ORAU TEAM
Dose Reconstruction Project for NIOSH

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☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
06/22/2007	00	Approved new technical information bulletin for assigning Mound internal doses based on coworker bioassay data. Incorporates formal internal and NIOSH review comments. There is no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Clark B. Barton.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AMAD	activity median aerodynamic diameter
Bq	becquerel
d	day
DOE	U.S. Department of Energy
DTPA	diethylene triamine pentaacetic acid
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
GI	gastrointestinal
GSD	geometric standard deviation
hr	hour
HSPU	heat-source plutonium
IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
m	meter
mL	milliliter
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
pCi	picocurie
PER	Program Evaluation Report
POC	probability of causation
TIB	technical information bulletin
U.S.C.	United States Code
WGPU	weapons-grade plutonium
μg	microgram
μm	micrometer
§	section or sections

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 if additional relevant information is obtained. TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

In this document the word “facility” is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy [DOE] facility” as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384l(5) and (12)].

Analysis of Coworker Bioassay Data for Internal Dose Assignment (ORAUT 2005) describes the general process that is used to analyze bioassay data for assigning doses to individuals based on coworker results. *Coworker Data Exposure Profile Development* (ORAUT 2004a) describes the approach and processes to be used to develop reasonable exposure profiles based on available dosimetric information for workers at DOE sites.

Bioassay results were obtained through the PORECON (Polonium Reconstruction) and PURECON (Plutonium Reconstruction) databases that were created at the Mound Laboratory from logbooks and other original hard-copy records. Based on a spot check, this data set coincides well with original Mound paper records. It is appropriate for use only at Mound. Furthermore, the databases are representative of worker bioassay results at Mound during a substantial part of the operating history at this site.

The database results were labeled with units that varied among the radionuclides, analysis techniques, and measurement periods. These units were assembled into a common format to expedite the statistical analysis. The specific units for each radionuclide are provided in the appropriate sections of this document.

A statistical analysis of the data was performed as specified in ORAUT (2005) and it’s implementing procedure, *Generating Summary Statistics for Coworker Bioassay Data* (ORAUT 2006). The results were entered in the Integrated Modules for Bioassay Analysis (IMBA) computer software to obtain intake rates for assigning dose distributions.

2.0 PURPOSE

Some employees at DOE sites might not have been monitored for potential intakes of radioactive material. For other employees the records of such monitoring might be incomplete or unavailable. In such cases, data from monitored coworkers can be used to estimate an individual’s potential intake of radioactive material and the resulting internal dose. The purpose of this TIB is to provide monitored coworker information for calculating and assigning occupational internal doses to employees at Mound whose job titles, facility assignments, and other case-specific information indicate that they have the potential for unmonitored intakes of ^{210}Po or plutonium.

Attributions and annotations, indicated by bracketed callouts used to identify the source, justification, or clarification of the associated information, are presented in § 6.0.

3.0 DATA OVERVIEW

This section provides information on the general selection characteristics of the data and the methods of analysis. Plutonium and ^{210}Po are the radionuclides of interest, and significant numbers of monitoring records exist for them. More detailed radionuclide-specific information for these two nuclides is provided in Section 4.0.

3.1 BIOASSAY DATA SELECTION

3.1.1 Polonium Urinalysis Data

The urine bioassay data were extracted from the *verified* PORECON_FINAL_COPY database, “dbo_SAMPLES” table, “BQ_DAY” field. By verified, it is meant that the original PORECON database was created by Mound from information recorded on cards, as well as from a review of the original chemistry logbooks from which the cards were created. Data entry clerks entered the data using double-entry methods. Following this task, data entry was reviewed by health physicists. Samples with PROBLEM_FLG = “R” or BQ_DAY = blank were not included in the statistical analysis [1].

3.1.2 Plutonium Urinalysis Data

Urine bioassay data (SAMPLE_TYPE = U) and the analysis date (Date = SAMPLE_DATE) were extracted from the PURECON table of the *verified* PURECON_MERGED database. By verified, it is meant that the original PURECON database used for this analysis was created by Mound from logbooks and other original hard-copy records. Results with any of the following identifiers were excluded: PROBLEM_FLG = nonblank, DTPA = nonblank, LNAME = QC, or Result field (PICOC_PU238 or PICOC_PU239) = blank. There was a comment field associated with each result and, in most cases with a PROBLEM_FLG = nonblank, the comment indicated the reason for the flag. These included samples with low recovery, no tracer added, samples lost in process, insufficient volume for analysis, samples with no result, samples following diethylene triamine pentaacetic acid (DTPA) administration (chelation therapy), and samples that were analyzed for nuclides other than plutonium. Note that 1,413 of 58,893 results were marked with a problem flag. In the first quarter of 1983, 26 sample results were excluded because the comment field indicated that ^{239}Pu was added to the sample [2].

3.2 ANALYSIS

3.2.1 Polonium Bioassay Analysis

Data were analyzed by calendar quarter from July 1944 through the end of 1970 and by year from 1971 through part of 1973. Results of samples reported with dates in 1940 and 1941 were not used because the site was not yet operational. Spot samples were collected for analysis; 50- or 100-mL aliquots were analyzed, and the results were typically reported in units of counts per minute or disintegrations per minute. Values in the “BQ_DAY” field originally had been calculated and entered into the database assuming a counting efficiency of 50% and a chemical recovery of 85%. They were normalized to a 24-hr sample assuming an excretion rate of 1,400 mL/d. Before the statistical analysis was run, the results from 1944 through 1963 were multiplied by a factor of 8.5 according to the guidance in *Technical Basis Document for the Mound Site – Occupational Internal Dosimetry* (ORAUT 2004b), which specifies a recovery efficiency of 10% (instead of 85%) for this time frame. A factor of 1.35 was applied to results from 1964 through 1973, again according to ORAUT (2004b), which specifies a recovery efficiency of 63% (instead of 85%) for this time frame.

A lognormal distribution was assumed for the urinary excretion data, and the 50th- and 84th-percentile excretion rates were calculated using the method prescribed in ORAUT (2006). These excretion rates are given in Tables A-1 and A-2. Bioassay data collected over a specified period were analyzed to determine the 50th- and 84th-percentile excretion rates for that period. The effective bioassay dates are the midpoints of the periods, and they were used in IMBA to calculate the intake rates.

3.2.2 Plutonium Bioassay Analysis

Data were analyzed by year from 1956 through the end of 1961 and by calendar quarter from 1962 through 1990. The results from 1954 through 1960 were multiplied by a factor of 8.5, as specified in ORAUT (2004b). Analyses before June 1, 1981, which measured total plutonium alpha, were reported in the "PICOC_PU238" field, whereas later results, which were isotopic plutonium, were reported in the fields "PICOC_PU238" and "PICOC_PU239." The ^{238}Pu and $^{239/240}$Pu results for each sample analyzed after June 1, 1981, were summed to create a total plutonium result for these samples.

A lognormal distribution was assumed for the urinary excretion data, and the 50th- and 84th-percentile excretion rates were calculated using the method in ORAUT (2006). These excretion rates are given in Tables A-5 and A-6. Bioassay data collected over a specified period were analyzed to determine the 50th- and 84th-percentile excretion rates for that period. The effective bioassay dates are the midpoints of the periods and they are to be used in IMBA to calculate the intake rates.

4.0 INTAKE MODELING

This section discusses intake modeling assumptions, fitting, and materials (polonium and plutonium).

4.1 ASSUMPTIONS

4.1.1 Polonium Assumptions

Each urinary excretion rate used in the intake calculations was assumed to be normally distributed. A uniform absolute error of 1 was applied to all results, which thus assigned the same weight to each result [4]. IMBA requires results in units of activity per day; therefore, all urinalysis results were normalized, as needed, to 24-hr samples using 1,400 mL, which is the volume of urine excreted by Reference Man in a 24-hr period [3].

The excretion data were modeled with IMBA for multiple chronic intakes of type F or type M ^{210}Po. Examination of excretion results for polonium indicated that relatively chronic exposures appear to have been likely at the start of the polonium program. Therefore, a chronic exposure pattern was assumed throughout the program because it also approximates a series of acute intakes with unknown intake dates. Intakes were assumed to be via inhalation with a default breathing rate of 1.2 m^3/hr and a 5-µm activity median aerodynamic diameter (AMAD) particle size distribution [4].

