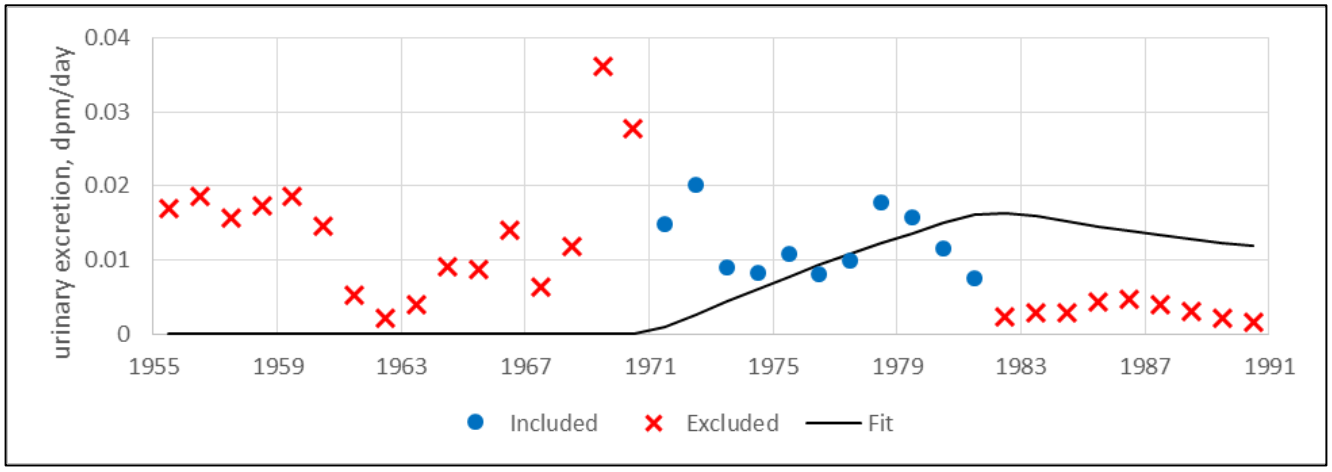


Figure F-36. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1971 to 1981, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

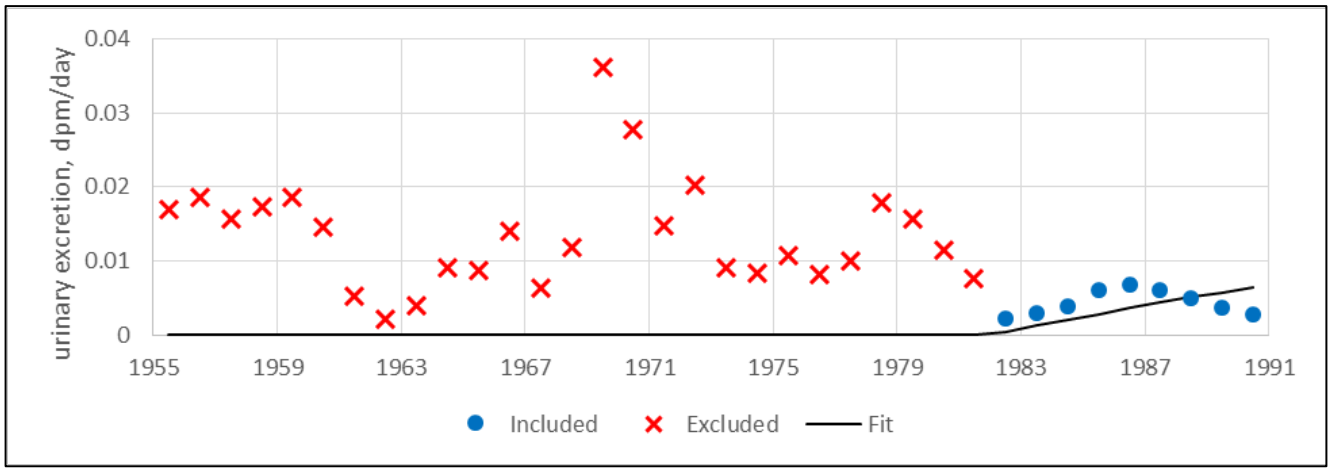


Figure F-37. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1990, type S.

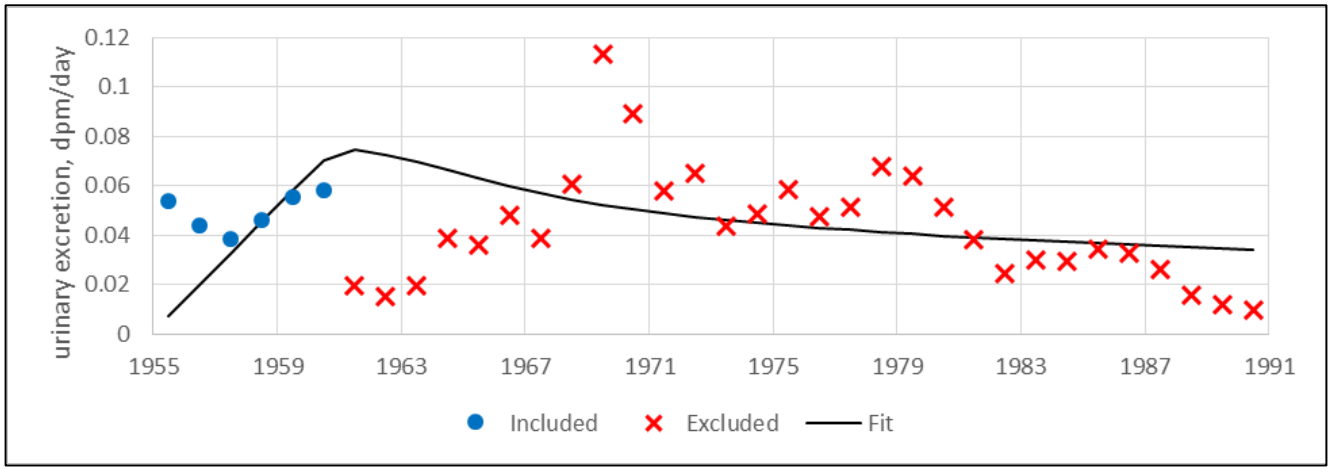


Figure F-38. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1960, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

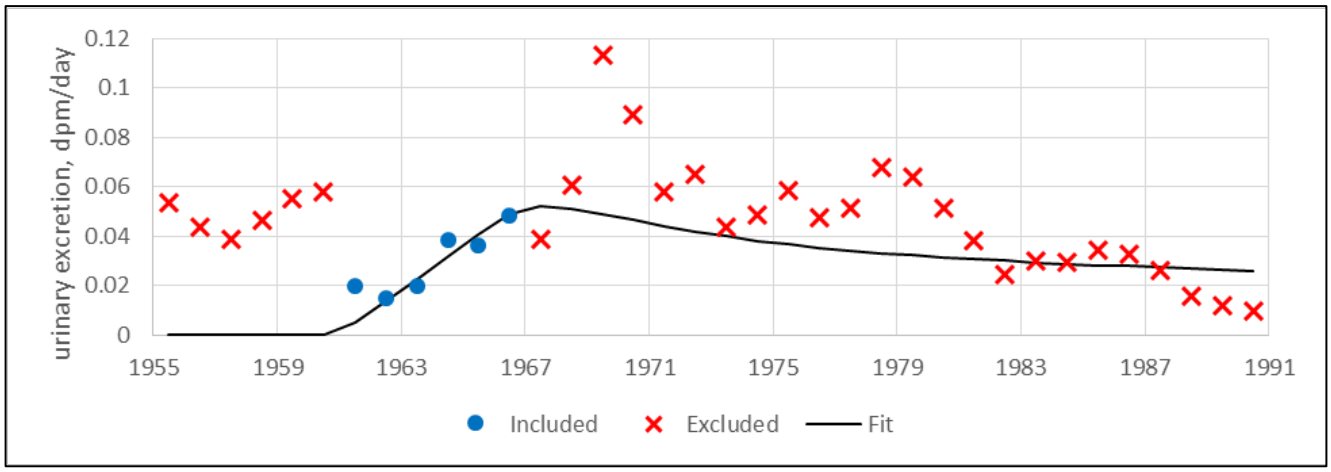


Figure F-39. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1966, type S.

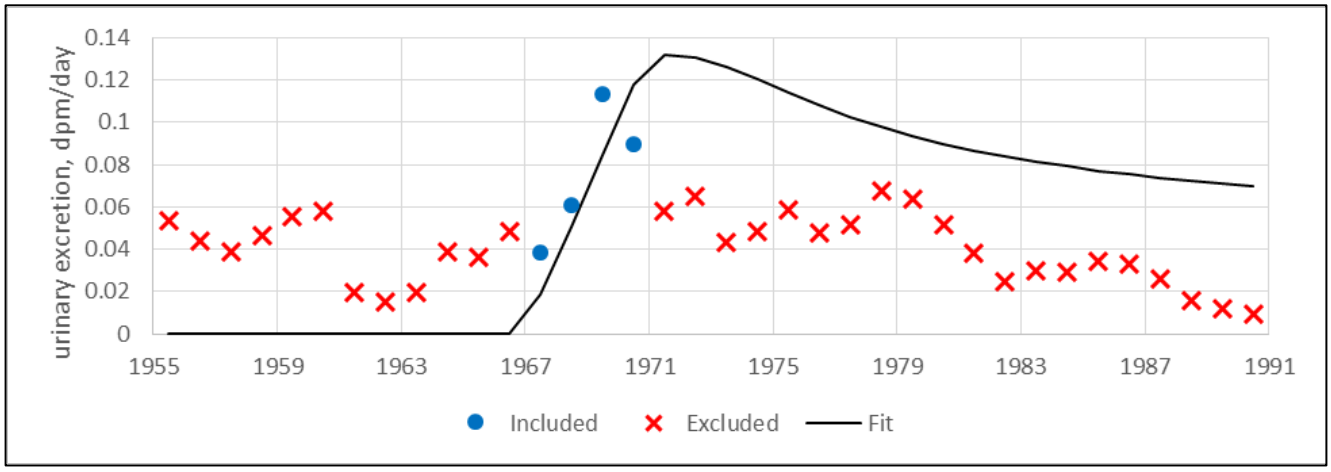


Figure F-40. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1970, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

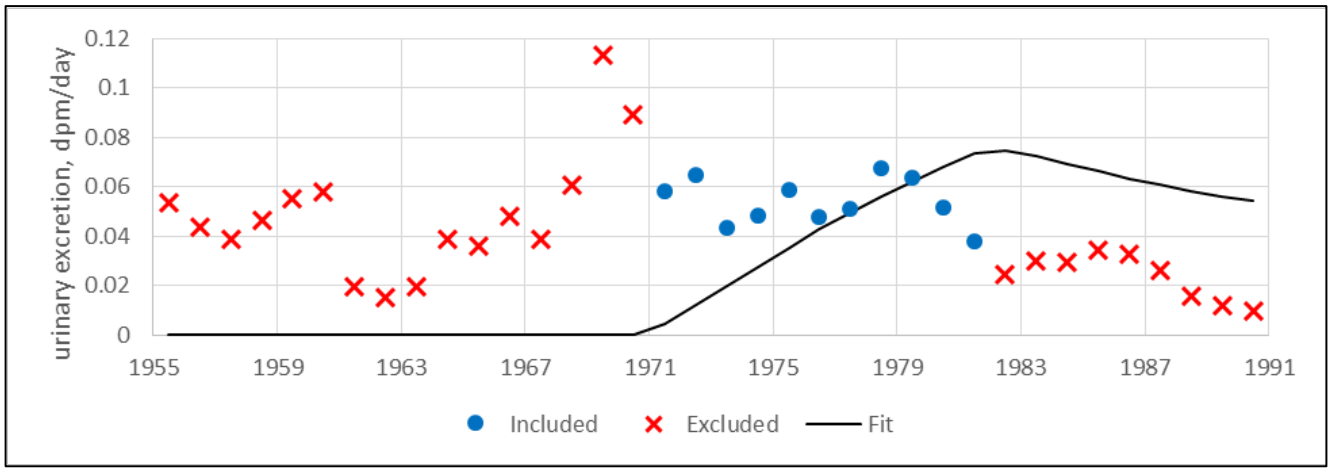


Figure F-41. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1971 to 1981, type S.

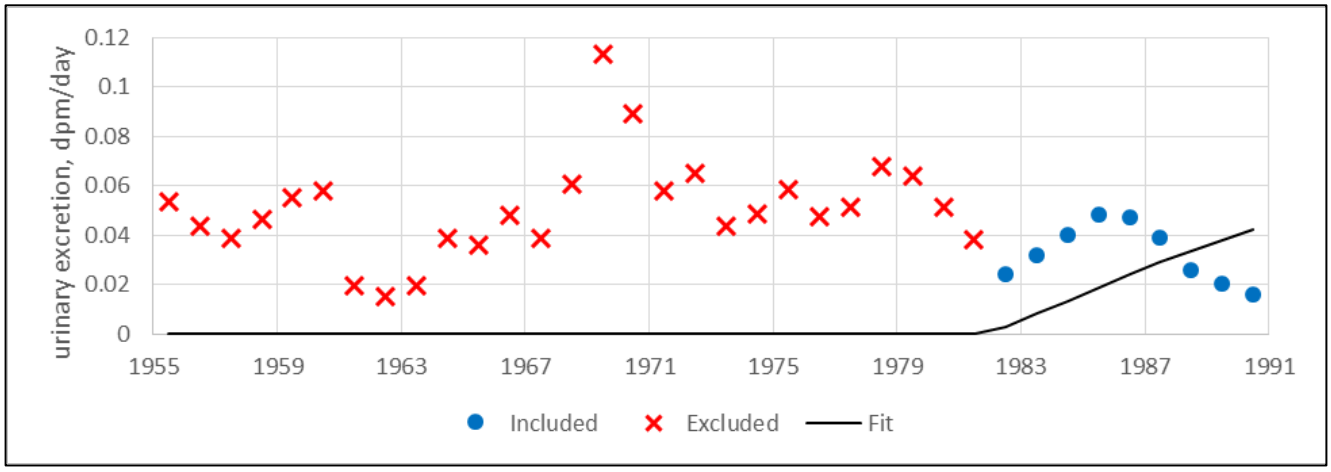


Figure F-42. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1990, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

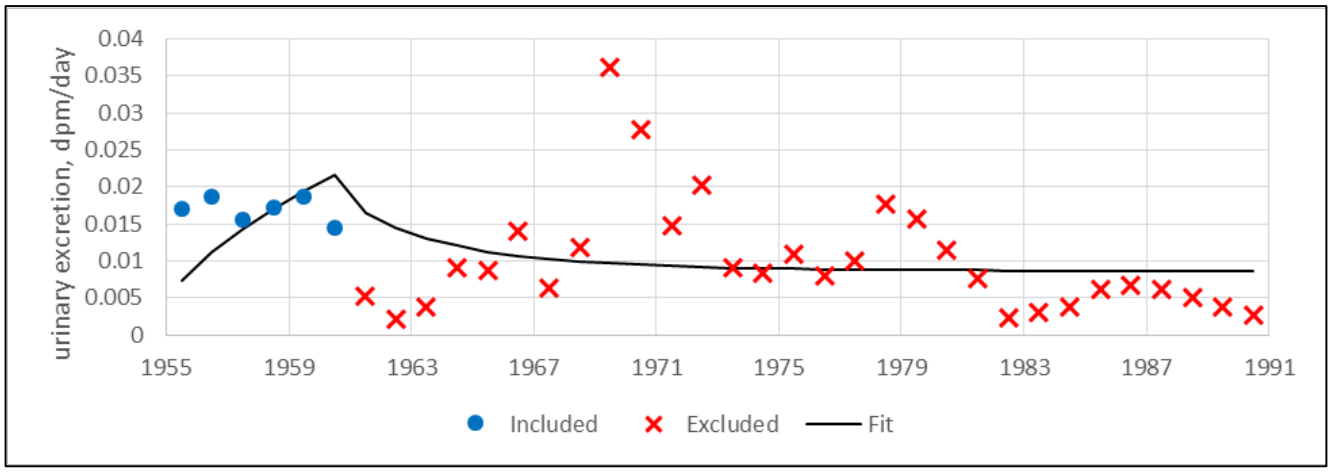


Figure F-43. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1960, type SS.

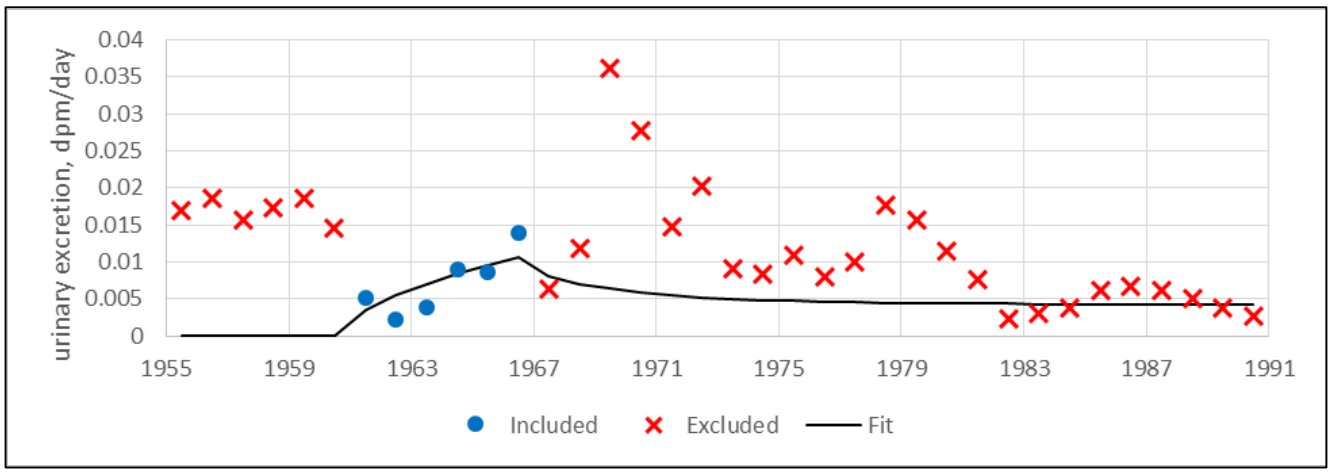


Figure F 44. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1966, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

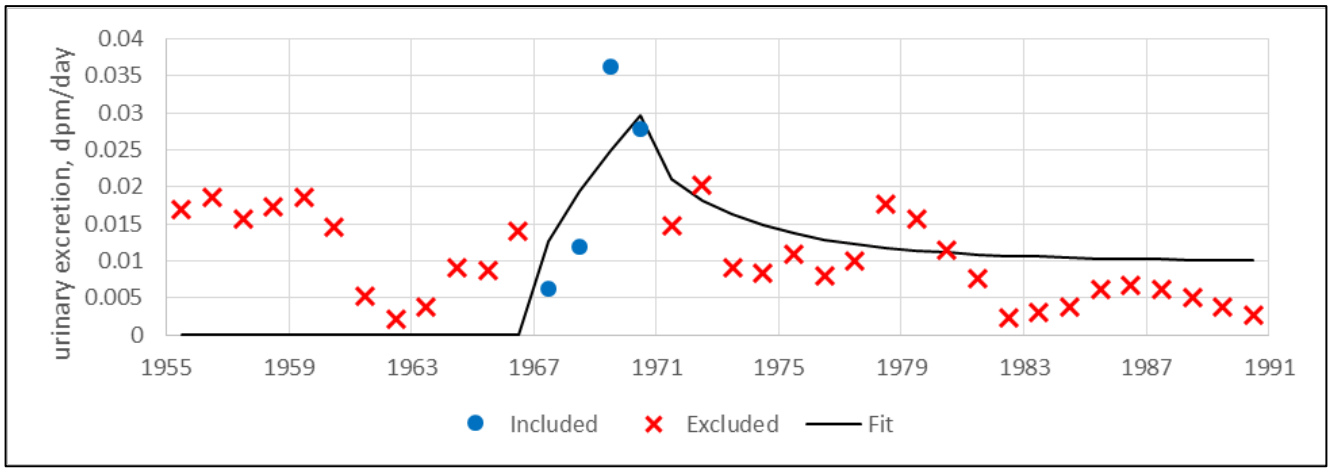


Figure F-45. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1970, type SS.

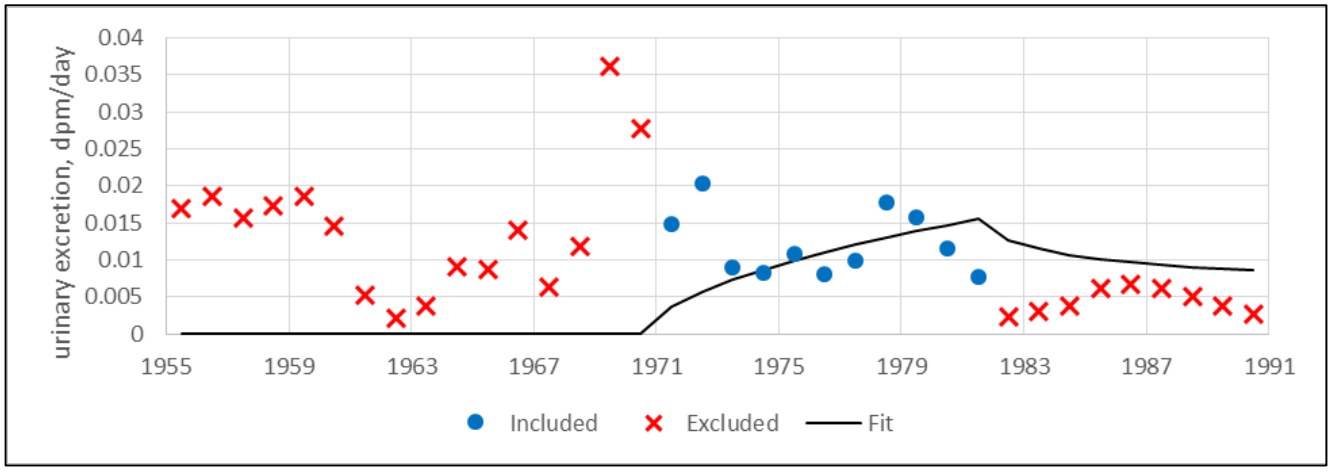


Figure F-46. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1971 to 1981, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

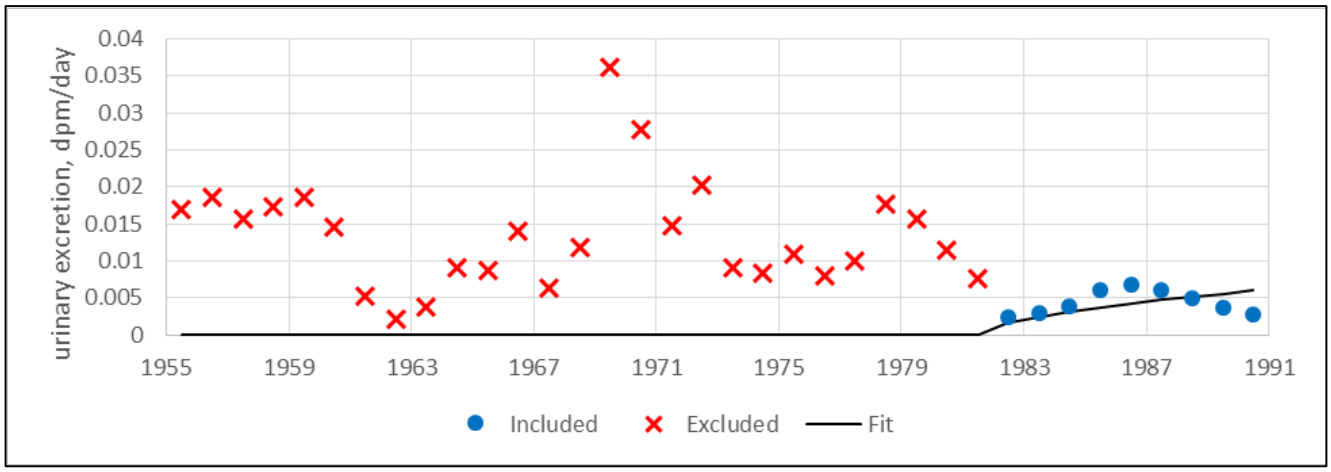


Figure F-47. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1990, type SS.

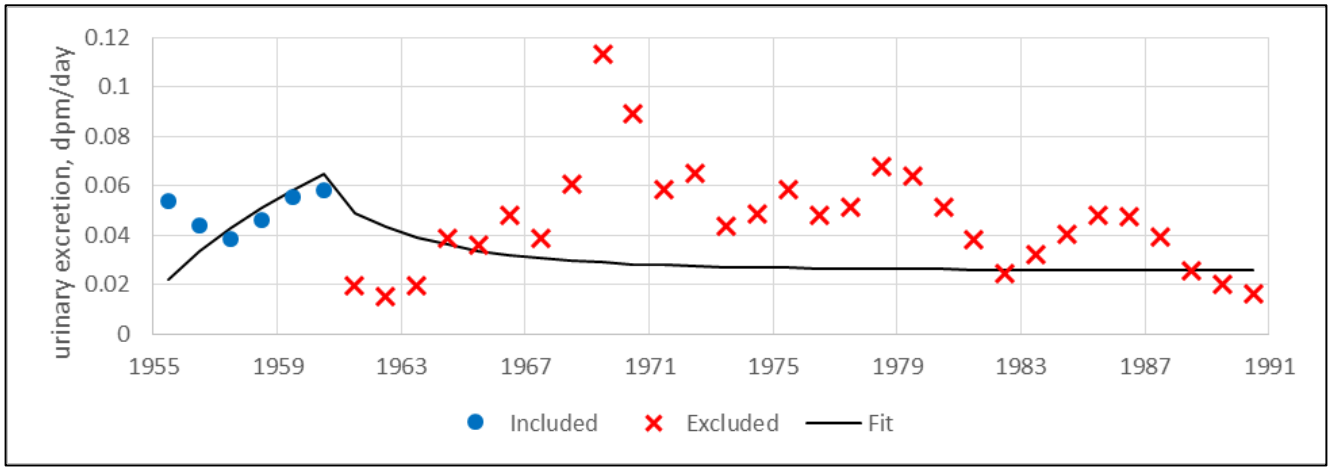


Figure F-48. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1960, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

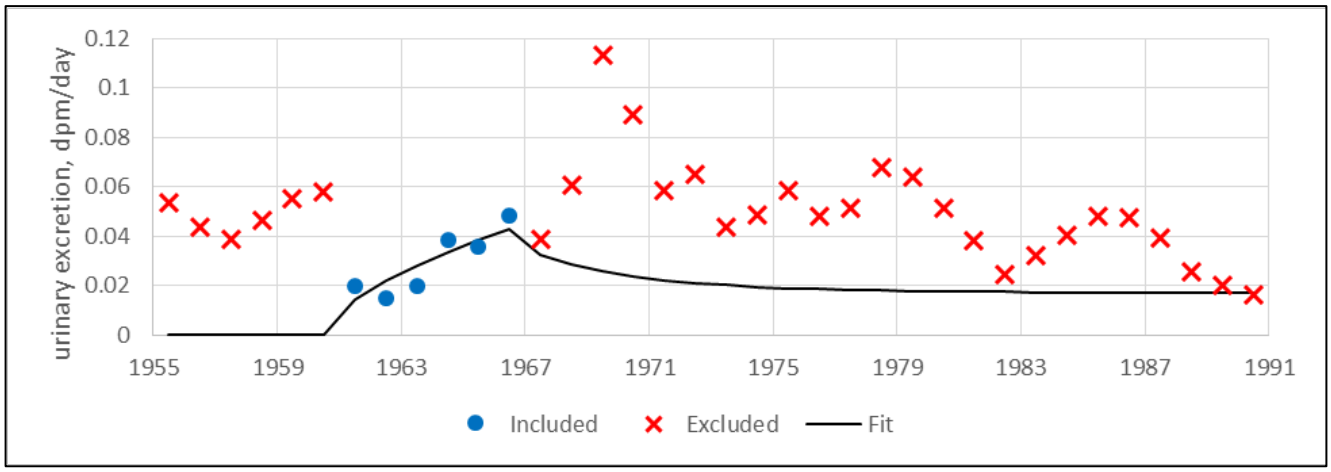


Figure F-49. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1966, type SS.

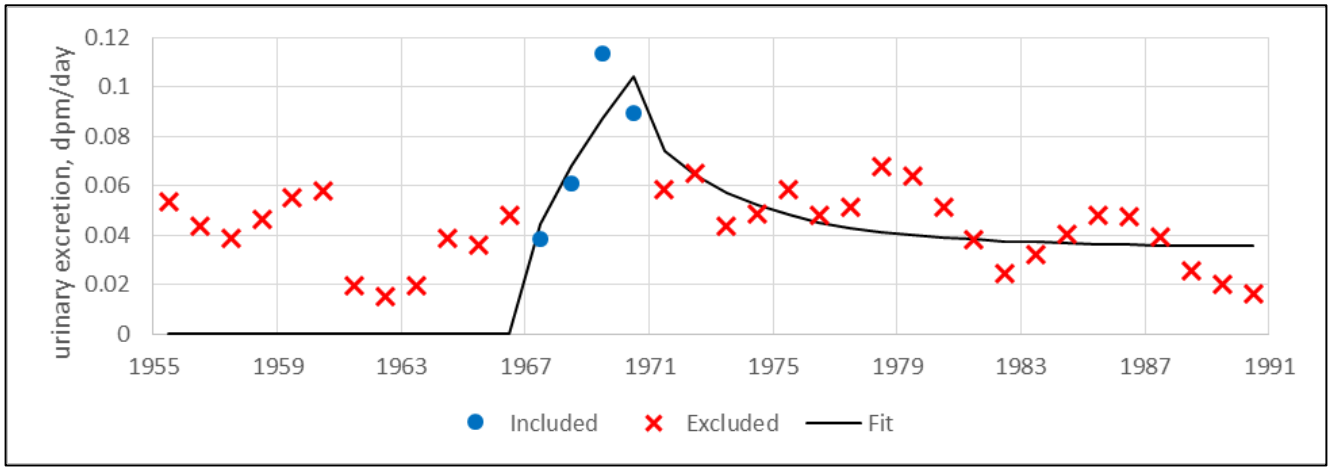


Figure F-50. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1970, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

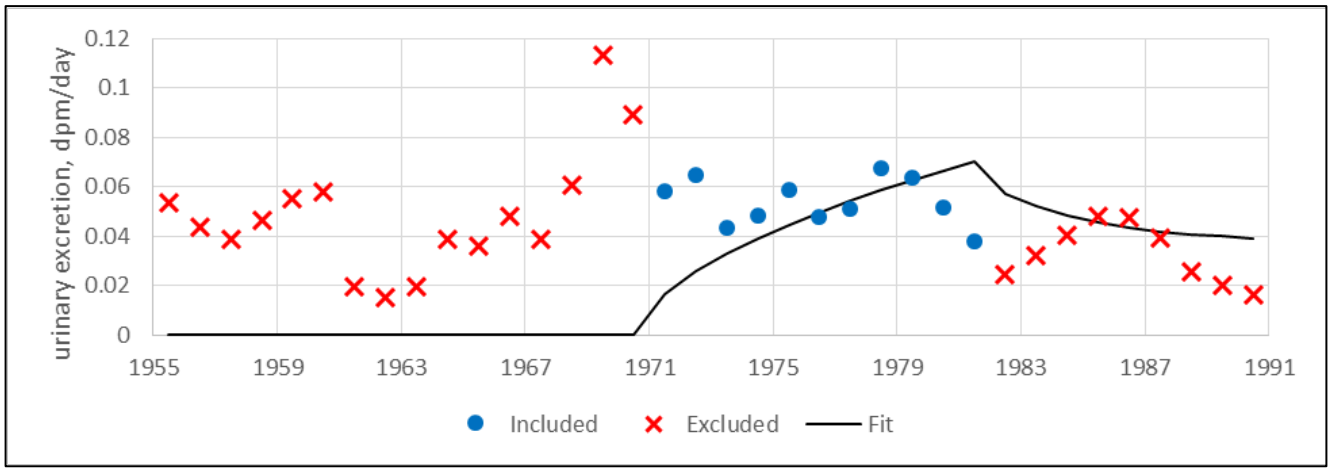


Figure F-51. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1971 to 1981, type SS.

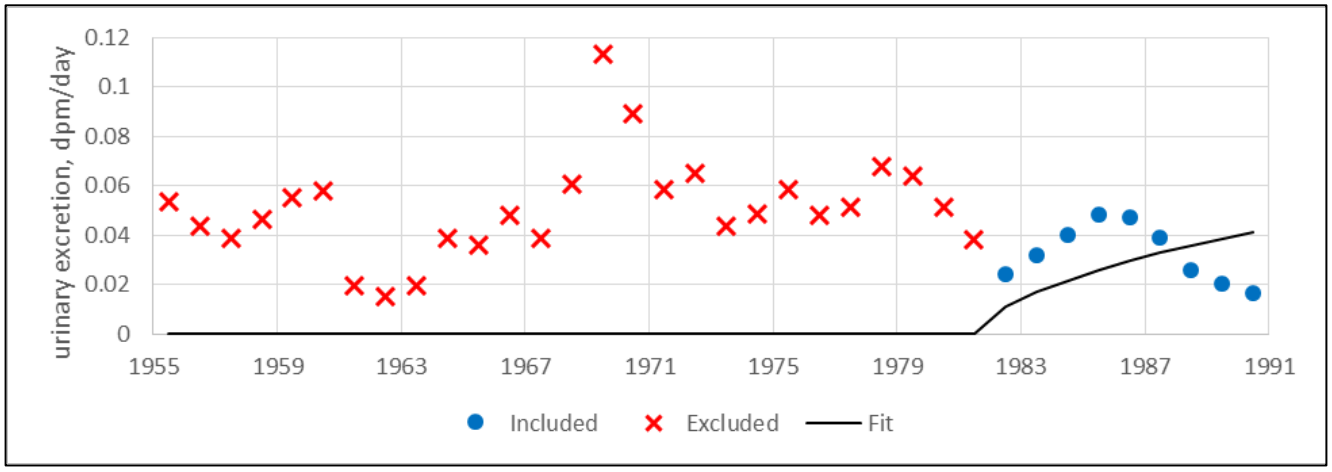


Figure F-52. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1990, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

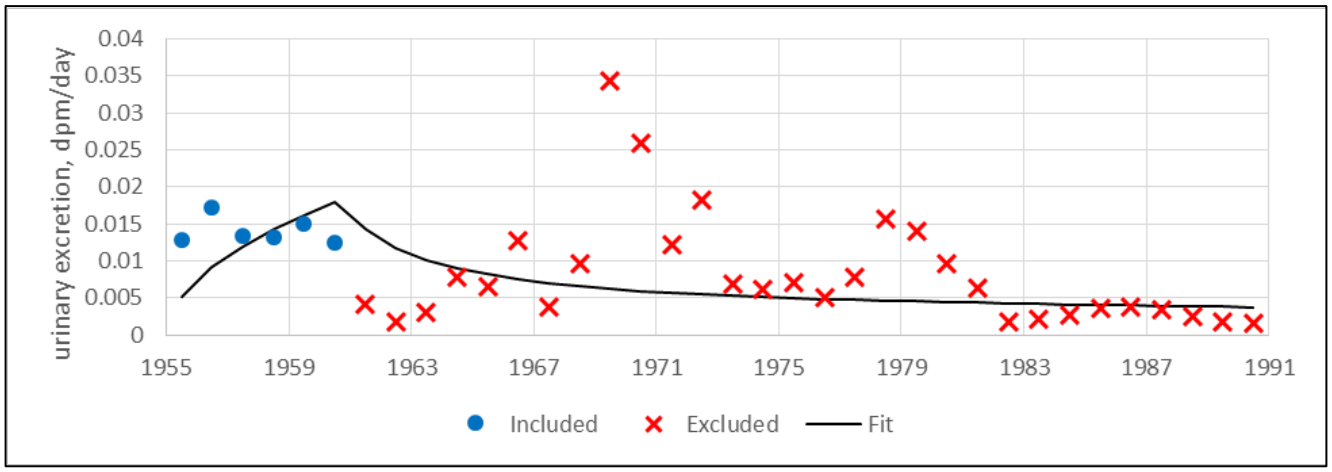


Figure F-53. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1960, type M.

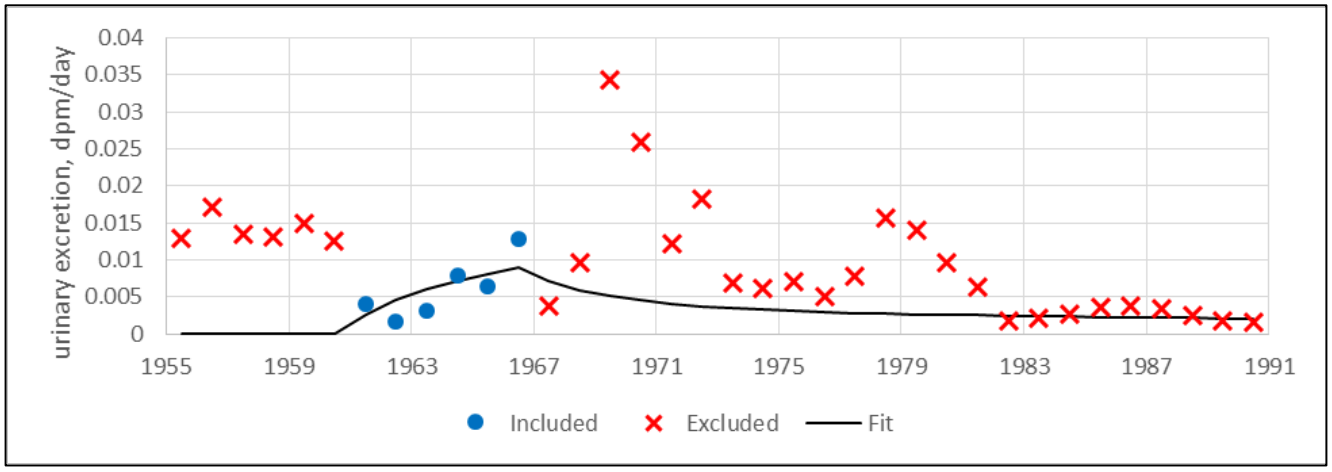


Figure F-54. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1966, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

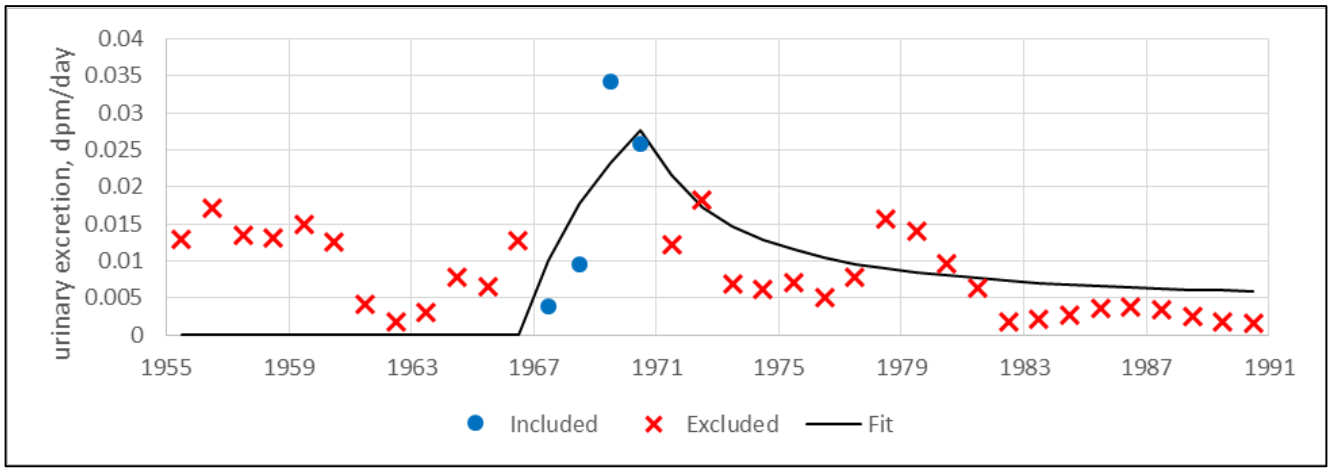


Figure F-55. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1970, type M.