4.1.2 Plutonium Assumptions

All urinary excretion rates were modeled as normally distributed 24-hr urine samples having a uniform absolute error of 1, which thus assigned the same weight to each urinary excretion rate. The excretion data were modeled with IMBA for multiple chronic intakes of type M or a single chronic intake of type S plutonium. While it is unlikely that workers at Mound were chronically exposed to plutonium, this approach approximates a series of acute intakes with unknown intake dates. Intakes were assumed to be via inhalation with a default breathing rate of 1.2 m^3/hr and a 5-µm AMAD particle size distribution [5].

4.2 BIOASSAY FITTING

4.2.1 Polonium Fitting

The excretion data were modeled with IMBA for multiple chronic intakes of type F or type M ^{210}Po. Polonium data from 1944 through 1973 were fit as a series of chronic intakes.

The intake assumptions were based on patterns that were observed in the bioassay data. Periods with constant chronic intake rates were chosen by selecting periods during 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 period from 1944 through 1973 was divided into multiple chronic intake periods [6].

4.2.2 Plutonium Fitting

The excretion data were modeled with IMBA for multiple chronic intakes of type M or a single chronic intake of type S plutonium. Plutonium data from 1956 through 1990 were fit as a series of chronic intakes.

The intake assumptions were based on patterns that were observed in the bioassay data. Periods with constant chronic intake rates were chosen by selecting periods during 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 period from 1956 through 1990 was divided into multiple chronic intake periods for type M plutonium. For type S plutonium, however, a single intake period from 1956 to 1990 was used [7].

4.3 MATERIAL TYPES

ORAUT (2004b) discusses Mound internal dosimetry data including guidance for the appropriate use of that information. According to that document, workers at Mound had the potential to receive intakes of polonium and plutonium.

4.3.1 Polonium

Excretion data for the 50th- and 84th-percentile values of ^{210}Po for 1944 through 1957 are shown in Table A-1. Excretion data for the 50th- and 84th-percentile values of ^{210}Po for 1958 through 1973 are shown in Table A-2. Note that in Table A-2 the third quarter of 1970 was omitted because of poor statistics [8]. The solid lines in Figures B-1 and B-2 show the individual fits to the 50th- and 84th-percentile excretion rates, respectively, for type M ^{210}Po material. The solid lines in Figures B-3 and B-4 show the individual fits to the 50th- and 84th-percentile excretion rates, respectively, for type F ^{210}Po material [9].

4.3.2 Plutonium

Because plutonium of either type S or M has a very long half-life and the material is retained in the body for long periods, excretion results are not independent. For example, an intake in the early 1950s could contribute to urinary excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked for relatively short periods, each type M intake period was fit independently using only the bioassay results from that intake period. 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. For type S plutonium, only one intake period, based on the latest and lowest excretion point, was used to create an underestimate for employment during any period [10].

Plutonium urinalysis results were analyzed with IMBA using type M and S materials to derive intake rates for 1956 to 1990. Type M intakes should be applied to all systemic organs. Type S must be considered for nonsystemic [i.e., lung and gastrointestinal (GI) tract] cancers [11].

Plutonium type M: The solid lines in Figures B-5 to B-10 show the individual fits to the 50th-percentile excretion rates for type M materials. The solid lines in Figures B-11 to B-17 show the individual fits to the 84th-percentile excretion rates for type M materials. The same intake periods were not applied for both percentiles because the values followed different patterns [12].

Plutonium type S: Because type S plutonium clears more slowly from the lungs than types M and F, the plutonium exposure was fit as a single chronic intake from 1956 through 1990. This period was used because the measurements were relatively consistent; in addition, as the most recent measurements, they had the lowest minimum detectable activity and, therefore, were presumably the most accurate. The solid lines in Figures B-18 and B-19 show the individual fits to the 50th- and 84th-percentile excretion rates, respectively, for type S materials [13].

The type S intake rate can be used only as an underestimate. If an overestimate or best estimate is needed for type S material, an individualized fit to the bioassay data for the specific work period of the energy employee being evaluated must be performed. Tables A-5 and A-6 provide the bioassay data for performing the individualized fit [14].

5.0 ASSIGNING INTAKES AND DOSES

This section describes the derived intake rates and provides guidance for assigning doses.

5.1 INTAKE RATE SUMMARY

5.1.1 Polonium

Five intake periods were fit to the derived 50th- and 84th-percentile polonium excretion data. Because many of the geometric standard deviations (GSDs) were relatively similar, they were combined and the largest value within a given time frame was assigned for simplicity [15].

The intake rates, GSDs, and periods in which they are applicable are given in Table A-3 for type M ^{210}Po and Table A-4 for type F ^{210}Po. In most cases, doses for individuals potentially exposed routinely are calculated from the 50th-percentile intake rates by assuming the solubility type that results in the largest probability of causation (POC)[1]. Table 5-1 summarizes the derived polonium intake rates that produced the data-fitting results in Attachment B. Note that the results in Table 5-1 are in becquerels per day, because the original data were recorded as such [16]. If pCi/day are preferred, multiply the Bq/d values by 27.

1. [1] The U.S. Department of Labor is responsible under EEOICPA for determining the POC.

Table 5-1. Derived polonium intakes, 1944 to 1973.

	Type F material		Type M material	
Period	50th percentile (Bq/d)	GSD	50th percentile (Bq/d)	GSD
07/1944–03/1946	1,189.5	3.89	4,097.6	3.9
04/1946–03/1949	254.96	5.56	800.19	5.8
04/1949–03/1960	12.192	7.99	39.851	8.0
04/1960–03/1965	2.0696	6.70	5.7883	6.2
04/1965–12/1973	0.10303	8.88	0.34853	8.8

5.1.2 Plutonium

Seven intake periods were fit to the derived 50th- and 84th-percentile plutonium excretion data for type M material. One intake period was fit to the derived 50th- and 84th-percentile plutonium excretion data for type S material. If the GSD was less than 3, the value was set to 3 to account for biological variation when determining dose. Because of the interdependence among the bioassay results, it is not possible to fit type S plutonium to the data in a manner that would be representative of all individuals for all periods. Therefore, only a minimizing intake has been calculated for type S plutonium. Type M plutonium should be applied for all systemic organs. Type S plutonium should be applied for all nonsystemic (respiratory and GI tract) organs [17].

The intake rates, GSDs, and applicable periods are given in Table A-7 for type M plutonium and Table A-8 for type S plutonium. In most cases, doses for individuals potentially exposed routinely are calculated from the 50th-percentile intake rates by assuming the solubility type that results in the largest POC[2]. Table 5-2 summarizes the derived plutonium intake rates that produced the data-fitting results in Attachment B. Note that the results in Table 5-2 are in picocuries per day, because the original data were recorded as such [18]. If Bq/day are preferred, divide the pCi/d values by 27.

Table 5-2. Derived plutonium intake rates, 1956 to 1990.

Period	50th percentile (pCi/d)	GSD
Type M material		
1956–1957	750.98	3.00[a]
1958–1960	436.49	3.00[a]
1961–1967	12.141	5.42
1968–1969	12.141	11.69
1970–1977	2.2361	9.14
1978–1984	2.2361	5.82
1985–1990	0.59706	8.16
Type S material (underestimate)		
1956–1990	0.54041	3.89

a. Actual GSD <3. Adjusted to 3 for dose calculations.

For *nonsystemic* (respiratory and GI tract) organs, dose reconstructors should follow these steps:

1. Run the type M intakes. If this action does not result in a POC >50%, then

2. Run the minimizing type S intake. If this action still does not yield a POC >50%, then

2. [2] The U.S. Department of Labor is responsible under EEOICPA for determining the POC.

3. Manually fit the coworker bioassay data for the time frame of interest for the employee, using the assumption of type S material.

Standard fitting techniques should be used to fit the plutonium urinalysis from the employee's work period in Tables A-5 and A-6. Acute or chronic intakes can be assigned depending on the patterns in the data. The 50th-percentile intakes are used to assign the intake, and the 84th-percentile intakes are used to determine the GSD for each intake (GSD = 84th percentile/50th percentile). For input into the Interactive RadioEpidemiological Program (IREP), the dose from each intake must be determined separately [19].

5.2 DOSE ASSIGNMENT

For most cases, individual doses are calculated from the 50th-percentile intake rates. Dose reconstructors should select the material type that is the most favorable to claimants.

The lognormal distribution is selected in IREP, with the calculated dose entered as Parameter 1 and the associated GSD as Parameter 2. The GSD is associated with the intake, so it is applied to all annual doses determined from the intake period.

To calculate doses from plutonium, the intakes of "total Pu" should be classified as either weapons-grade plutonium (WGPU) or heat-source plutonium (HSPU) using the established protocol for Mound. HSPU is assumed to be 100% ^{238}Pu by activity, but determining the isotopic mix of WGPU is more complex. Table 5-3 lists three WGPU mixes aged 1, 3.2, and 10 years. These values are taken from the technical basis document (ORAUT 2004b). If the age of the isotopic mix is not known, the 10-yr aged material should be selected to be favorable to claimants regarding the in-growth of ^{241}Am from ^{241}Pu. [20]

Table 5-3. Dose calculations for WGPU intakes.

Material age (yr)	Percentage of alpha activity			Beta activity (times $A_{Pu\text{-}239/240}$)
	Pu-239/240	**Pu-238**	**Am-241**	**Pu-241**
1	92.9	6.6	0.55	4.8
3.2	91.6	6.4	2.0	4.3
10	88.4	6.0	5.6	3.1

6.0 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in worker dose reconstruction. These callouts are listed here in this 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 Site Research Database.

Thomas LaBone serves as a Site Expert for this document. As such, he is responsible for advising on site-specific issues and incidents as necessary and ensures the completeness and accuracy of the document. Because of his prior work experience for the site, he possesses, or is aware of information that is relevant for reconstructing radiation doses experienced by claimants who worked at the site. In all cases where such information or prior studies or writings are included or relied upon by the document owner, those materials are fully attributed. Mr. LaBone's Disclosure Statement is available at www.oraucoc.org.

[1] Lochamy, Joseph C. ORAU Team. Senior Health Physicist. February 2007.
PORECON records with “R” (Rejected) entries in the PROBLEM_FLG field were not used because they had been flagged as unreliable for some reason. Null entries in the results (BQ_DAY) field obviously can not be used, since there are no data to use.

[2] Lochamy, Joseph C. ORAU Team. Senior Health Physicist. February 2007.
PURECON records with nonblank fields for PROBLEM_FLG or DTPA, LNAME=QC, or a blank result field were not used because they were unreliable (e.g., nonblank PROBLEM_FLG), not representative of normal exposures (e.g., nonblank DPTA entry), a quality control sample (e.g., LNAME=QC) or contained no results.

[3] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
The uniform absolute error of 1 weights all results equally; other fitting schemes weight high values or low values disproportionally. Because the median and 84th percentile values were determined from statistical analysis of many samples in each interval, there was no *a priori* reason to weight results from any one interval over another. Additionally, the polonium results were recorded as activity/ml and the statistical analyses were performed in those units. However, the IMBA software requires that all excreta data be entered as total excretion per day; hence, the statistical parameters were converted to excretion per day before intake calculations were made using IMBA.

[4] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. The breathing rate and particle size distribution are project default values to be used unless site-specific information indicates otherwise. No information has been found concerning intakes at Mound that shows that the default values should not be used. See, for instance, OCAS-IG-002, “Internal Dose Reconstruction Implementation Guide,” and ICRP Publication 66, “Human Respiratory Tract Model for Radiological Protection.”

[5] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. The breathing rate and particle size distribution are project default values to be used unless site-specific information indicates otherwise. No information has been found concerning intakes at Mound that shows that the default values should not be used. See, for instance, OCAS-IG-002, “Internal Dose Reconstruction Implementation Guide,” and ICRP Publication 66, “Human Respiratory Tract Model for Radiological Protection.”

[6] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist.

[7] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist.

[8] Mahathy, Michael and Lochamy, Joseph C. ORAU Team. Coworker Statistics Analyst and Senior Health Physicist. February 2007. The table was compiled by Lochamy from data generated by Mahathy.

[9] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Figures were generated by LaBone from IMBA results.

[10] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist.

[11] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Determinations were made according to ORAUT (2005). The choice of types and applications were peer reviewed by the Principal Internal Dosimetrist.

[12] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Figures were generated by LaBone from IMBA results.

[13] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. Figures were generated by LaBone from IMBA results.

[14] LaBone, Thomas R and Lochamy, Joseph C.. ORAU Team. Deputy Principal Internal Dosimetrist and Senior Health Physicist. February 2007. Determinations were made by Labone according to ORAUT (2005). The tables were compiled by Lochamy from data generated by Lochamy.

[15] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist.

[16] LaBone, Thomas R., Mahathy, Michael, and Lochamy, Joseph C. ORAU Team. Deputy Principal Internal Dosimetrist, Coworker Statistics Analyst, and Senior Health Physicist. February 2007. Determinations were made by LaBone according to ORAUT (2005). The table was compiled by Lochamy from data generated by Mahathy.

[17] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007. Determinations were made according to ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. The minimum GSD of 3 is established in ORAUT-OTIB-0060, “Internal Dose Reconstruction.” It reflects the overall uncertainty associated with biokinetic modeling as well as usual radiochemical analysis, and indicates that even though the spread in coworker excreta results for a given population (e.g., a year of excreta samples) can have a GSD of <3, the uncertainty of intakes determined using the biokinetic models is no less than 3.

[18] LaBone, Thomas R. and Lochamy, Joseph C.. ORAU Team. Deputy Principal Internal Dosimetrist and Senior Health Physicist. February 2007. Determinations were made by LaBone according to ORAUT (2005). The tables were compiled by Lochamy from data generated by Lochamy.

[19] LaBone, Thomas R and Lochamy, Joseph C.. ORAU Team. Deputy Principal Internal Dosimetrist and Senior Health Physicist. February 2007. Determinations were made by LaBone according to ORAUT (2005). The tables were compiled by Lochamy from data generated by Lochamy.

[20] LaBone, Thomas R. and Lochamy, Joseph C. ORAU Team. Deputy Principal Internal Dosimetrist and Senior Health Physicist. February 2007. Determinations were made by LaBone according to ORAUT (2005) and ORAUT (2004b). The table was compiled by Lochamy from ORAUT (2004b).

REFERENCES

ORAUT (Oak Ridge Associated Universities Team), 2004a, *Coworker Data Exposure Profile Development*, ORAUT-PLAN-0014, Rev. 00, Oak Ridge, Tennessee, November 24.

ORAUT (Oak Ridge Associated Universities Team), 2004b, *Technical Basis Document for the Mound Site – Occupational Internal Dosimetry*, ORAUT-TKBS-0016-5, Rev. 00, Oak Ridge, Tennessee, September 9.

ORAUT (Oak Ridge Associated Universities Team), 2005, *Analysis of Coworker Bioassay Data for Internal Dose Assignment*, ORAUT-OTIB-0019, Rev. 01, Oak Ridge, Tennessee, October 7.

ORAUT (Oak Ridge Associated Universities Team), 2006, *Generating Summary Statistics for Coworker Bioassay Data*, ORAUT-PROC-0095, Rev. 00, Oak Ridge, Tennessee, June 5.

ATTACHMENT A
COWORKER DATA TABLES
Page 1 of 4

Table A-1. 50th- and 84th-percentile urinary excretion rates of ^{210}Po, 1944 to 1957 (Bq/d).