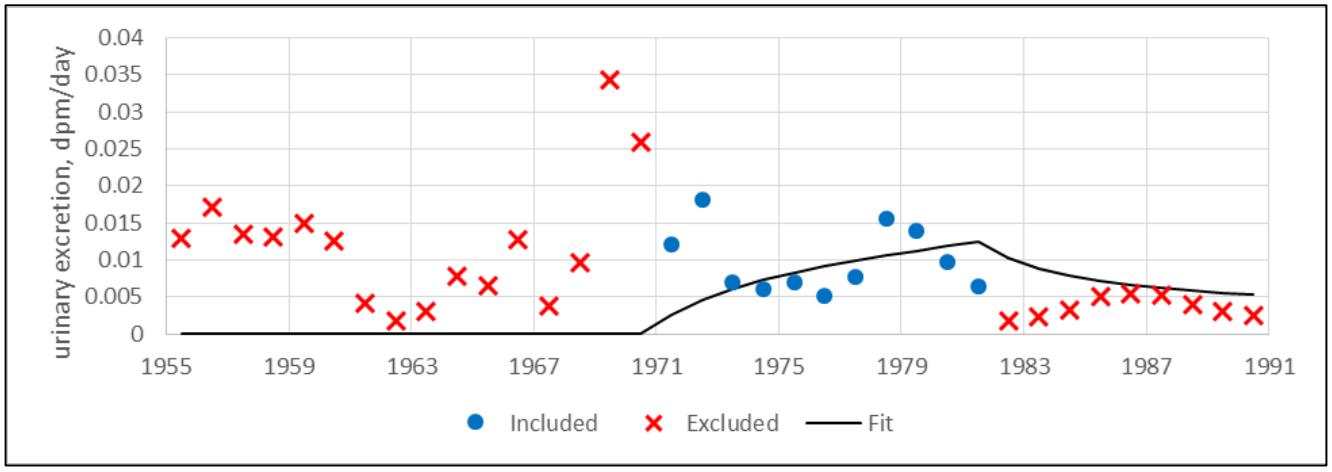


Figure F-56. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1971 to 1981, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

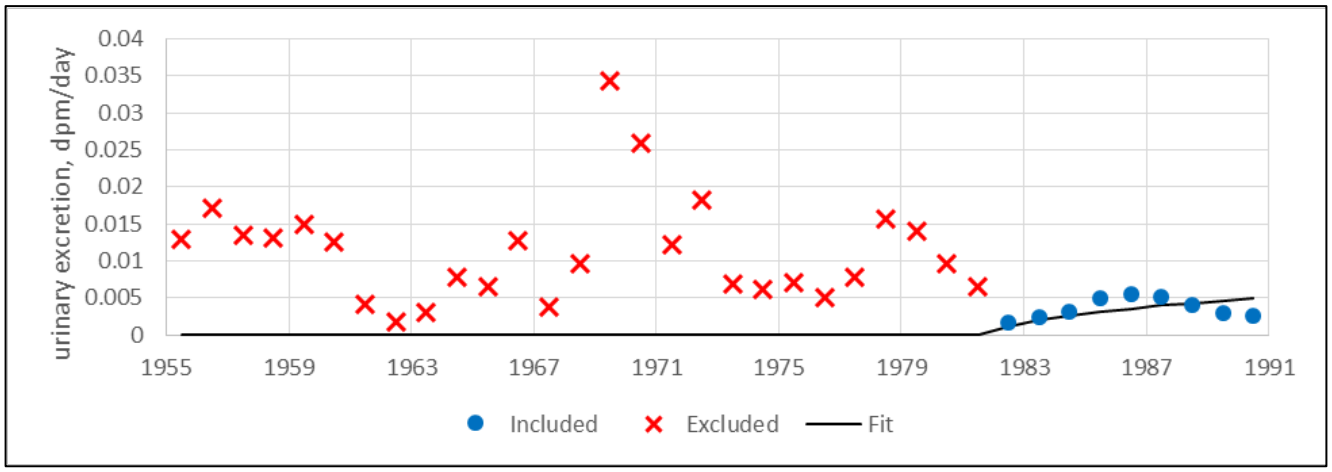


Figure F-57. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1982 to 1990, type M.

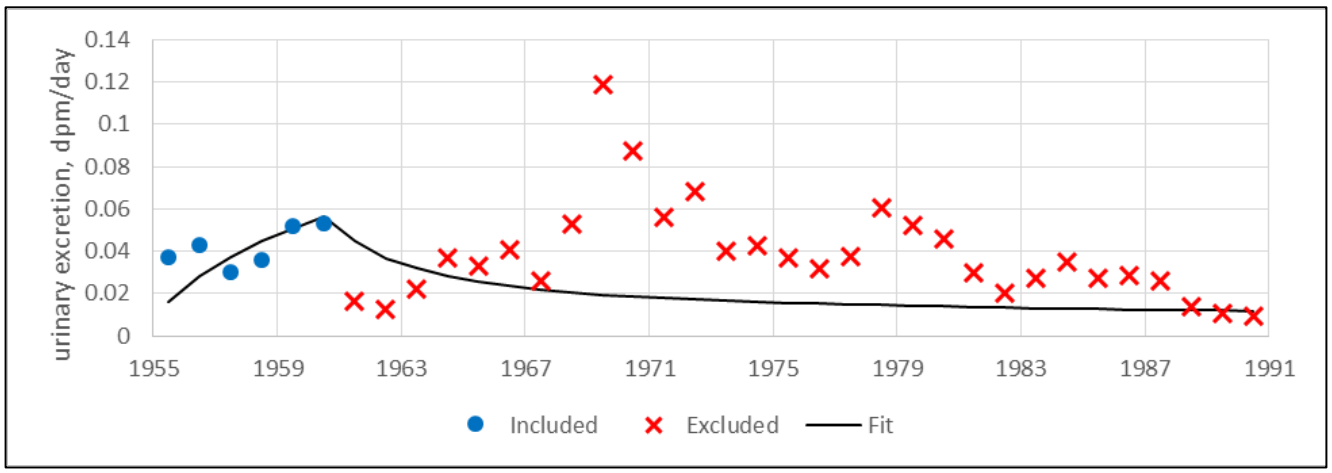


Figure F-58. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1960, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

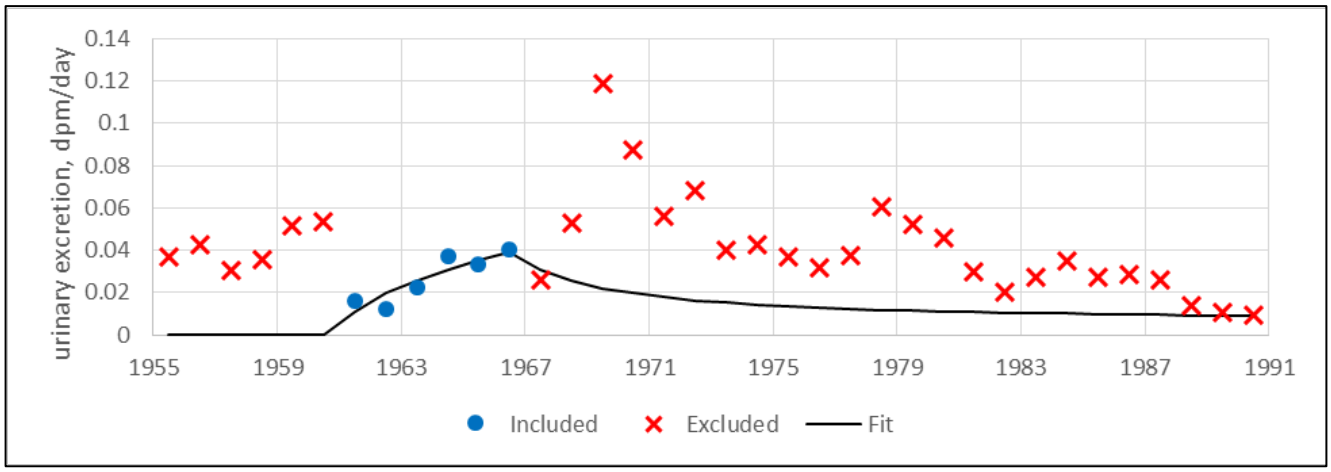


Figure F-59. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1966, type M.

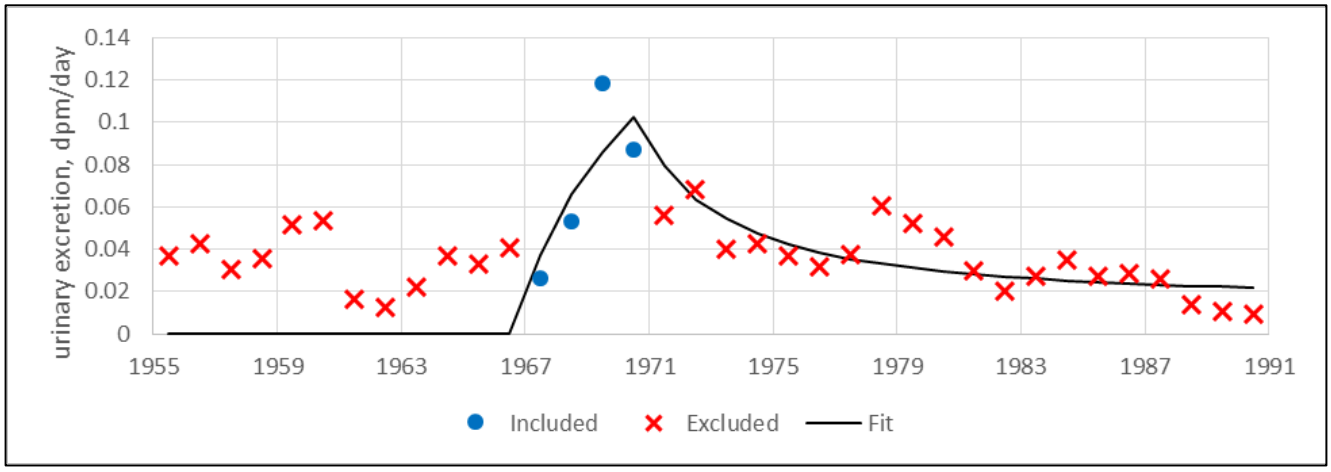


Figure F-60. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1970, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

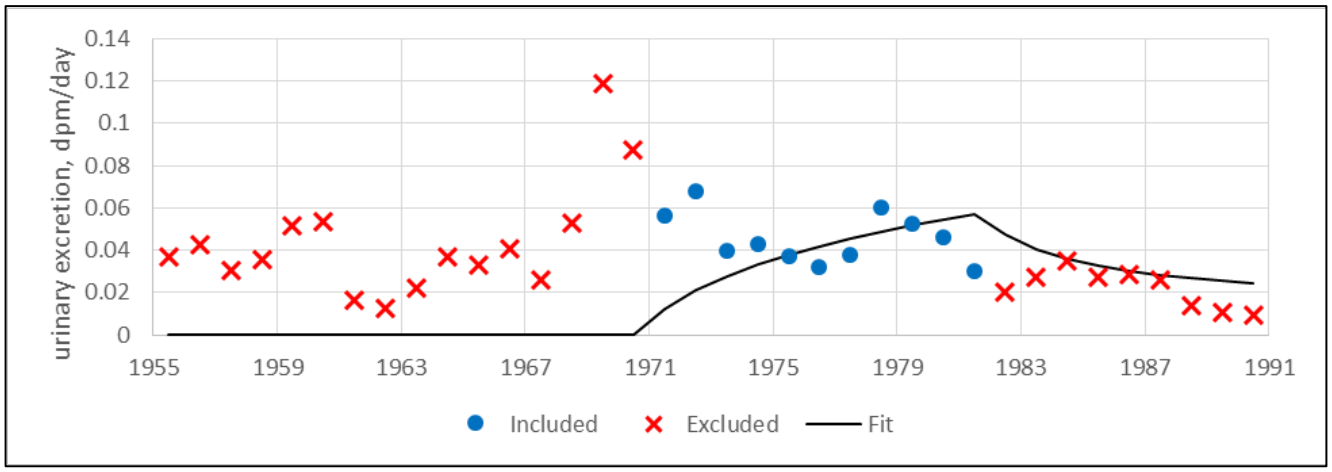


Figure F-61. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1971 to 1981, type M.

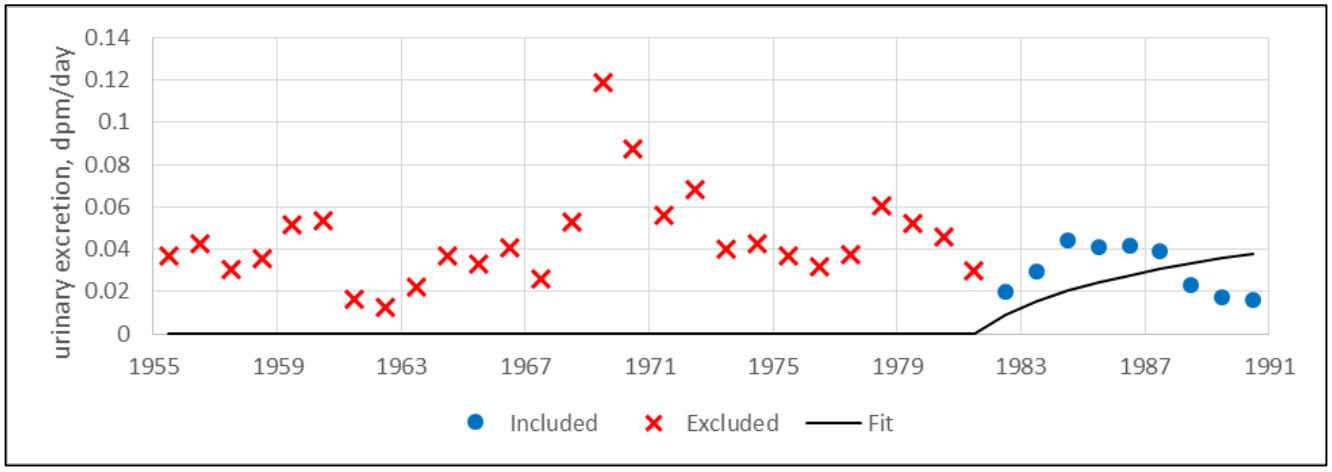


Figure F-62. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1982 to 1990, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

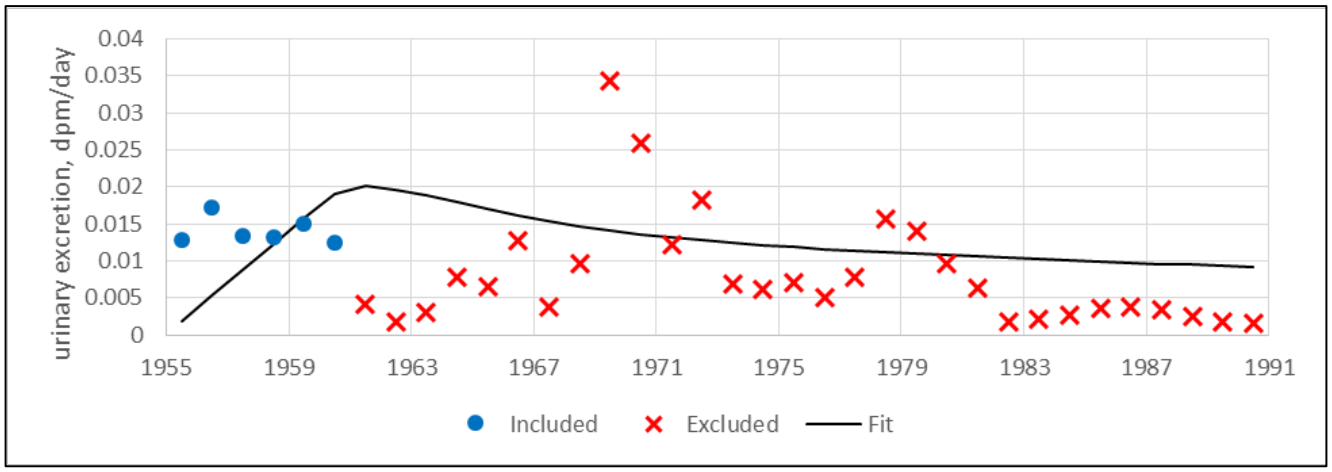


Figure F-63. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1960, type S.

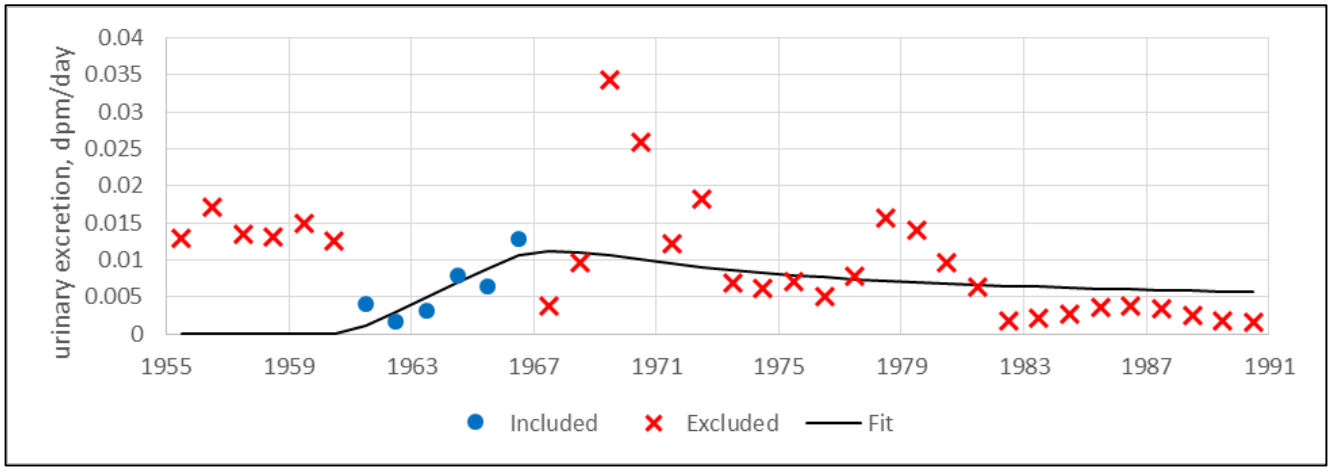


Figure F-64. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1966, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

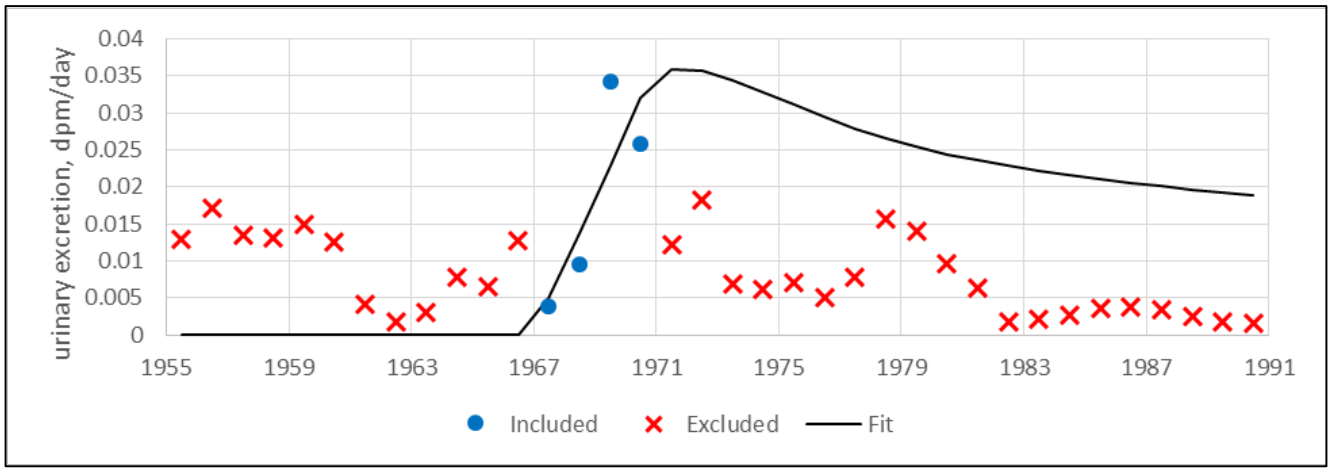


Figure F-65. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1970, type S.

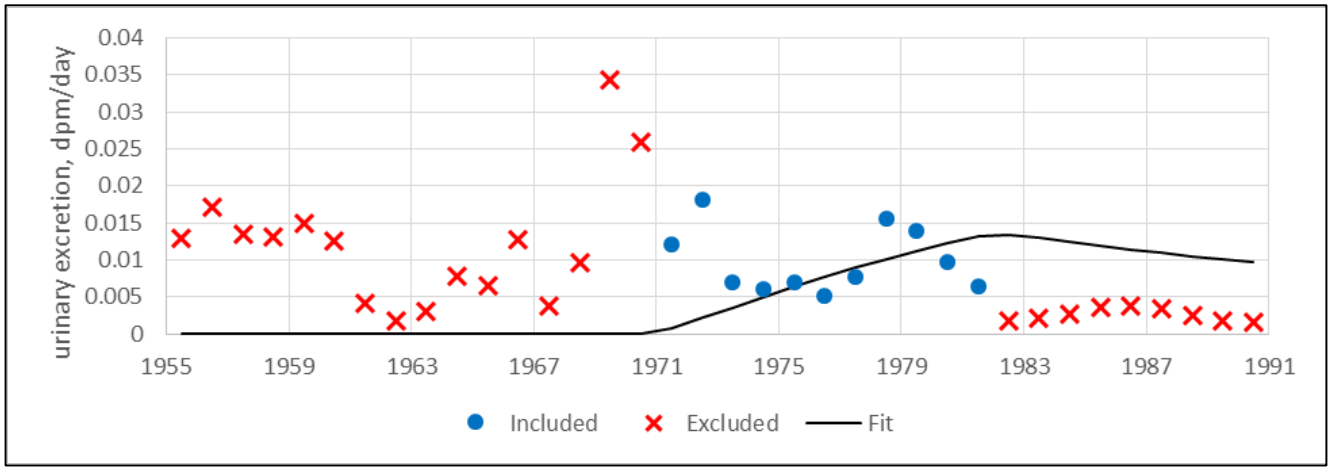


Figure F-66. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1971 to 1981, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

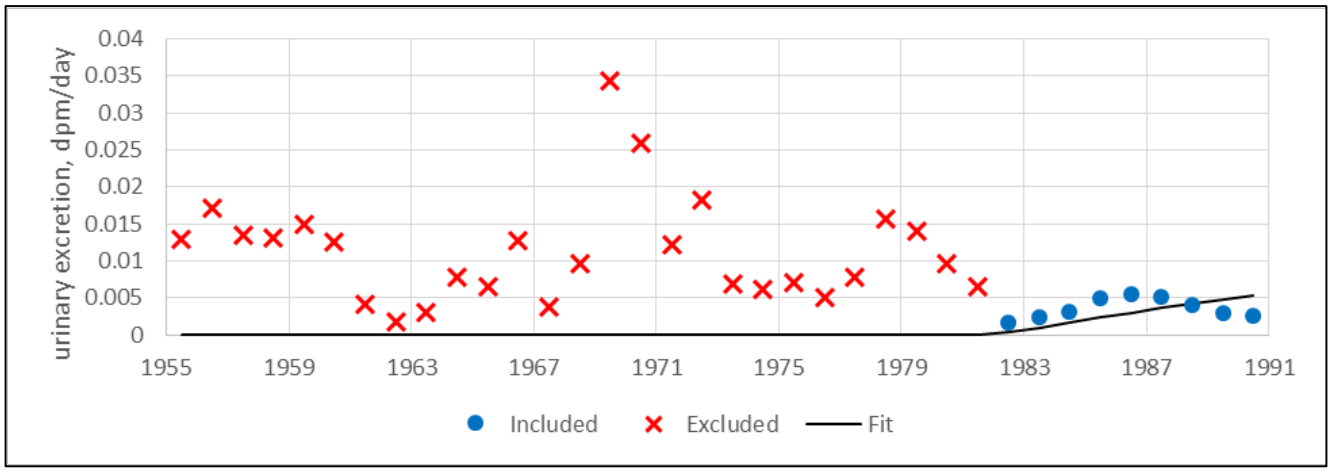


Figure F-67. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1982 to 1990, type S.

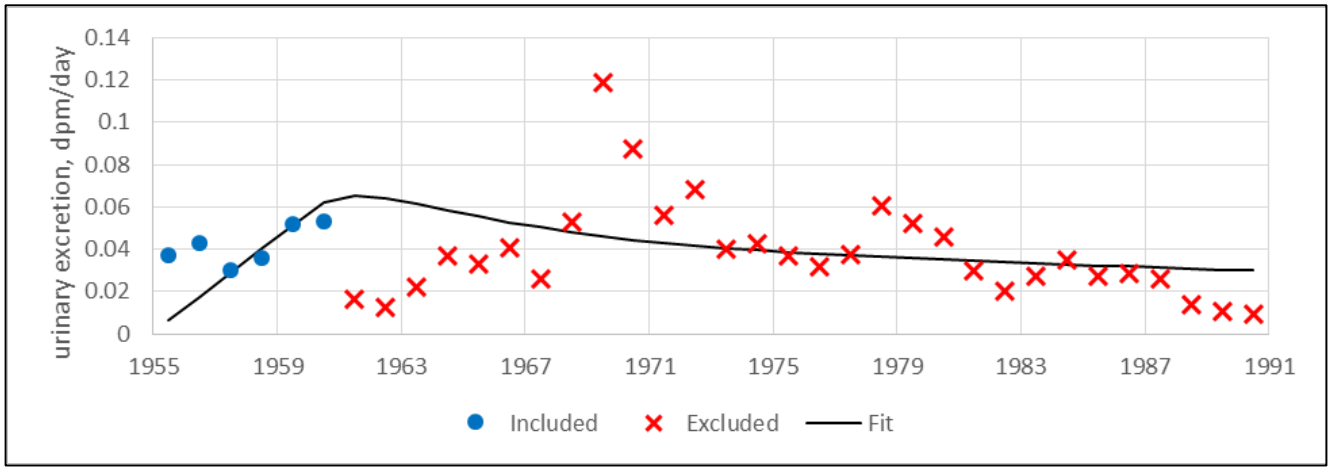


Figure F-68. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1960, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

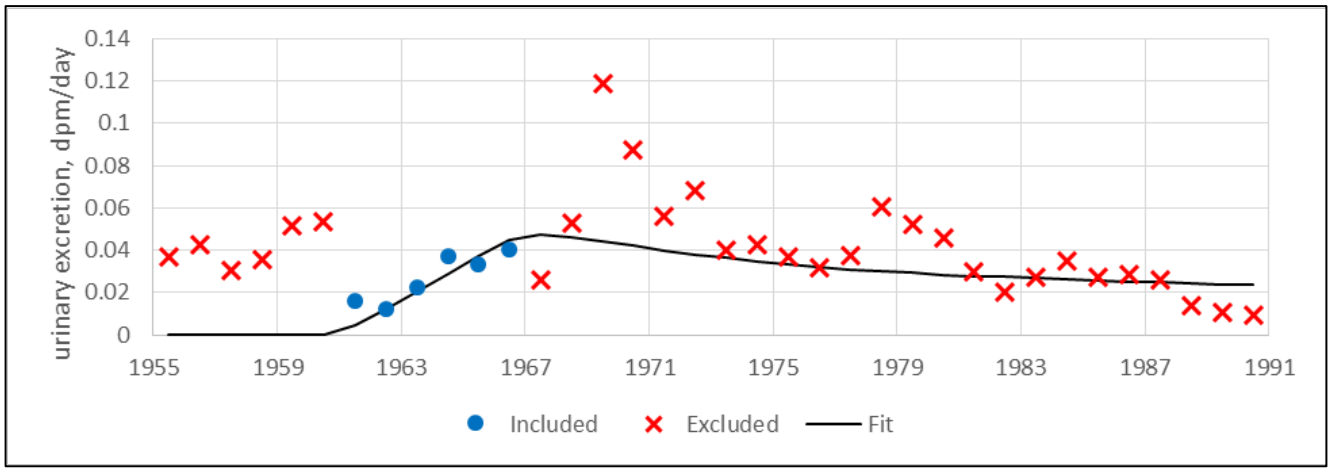


Figure F-69. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1966, type S.

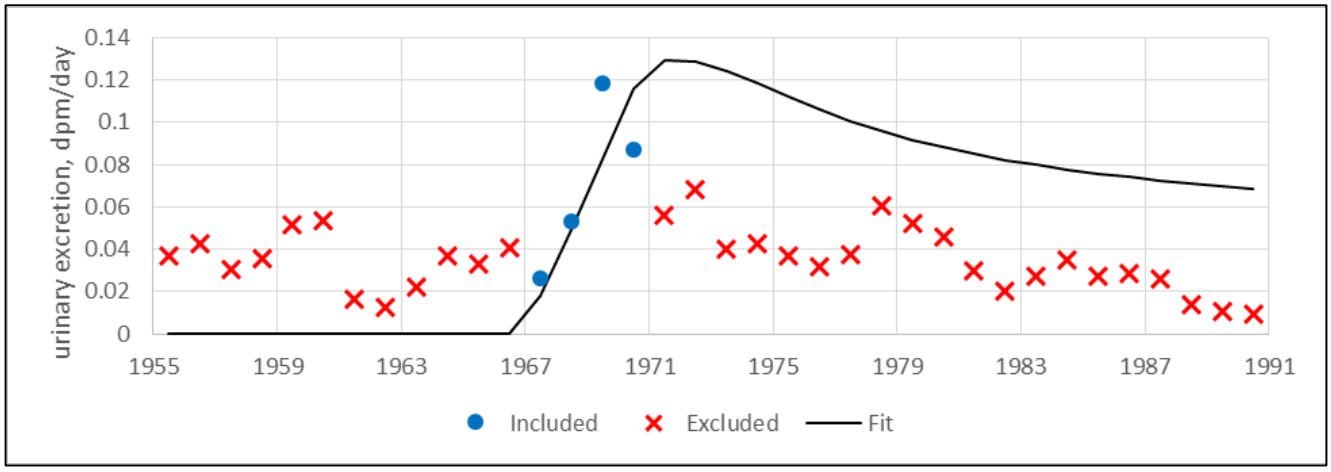


Figure F-70. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1970, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

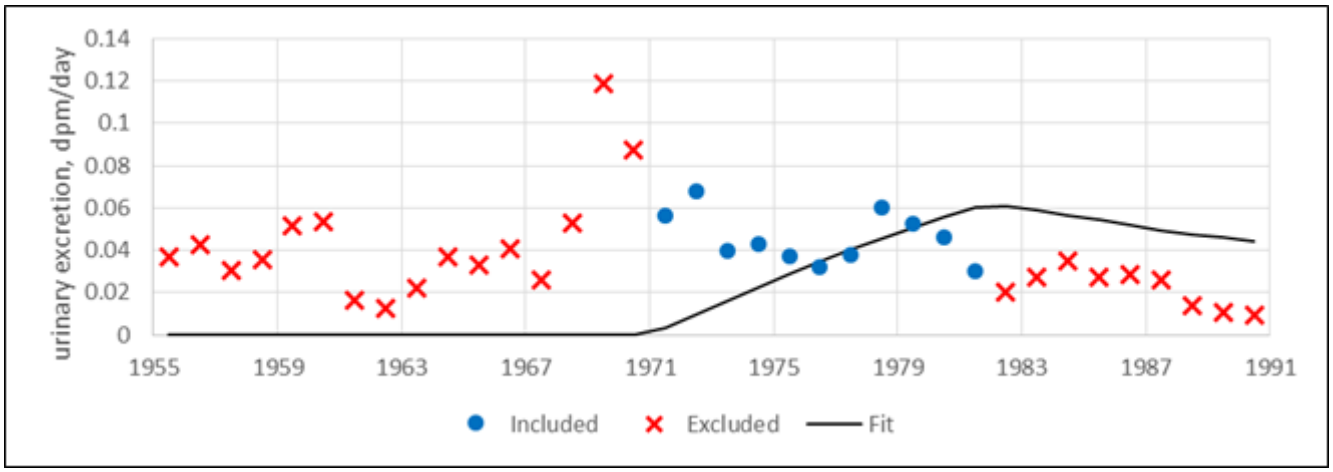


Figure F 71. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1971 to 1981, type S.

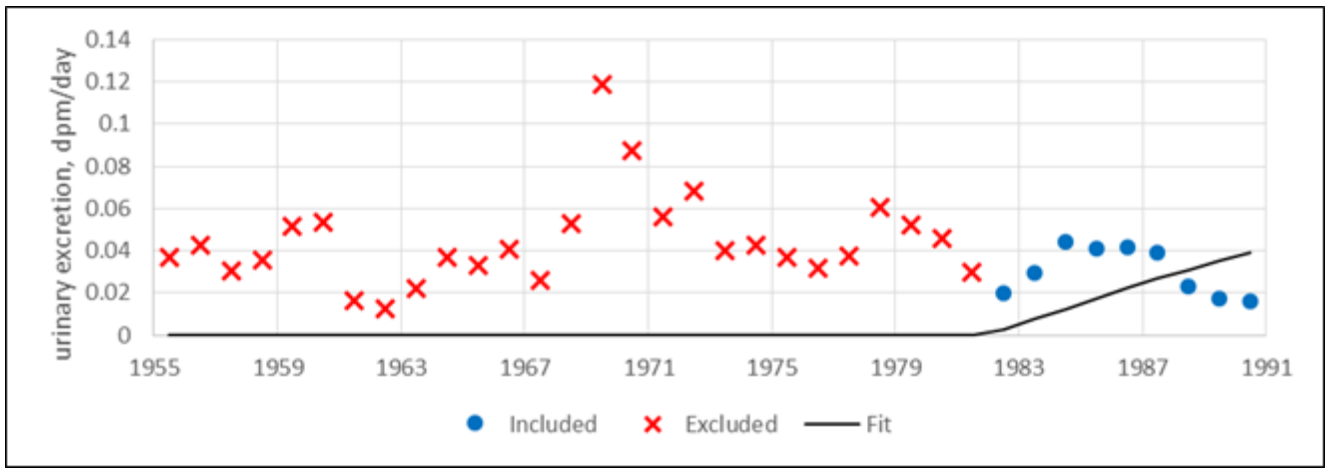


Figure F 72. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1982 to 1990, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

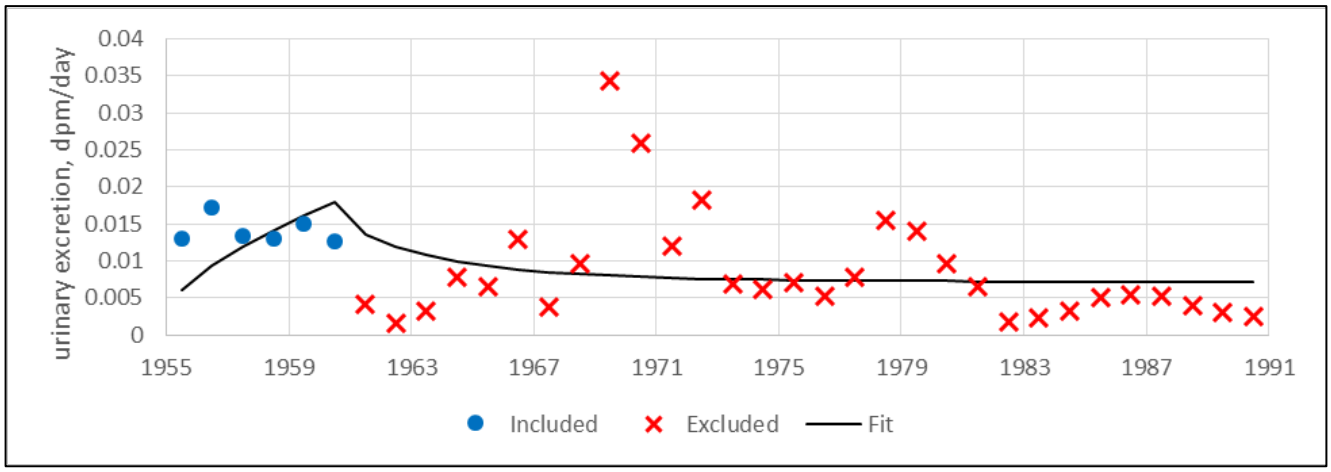


Figure F-73. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1960, type SS.

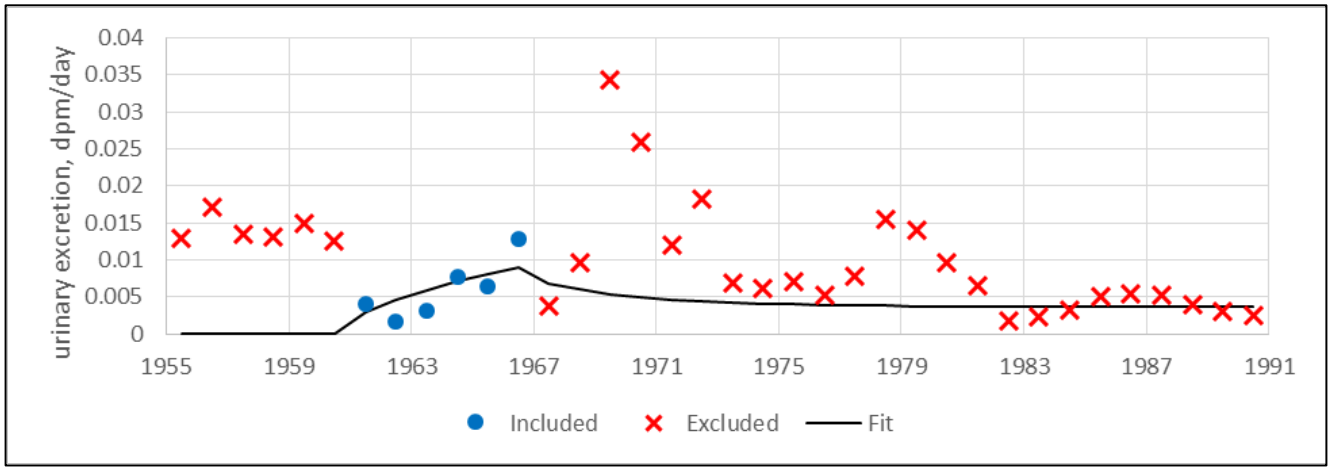


Figure F-74. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1966, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

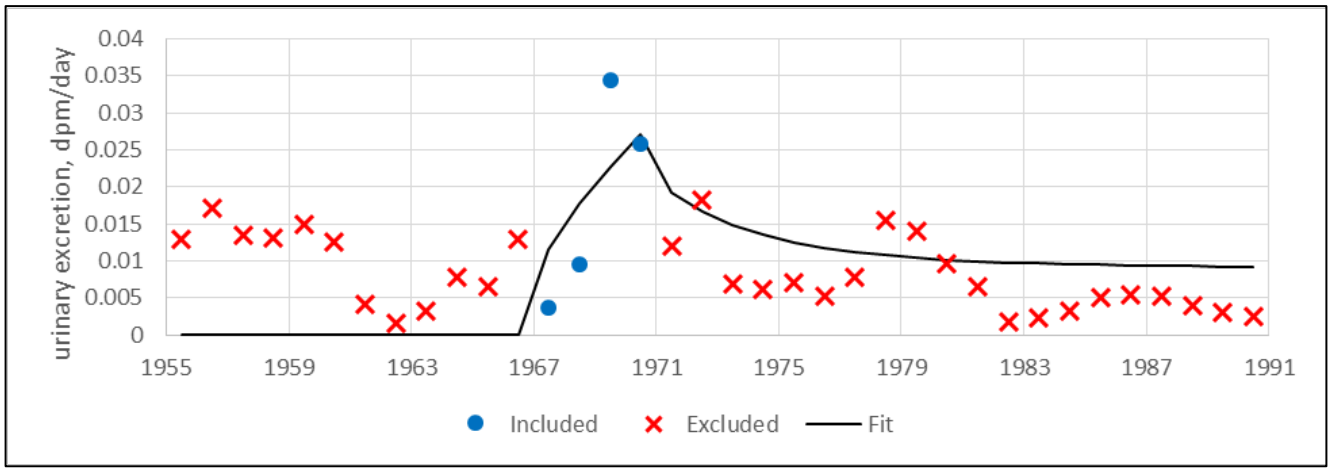


Figure F-75. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1970, type SS.