Effective date	50th percentile	84th percentile
08/15/1944	8.33E+01	5.07E+02
11/15/1944	8.89E+01	3.56E+02
02/15/1945	1.01E+02	2.97E+02
05/15/1945	1.39E+02	5.13E+02
08/15/1945	5.17E+01	2.03E+02
11/15/1945	5.45E+01	2.27E+02
02/15/1946	4.56E+01	1.99E+02
05/15/1946	8.63E+01	2.92E+02
08/15/1946	2.10E+01	1.04E+02
11/15/1946	1.88E+01	9.53E+01
02/15/1947	9.26E+00	6.78E+01
05/15/1947	1.01E+01	6.84E+01
08/15/1947	1.32E+01	8.68E+01
11/15/1947	2.16E+01	1.10E+02
02/15/1948	3.18E+01	1.71E+02
05/15/1948	2.62E+01	1.36E+02
08/15/1948	1.52E+01	8.99E+01
11/15/1948	1.90E+01	1.23E+02
02/15/1949	7.12E+00	7.36E+01
05/15/1949	2.88E+00	2.27E+01
08/15/1949	2.77E+00	2.02E+01
11/15/1949	2.29E+00	2.00E+01
02/15/1950	1.43E+00	1.39E+01
05/15/1950	7.55E-01	8.97E+00
08/15/1950	7.96E-01	7.03E+00
11/15/1950	6.05E-01	8.06E+00
02/15/1951	1.02E+00	7.32E+00
05/15/1951	1.30E+00	9.08E+00
08/15/1951	1.41E+00	8.73E+00
11/15/1951	1.10E+00	7.89E+00
02/15/1952	1.25E+00	6.68E+00
05/15/1952	9.10E-01	5.33E+00
08/15/1952	7.03E-01	4.84E+00
11/15/1952	1.18E+00	7.19E+00
02/15/1953	1.05E+00	7.53E+00
05/15/1953	9.60E-01	5.68E+00
08/15/1953	1.03E+00	4.51E+00
11/15/1953	4.56E-01	4.09E+00
02/15/1954	7.22E-01	6.44E+00
05/15/1954	1.47E+00	6.37E+00
08/15/1954	3.24E+00	9.88E+00
11/15/1954	1.41E+00	8.96E+00
02/15/1955	1.62E+00	5.72E+00
05/15/1955	5.26E-01	2.62E+00
08/15/1955	5.54E-01	3.90E+00
11/15/1955	9.41E-01	1.26E+01
02/15/1956	4.31E-01	7.80E+00
05/15/1956	8.55E-01	5.51E+00
08/15/1956	1.78E-01	2.44E+00
11/15/1956	6.41E-02	3.01E+00
02/15/1957	2.98E-01	6.07E+00
05/15/1957	4.53E-02	2.09E+00
08/15/1957	4.34E-01	3.23E+00
11/15/1957	6.68E-01	6.92E+00

ATTACHMENT A
COWORKER DATA TABLES
Page 2 of 4

Table A-2. 50th- and 84th-percentile urinary excretion rates of ^{210}Po, 1958 to 1973 (Bq/d).

Effective date	50th percentile	84th percentile	Effective date	50th percentile	84th percentile
02/15/1958	9.75E-01	6.67E+00	11/15/1964	4.35E-02	2.00E-01
05/15/1958	1.00E+00	1.20E+01	02/15/1965	3.60E-02	1.33E-01
08/15/1958	6.22E-01	9.34E+00	05/15/1965	1.90E-02	6.91E-02
11/15/1958	6.82E-01	8.50E+00	08/15/1965	3.27E-02	1.07E-01
02/15/1959	1.37E+00	1.28E+01	11/15/1965	1.34E-02	7.85E-02
05/15/1959	1.32E+00	7.19E+00	02/15/1966	8.63E-03	4.57E-02
08/15/1959	9.35E-01	7.44E+00	05/15/1966	1.12E-02	5.53E-02
11/15/1959	1.32E+00	1.08E+01	08/15/1966	1.53E-02	9.59E-02
02/15/1960	6.88E-01	6.49E+00	11/15/1966	1.77E-02	8.22E-02
05/15/1960	4.01E-01	4.16E+00	02/15/1967	2.11E-02	7.49E-02
08/15/1960	5.34E-01	4.58E+00	05/15/1967	9.13E-03	4.15E-02
11/15/1960	5.92E-01	4.91E+00	08/15/1967	2.00E-03	2.33E-02
02/15/1961	6.98E-01	6.04E+00	11/15/1967	7.77E-04	2.24E-02
05/15/1961	5.02E-01	3.75E+00	02/15/1968	4.09E-03	5.91E-02
08/15/1961	4.12E-01	2.57E+00	05/15/1968	1.30E-02	9.17E-02
11/15/1961	2.89E-01	2.33E+00	08/15/1968	2.19E-03	1.24E-01
02/15/1962	2.51E-01	1.42E+00	11/15/1968	7.16E-03	9.72E-02
05/15/1962	3.46E-01	1.98E+00	02/15/1969	1.87E-03	2.55E-02
08/15/1962	4.88E-01	2.63E+00	05/15/1969	5.10E-03	2.35E-02
11/15/1962	1.85E-01	1.80E+00	08/15/1969	1.14E-03	1.15E-02
02/15/1963	2.09E-01	1.57E+00	11/15/1969	3.99E-05	1.58E-03
05/15/1963	9.66E-02	7.90E-01	02/15/1970	1.45E-03	9.66E-03
08/15/1963	9.01E-02	5.51E-01	05/15/1970	1.37E-02	4.73E-02
11/15/1963	3.38E-01	1.66E+00	11/15/1970	2.20E-02	6.67E-02
02/15/1964	4.71E-02	2.68E-01	07/01/1971	5.96E-04	1.52E-02
05/15/1964	1.86E-02	1.56E-01	07/01/1972	1.06E-02	2.40E-01
08/15/1964	4.43E-02	2.03E-01	07/01/1973	4.38E-03	4.61E-01

Table A-3. Type M ^{210}Po intake rates (Bq/d) and dates.

Start date	End date	50th percentile	84th percentile	GSD
07/01/1944	03/31/1946	4097.6	15796	3.9
04/01/1946	03/31/1949	800.19	4602.3	5.8
04/01/1949	03/31/1960	39.851	320.28	8.0
04/01/1960	03/31/1965	5.7883	36.121	6.2
04/01/1965	12/31/1973	0.34853	3.0638	8.8

Table A-4. Type F ^{210}Po intake rates (Bq/d) and dates.

Start date	End date	50th percentile	84th percentile	GSD
07/01/1944	03/31/1946	1189.5	4628	3.89
04/01/1946	03/31/1949	254.96	1416.8	5.56
04/01/1949	03/31/1960	12.192	97.456	7.99
04/01/1960	03/31/1965	2.0696	13.856	6.70
04/01/1965	12/31/1973	0.10303	0.91451	8.88

ATTACHMENT A
COWORKER DATA TABLES
Page 3 of 4

Table A-5. 50th- and 84th-percentile urinary excretion rates of total plutonium, 1956 to 1975 (pCi/d).

Effective date	50th percentile	84th percentile	Effective date	50th percentile	84th percentile
07/01/1956	1.88E+00	4.49E+00	02/15/1968	5.01E-02	2.17E-01
07/01/1957	2.26E+00	4.03E+00	05/15/1968	7.91E-02	2.70E-01
07/01/1958	1.14E+00	2.00E+00	08/15/1968	6.23E-02	2.26E-01
07/01/1959	1.53E+00	2.73E+00	11/15/1968	4.47E-02	2.67E-01
07/01/1960	1.72E+00	9.81E+00	02/15/1969	5.42E-02	4.69E-01
07/01/1961	8.01E-02	6.50E-01	05/15/1969	5.14E-02	3.87E-01
02/15/1962	3.49E-02	2.25E-01	08/15/1969	8.76E-02	8.74E-01
05/15/1962	7.15E-02	4.42E-01	11/15/1969	4.45E-02	2.63E-01
08/15/1962	1.01E-01	3.63E-01	02/15/1970	2.42E-02	1.47E-01
11/15/1962	1.06E-01	4.27E-01	05/15/1970	3.27E-02	1.75E-01
02/15/1963	5.31E-02	2.88E-01	08/15/1970	2.93E-02	1.31E-01
05/15/1963	7.53E-02	5.73E-01	11/15/1970	1.98E-02	9.93E-02
08/15/1963	5.19E-02	3.41E-01	02/15/1971	2.90E-02	1.64E-01
11/15/1963	7.01E-02	3.65E-01	05/15/1971	2.03E-02	1.16E-01
02/15/1964	8.98E-02	3.53E-01	08/15/1971	2.21E-02	1.15E-01
05/15/1964	1.19E-01	3.64E-01	11/15/1971	2.77E-02	1.46E-01
08/15/1964	1.18E-01	3.62E-01	02/15/1972	2.83E-02	1.62E-01
11/15/1964	1.59E-01	6.00E-01	05/15/1972	2.01E-02	1.15E-01
02/15/1965	1.03E-01	5.95E-01	08/15/1972	2.05E-02	1.21E-01
05/15/1965	1.07E-01	5.11E-01	11/15/1972	2.21E-02	1.27E-01
08/15/1965	1.07E-01	5.58E-01	02/15/1973	3.80E-02	1.80E-01
11/15/1965	5.56E-02	2.62E-01	05/15/1973	3.32E-02	1.40E-01
02/15/1966	9.62E-02	3.70E-01	08/15/1973	2.29E-02	1.08E-01
05/15/1966	7.11E-02	2.94E-01	11/15/1973	1.21E-02	8.04E-02
08/15/1966	7.09E-02	2.29E-01	02/15/1974	3.65E-02	1.41E-01
11/15/1966	8.56E-02	2.87E-01	05/15/1974	4.34E-02	1.91E-01
02/15/1967	7.68E-02	2.87E-01	08/15/1974	3.70E-02	1.83E-01
05/15/1967	8.63E-02	3.37E-01	11/15/1974	4.74E-02	2.06E-01
08/15/1967	7.38E-02	2.91E-01	02/15/1975	1.10E-02	7.75E-02
11/15/1967	4.86E-02	2.27E-01	05/15/1975	1.13E-02	9.84E-02

ATTACHMENT A
COWORKER DATA TABLES

Table A-6. 50th- and 84th-percentile urinary excretion rates of total plutonium, 1975 to 1990 (pCi/d).

Effective date	50th percentile	84th percentile
08/15/1975	3.49E-02	1.69E-01
11/15/1975	1.71E-02	8.51E-02
02/15/1976	3.49E-02	1.66E-01
05/15/1976	1.19E-02	7.15E-02
08/15/1976	1.46E-02	6.91E-02
11/15/1976	1.80E-02	8.28E-02
02/15/1977	2.13E-02	9.59E-02
05/15/1977	2.13E-02	9.50E-02
08/15/1977	1.15E-02	7.02E-02
11/15/1977	1.56E-02	8.01E-02
02/15/1978	7.79E-03	4.92E-02
05/15/1978	4.68E-03	4.20E-02
08/15/1978	4.44E-03	2.99E-02
11/15/1978	8.12E-03	6.62E-02
02/15/1979	2.78E-03	2.96E-02
05/15/1979	6.74E-03	5.00E-02
08/15/1979	1.80E-02	7.82E-02
11/15/1979	7.70E-03	6.01E-02
02/15/1980	6.84E-03	4.16E-02
05/15/1980	1.77E-02	9.15E-02
08/15/1980	1.80E-02	7.22E-02
11/15/1980	2.41E-02	1.33E-01
02/15/1981	2.22E-02	1.06E-01
05/15/1981	2.63E-02	8.57E-02
08/15/1981	2.02E-02	9.85E-02
11/15/1981	2.17E-02	1.17E-01
02/15/1982	1.89E-02	9.22E-02
05/15/1982	9.69E-03	5.85E-02
08/15/1982	1.23E-02	7.39E-02
11/15/1982	2.97E-02	9.91E-02
02/15/1983	1.24E-02	6.12E-02
05/15/1983	1.24E-02	7.51E-02
08/15/1983	1.08E-02	6.97E-02
11/15/1983	7.71E-03	5.37E-02
02/15/1984	9.94E-03	5.88E-02
05/15/1984	1.22E-02	6.80E-02
08/15/1984	7.50E-03	4.01E-02
11/15/1984	8.39E-03	4.20E-02
02/15/1985	2.49E-03	2.29E-02
05/15/1985	3.05E-03	2.84E-02
08/15/1985	1.12E-03	1.44E-02
11/15/1985	1.28E-03	1.51E-02
02/15/1986	2.25E-03	2.05E-02
05/15/1986	3.86E-03	3.76E-02
08/15/1986	3.09E-03	2.71E-02
11/15/1986	4.11E-03	3.44E-02
02/15/1987	6.20E-03	3.27E-02
05/15/1987	6.85E-03	4.20E-02
08/15/1987	4.05E-03	2.85E-02
11/15/1987	4.61E-03	3.01E-02
02/15/1988	5.23E-03	3.55E-02
05/15/1988	5.50E-03	3.60E-02
08/15/1988	3.47E-03	2.52E-02
11/15/1988	2.65E-03	3.32E-02
02/15/1989	3.17E-03	3.06E-02
05/15/1989	3.90E-03	3.11E-02
08/15/1989	1.88E-03	1.83E-02
11/15/1989	1.23E-03	1.66E-02
02/15/1990	1.16E-03	1.52E-02
05/15/1990	1.27E-03	1.40E-02
08/15/1990	6.78E-04	1.07E-02
11/15/1990	1.83E-03	1.18E-02

Table A-7. Type M plutonium intake rates (pCi/d) and dates.

Start date	End date	50th percentile	84th percentile	GSD
01/01/1956	12/31/1957	750.98	1,073.4	1.43[a]
01/01/1958	12/31/1960	436.49	1,073.4	2.46[a]
01/01/1961	12/31/1967	12.141	65.823	5.42
01/01/1968	12/31/1969	12.141	141.98	11.69
01/01/1970	12/31/1977	2.2361	20.445	9.14
01/01/1978	12/31/1984	2.2361	13.013	5.82
01/01/1985	12/31/1990	0.59706	4.872	8.16

a. Actual. Adjust all GSD <3 to 3 for dose calculations.

Table A-8. Type S plutonium intake (pCi/d) rates and dates.

Start date	End date	50th percentile	84th percentile	GSD
01/01/1956	12/31/1990	0.54041	8.4956	3.89

ATTACHMENT B
COWORKER DATA FIGURES

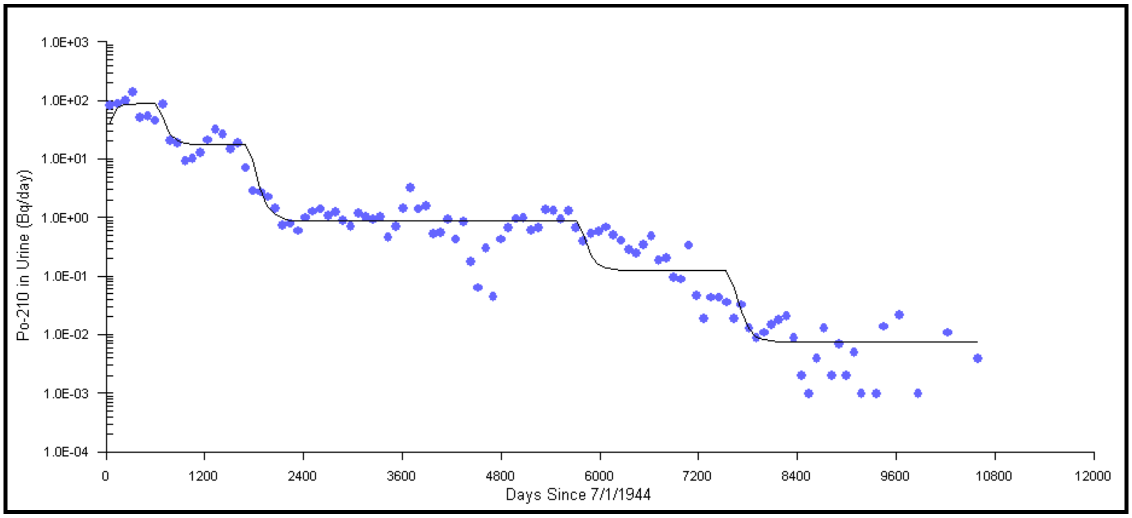

Figure B-1. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M ^{210}Po.