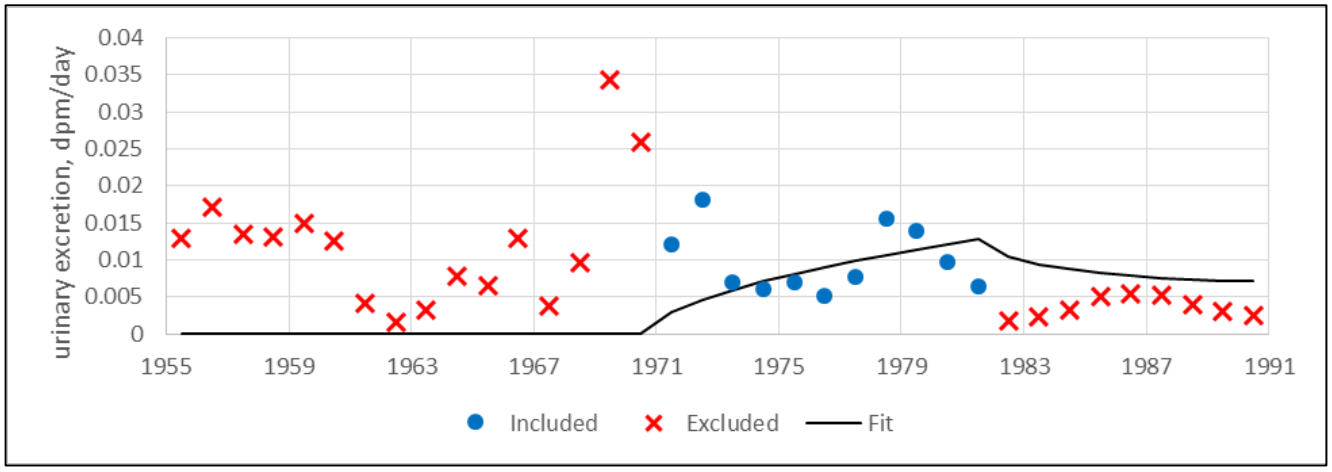


Figure F-76. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1971 to 1981, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

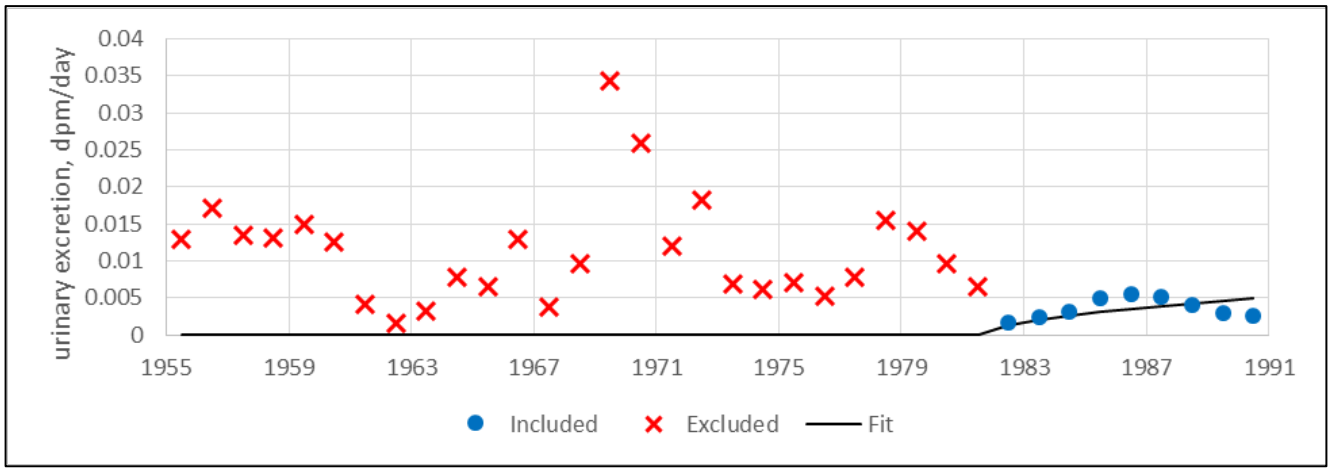


Figure F-77. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1982 to 1990, type SS.

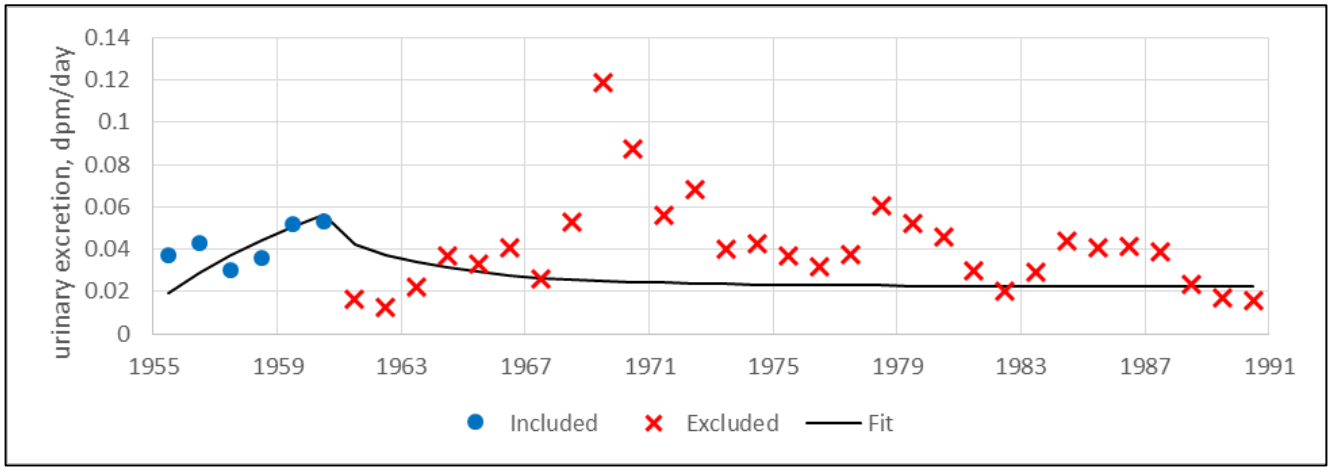


Figure F-78. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1960, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

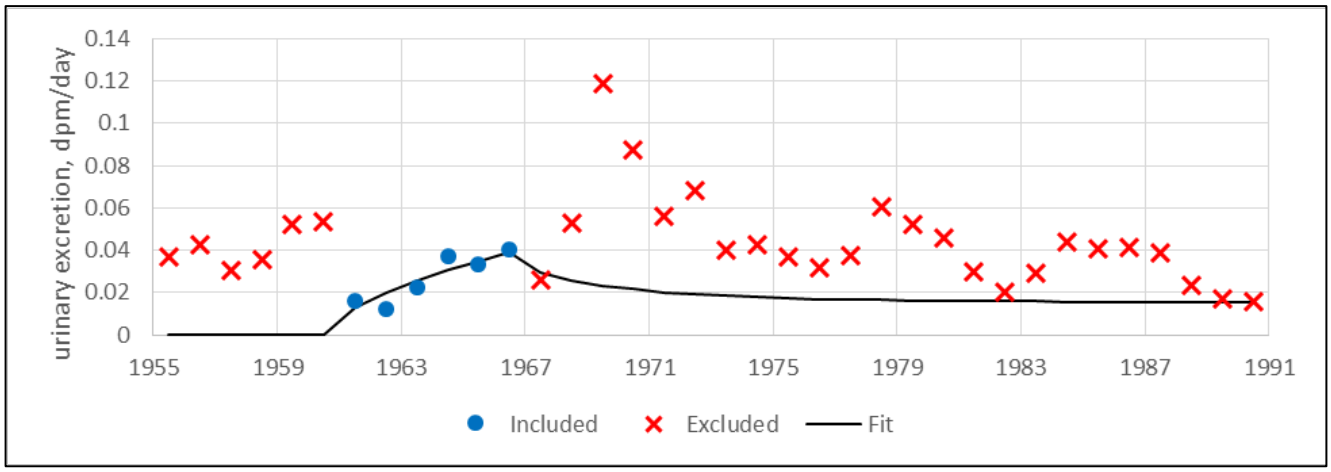


Figure F-79. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1966, type SS.

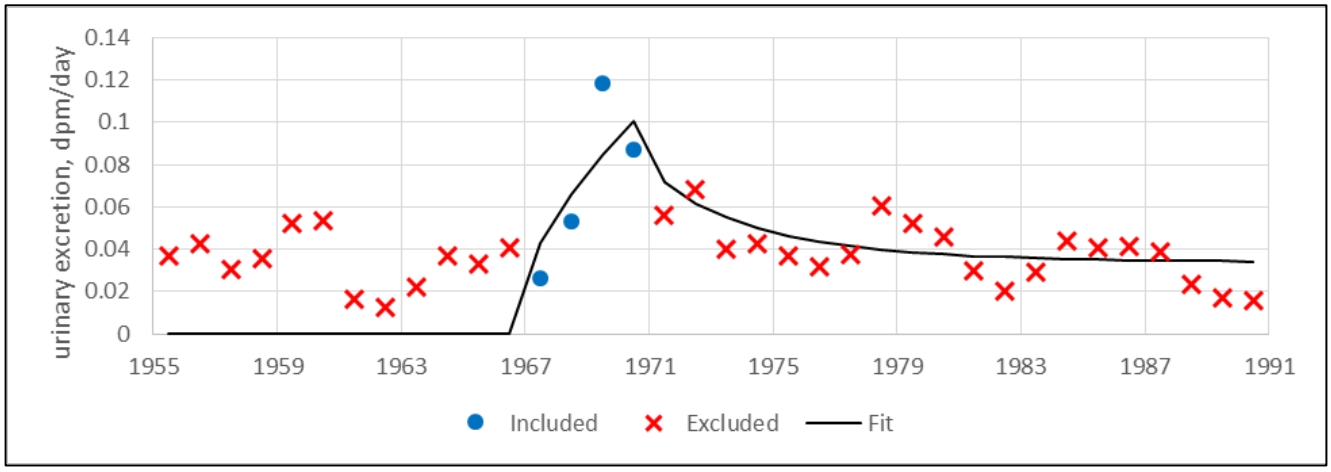


Figure F-80. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1970, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

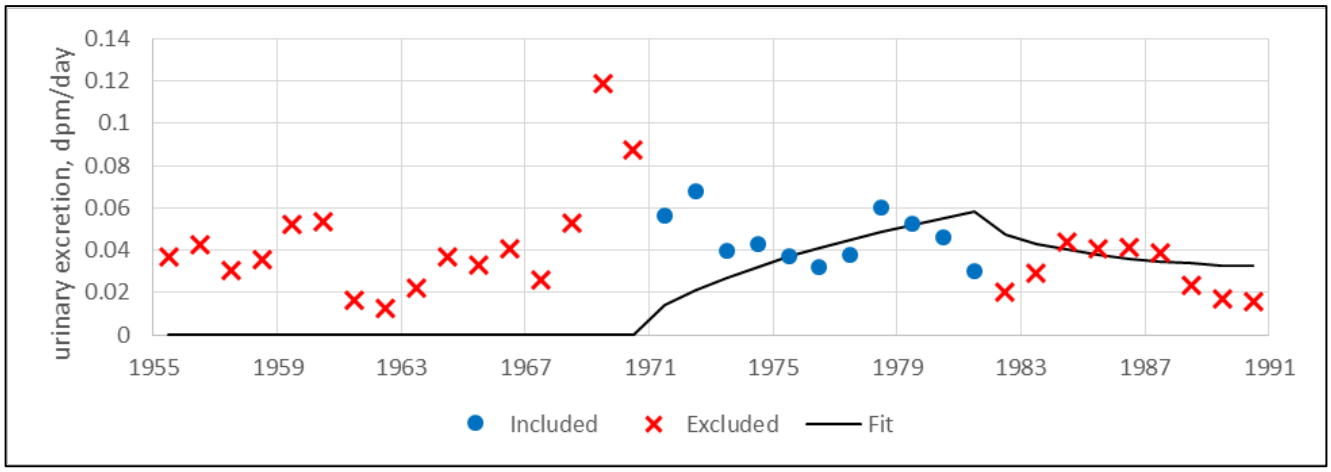


Figure F-81. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1971 to 1981, type SS.

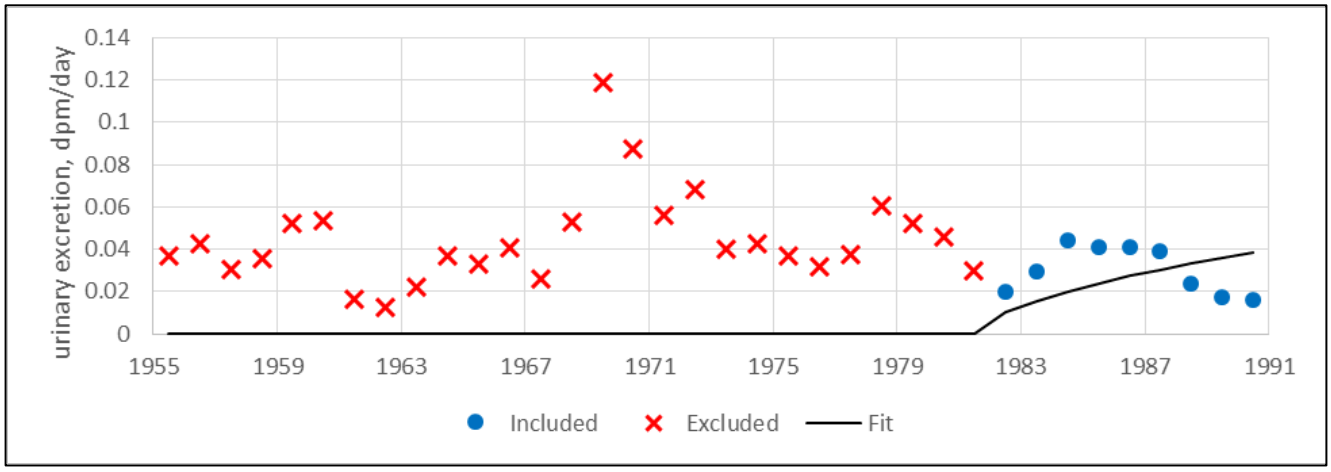


Figure F-82. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1982 to 1990, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

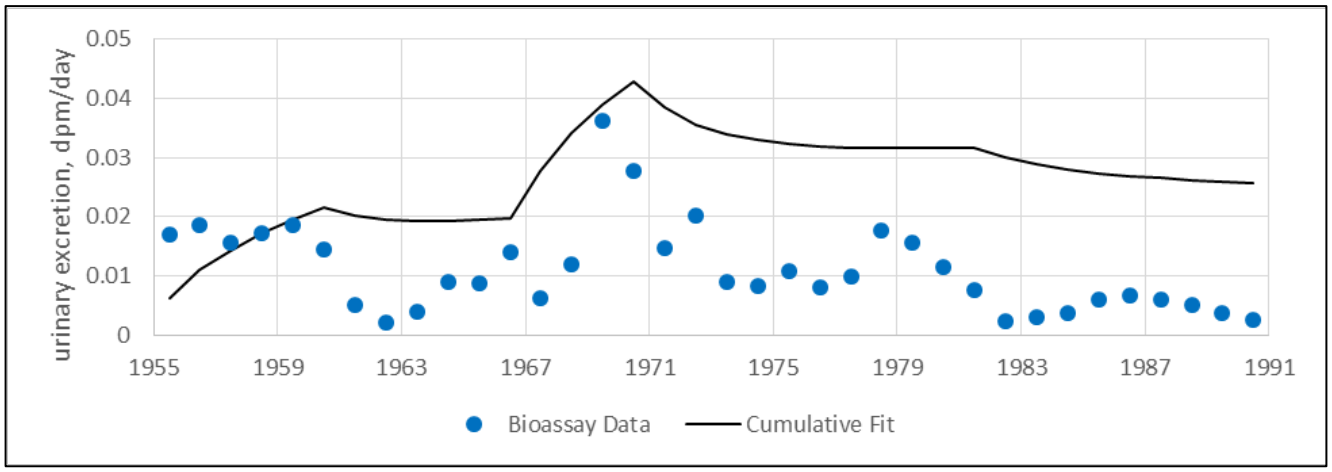


Figure F-83. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type M.

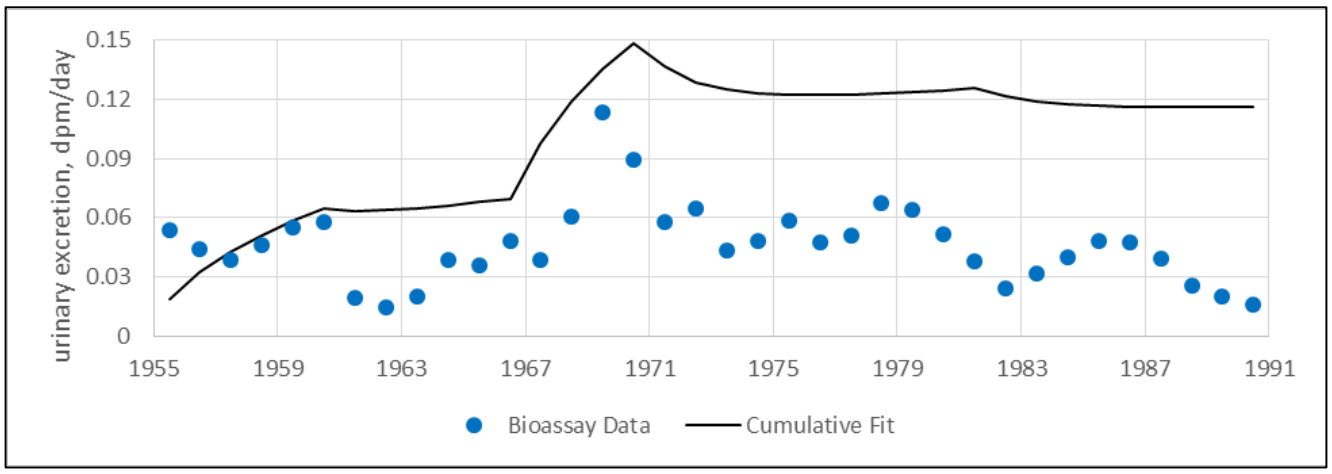


Figure F-84. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

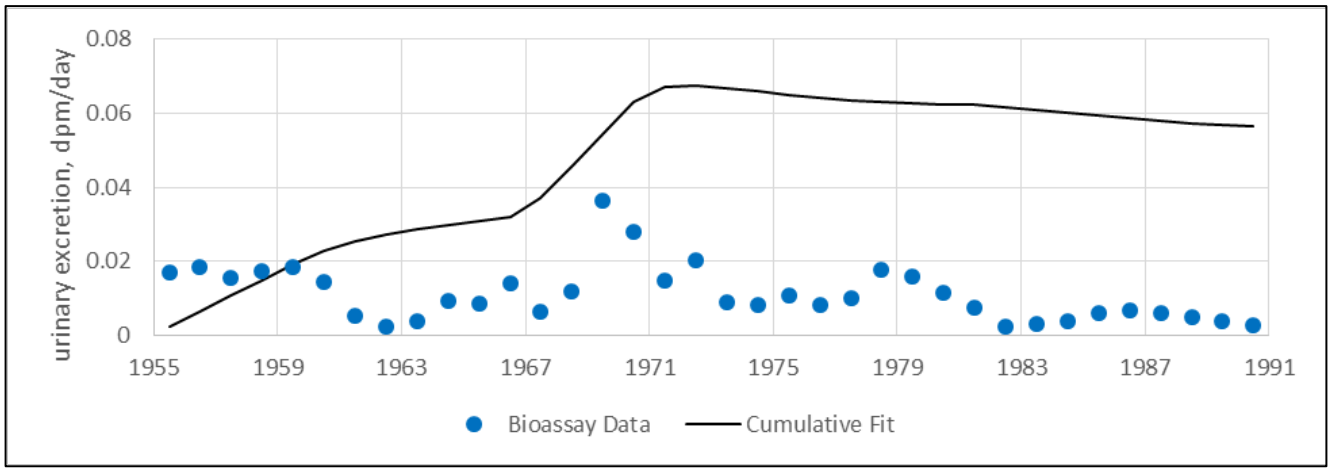


Figure F-85. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type S.

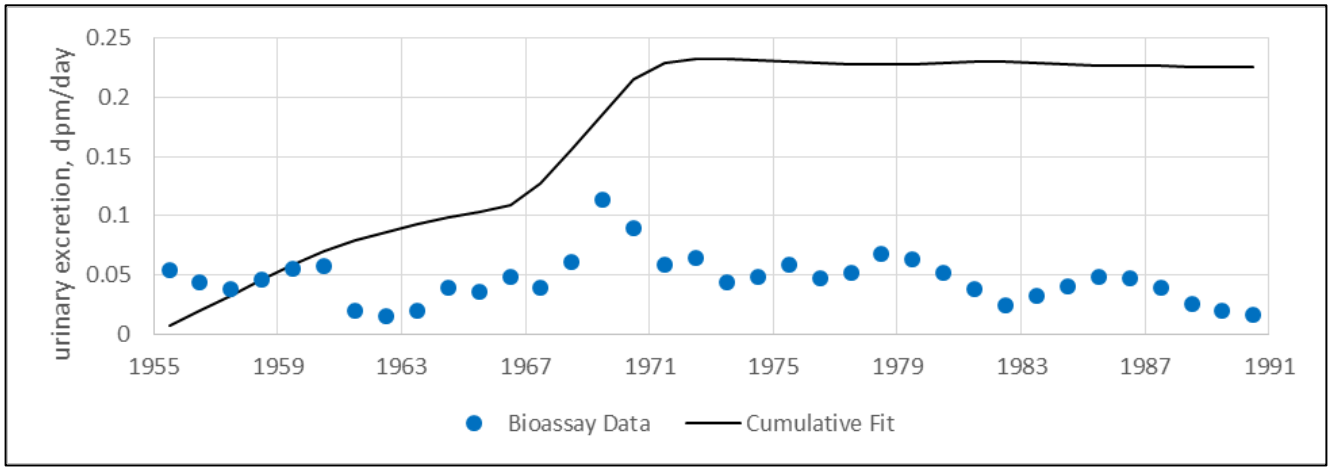


Figure F-86. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

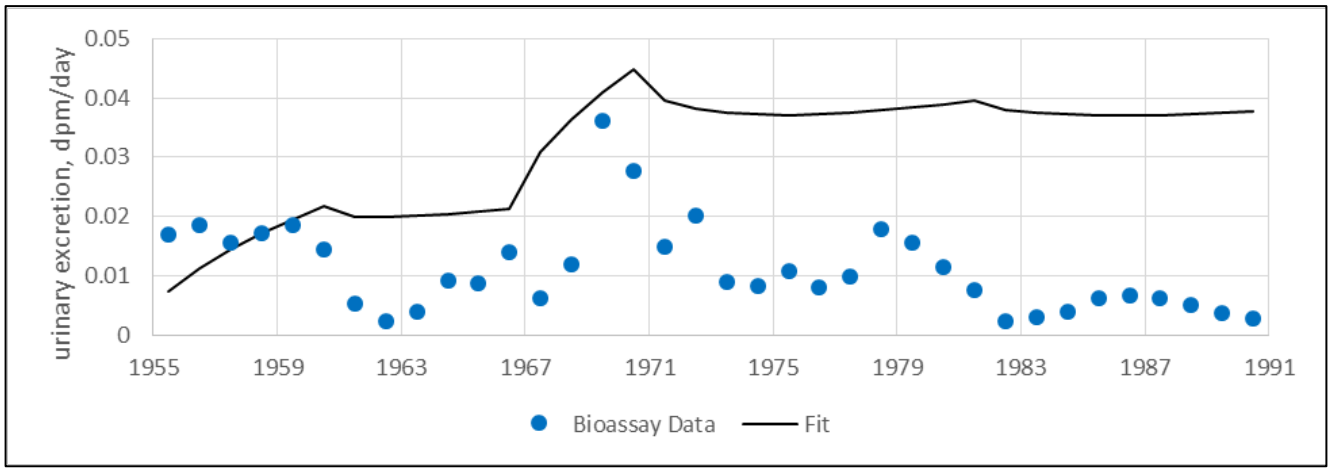


Figure F-87. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 50th percentile, all years, type SS.

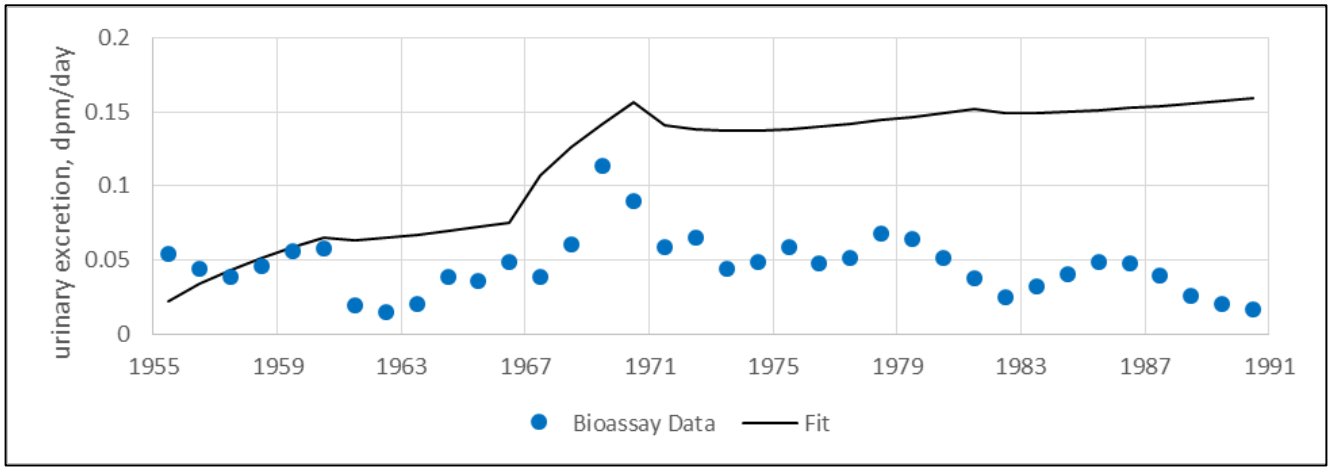


Figure F-88. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), nonCTW 84th percentile, all years, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

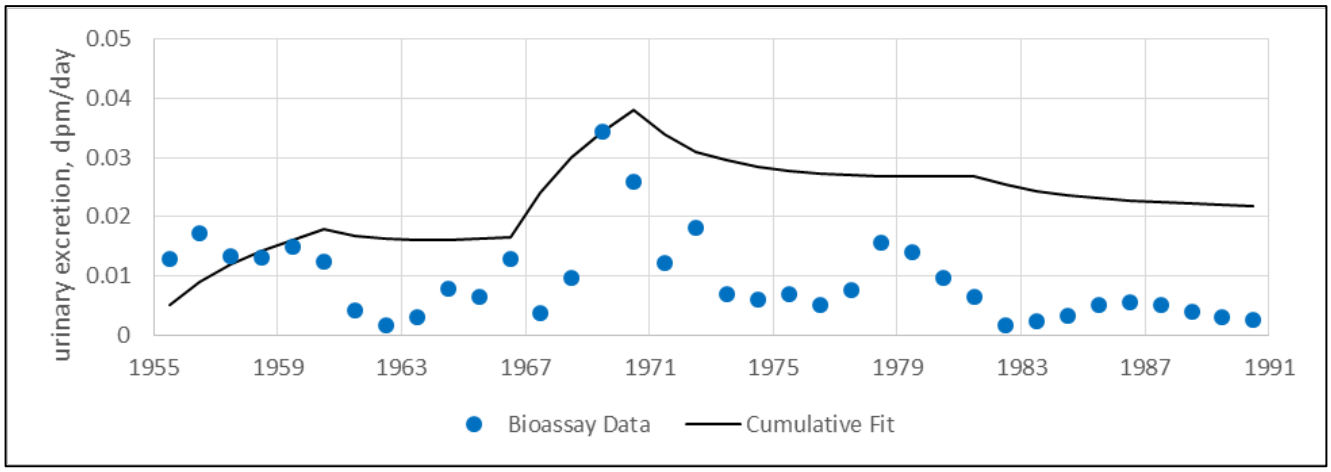


Figure F-89. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type M.

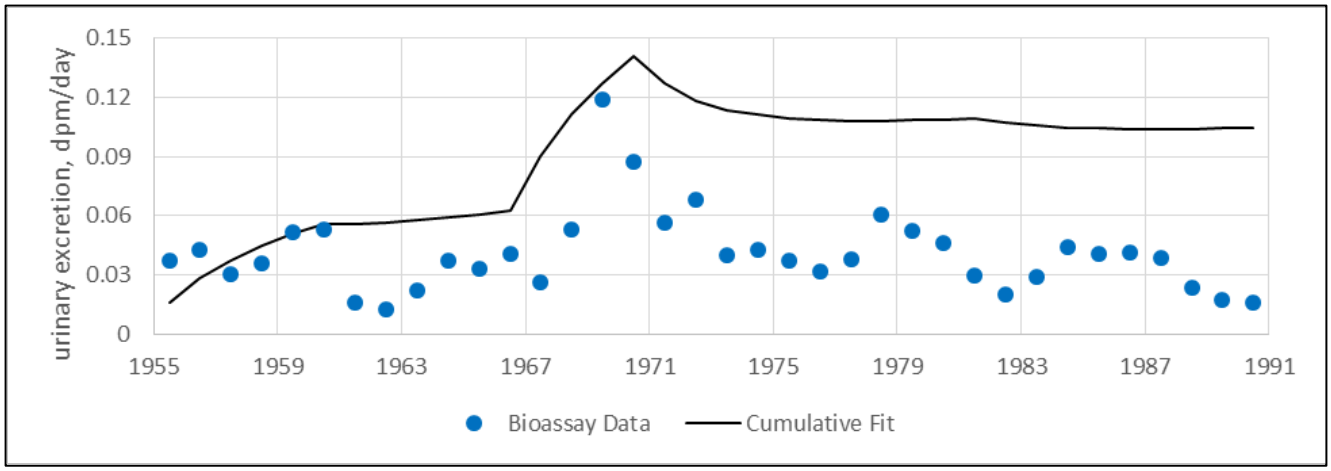


Figure F-90. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type M.

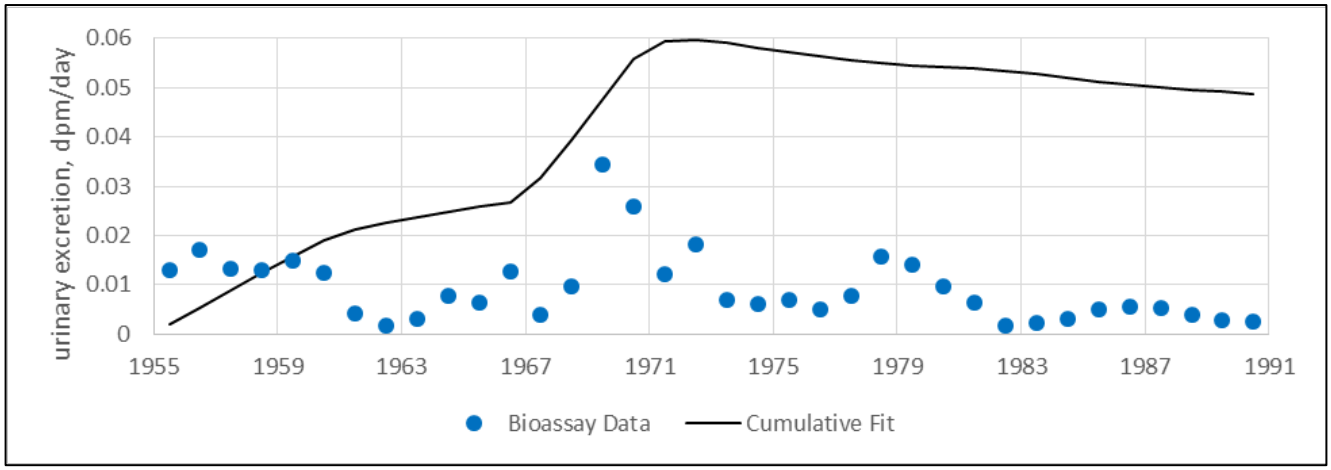


Figure F-91. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

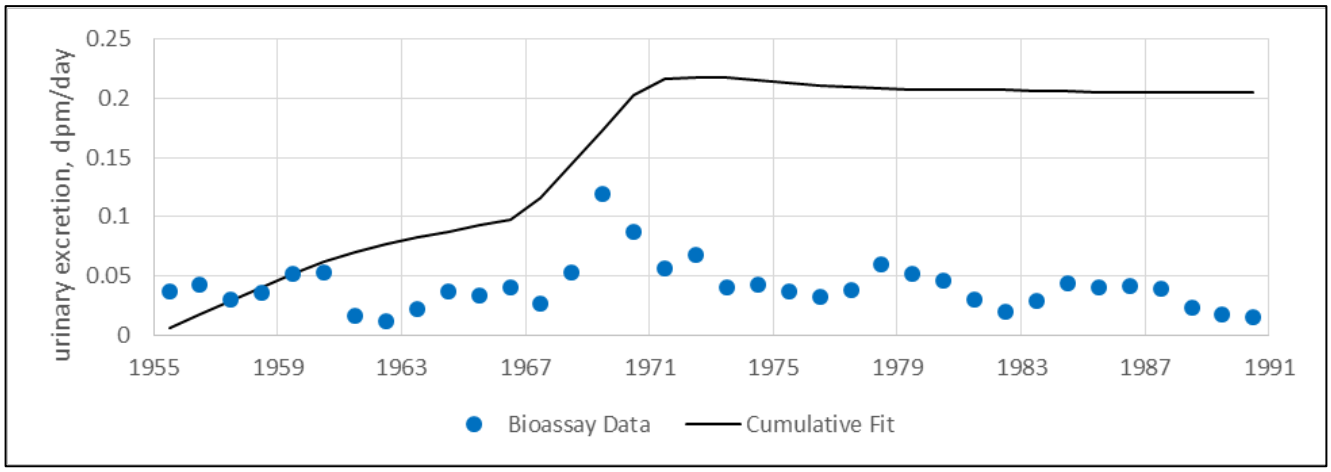


Figure F-92. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type S.

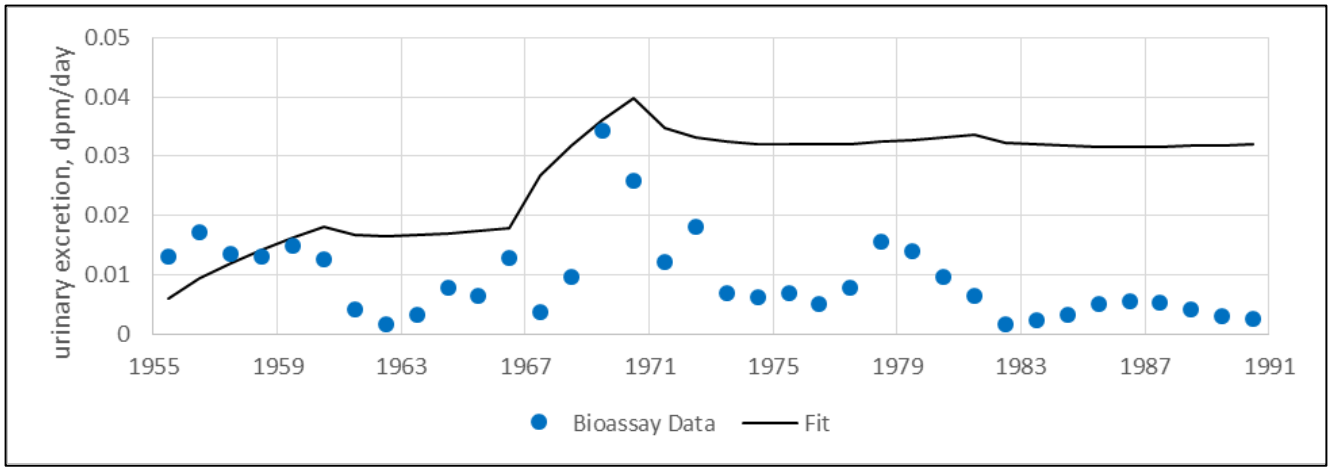


Figure F-93. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 50th percentile, all years, type SS.

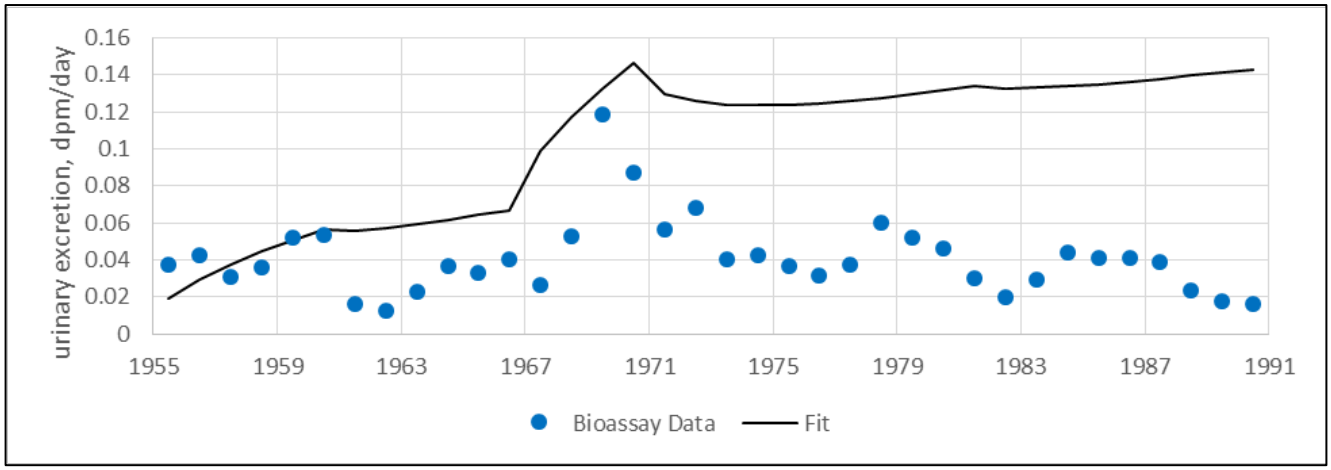


Figure F-94. Predicted plutonium bioassay results calculated using IDOT-derived plutonium intake rates (line) compared with measured bioassay results (dots), CTW 84th percentile, all years, type SS.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

Table F-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

Table F-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 F-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 F-6. Summary of plutonium CTW 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	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

Table F-7. Summary of plutonium CTW 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	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

Table F-8. Summary of plutonium CTW 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	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

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
01/01/1982	12/31/1990	81.6	636	7.79	7.79	2,391

F.3 URANIUM INTAKE MODELING RESULTS

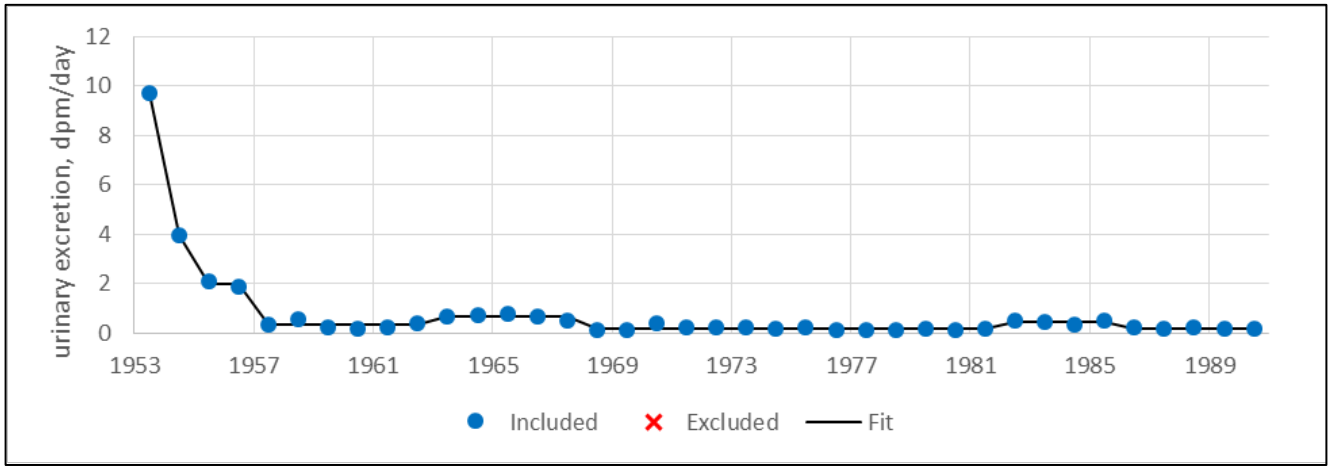


Figure F-95. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type F.