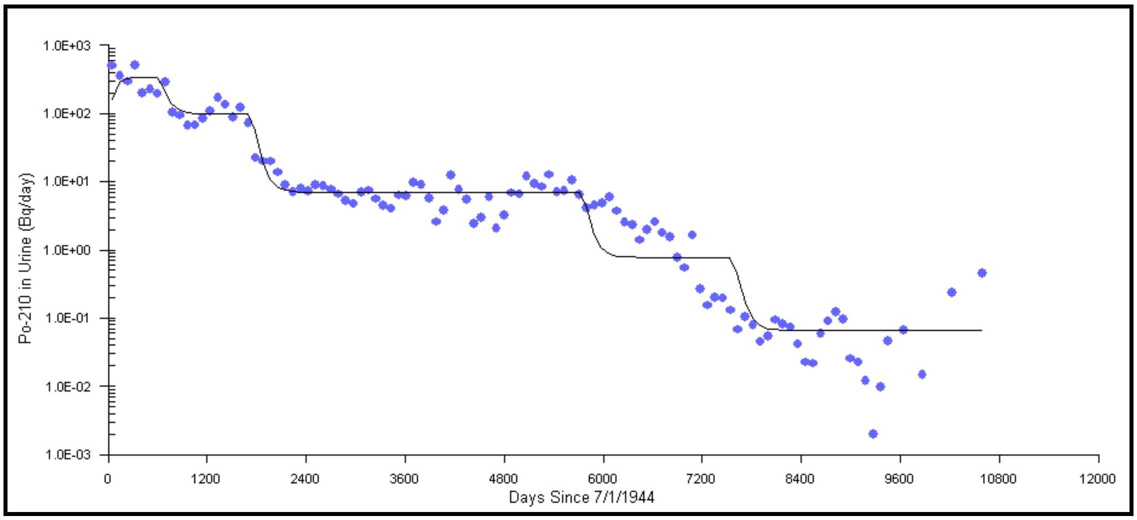

Figure B-2. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M ^{210}Po.

ATTACHMENT B
COWORKER DATA FIGURES
Page 2 of 10

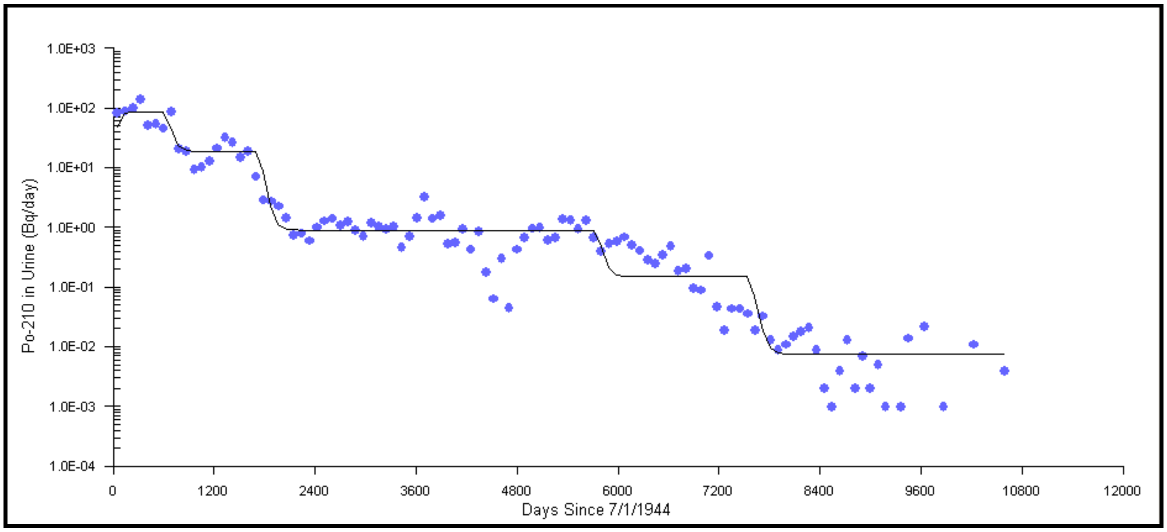

Figure B-3. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type F ^{210}Po.

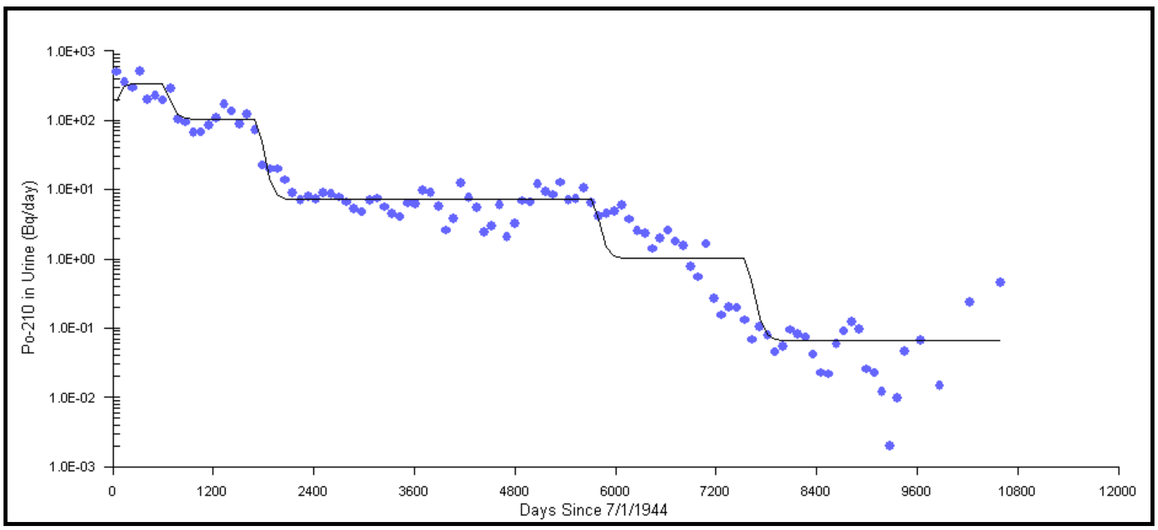

Figure B-4. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type F ^{210}Po.

ATTACHMENT B
COWORKER DATA FIGURES
Page 3 of 10

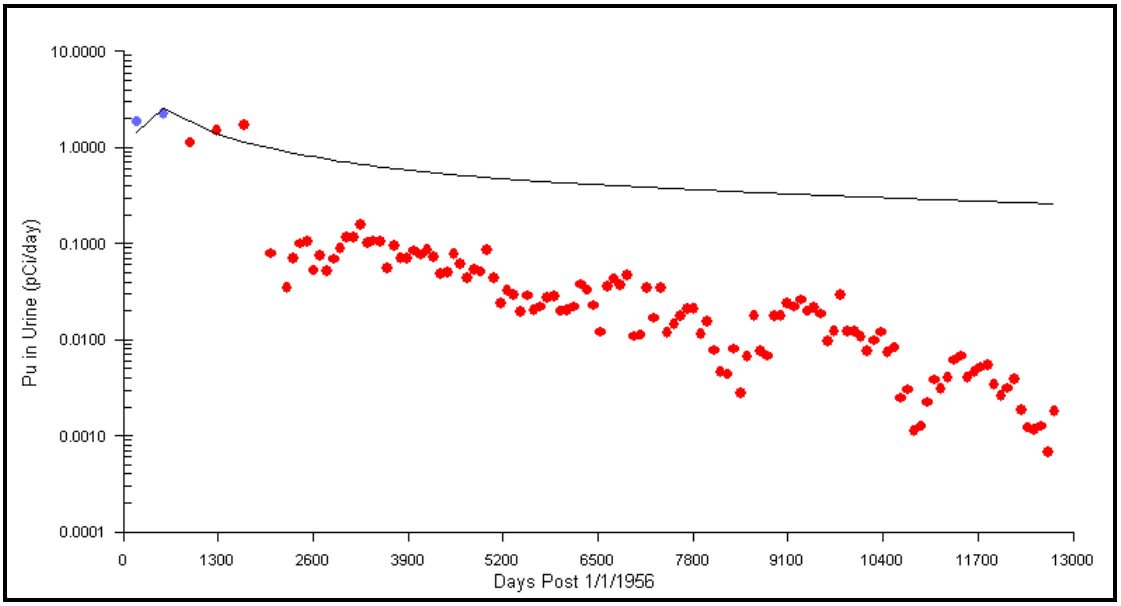

Figure B-5. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 1957.