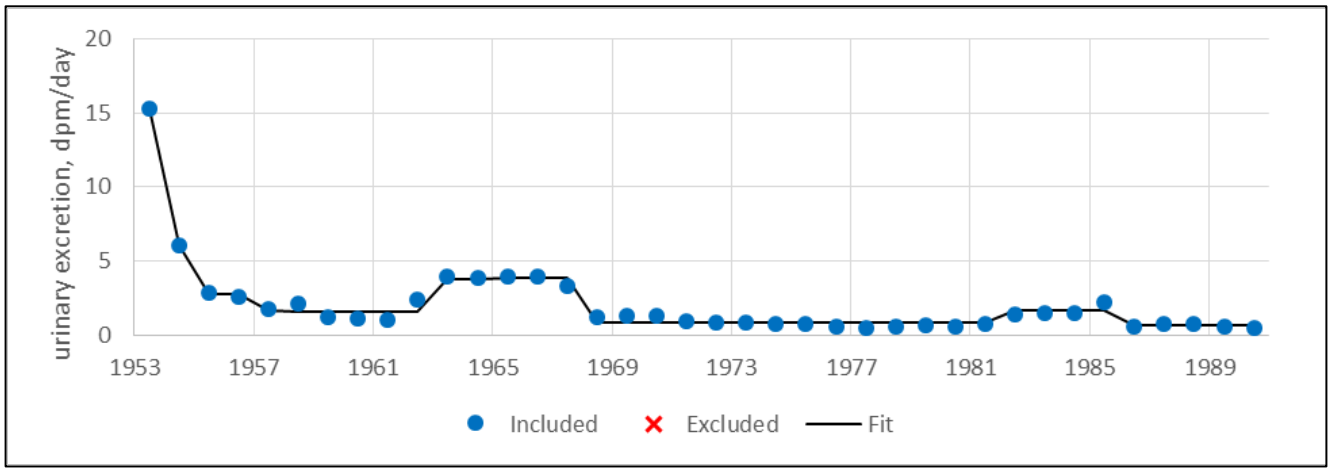


Figure F-96. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type F.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

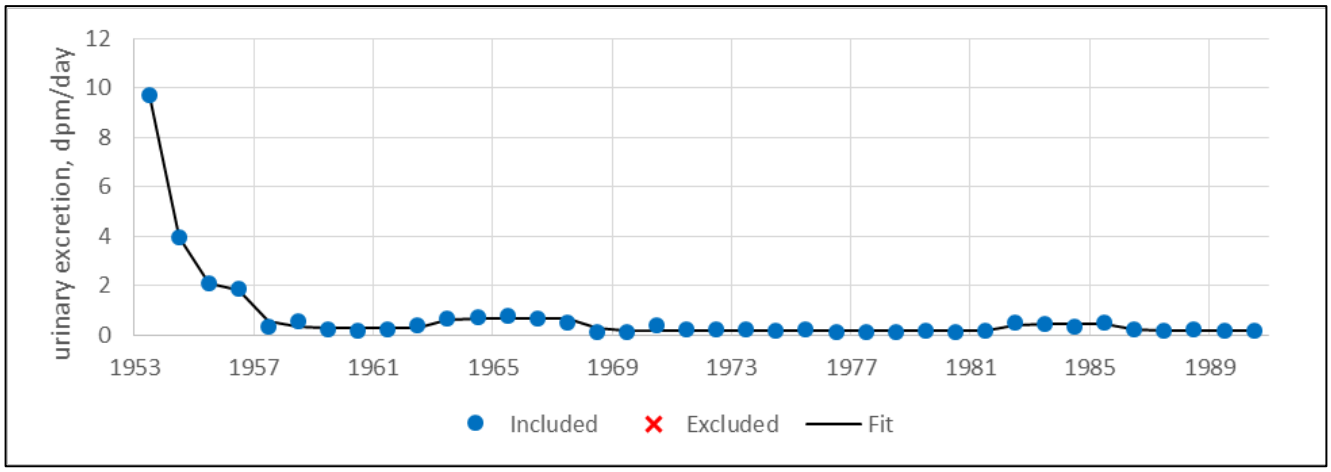


Figure F-97. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type M.

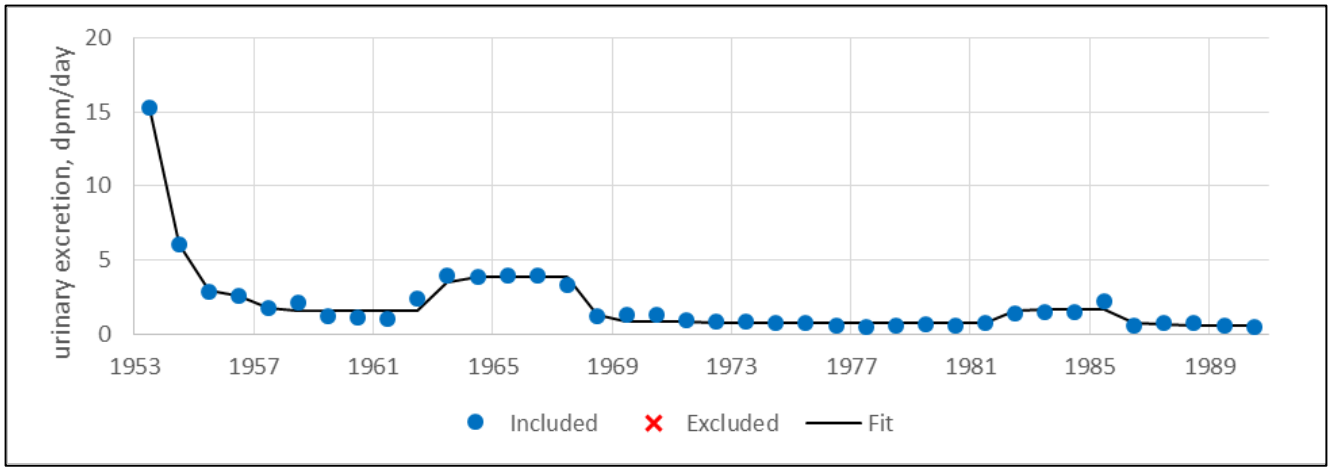


Figure F-98. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type M.

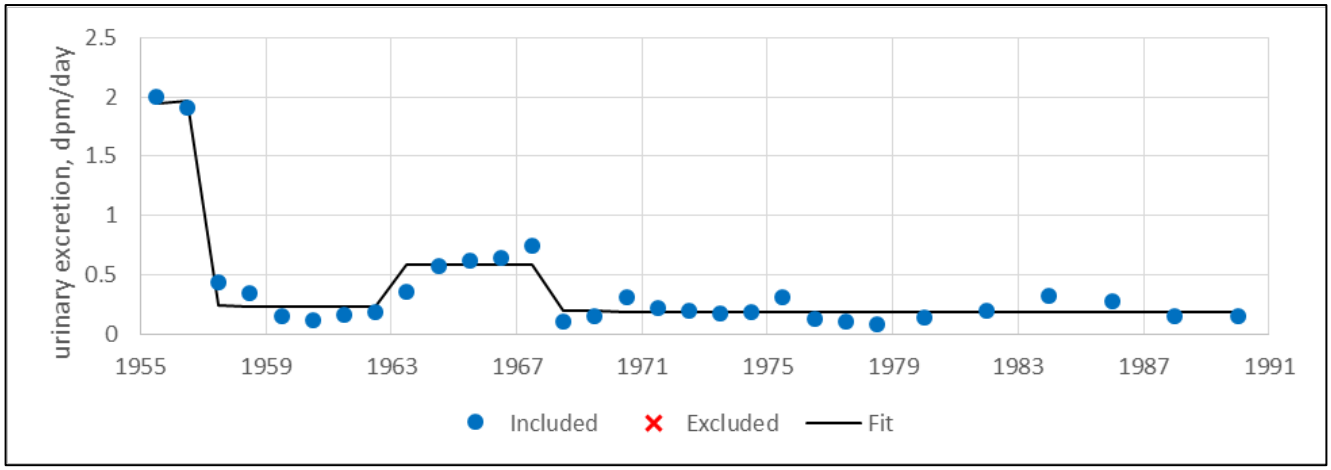


Figure F-99. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type F.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

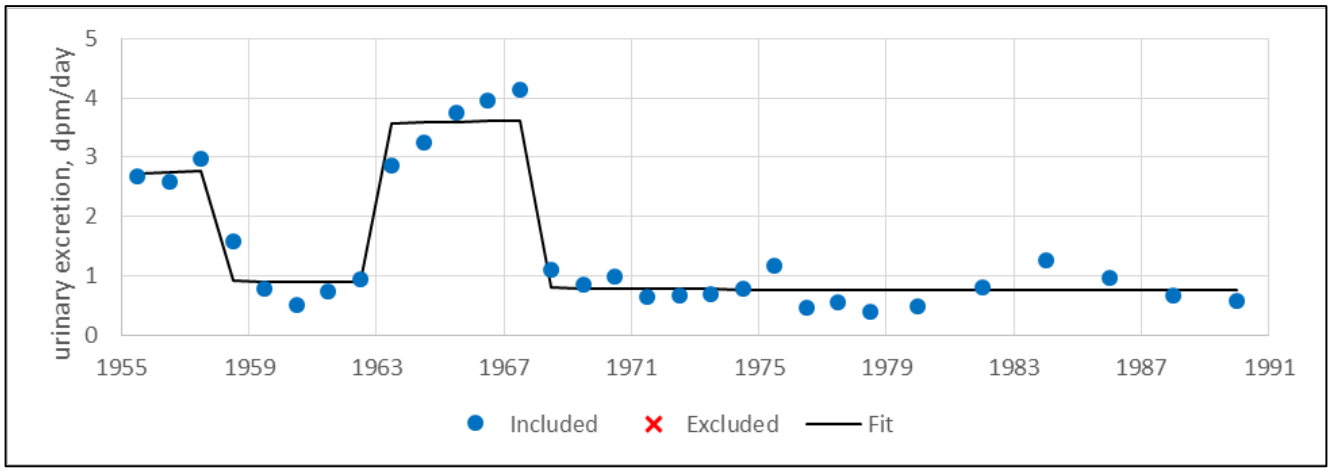


Figure F-100. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type F.

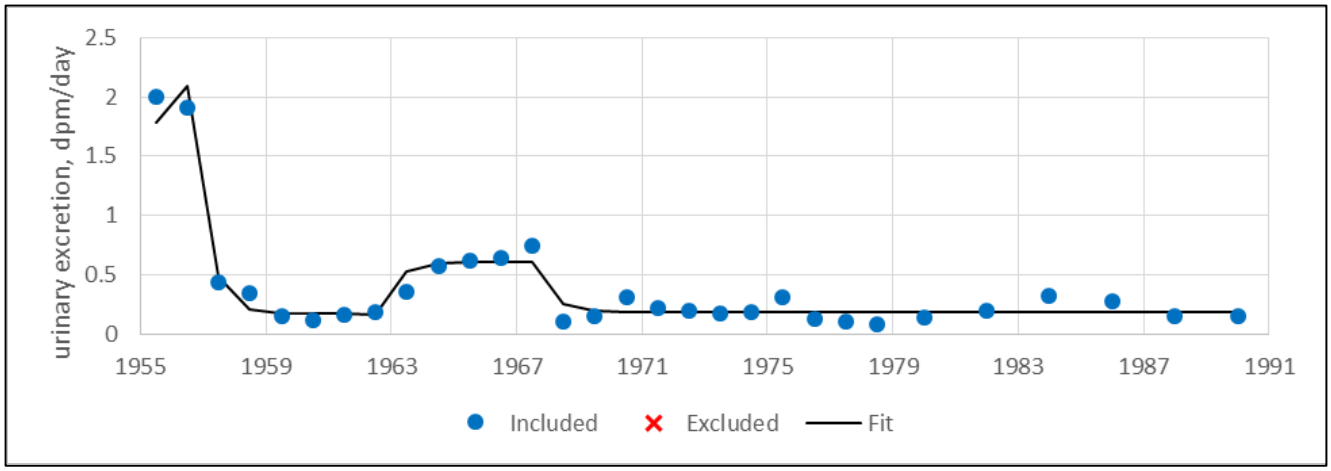


Figure F-101. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type M.

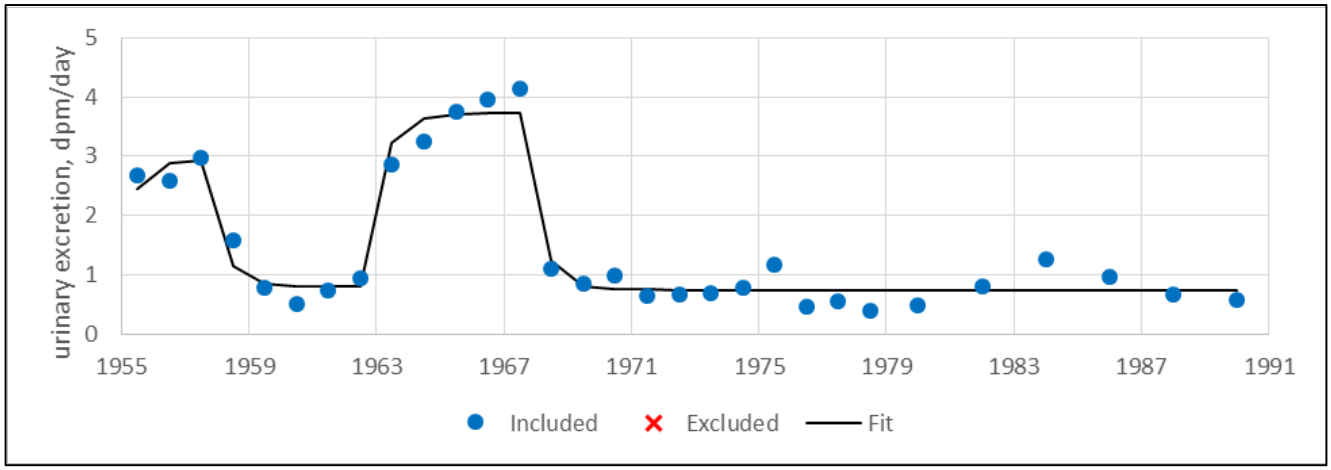


Figure F-102. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

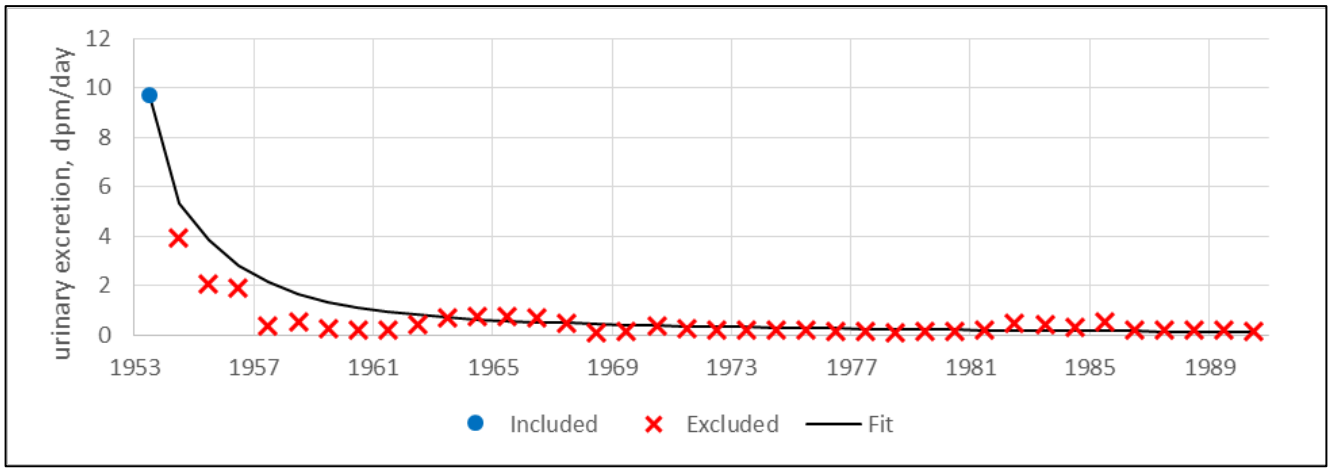


Figure F-103. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW, 1953, type S.

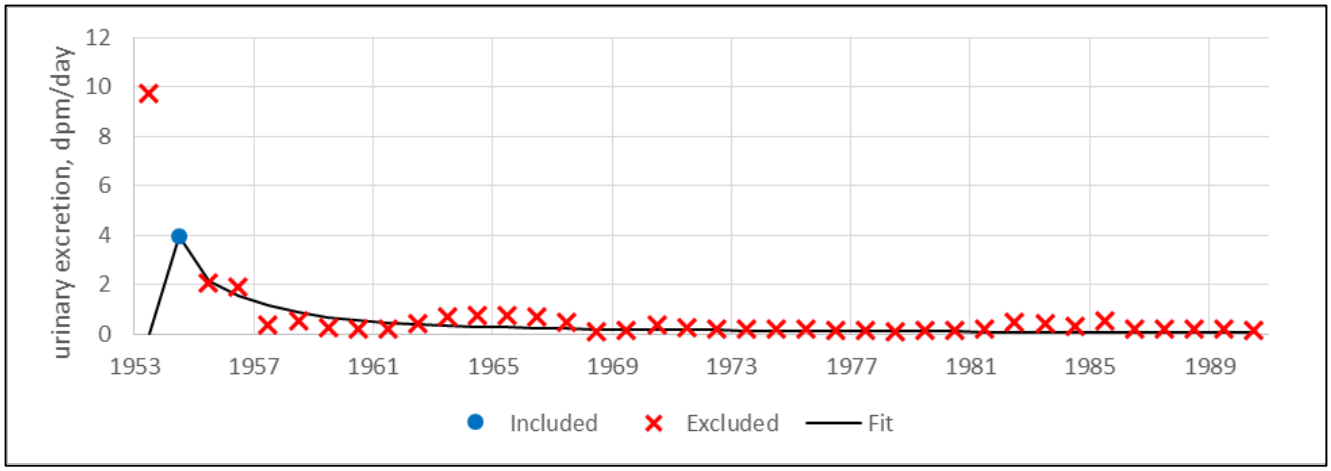


Figure F-104. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW, 1954, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

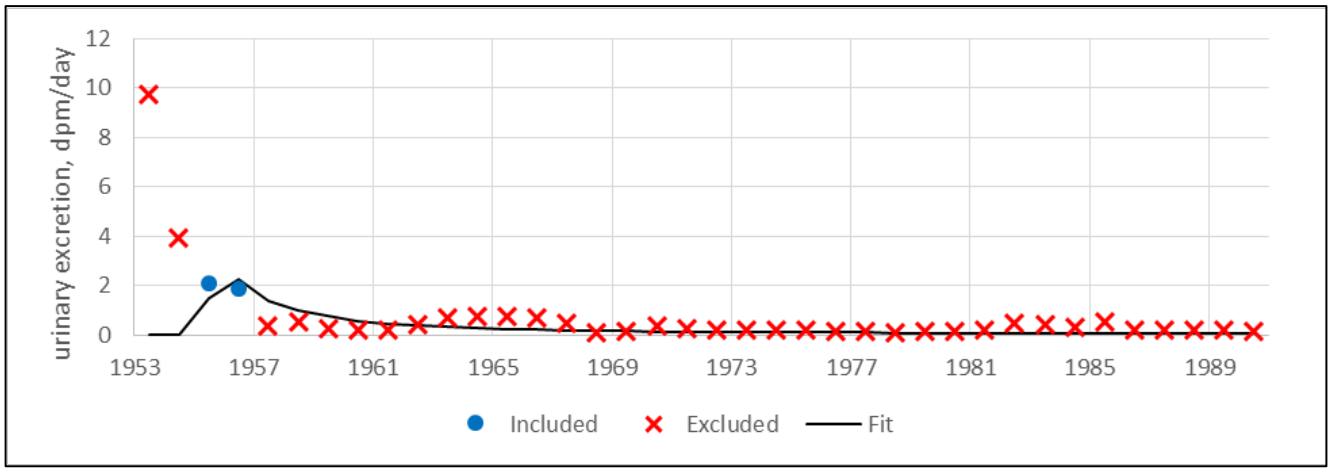


Figure F-105. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1955 to 1956, type S.

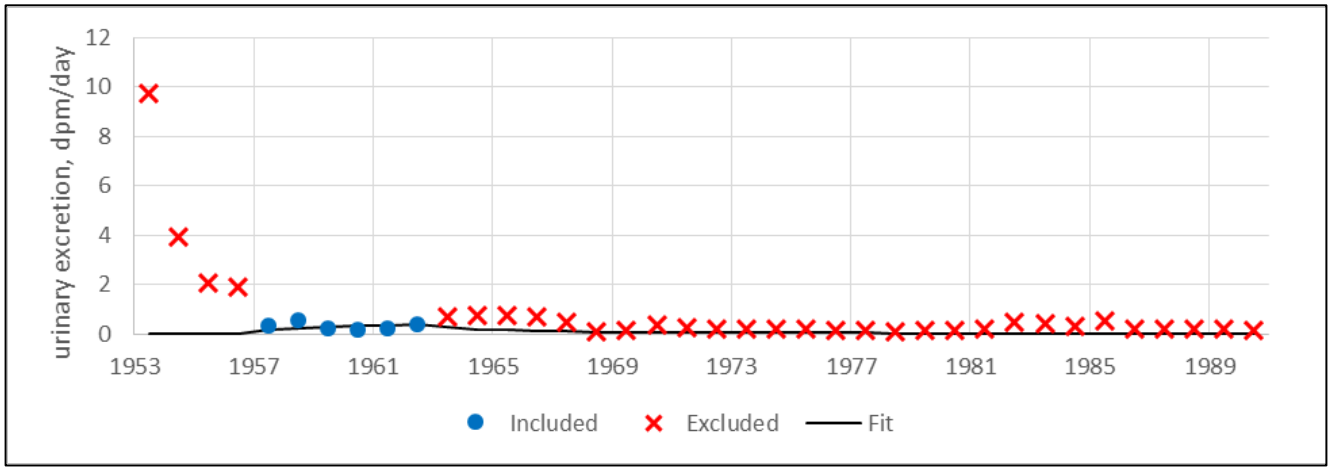


Figure F-106. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1957 to 1962, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

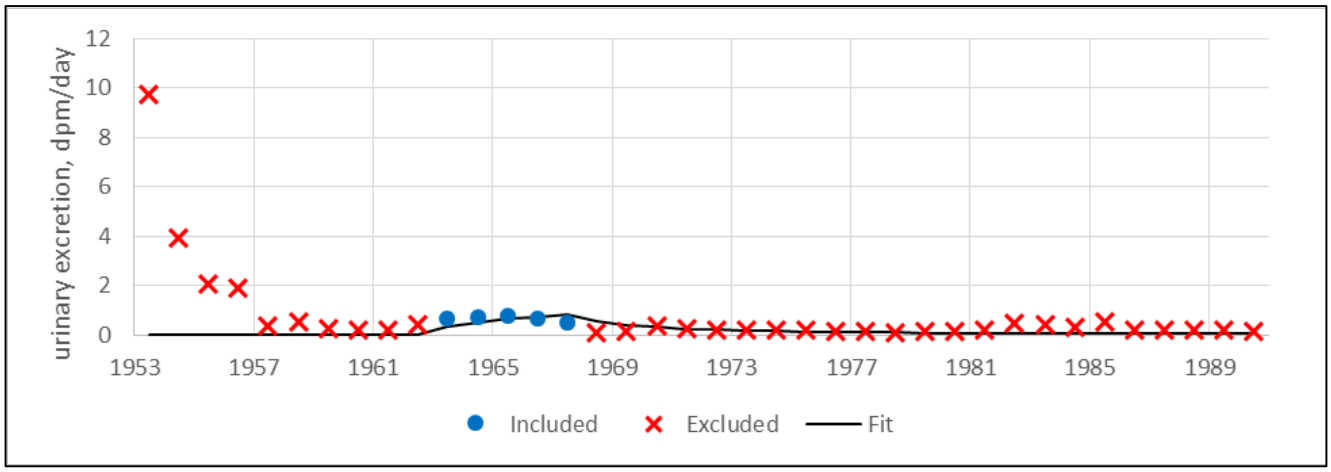


Figure F-107. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1963 to 1967, type S.

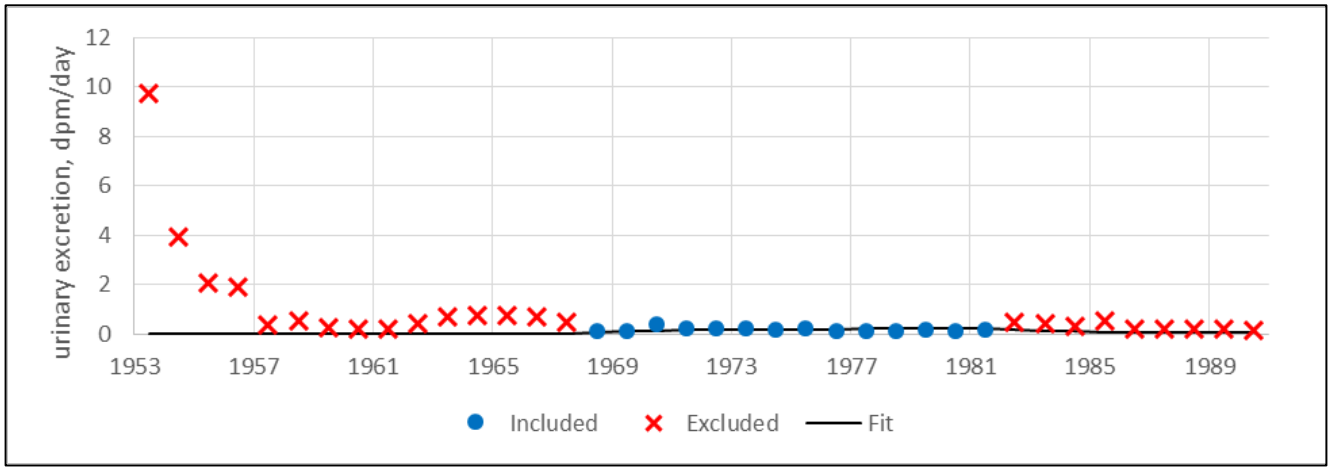


Figure F-108. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1968 to 1981, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

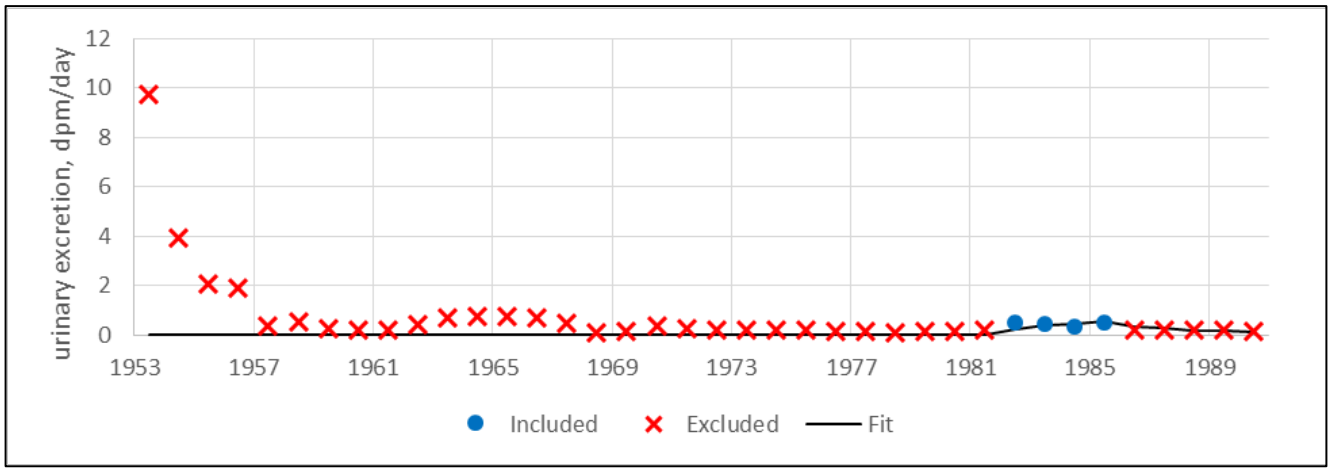


Figure F-109. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1982 to 1985, type S.

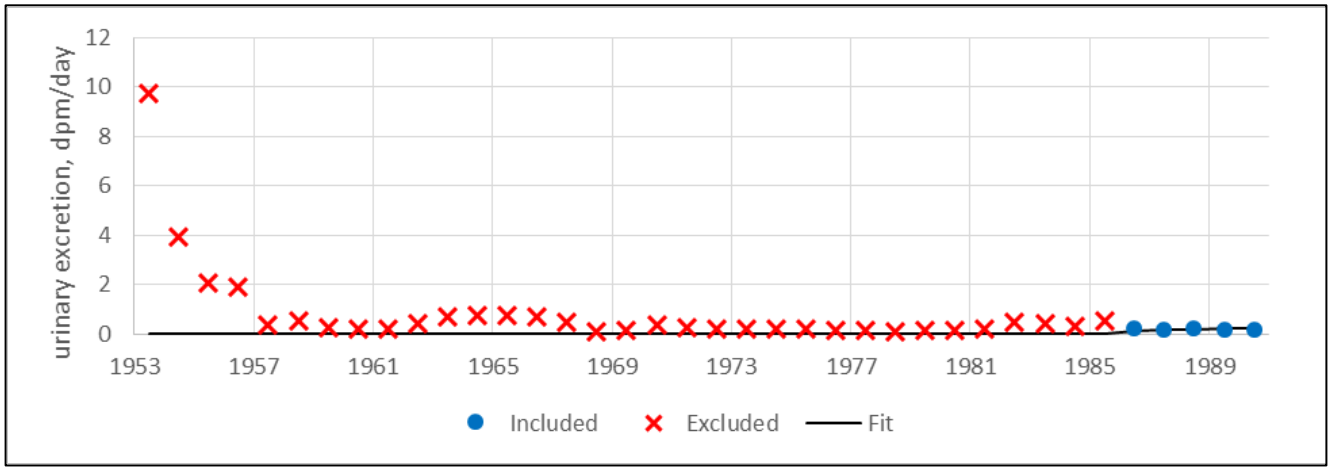


Figure F-110. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1986 to 1990, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

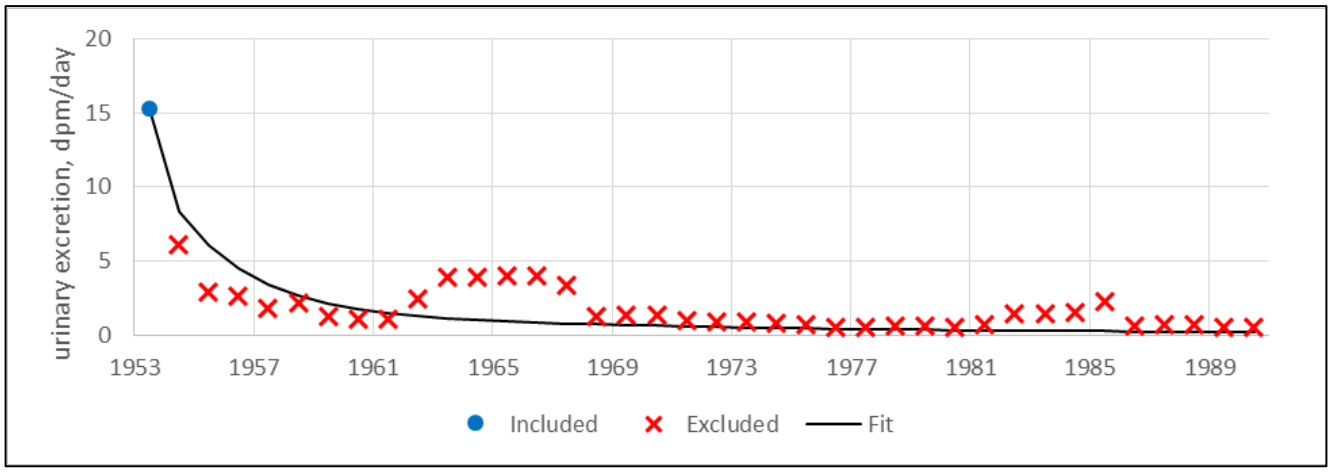


Figure F-111. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1953, type S.

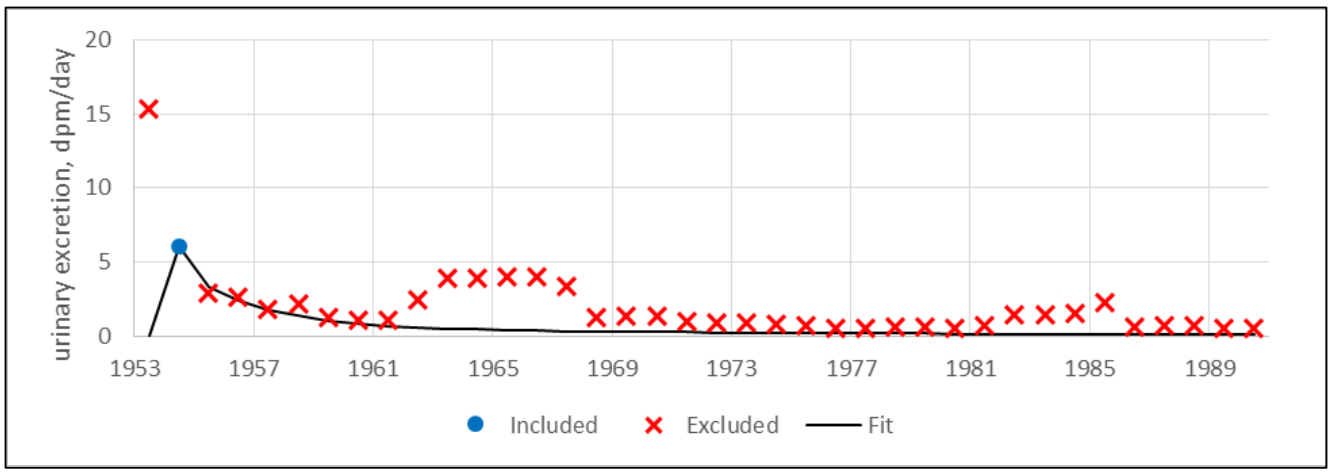


Figure F-112. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1954, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

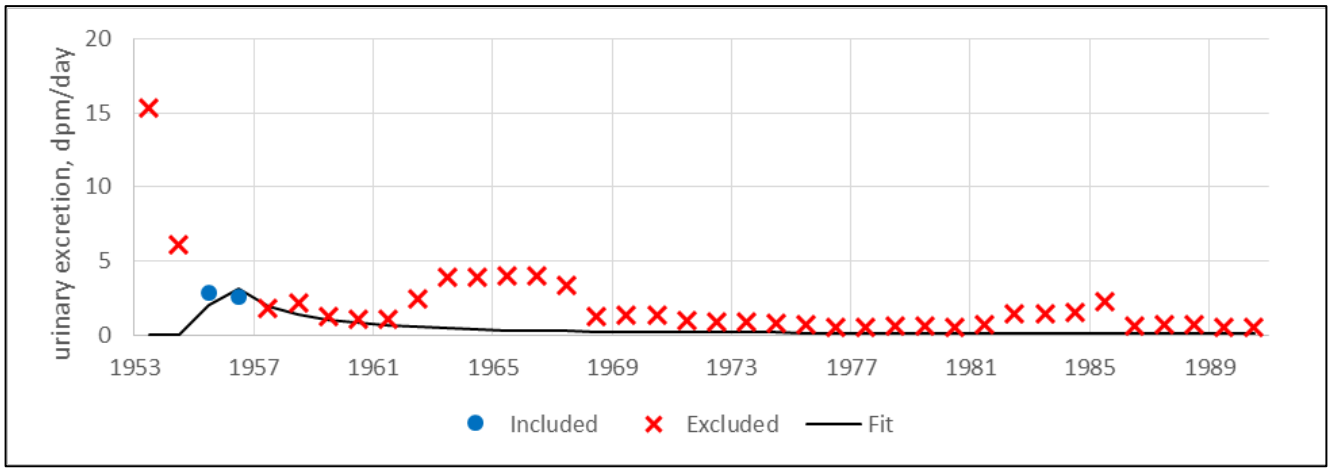


Figure F-113. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1955 to 1956, type S.

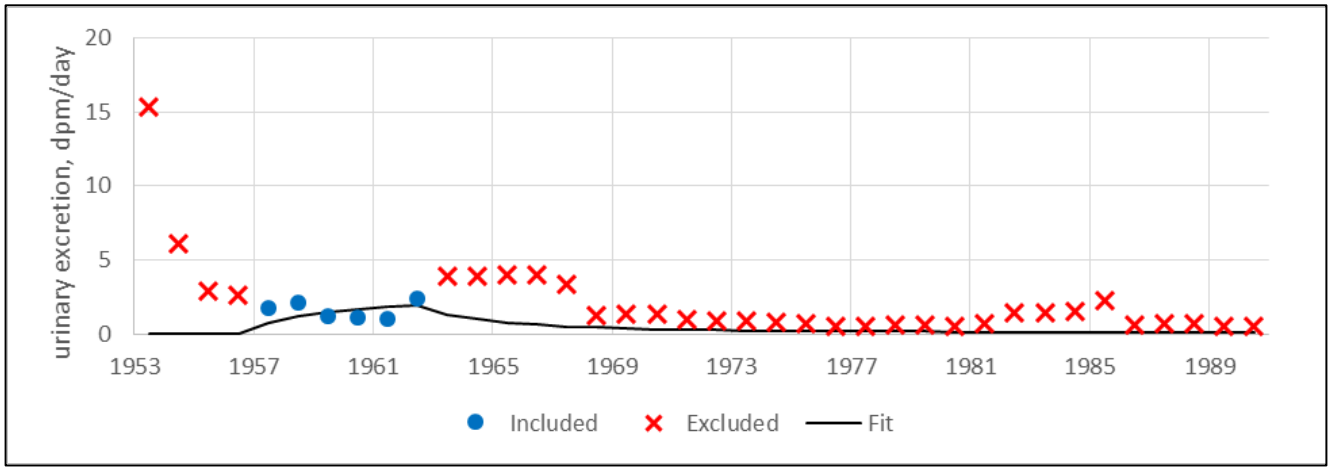


Figure F-114. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1957 to 1962, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

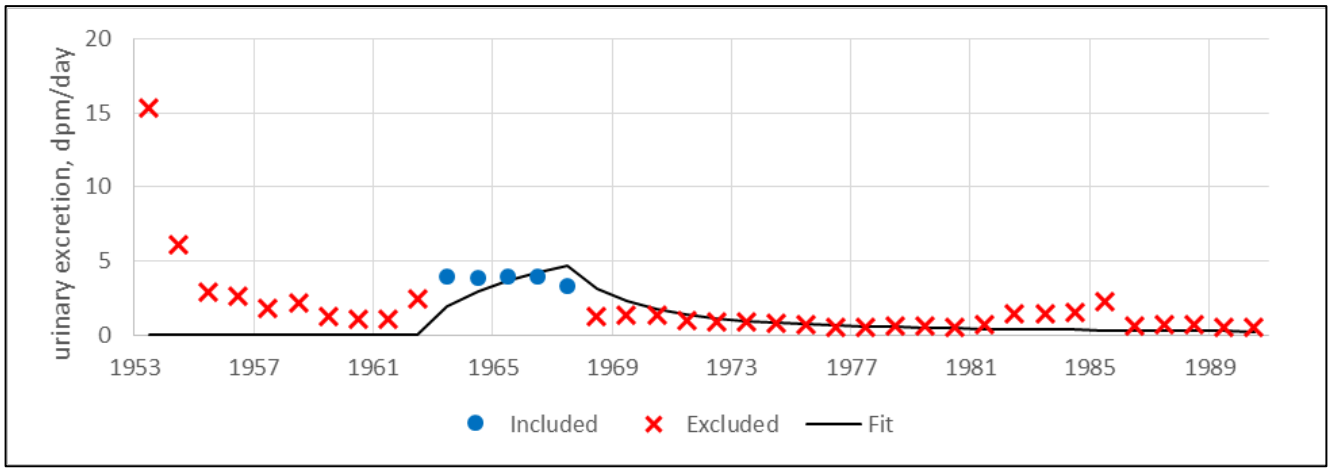


Figure F-115. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1963 to 1967, type S.