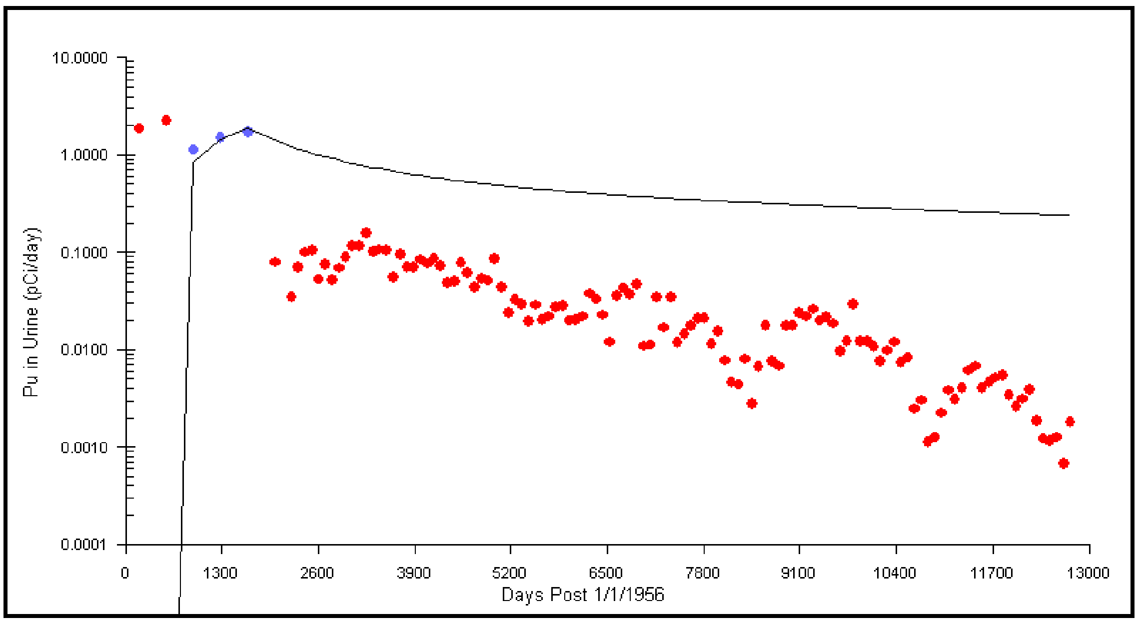

Figure B-6. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1958 to 1960.

ATTACHMENT B
COWORKER DATA FIGURES
Page 4 of 10

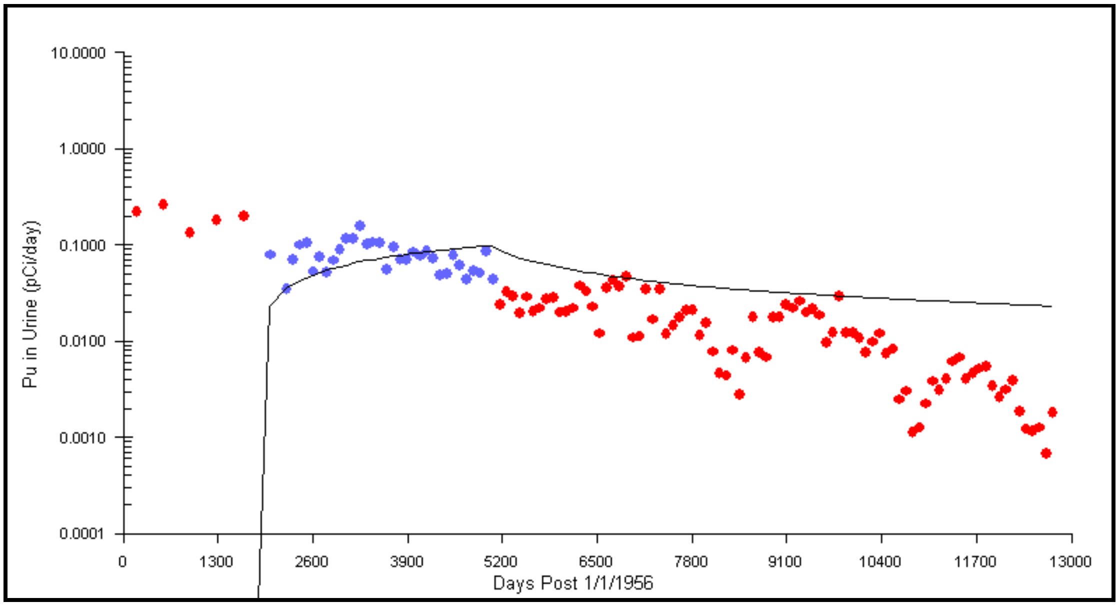

Figure B-7. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1961 to 1969.

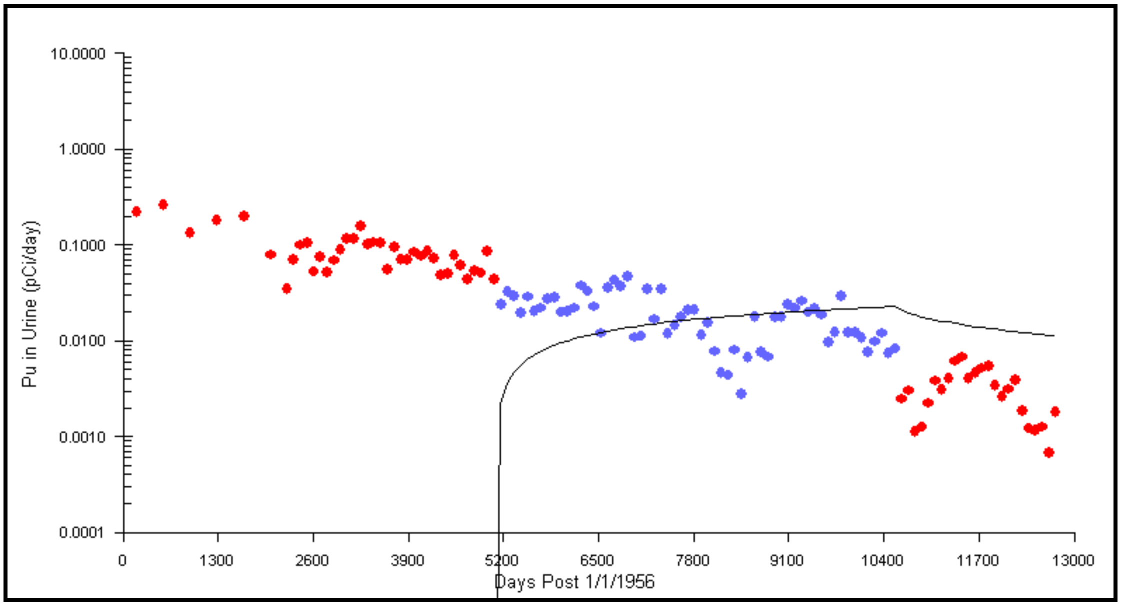

Figure B-8. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1970 to 1984.