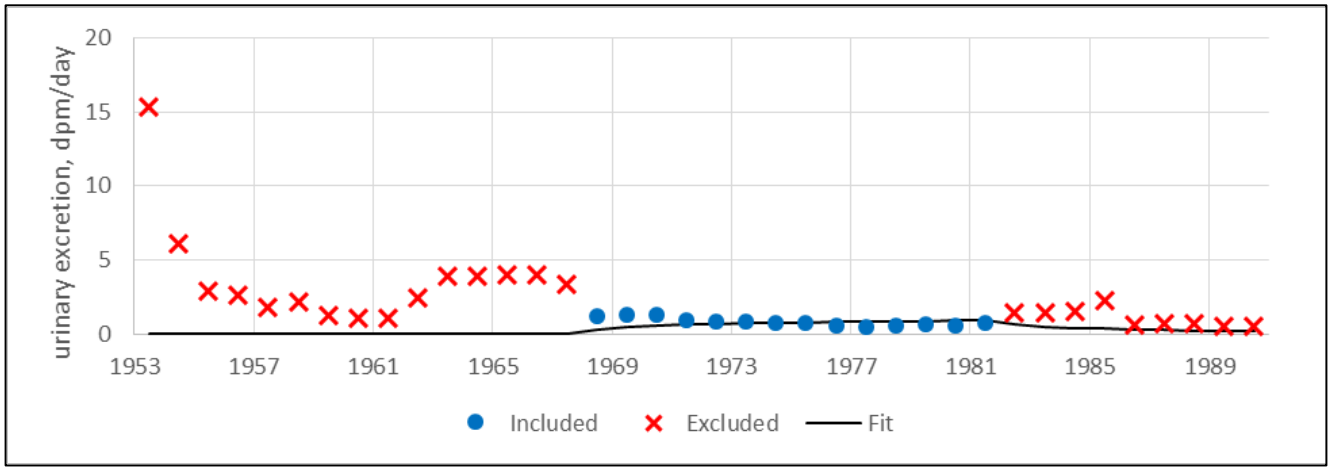


Figure F-116. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1968 to 1981, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

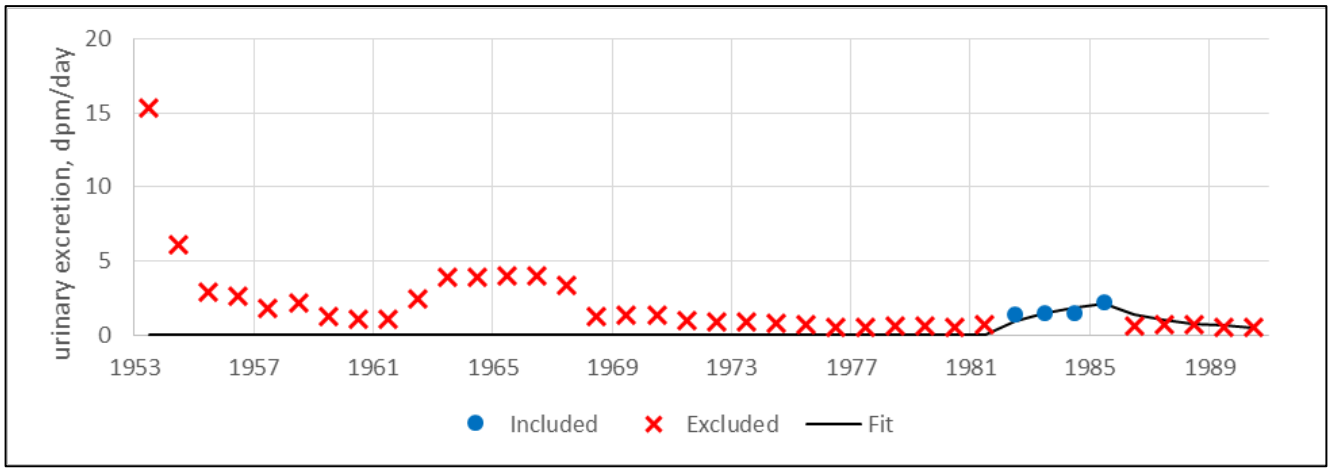


Figure F-117. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1982 to 1985, type S.

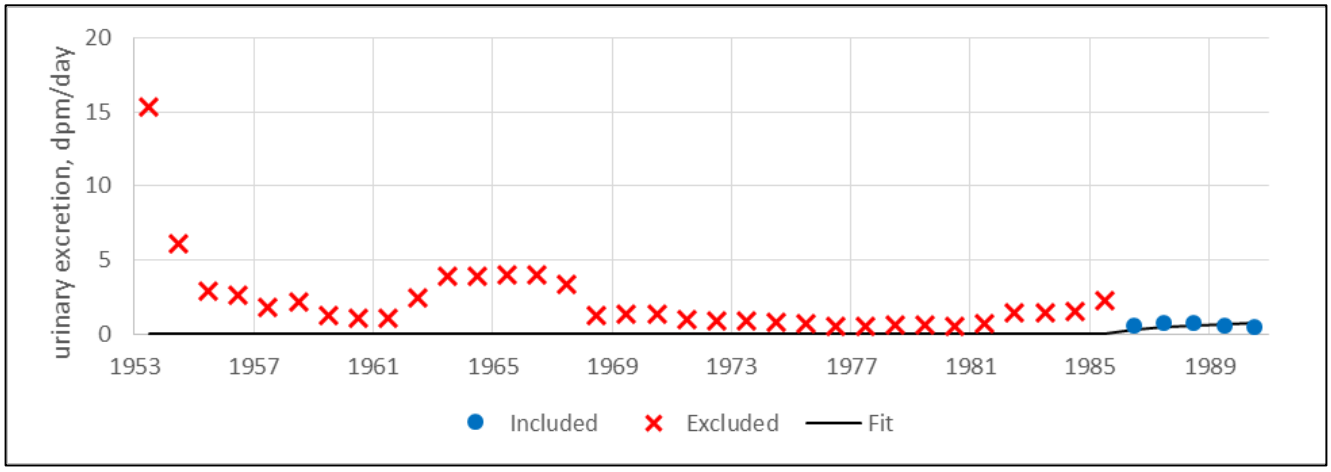


Figure F-118. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1986 to 1990, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

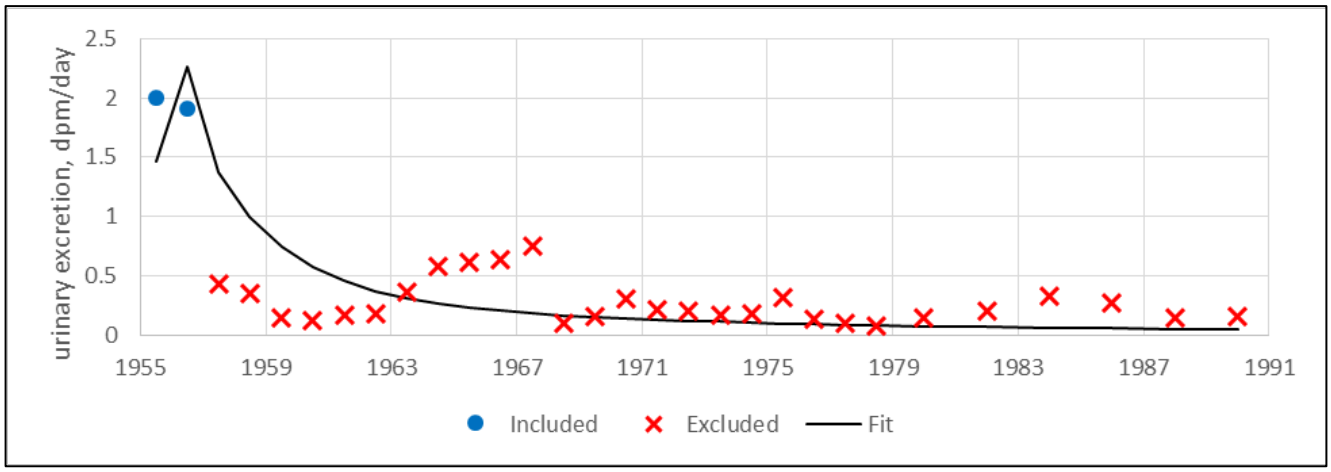


Figure F-119. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1955 to 1956, type S.

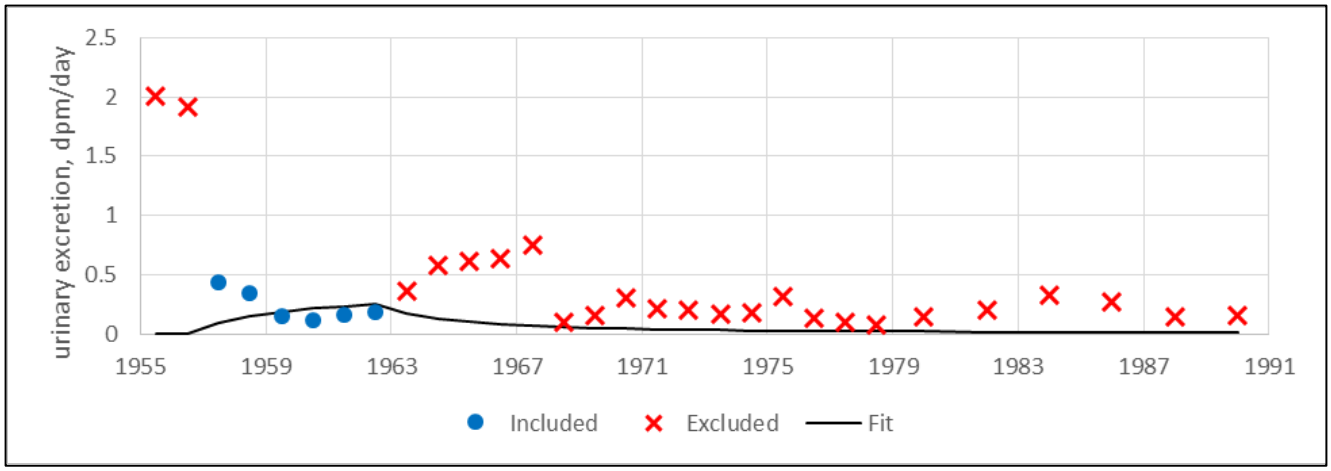


Figure F-120. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1957 to 1962, type S.

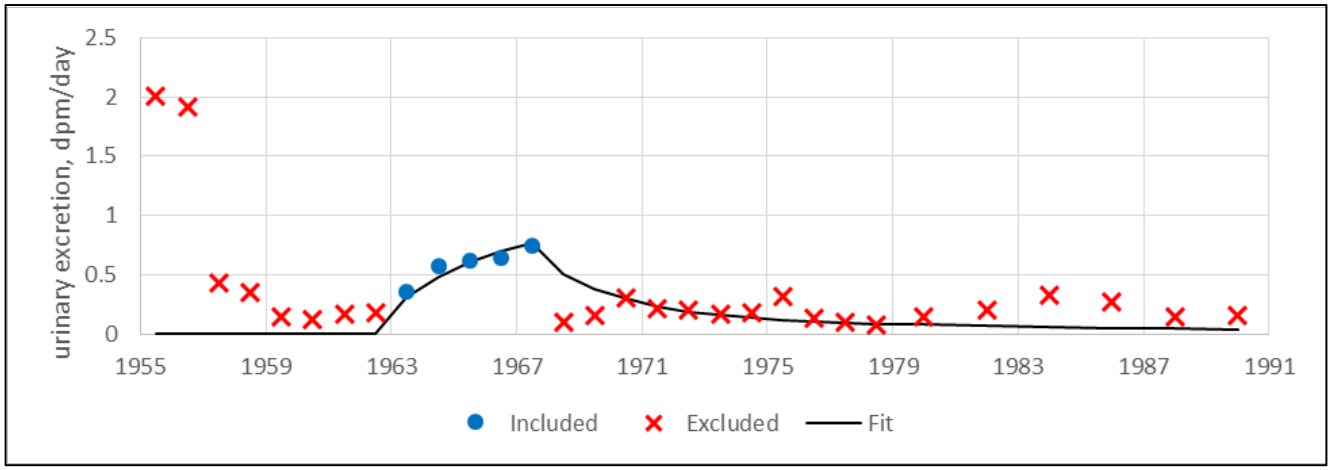


Figure F-121. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1963 to 1967, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

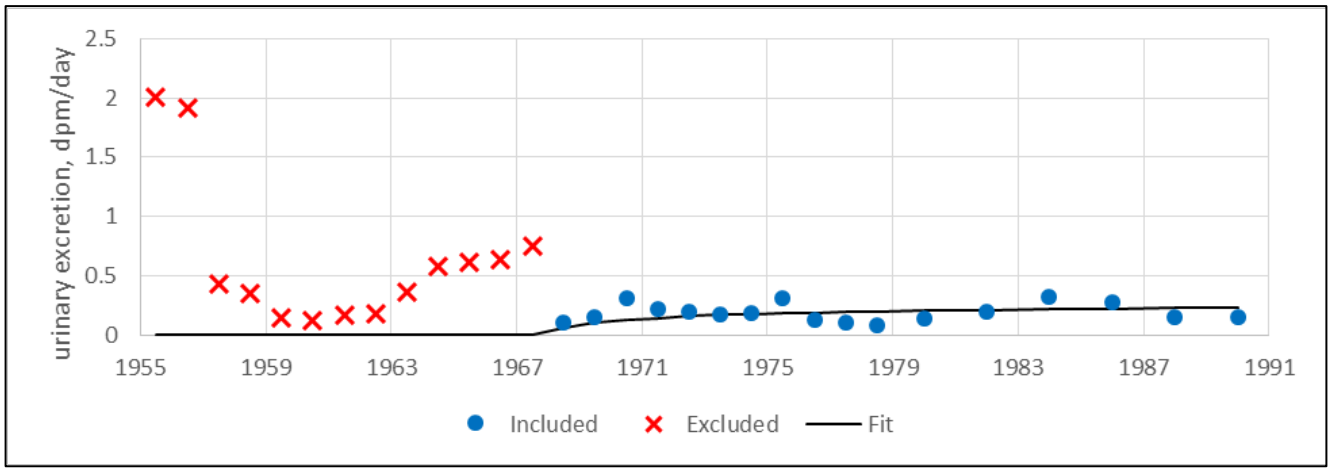


Figure F-122. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1968 to 1990, type S.

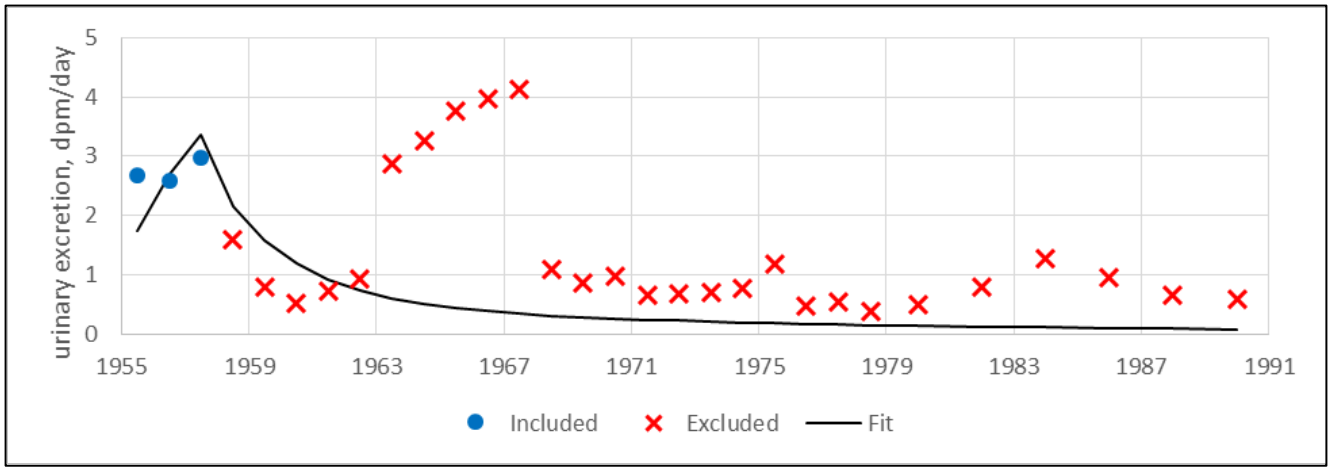


Figure F-123. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1955 to 1957, type S.

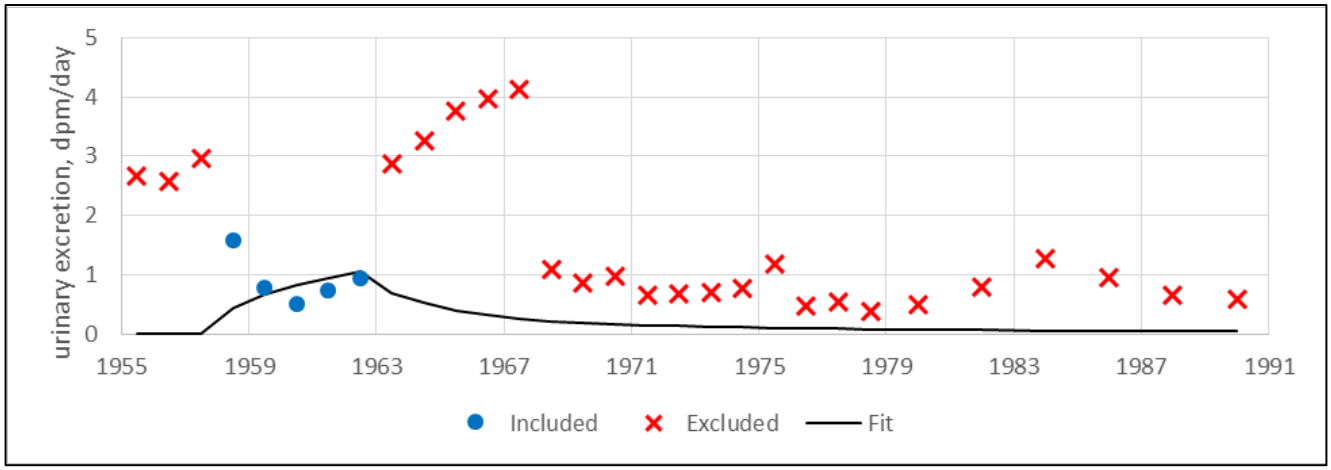


Figure F-124. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1958 to 1962, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

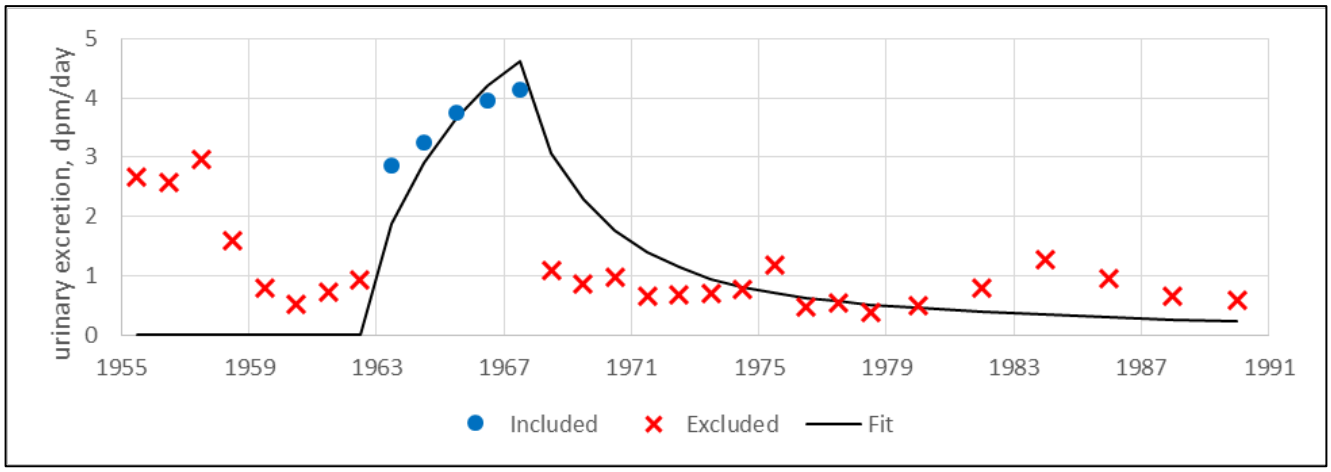


Figure F-125. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1963 to 1967, type S.

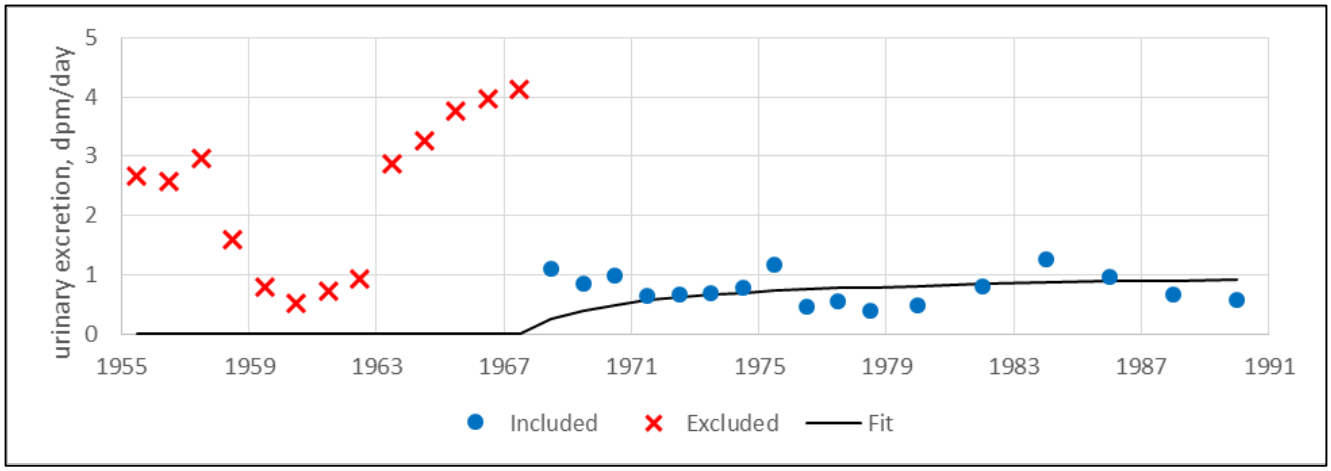


Figure F-126. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1968 to 1990, type S.

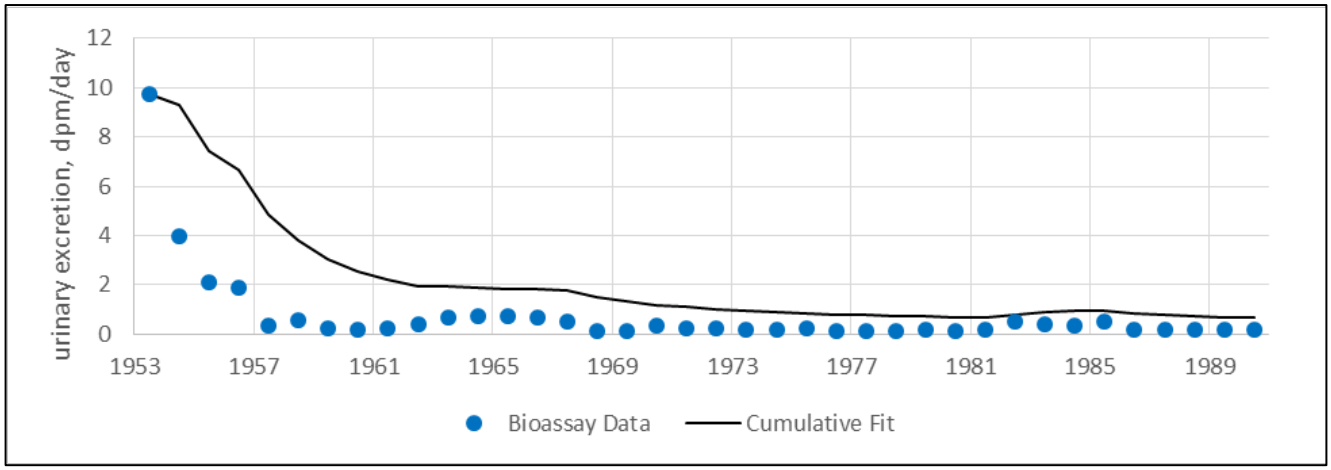


Figure F-127. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

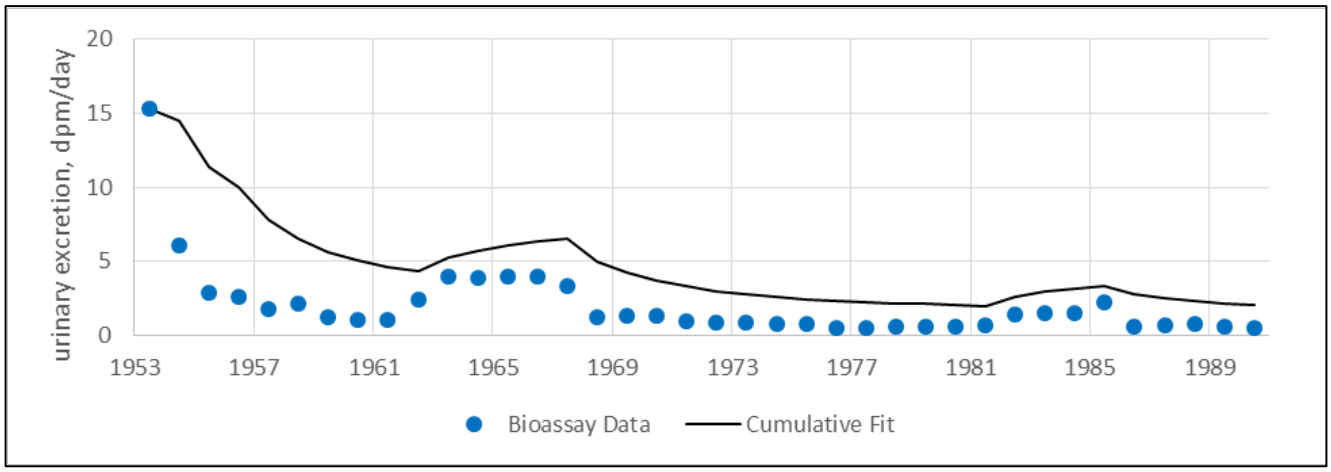


Figure F-128. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type S.

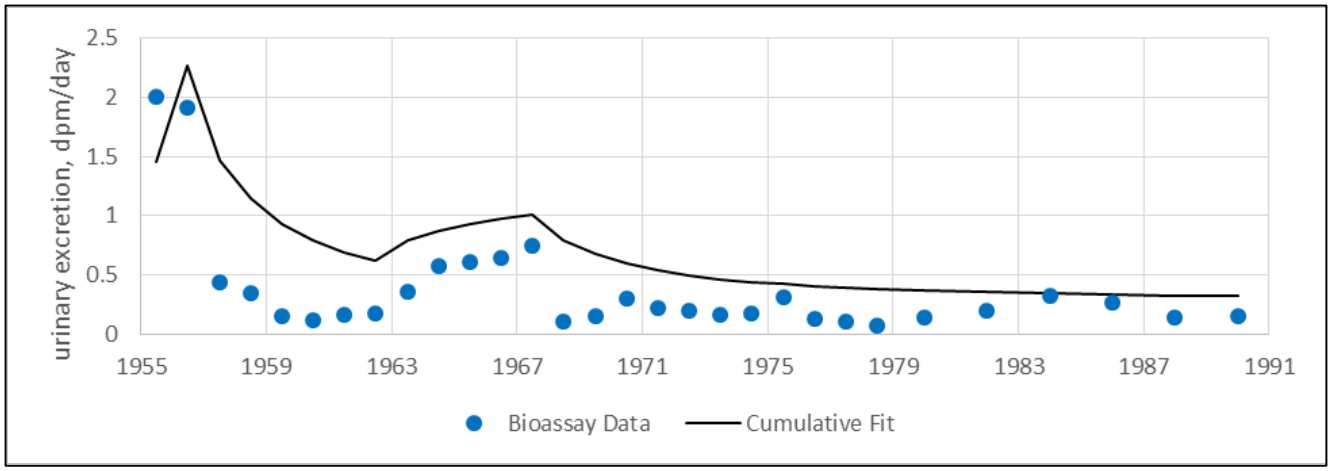


Figure F-129. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type S.

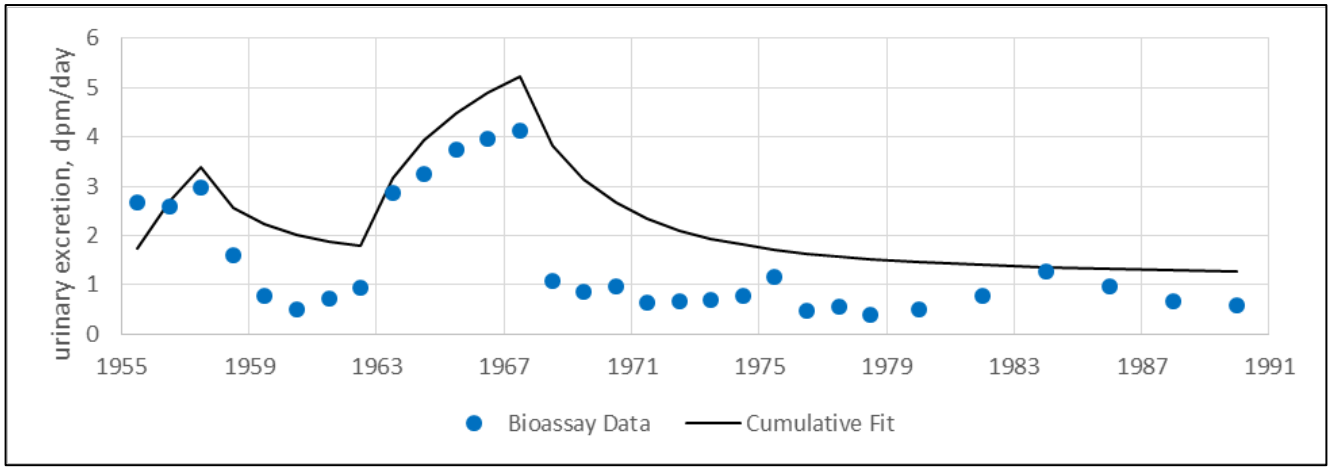


Figure F-130. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

Table F-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 F-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

Table F-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 F-12. Summary of uranium CTW intake rates (dpm/d) and dates, type F.

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

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

Table F-13. Summary of uranium CTW intake rates (dpm/d) and dates, type M.

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

Table F-14. Summary of uranium CTW intake rates (dpm/d) and dates, type S.

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

F.4 STRONTIUM INTAKE MODELING RESULTS

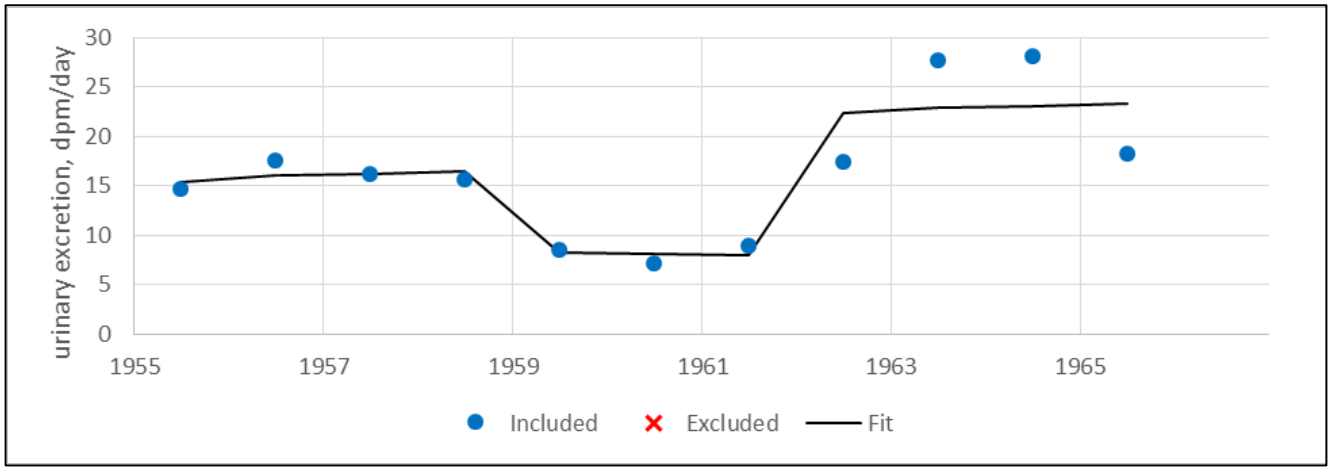


Figure F-131. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

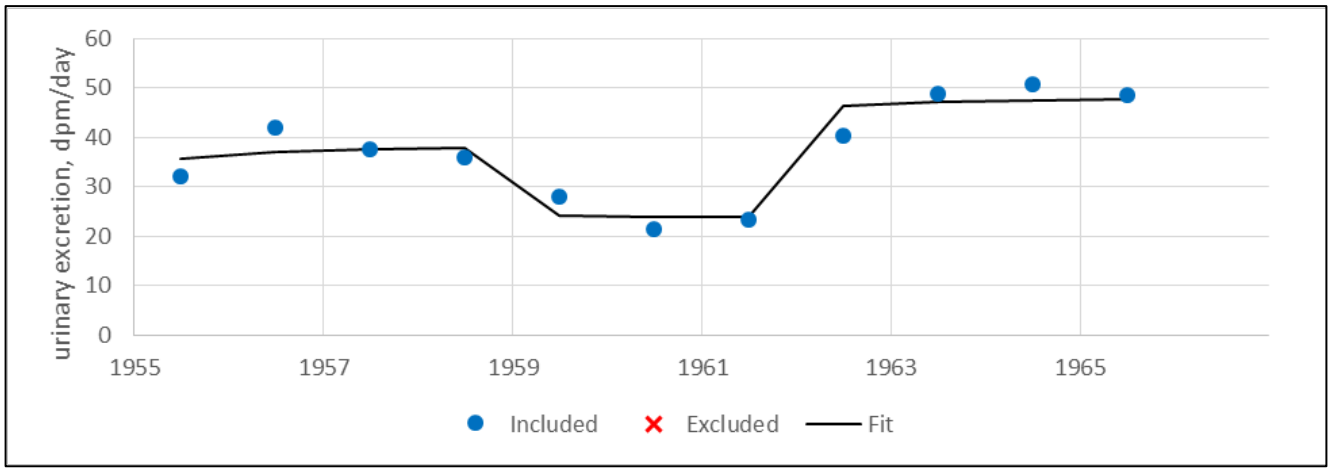


Figure F-132. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years.

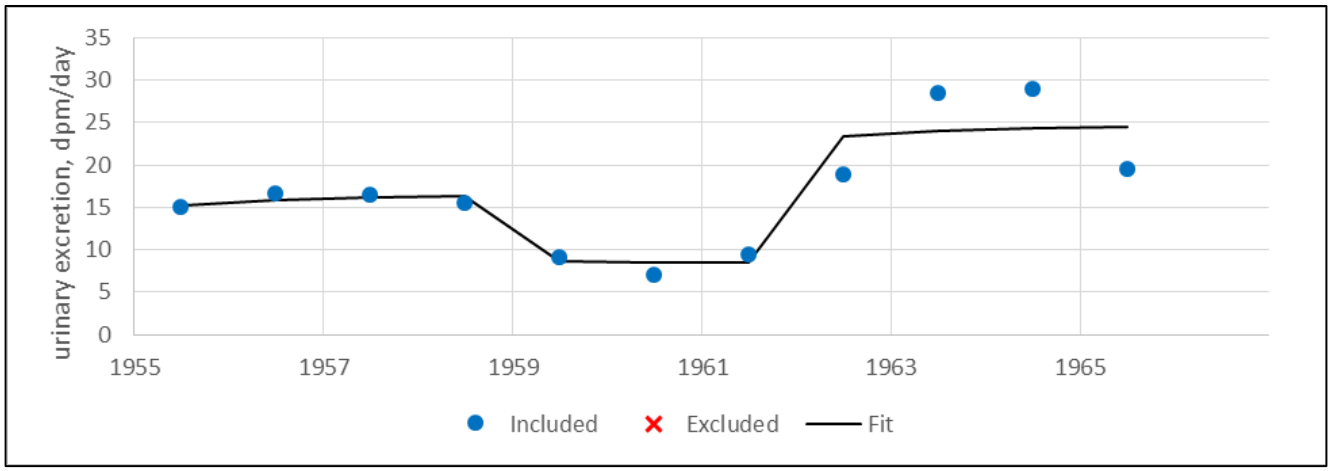


Figure F-133. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

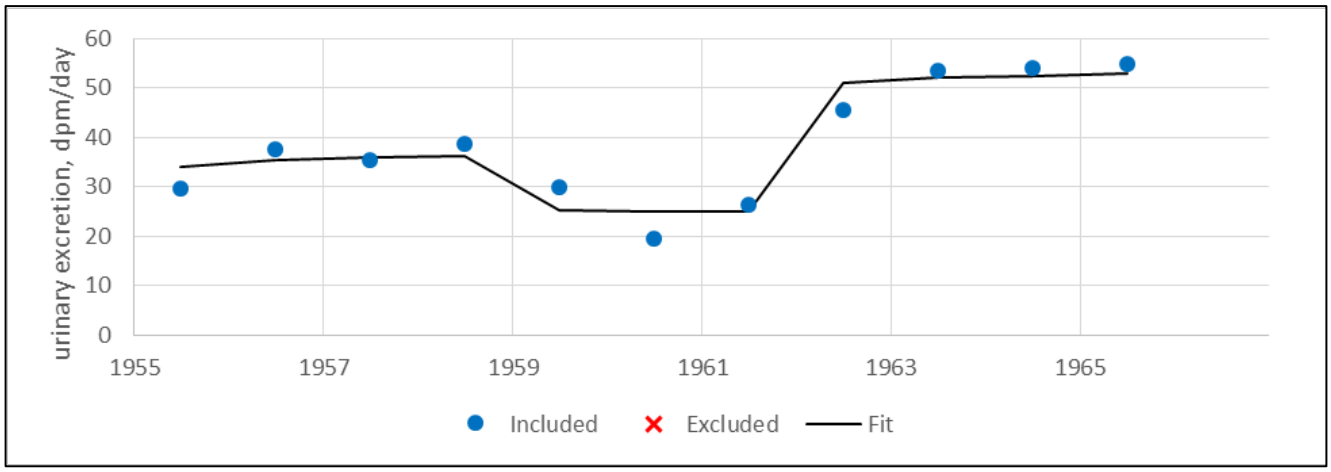


Figure F-134. Predicted FP (strontium) bioassay results calculated using IMBA-derived strontium intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years.

Table F-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	97.43	199.9	2.05	3.00	594

Table F-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

F.5 COBALT-60 INTAKE MODELING RESULTS

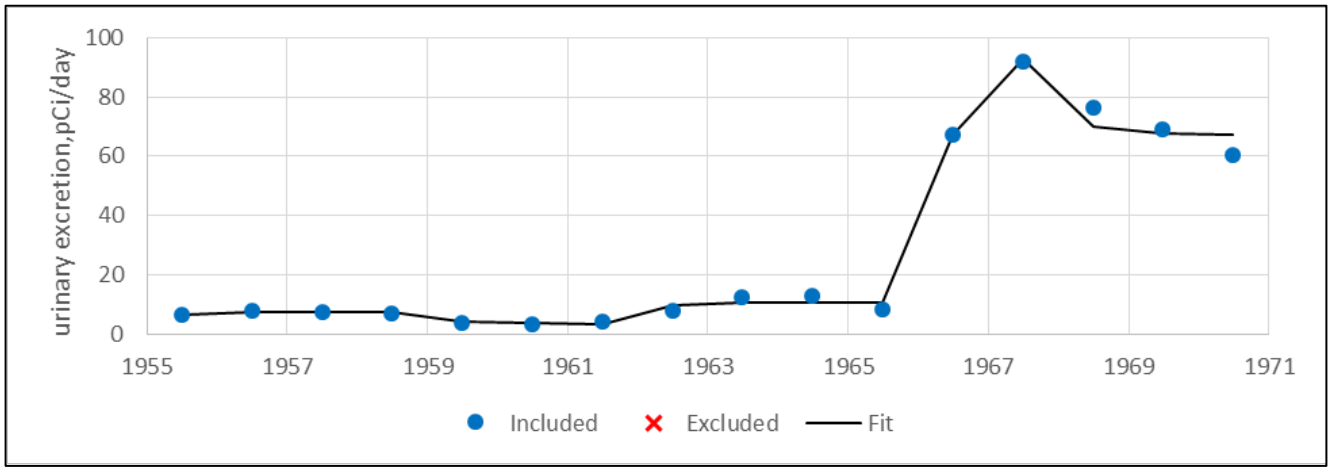


Figure F-135. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

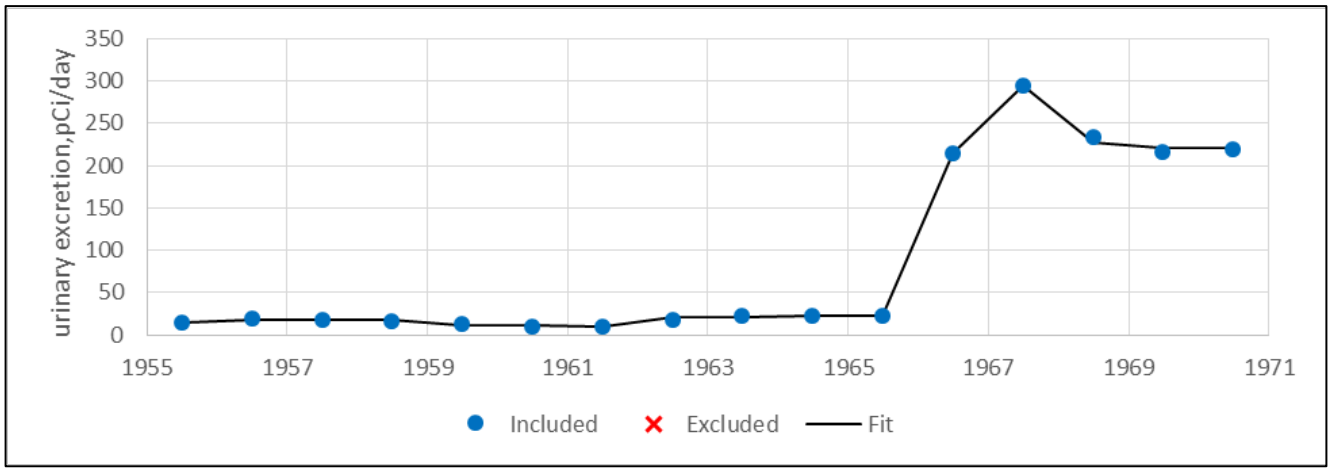


Figure F-136. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type M.

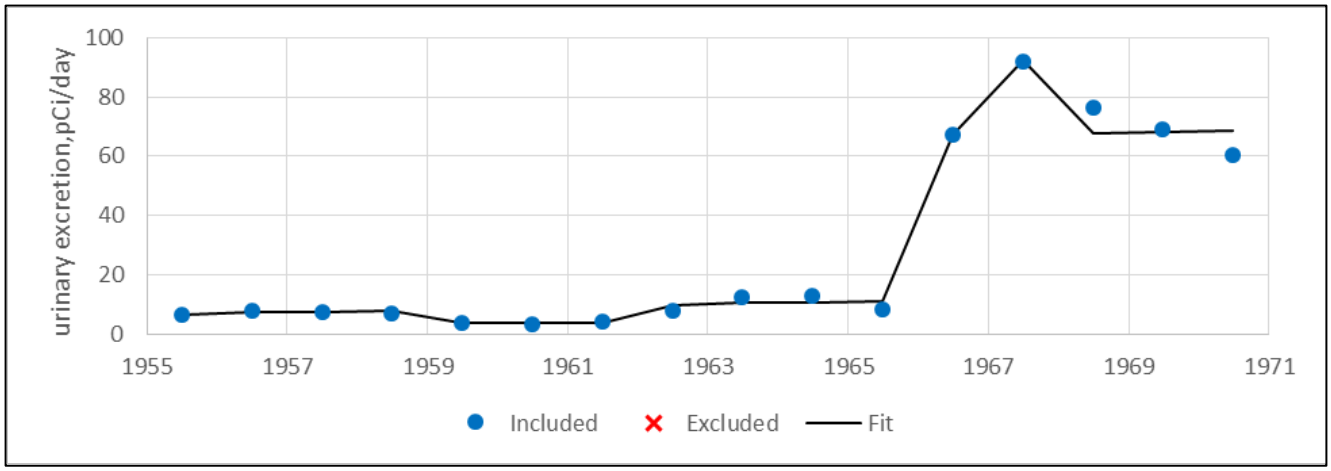


Figure F-137. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type S.

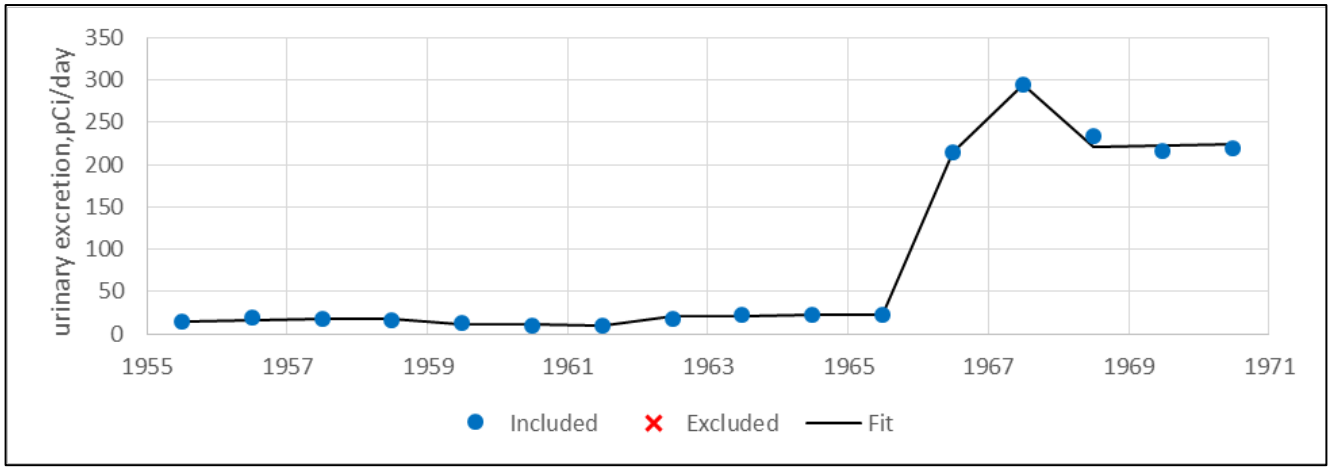


Figure F-138. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

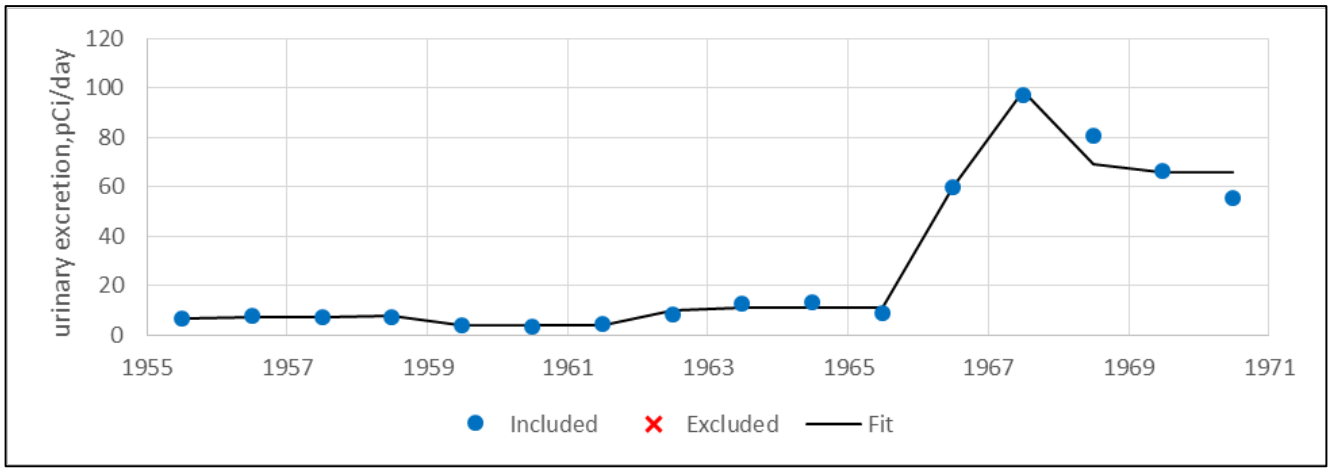


Figure F-139. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type M.

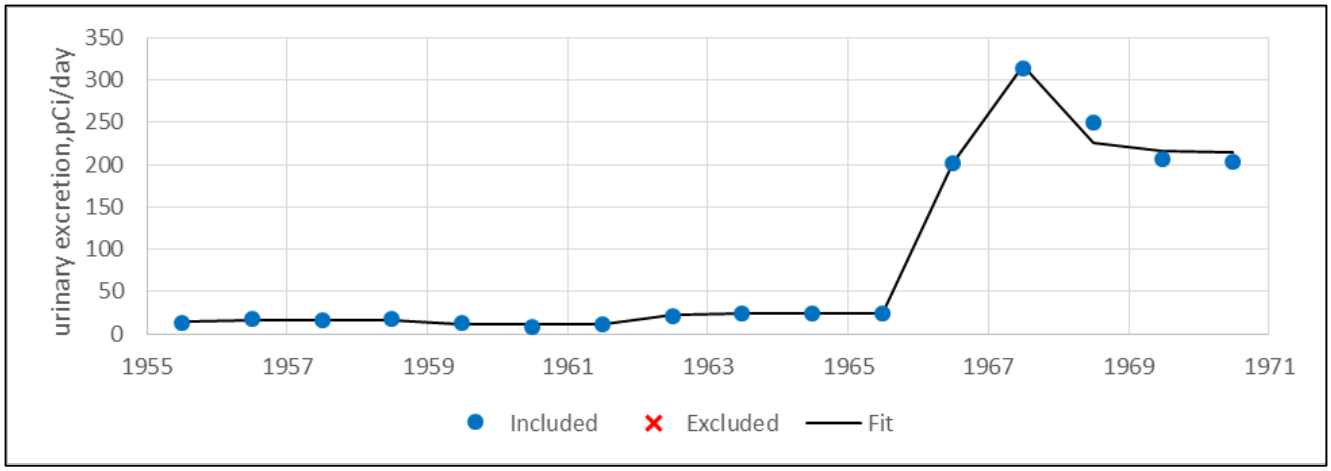


Figure F-140. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type M.

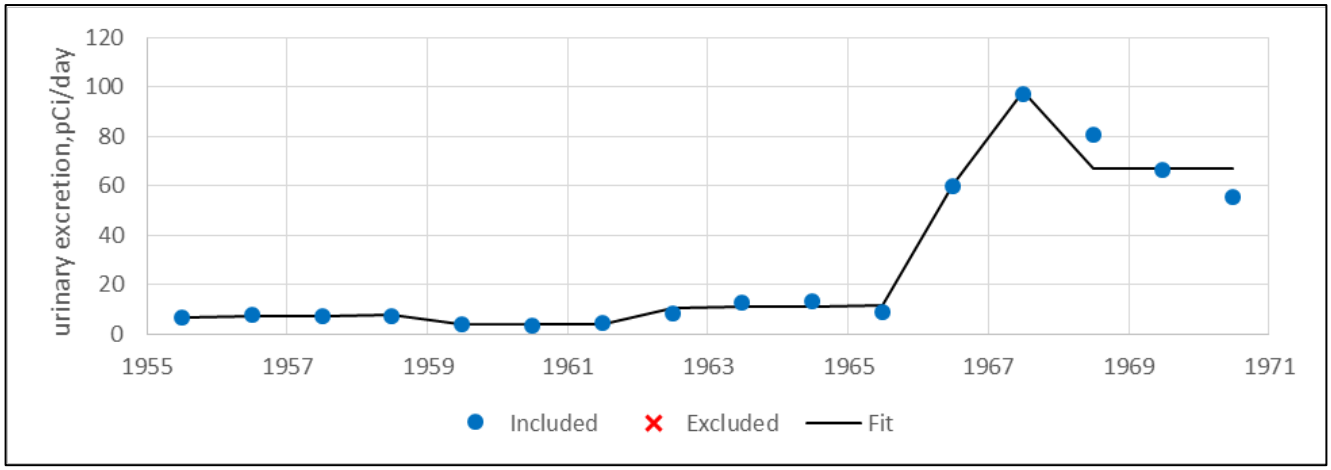


Figure F-141. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

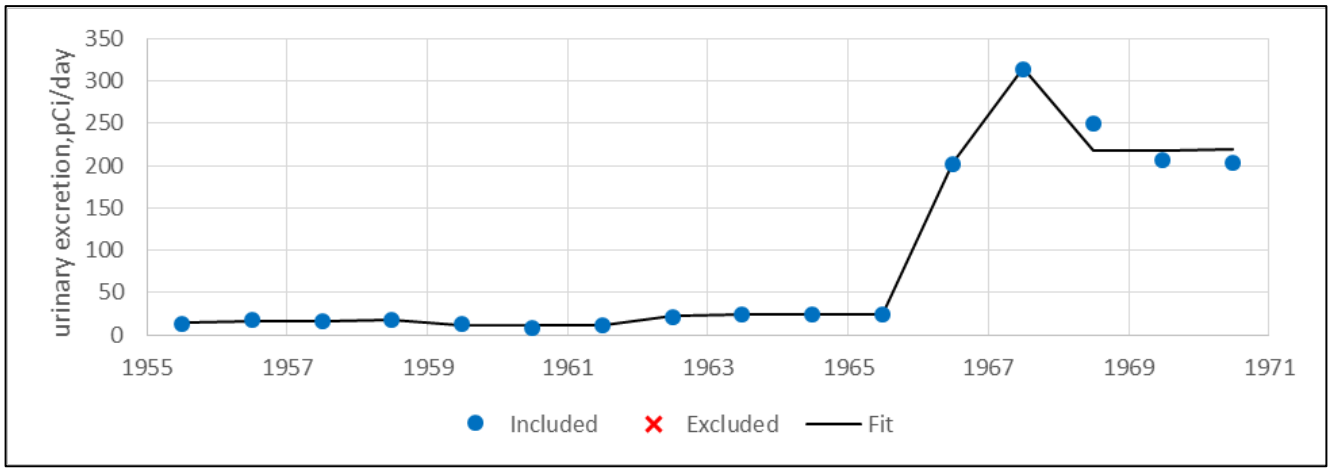


Figure F-142. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type S.

Table F-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 F-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 F-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

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

Table F-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

F.6 CESIUM-137 INTAKE MODELING RESULTS

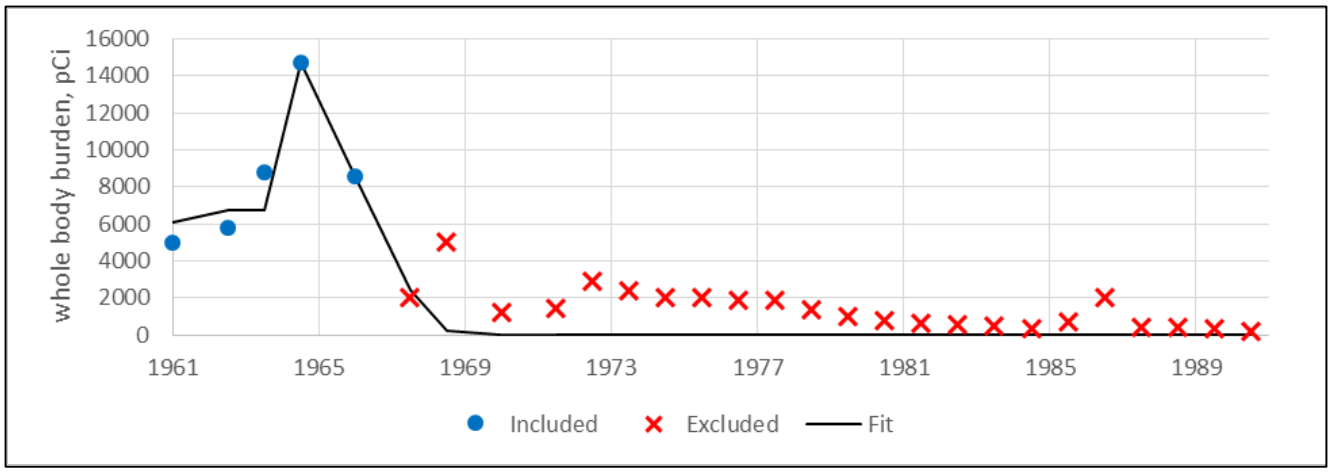


Figure F-143. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1960 to 1966, type F.

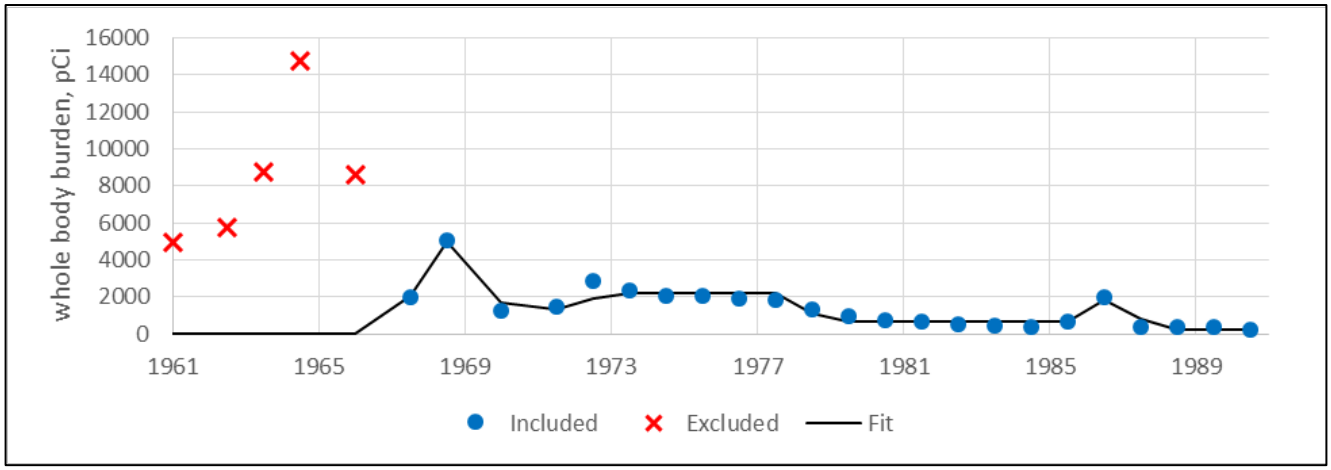


Figure F-144. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1967 to 1990, type F.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

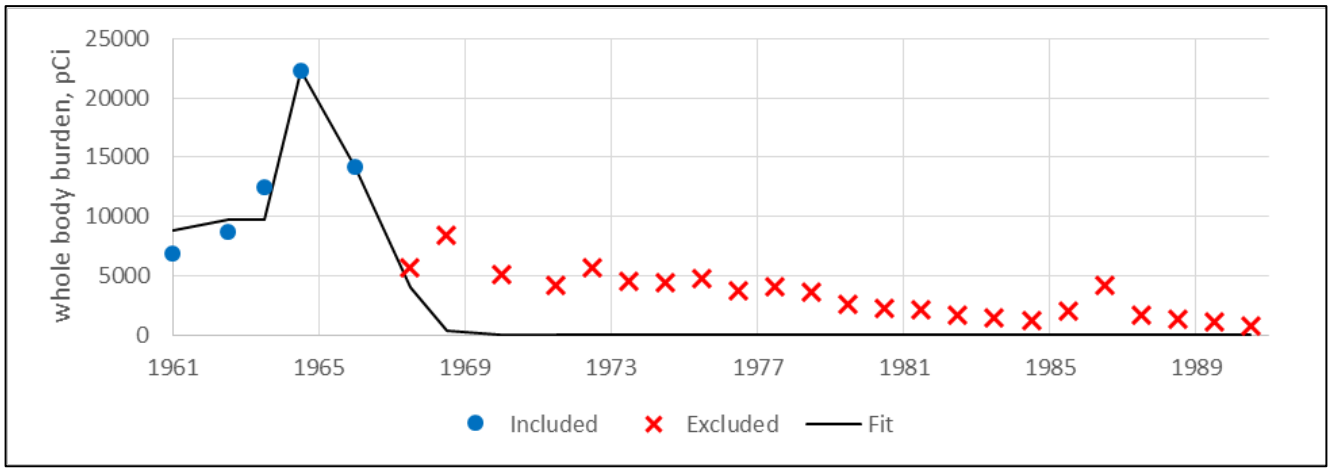


Figure F-145. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1960 to 1966, type F.

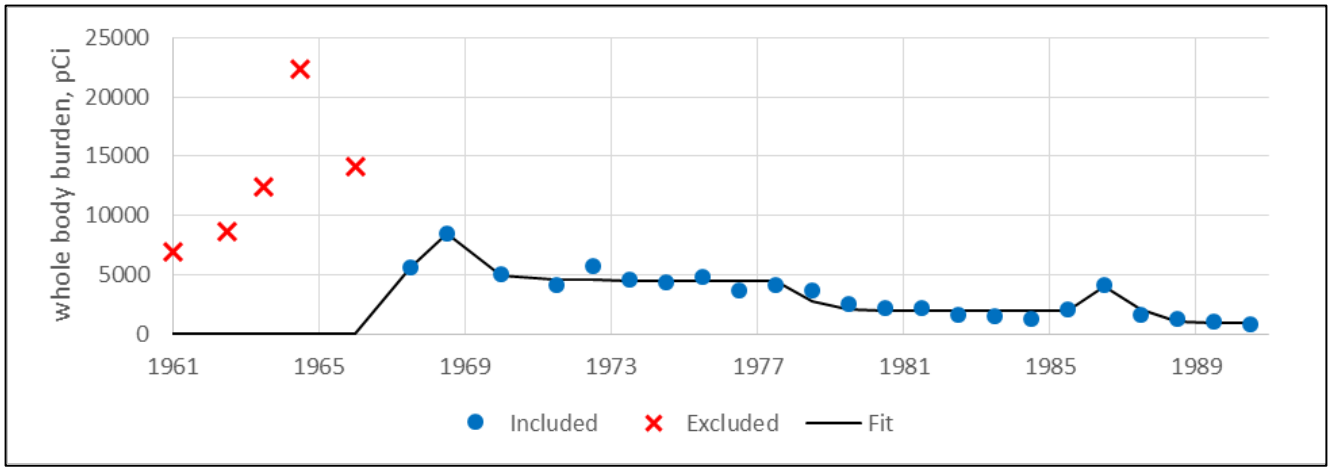


Figure F-146. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1967 to 1990, type F.

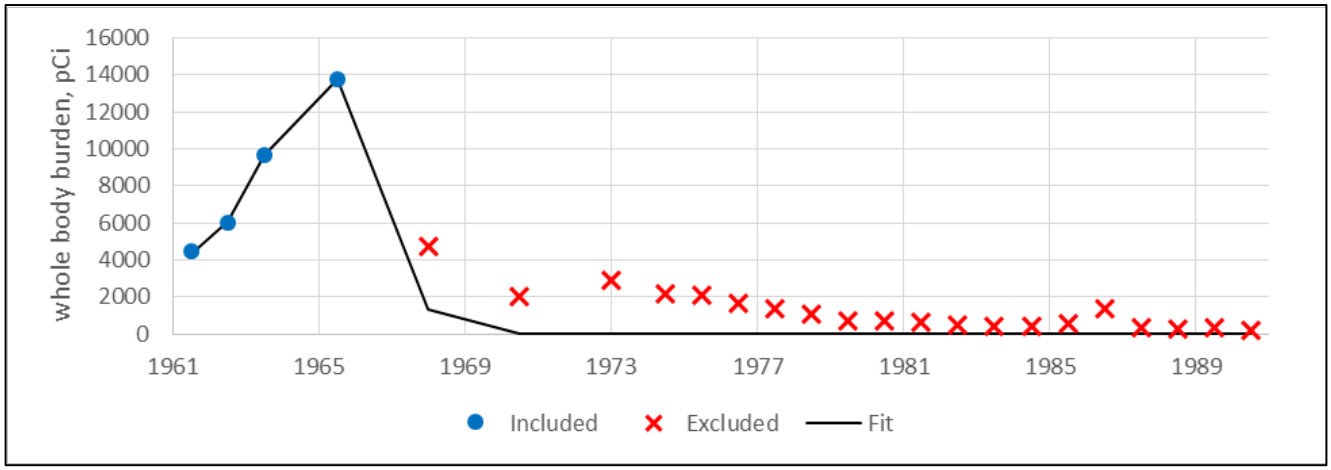


Figure F-147. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1960 to 1966, type F.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

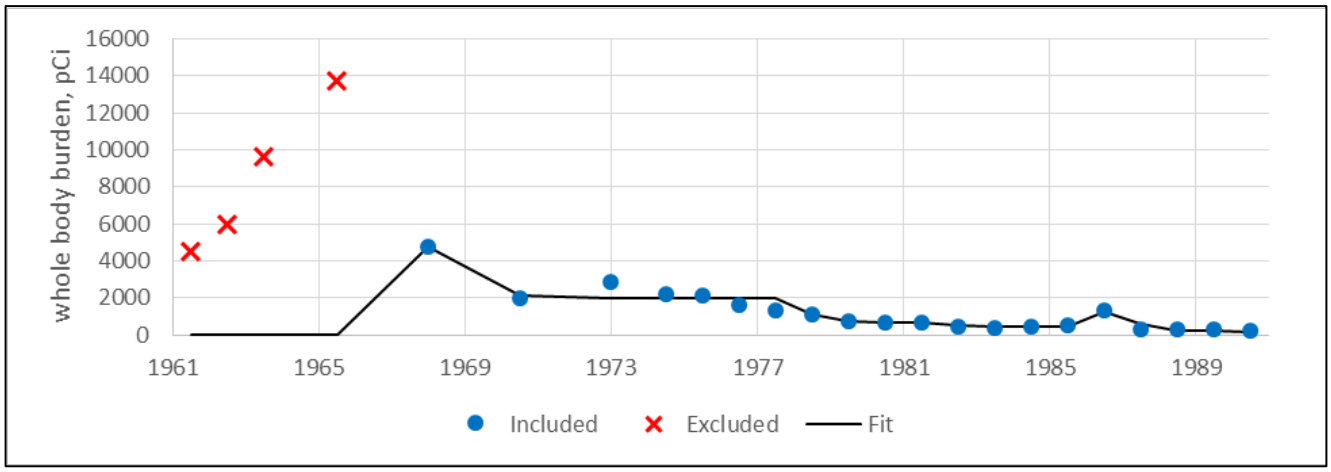


Figure F-148. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1967 to 1990, type F.

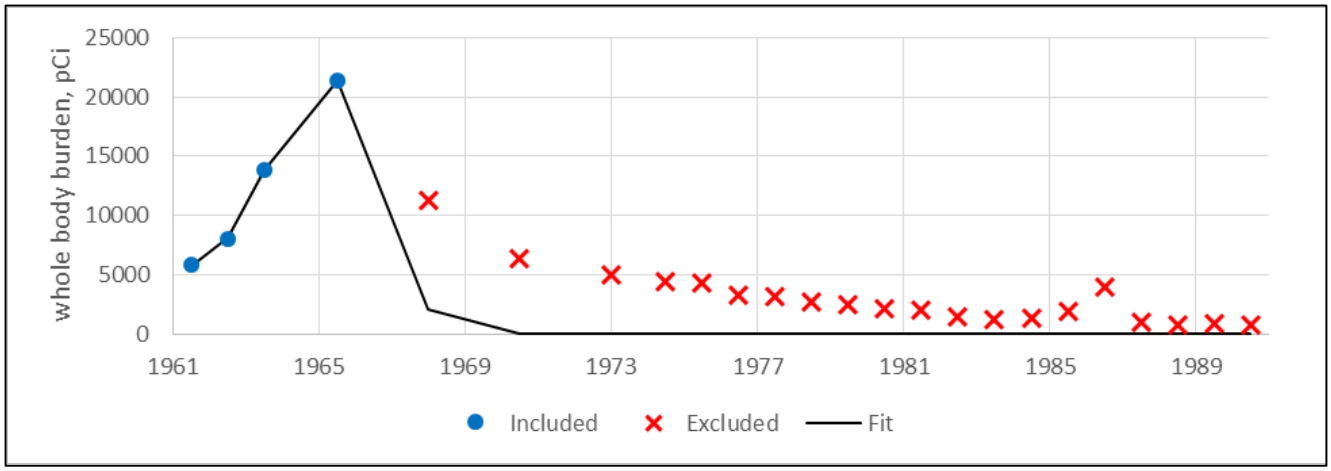


Figure F-149. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1960 to 1966, type F.

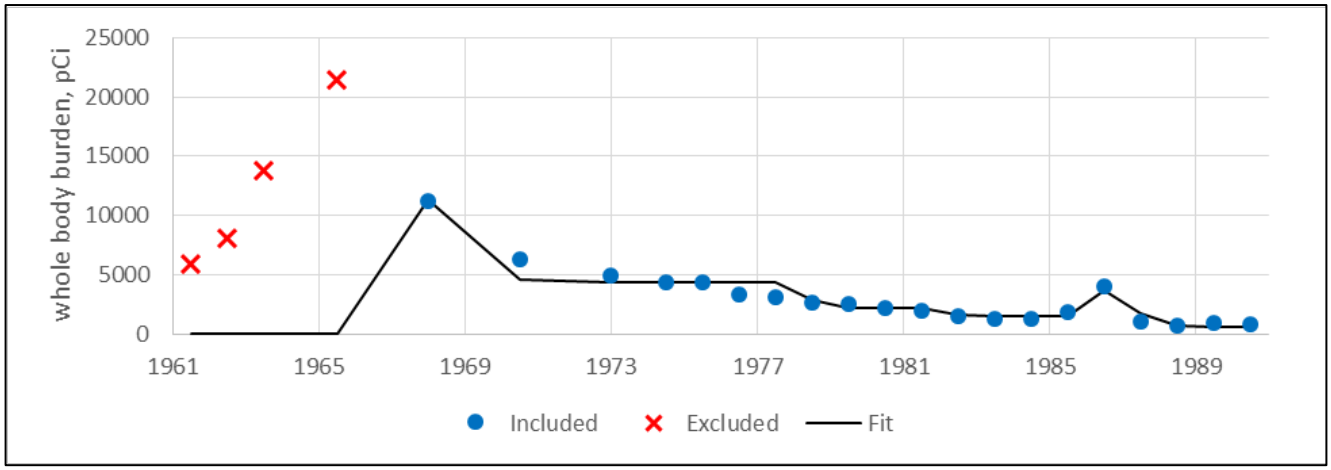


Figure F-150. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1967 to 1990, type F.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

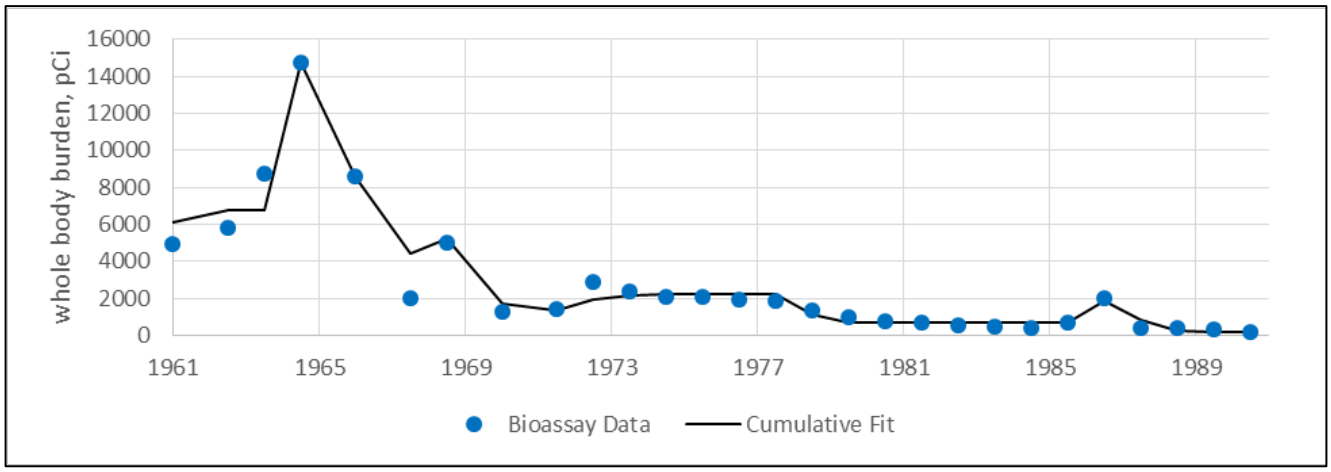


Figure F-151. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, type F.

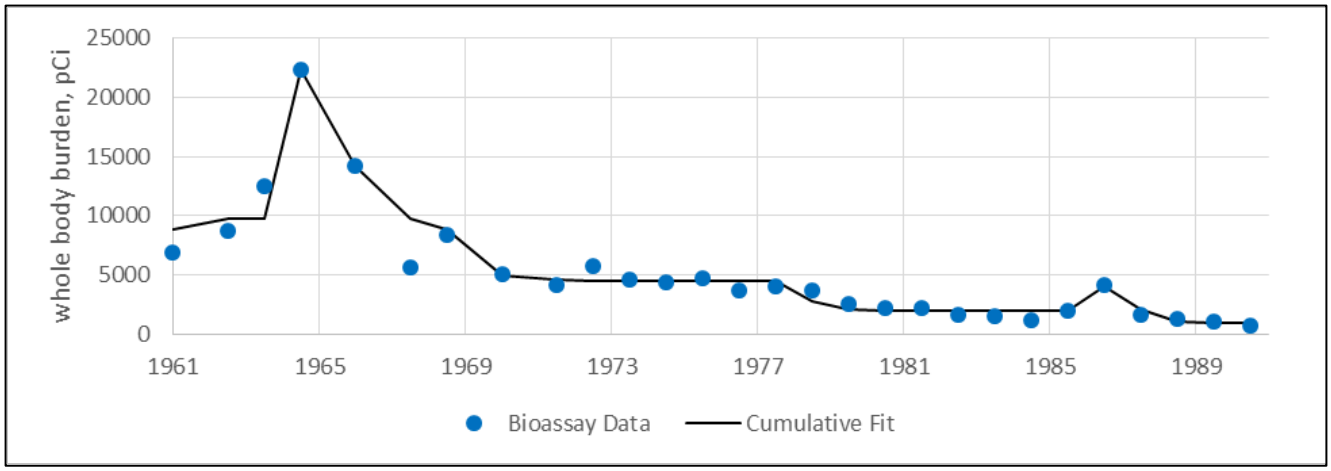


Figure F-152. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, type F.

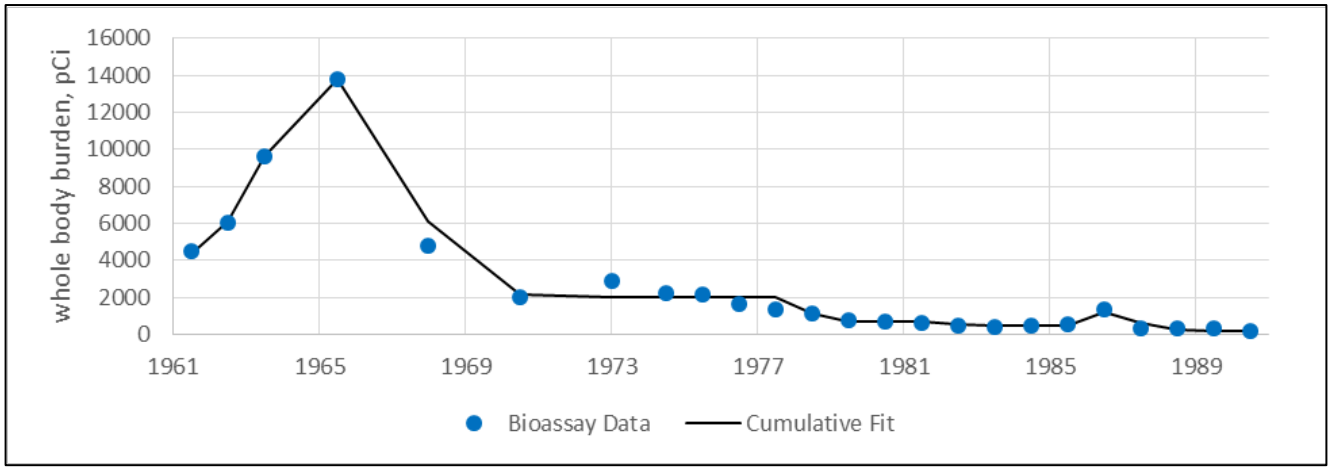


Figure F-153. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, type F.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

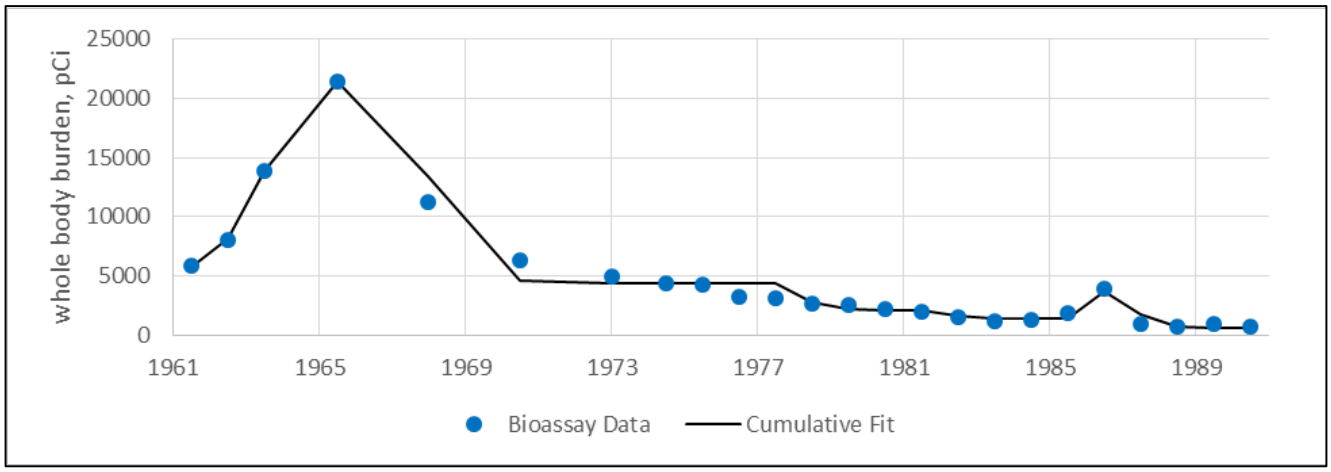


Figure F-154. Predicted ^{137}Cs bioassay results calculated using IMBA-derived ^{137}Cs intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, type F.

Table F-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 F-22. Summary of ^{137}Cs CTW type F intake rates (pCi/d) and dates.

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	54.81	148.6	2.71	3.00	333.98
01/01/1969	12/31/1977	29.31	63.11	2.15	3.00	178.60
01/01/1978	12/31/1981	9.71	31.13	3.21	3.21	66.00
01/01/1982	12/31/1985	6.557	20.9	3.19	3.19	44.14
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

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

F.7 NEPTUNIUM INTAKE MODELING RESULTS

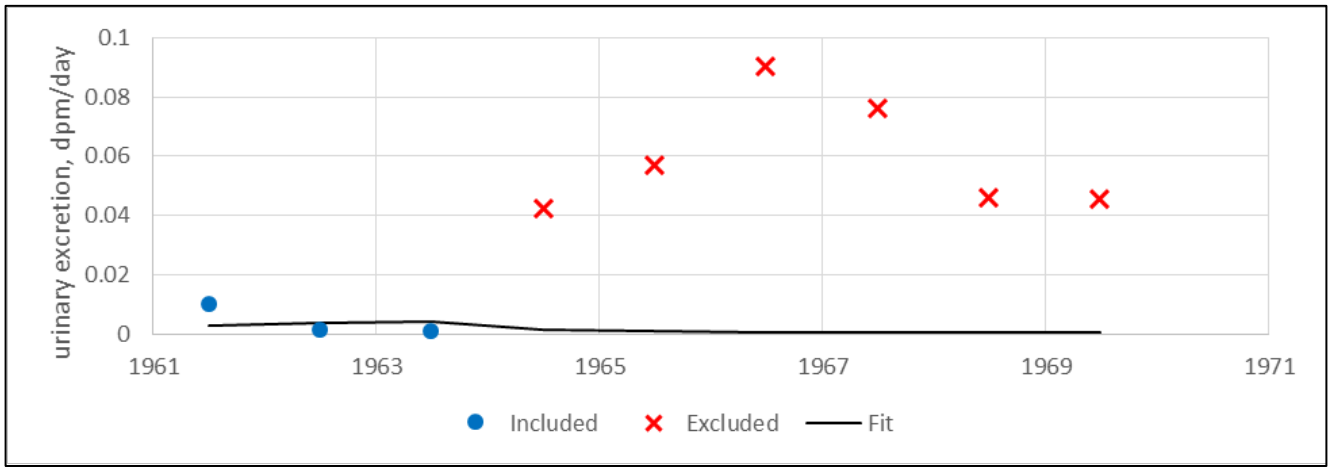


Figure F-155. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1961 to 1963.

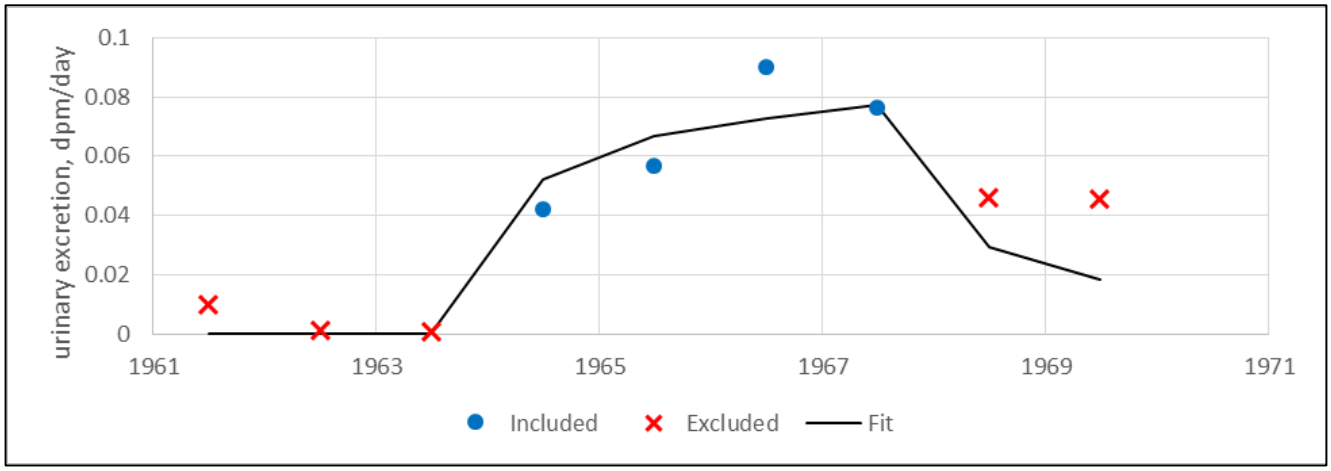


Figure F-156. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1964 to 1967.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

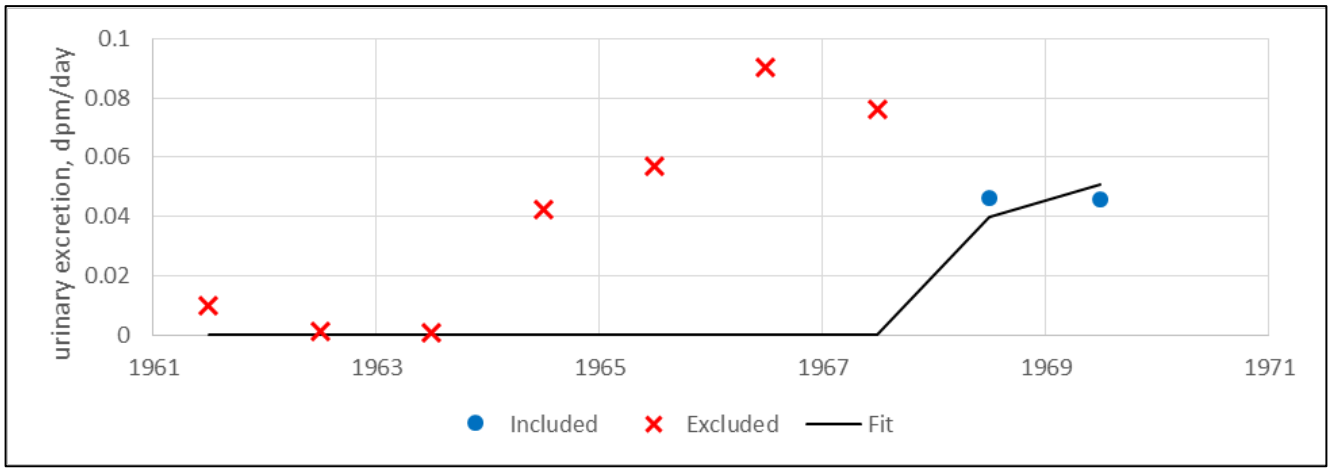


Figure F-157. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1968 to 1969.

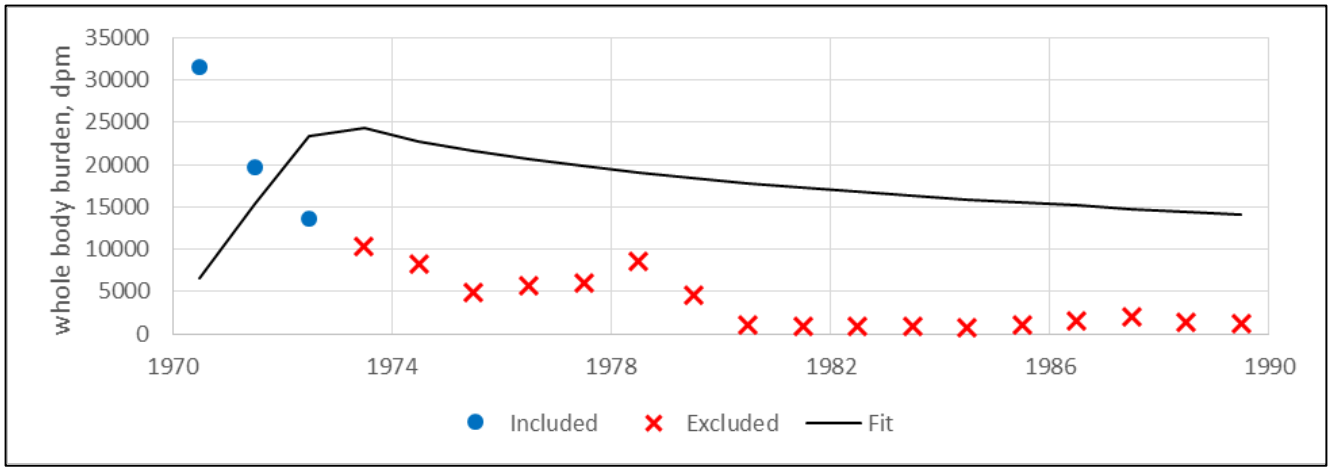


Figure F-158. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1970 to 1972.

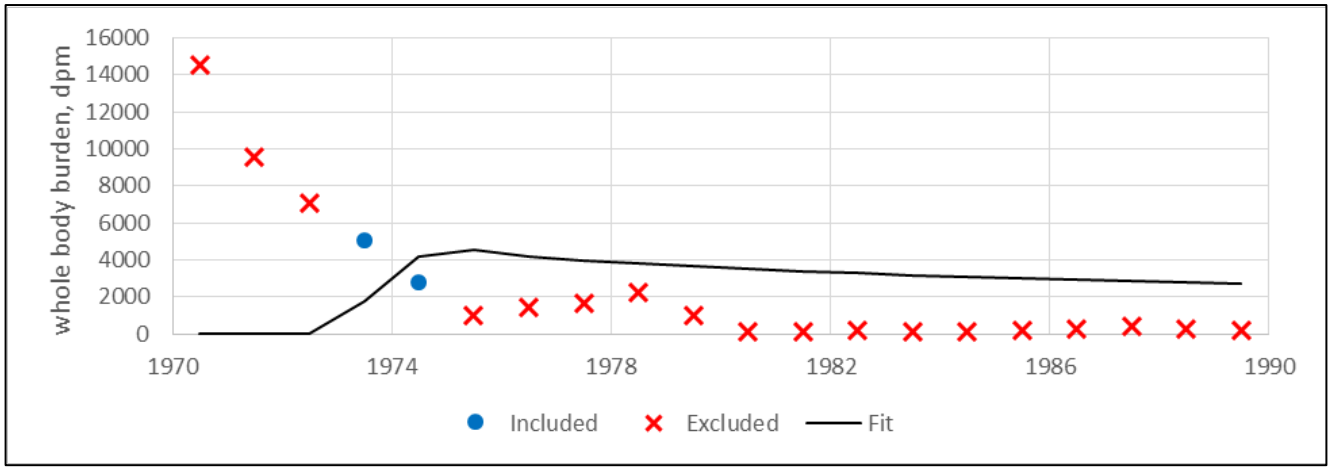


Figure F-159. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1973 to 1974.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

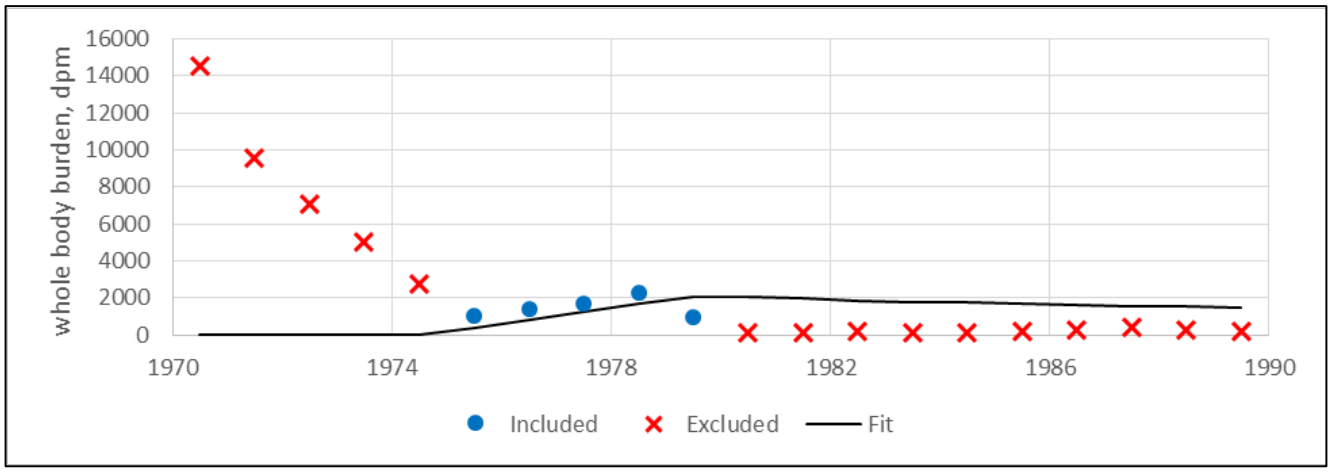


Figure F-160. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1975 to 1979.

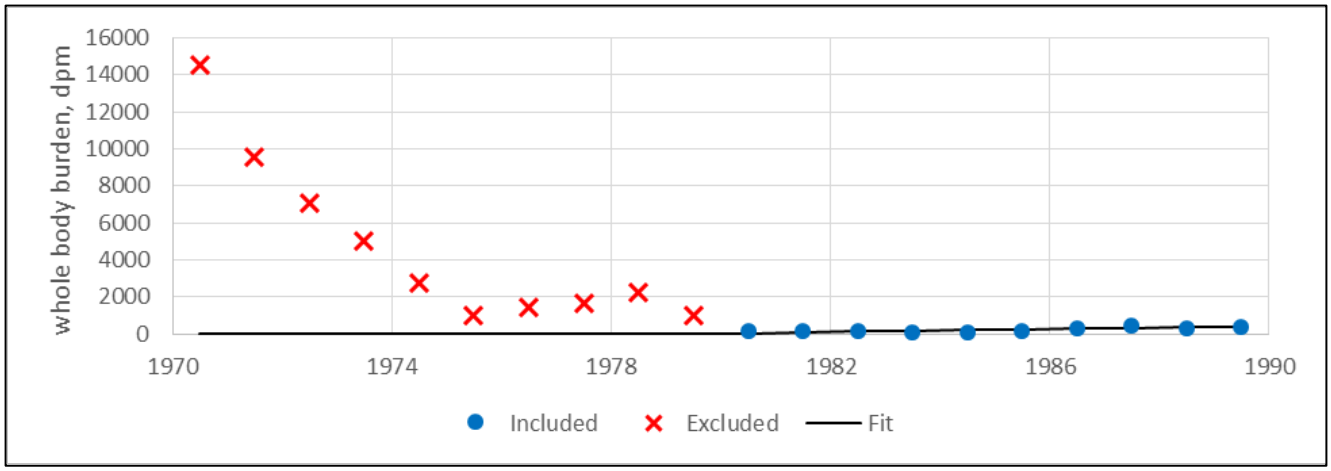


Figure F-161. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 1980 to 1989.

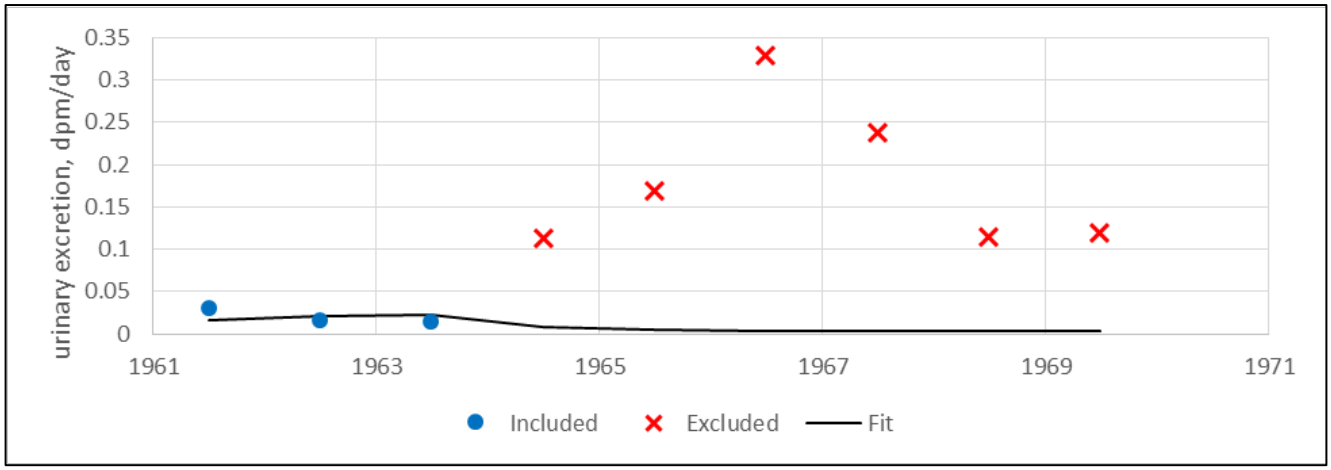


Figure F-162. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1961 to 1963.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

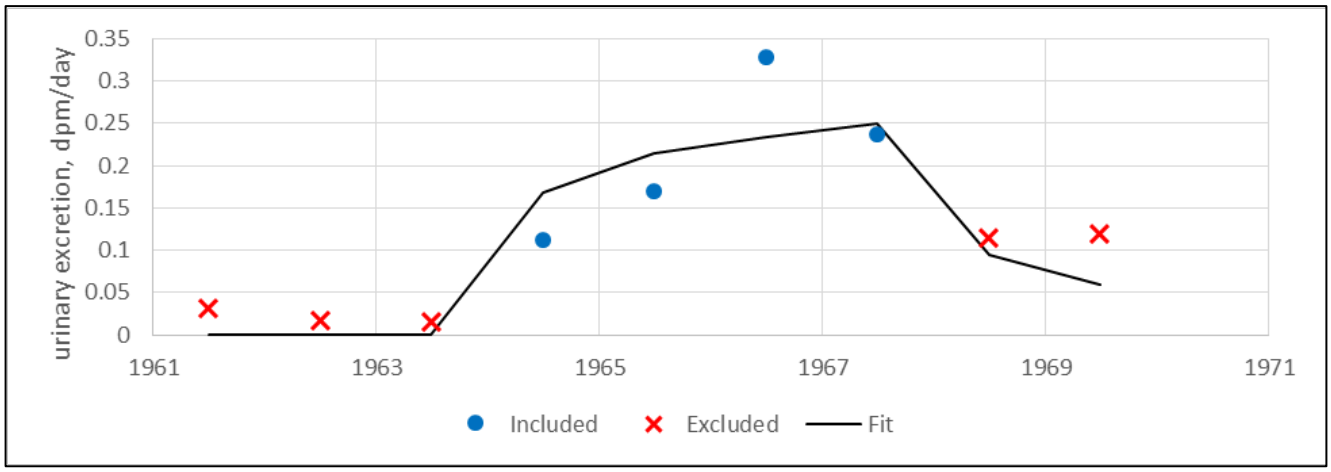


Figure F-163. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1964 to 1967.

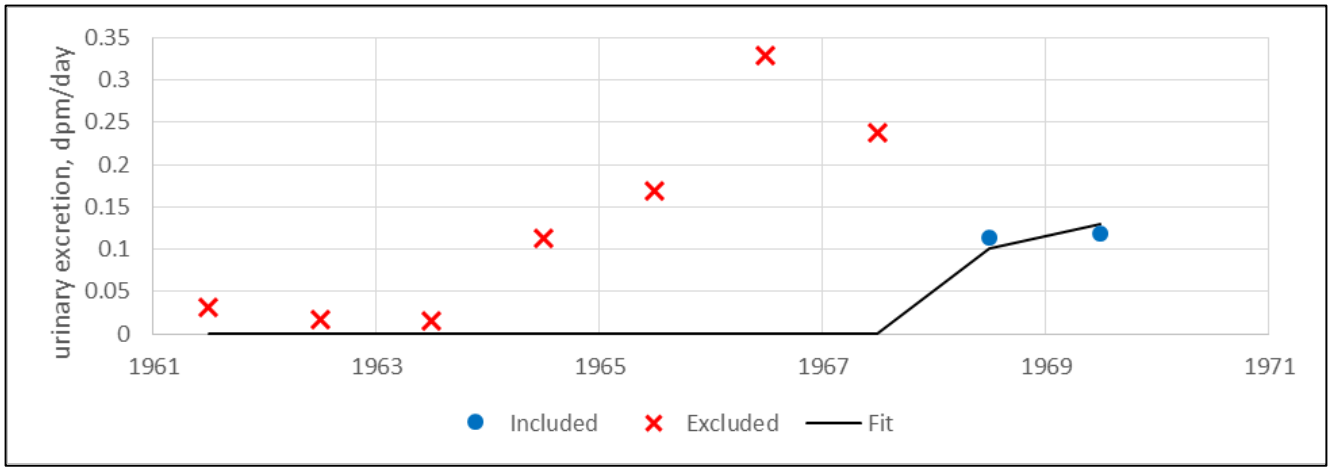


Figure F-164. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1968 to 1969.

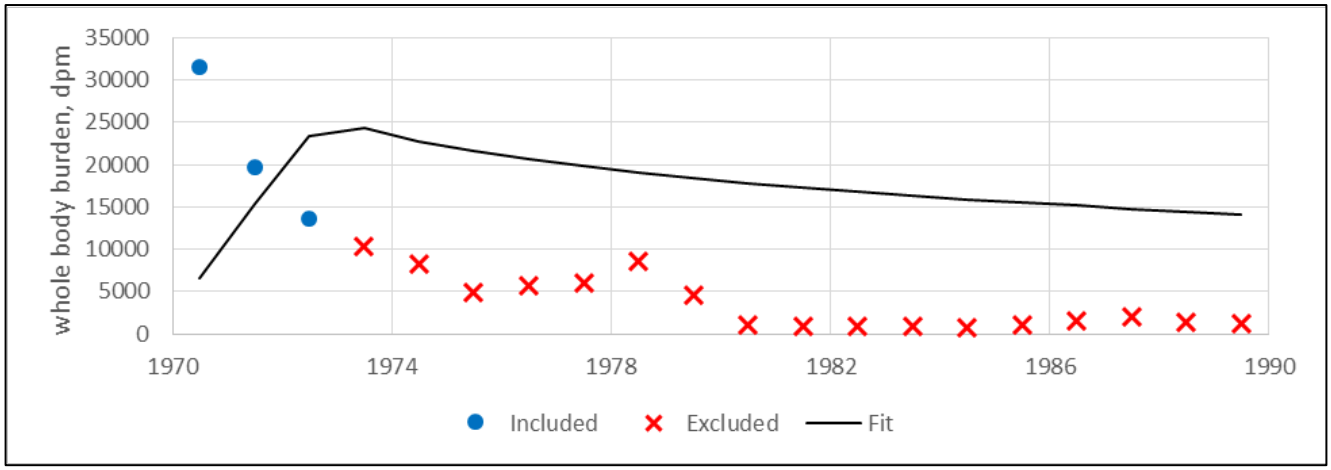


Figure F-165. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1970 to 1972.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

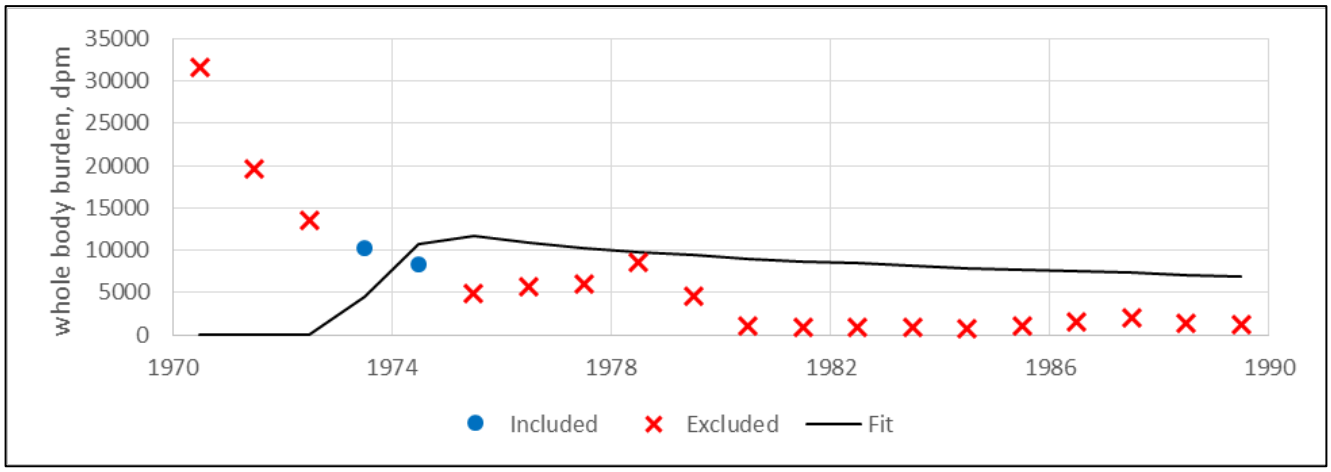


Figure F-166. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1973 to 1974.

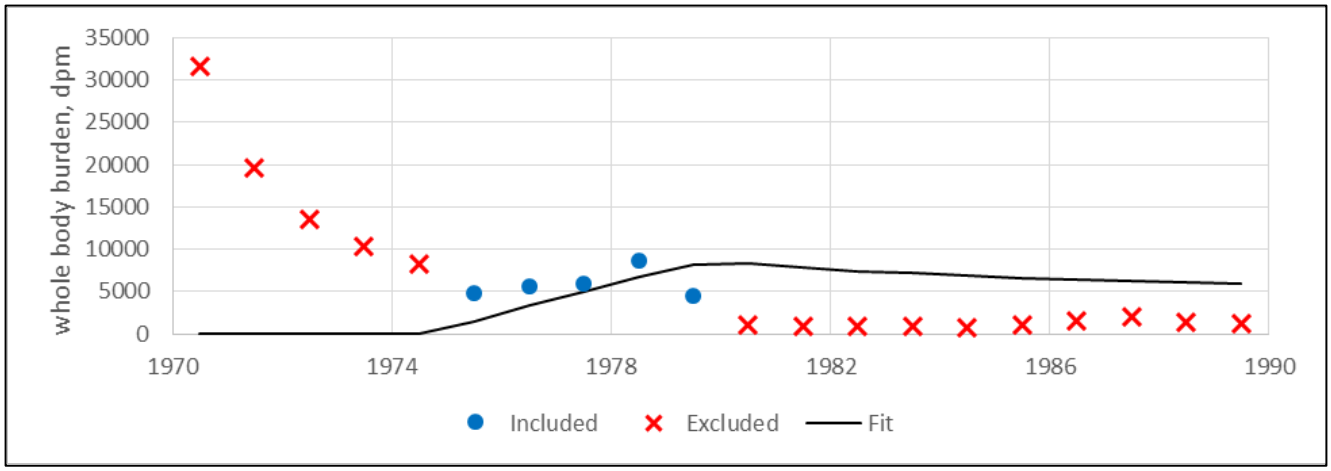


Figure F-167. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1975 to 1979.

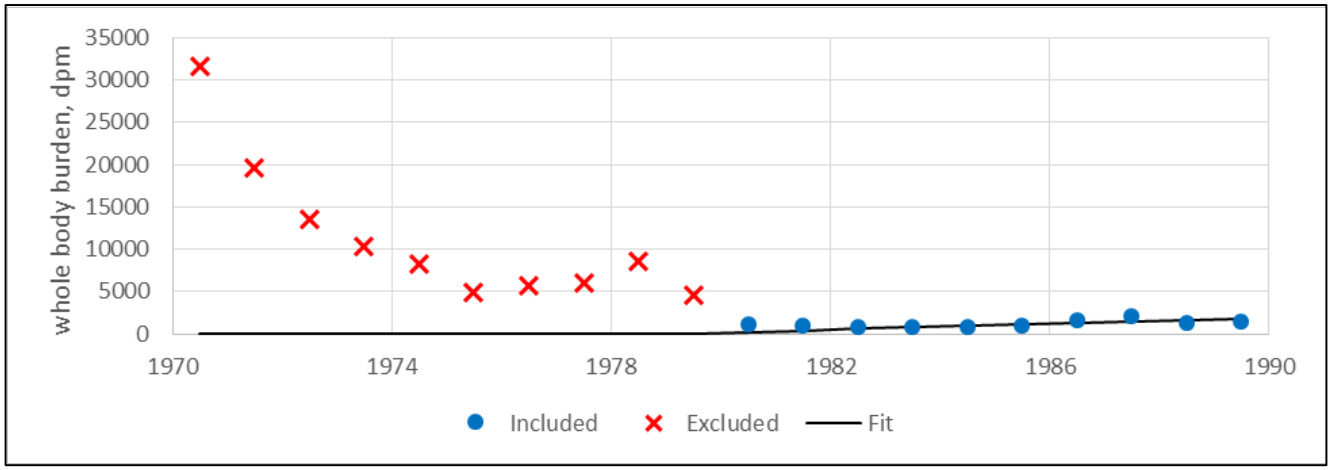


Figure F-168. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 1980 to 1989.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

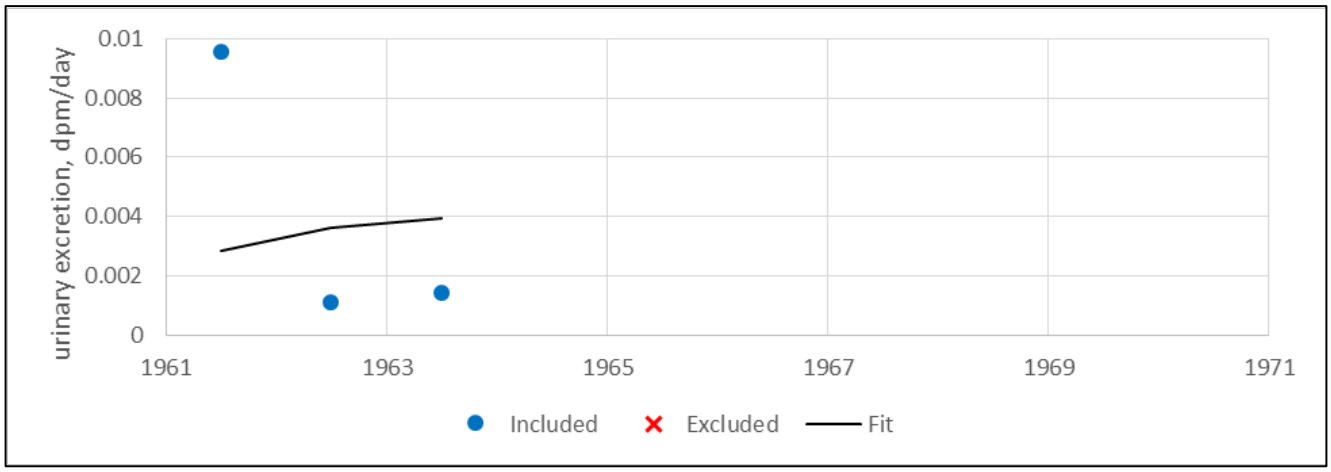


Figure F-169. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1961 to 1963.

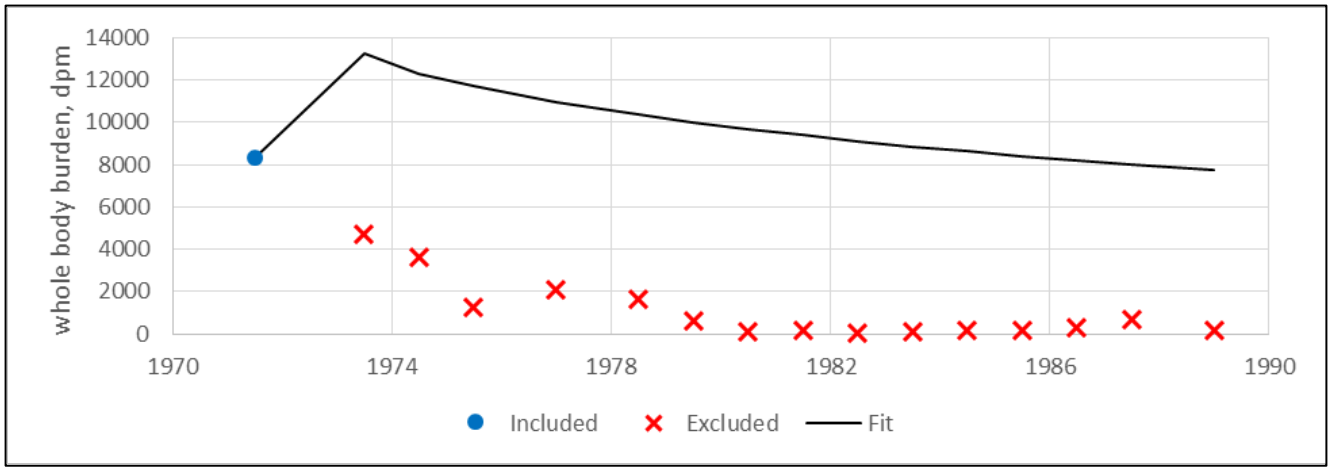


Figure F-170. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1970 to 1972.

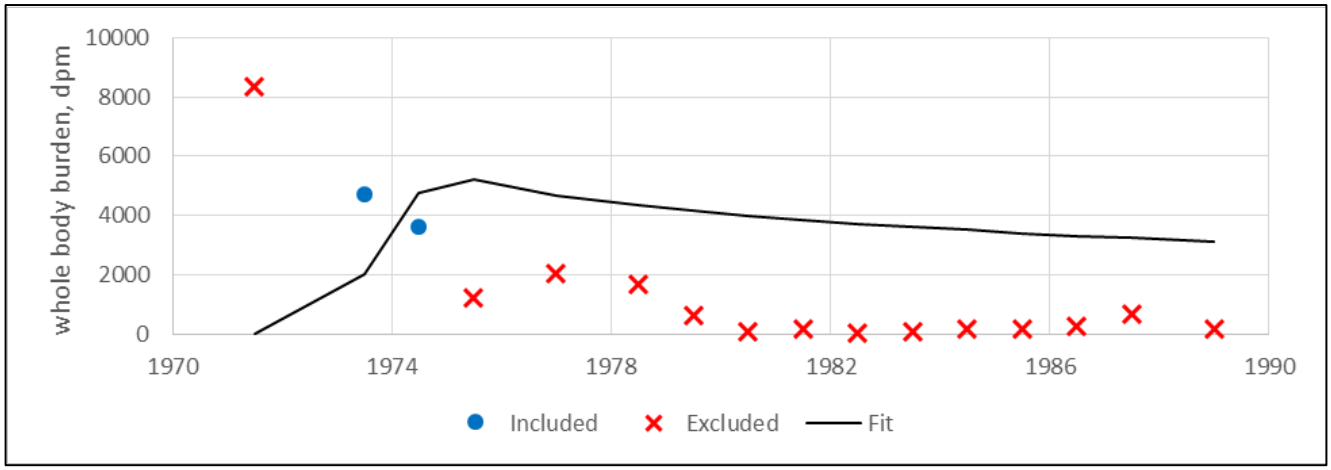


Figure F-171. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1973 to 1974.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

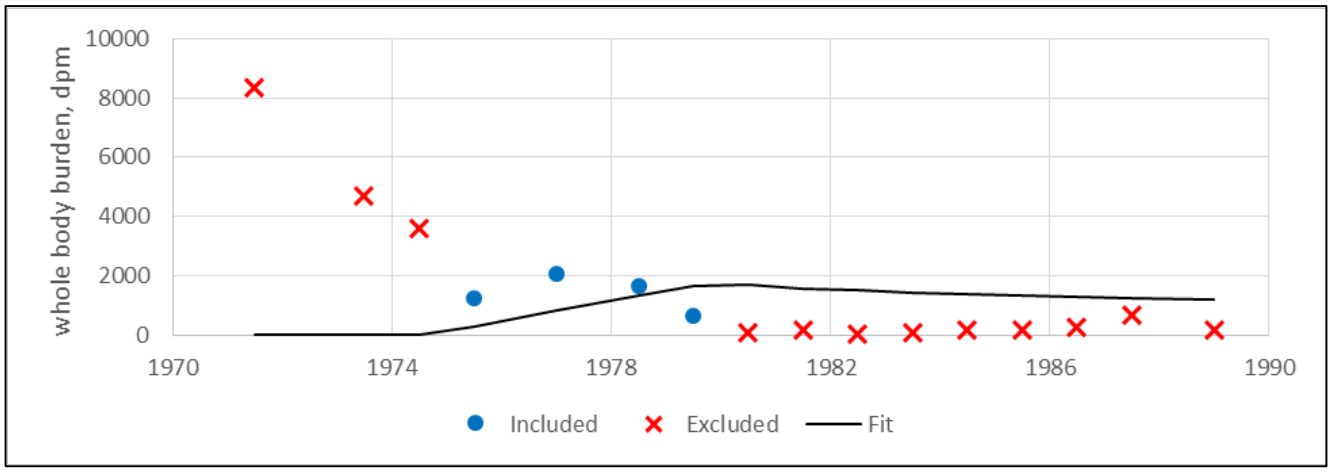


Figure F-172. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1975 to 1979.

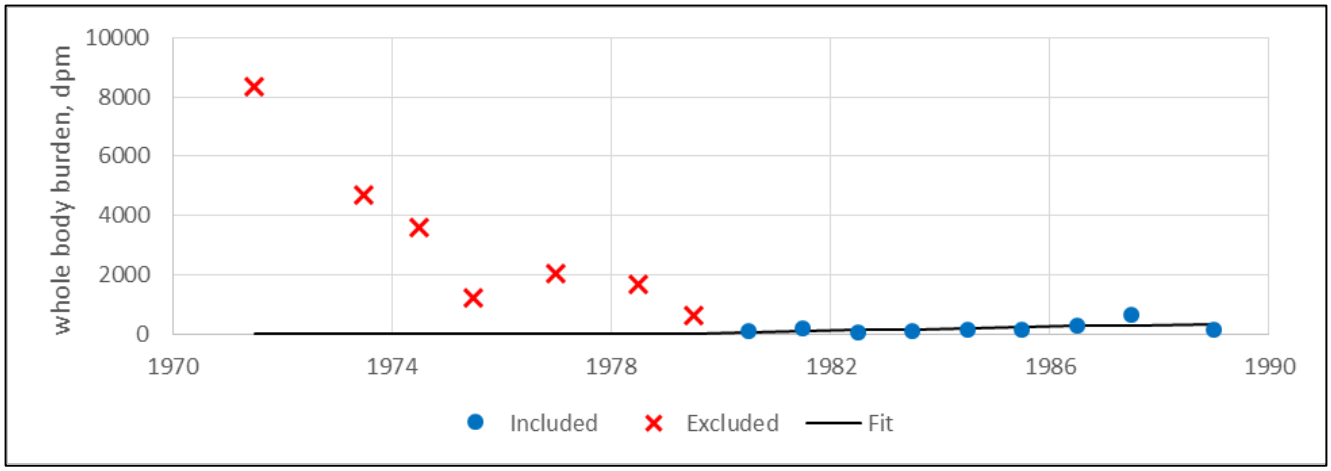


Figure F-173. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 1980 to 1989.

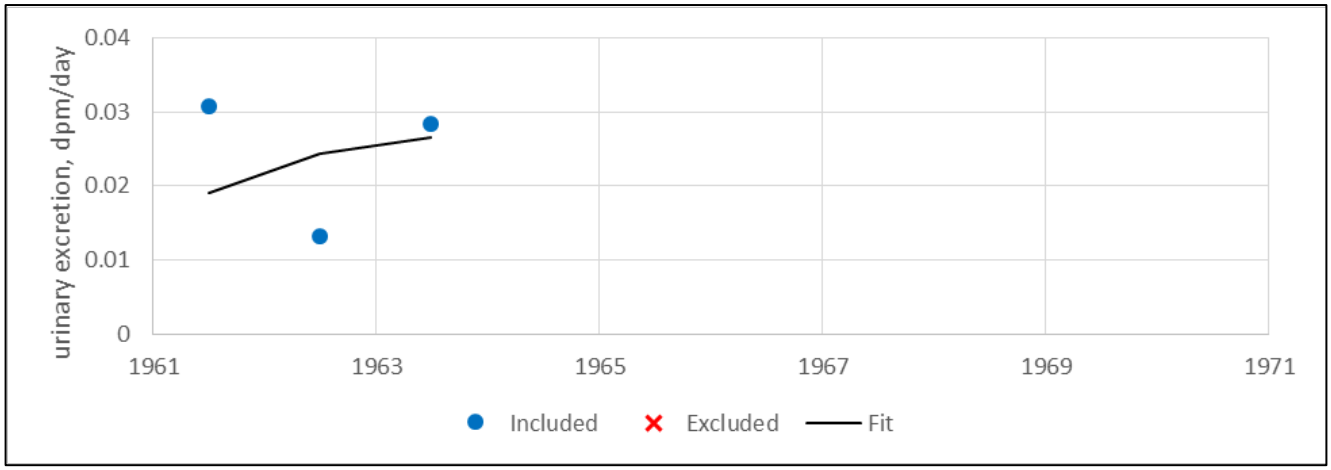


Figure F-174. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1961 to 1963.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

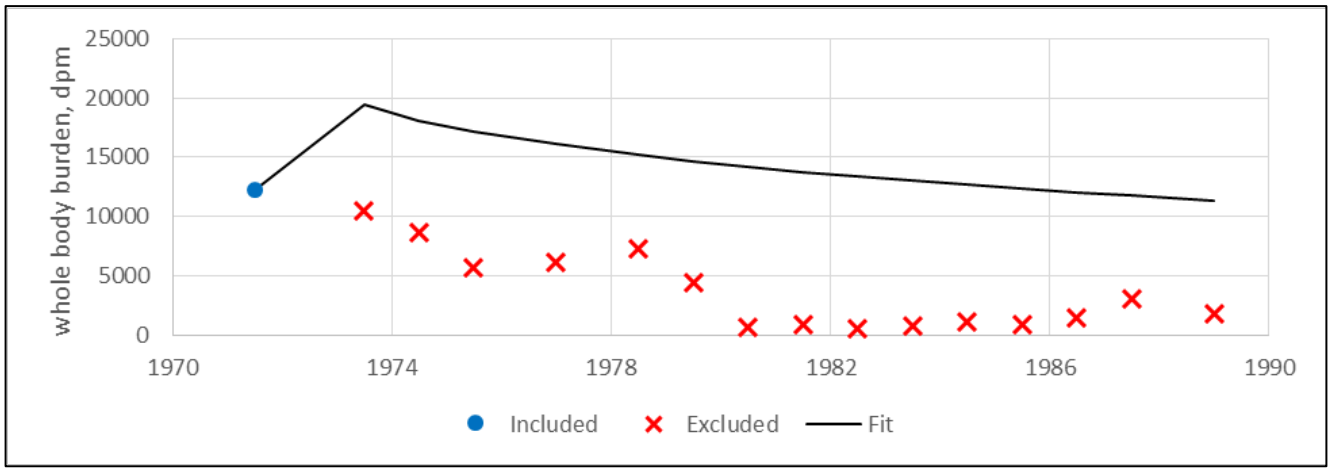


Figure F-175. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1970 to 1972.

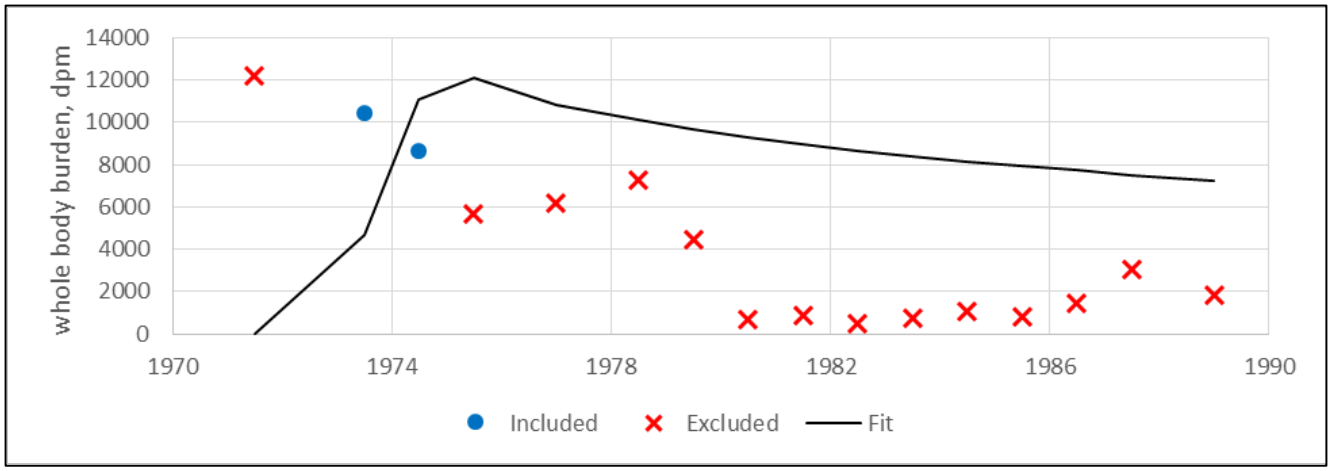


Figure F-176. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1973 to 1974.

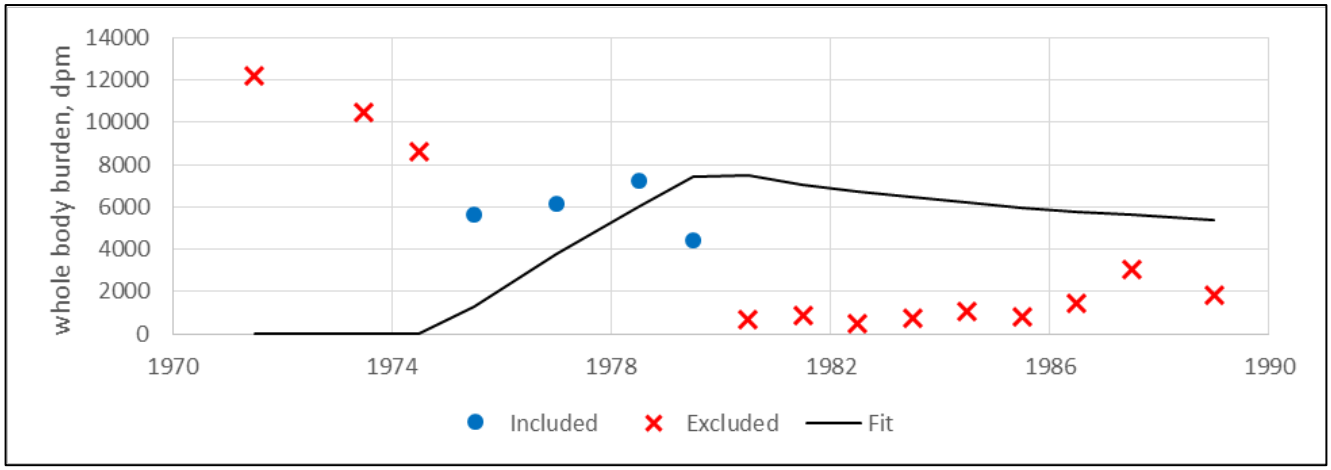


Figure F-177. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1975 to 1979.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

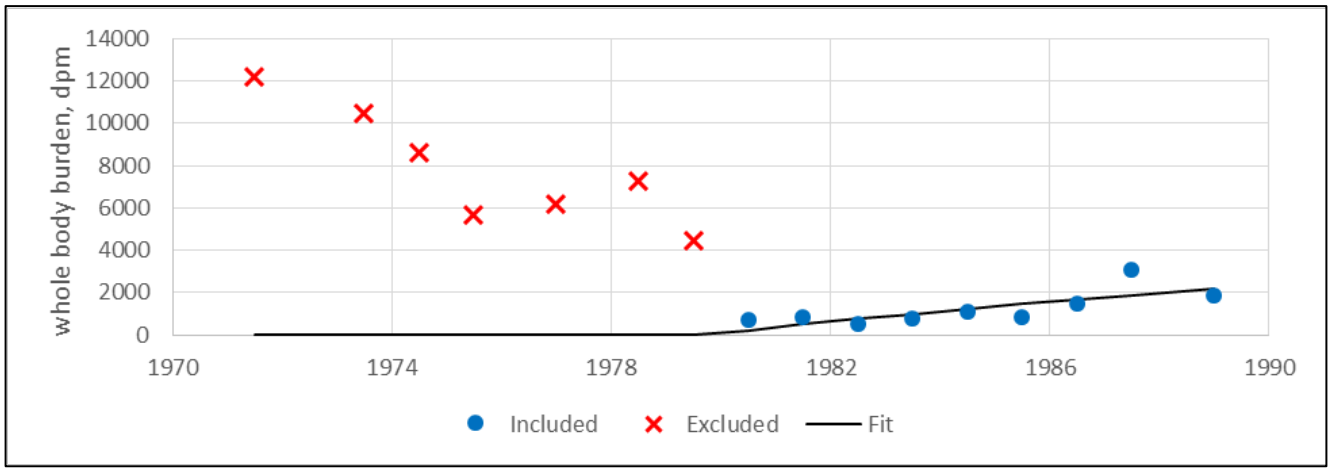


Figure F-178. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 1980 to 1989.

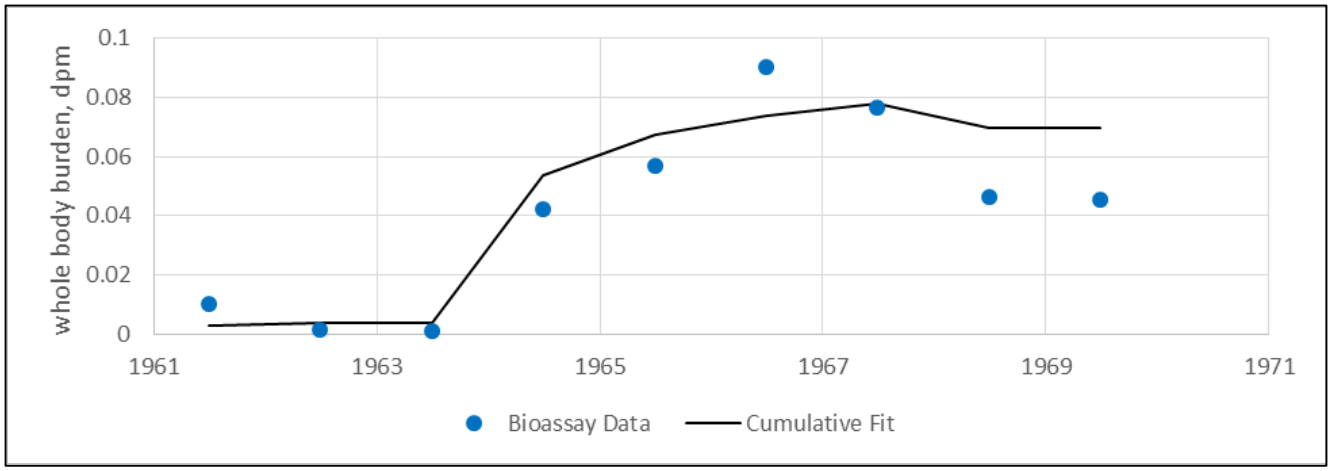


Figure F-179. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, urinalysis results.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

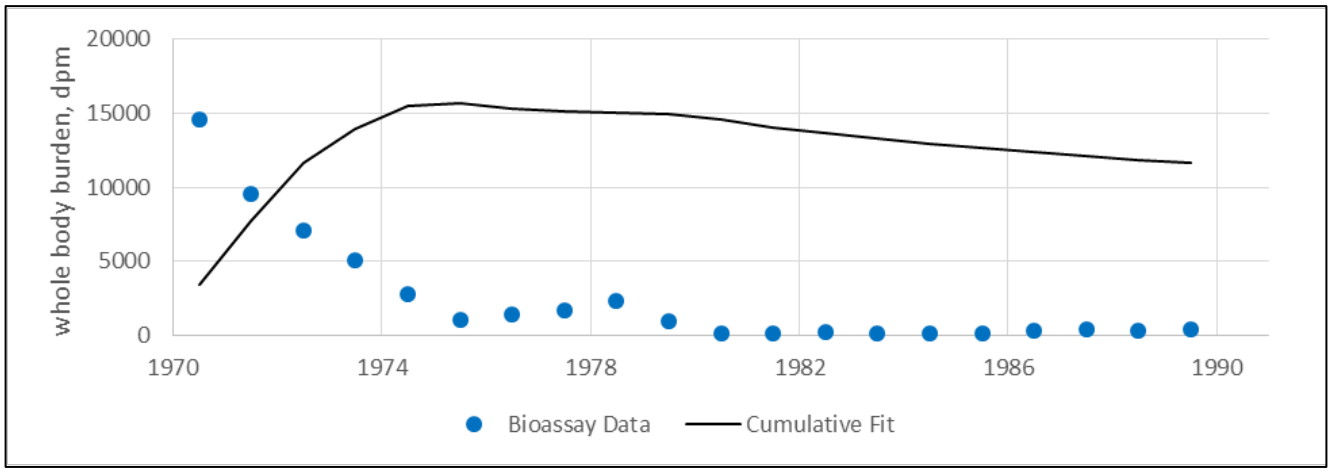


Figure F-180. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW all years, WBCs.

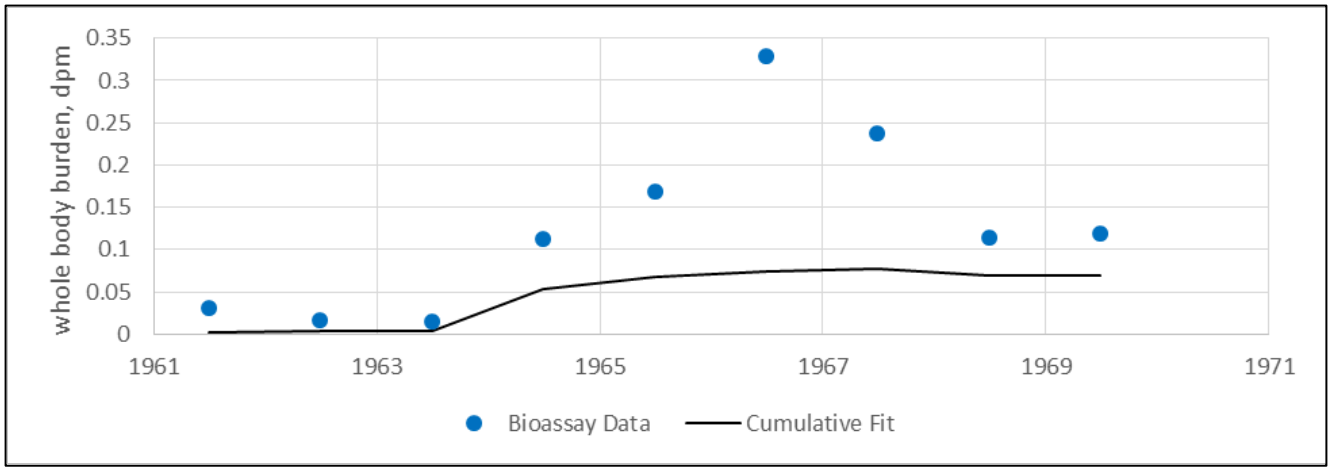


Figure F-181. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, urinalysis results.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

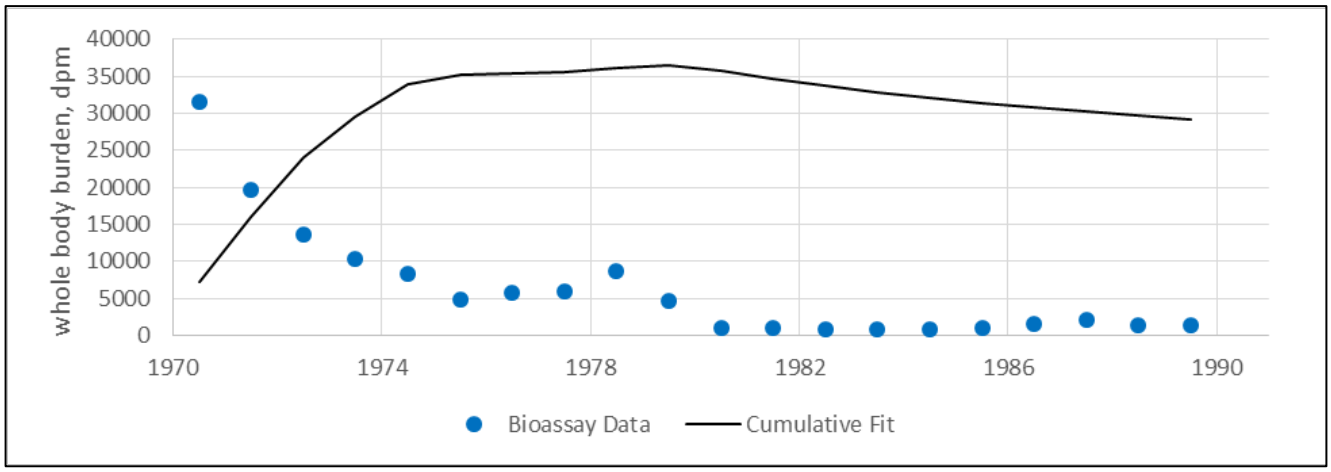


Figure F-182. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW all years, WBCs.

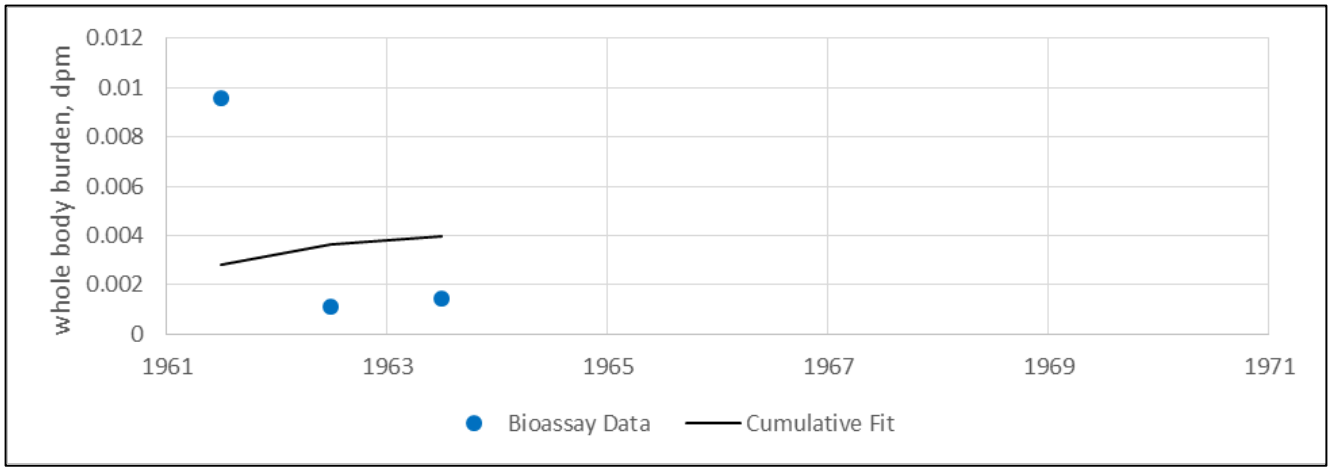


Figure F-183. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, urinalysis results.

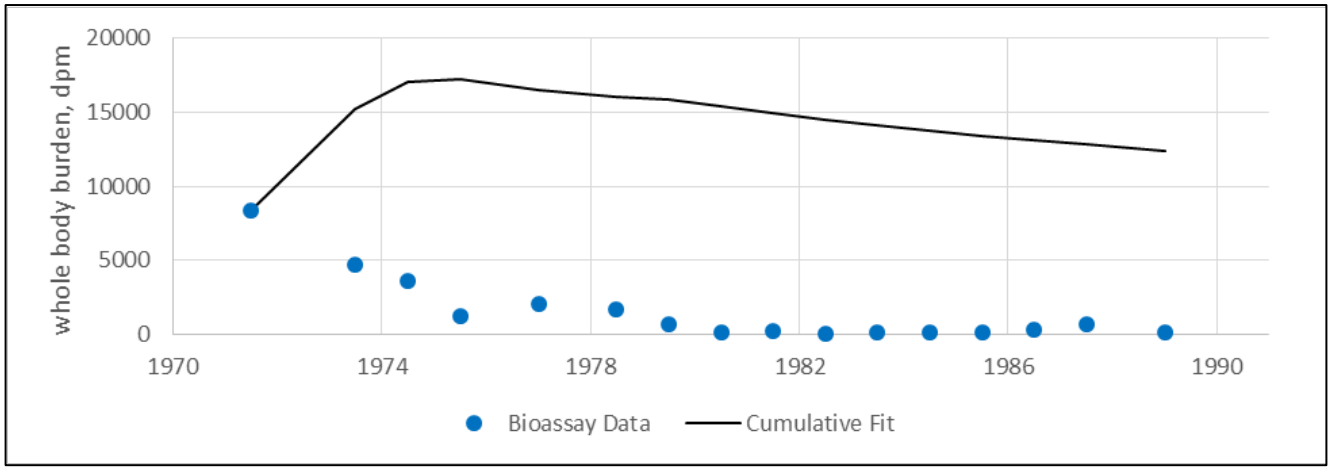


Figure F-184. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW all years, WBCs.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

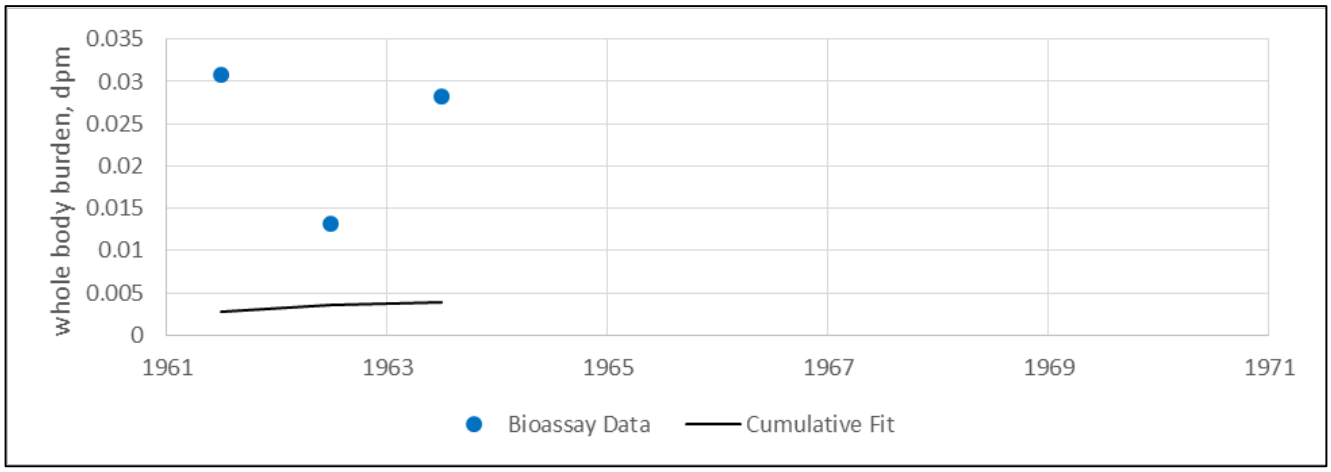


Figure F-185. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, urinalysis results.

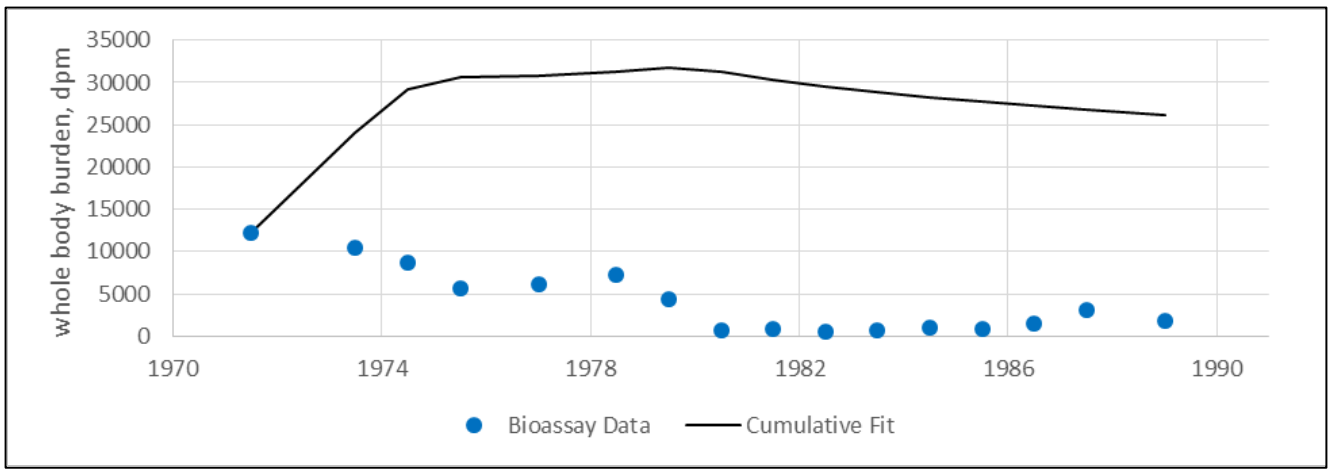


Figure F-186. Predicted ^{237}Np bioassay results calculated using IMBA-derived ^{237}Np intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW all years, WBCs.

Table F-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 F
CO-EXPOSURE DATA FIGURES (continued)

Table F-24. Summary of ^{237}Np CTW intake rates (dpm/d) and dates.

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

F.8 THORIUM INTAKE MODELING RESULTS

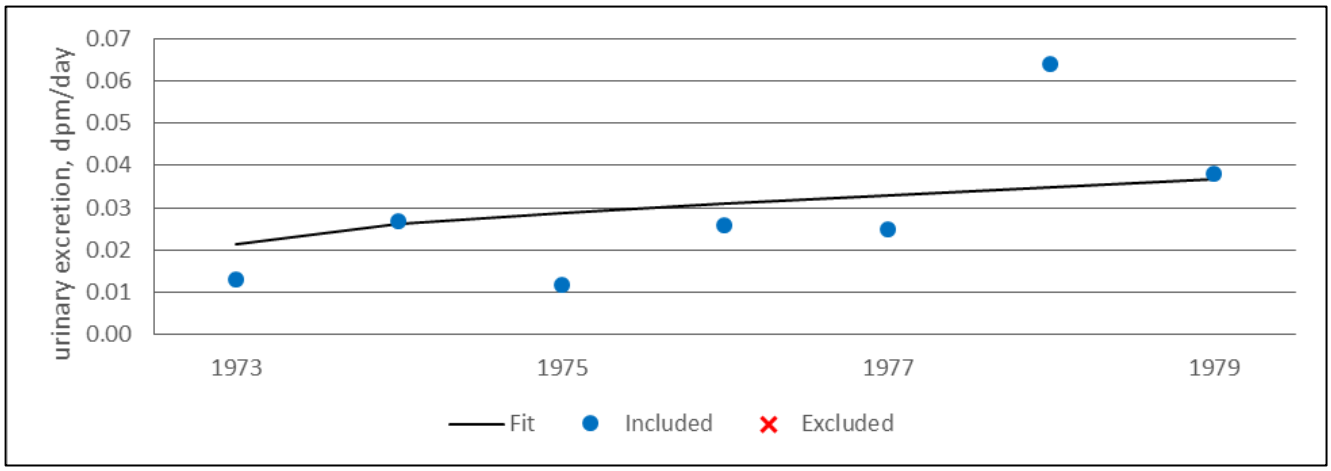


Figure F-187. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 11/01/1972 to 05/31/1980, type M.

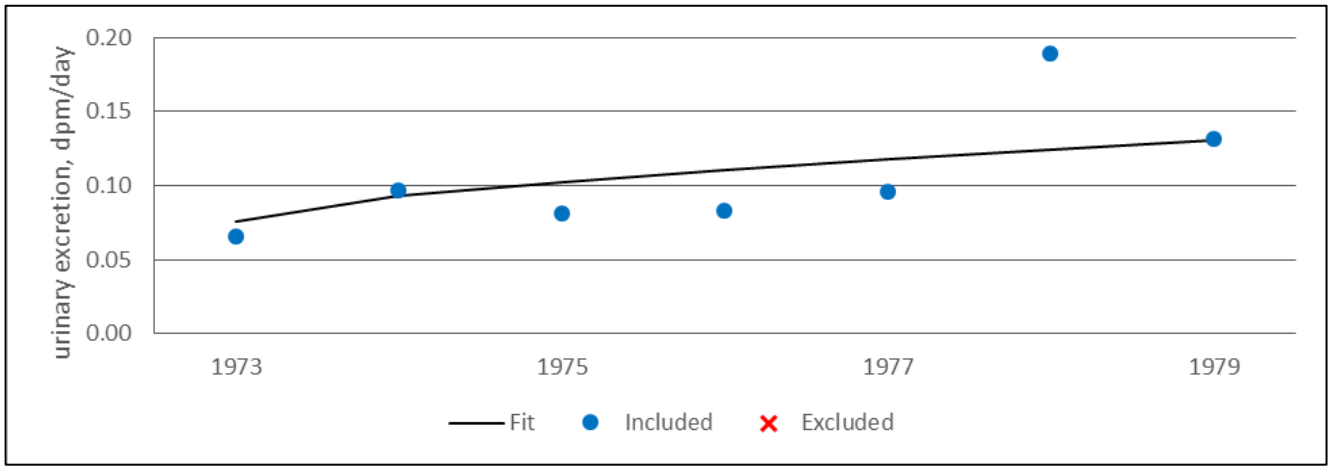


Figure F-188. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 11/01/1972 to 05/31/1980, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

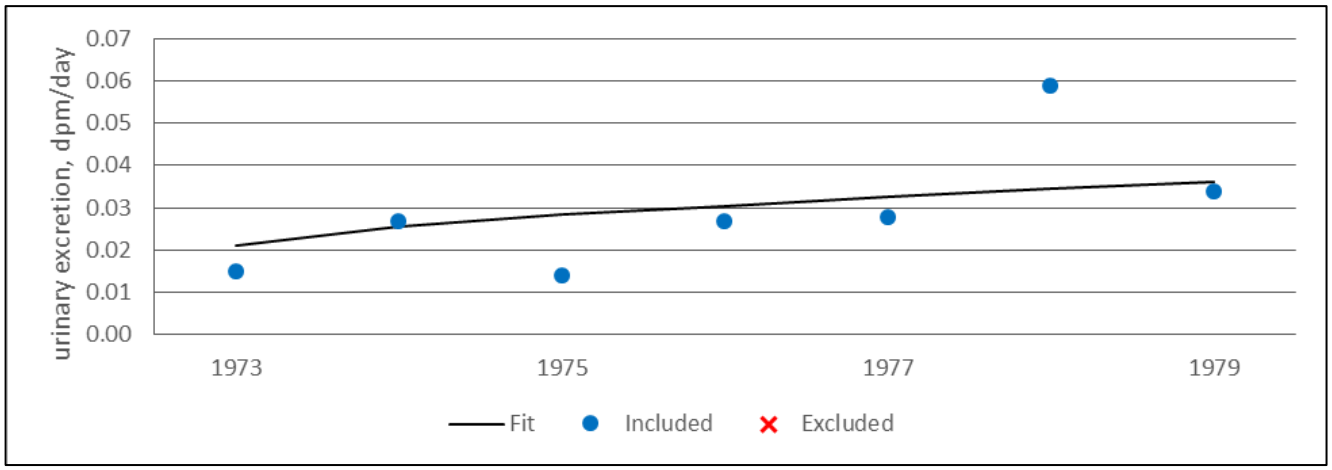


Figure F-189. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 11/01/1972 to 05/31/1980, type M.

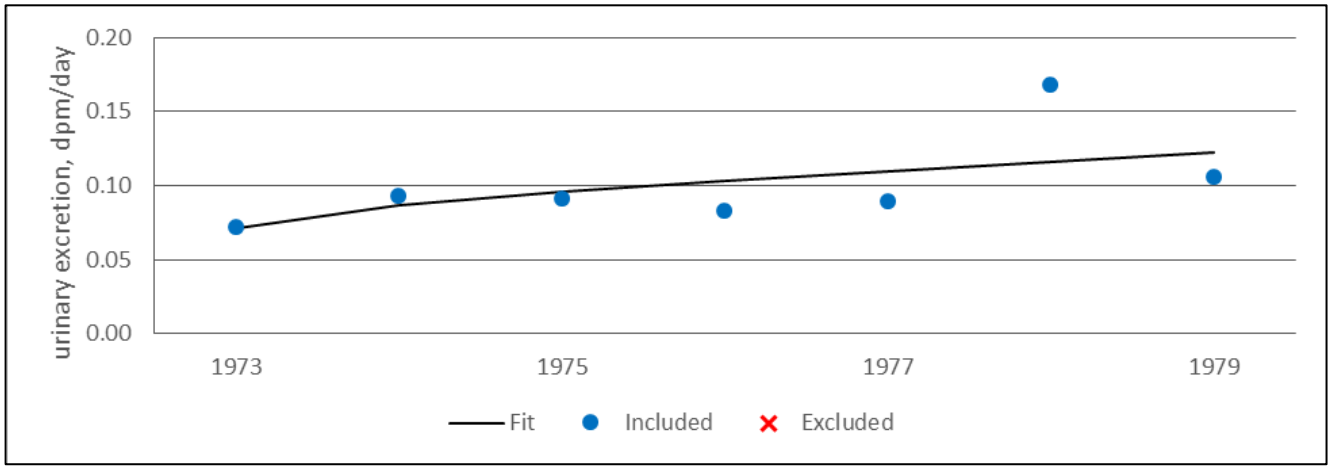


Figure F-190. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 11/01/1972 to 05/31/1980, type M.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

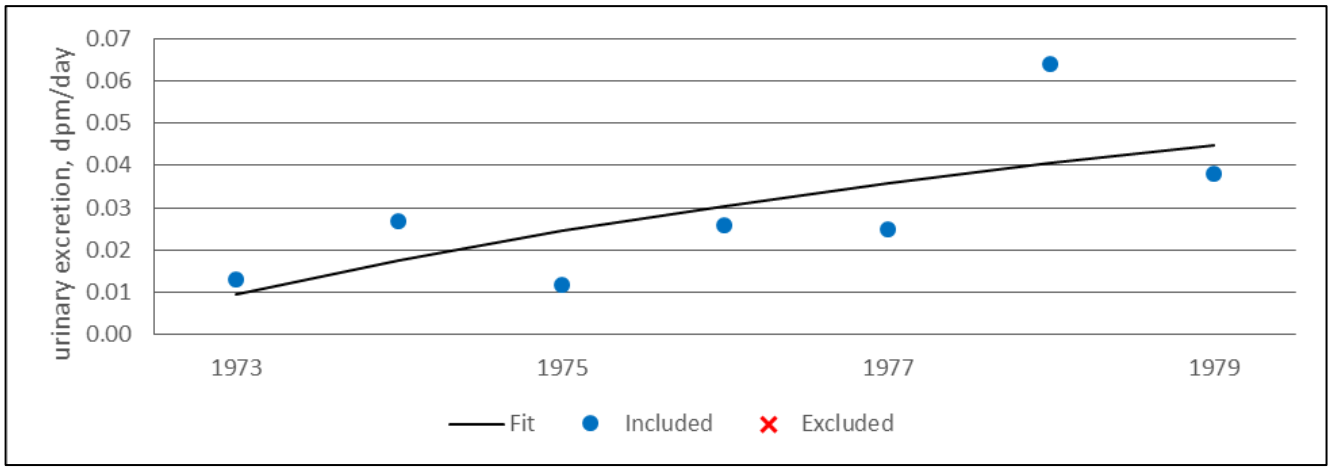


Figure F-191. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, nonCTW 11/01/1972 to 05/31/1980, type S.

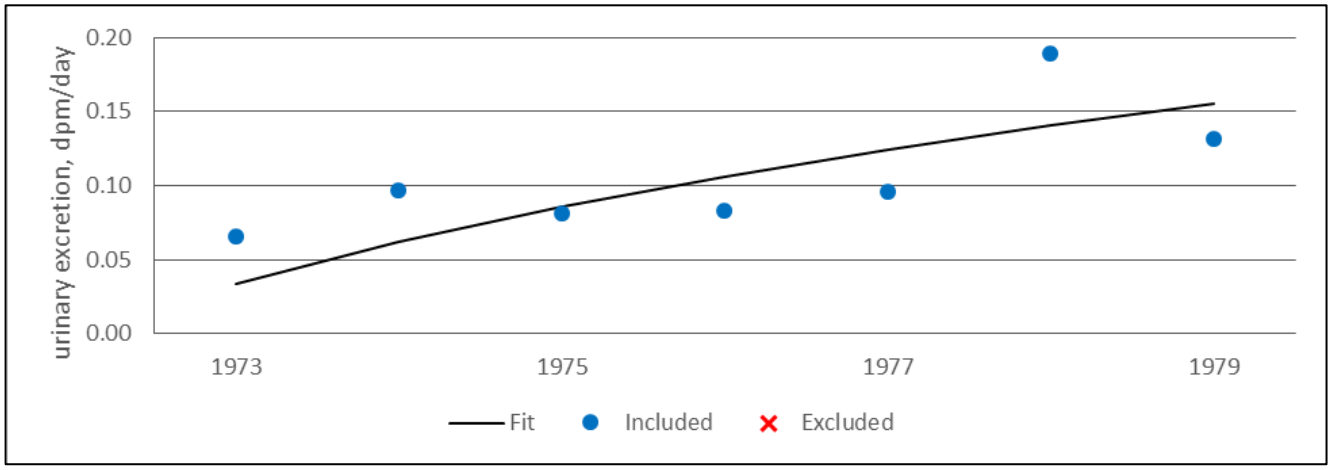


Figure F-192. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, nonCTW 11/01/1972 to 05/31/1980, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

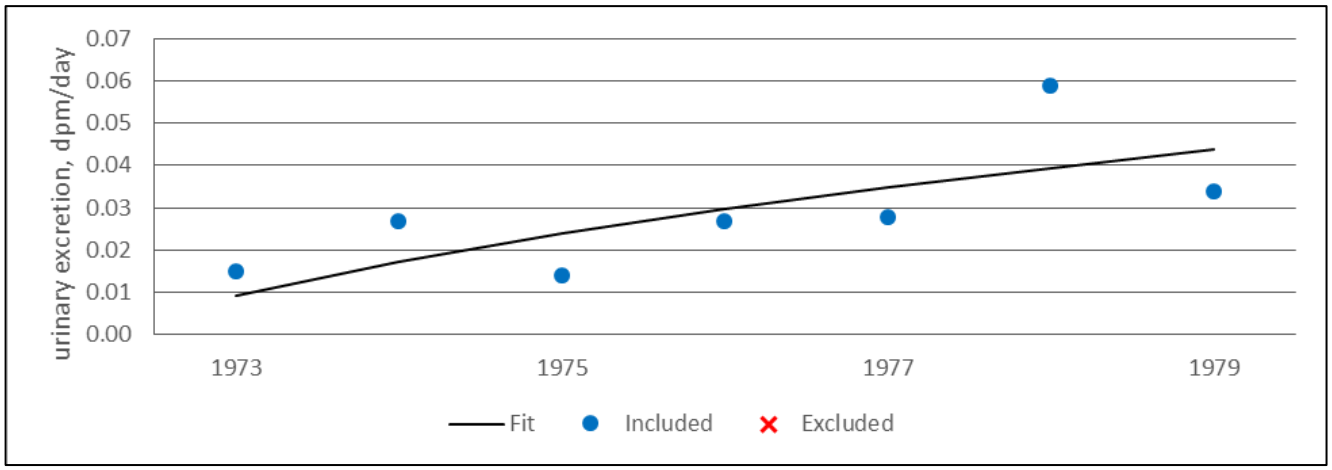


Figure F-193. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 50th percentile, CTW 11/01/1972 to 05/31/1980, type S.

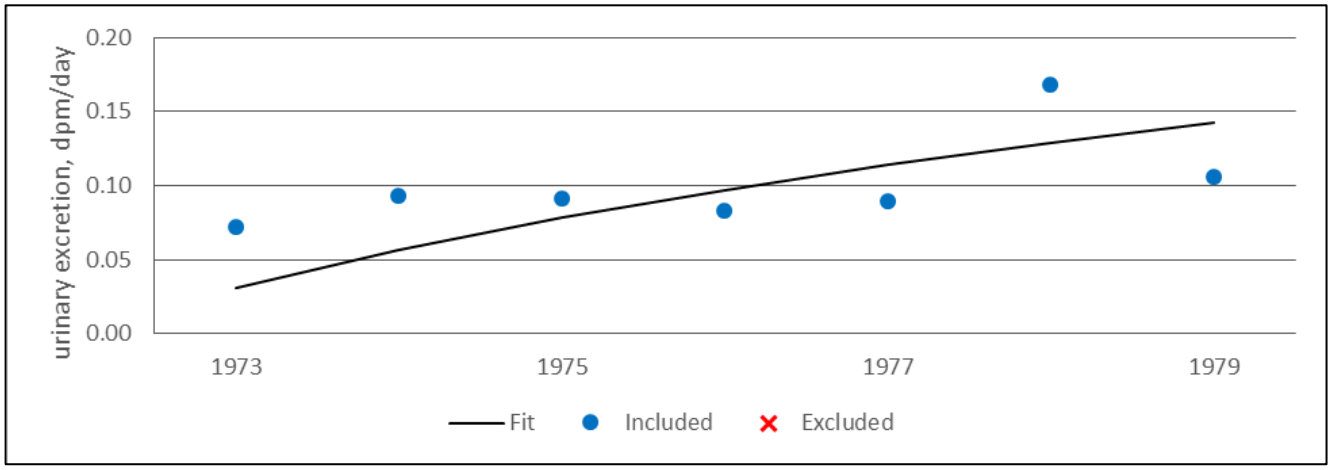


Figure F-194. Predicted ^{232}Th bioassay results calculated using IMBA-derived ^{232}Th intake rates (line) compared with measured bioassay results (dots), 84th percentile, CTW 11/01/1972 to 05/31/1980, type S.

ATTACHMENT F
CO-EXPOSURE DATA FIGURES (continued)

Table F-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	4.203	14.97	3.56	3.56	34.0

CTW

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
11/01/1972	05/31/1980	4.145	13.96	3.37	3.37	30.6

Table F-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	81.49	282.8	3.47	3.47	631

CTW

Start	End	50th percentile	84th percentile	GSD	Adjusted GSD	95th percentile
11/01/1972	05/31/1980	79.41	259.2	3.26	3.26	556