ATTACHMENT B
COWORKER DATA FIGURES
Page 5 of 10

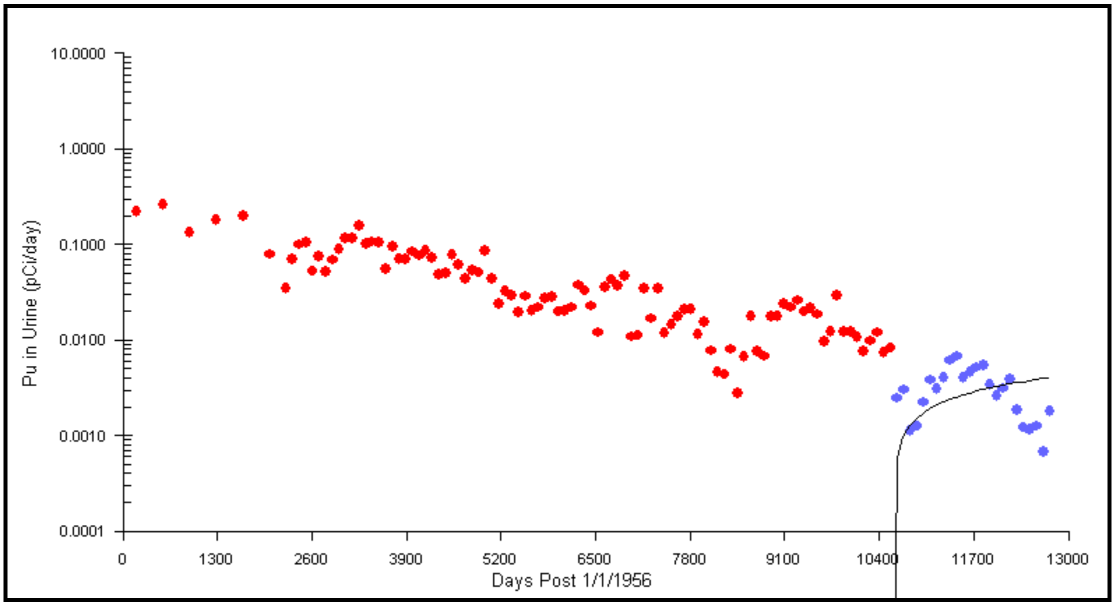

Figure B-9. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1985 to 1990.

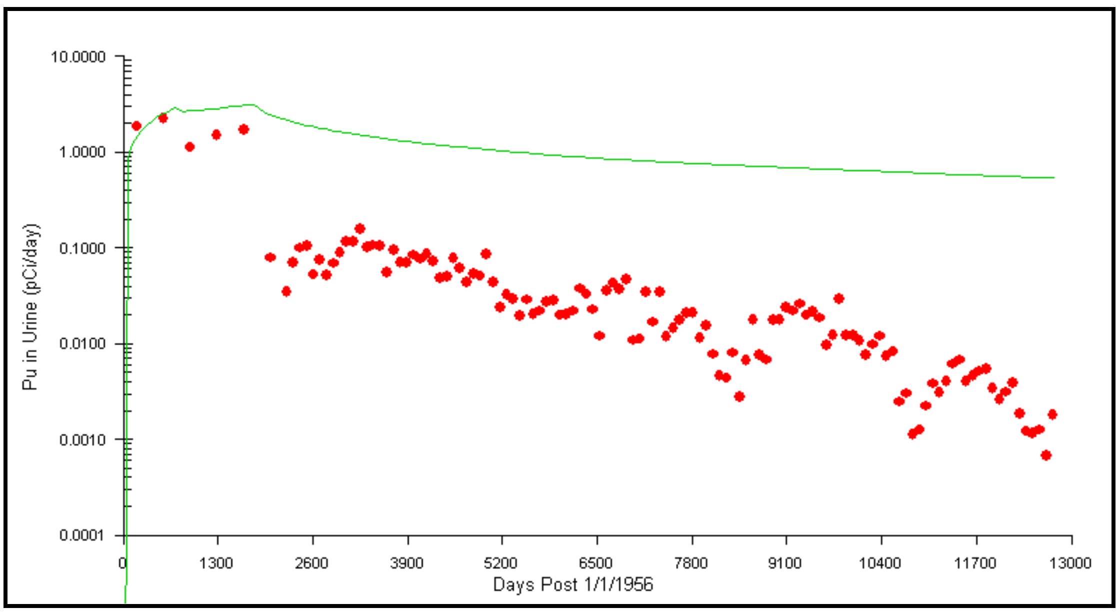

Figure B-10. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 1990.

ATTACHMENT B
COWORKER DATA FIGURES

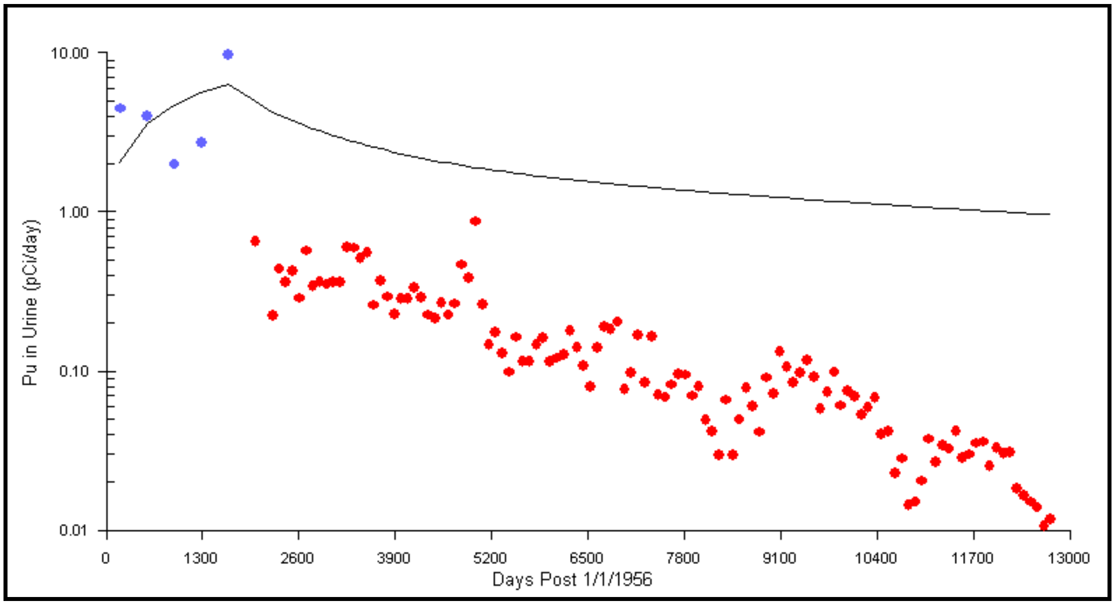

Figure B-11. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 1960.

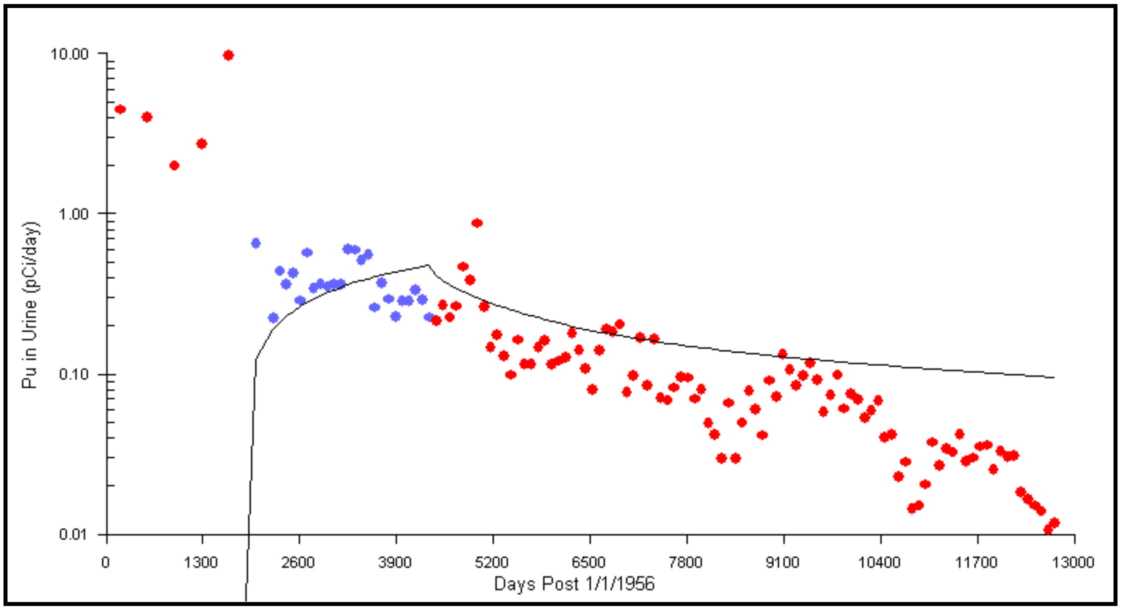

Figure B-12. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1961 to 1967.

ATTACHMENT B
COWORKER DATA FIGURES
Page 7 of 10

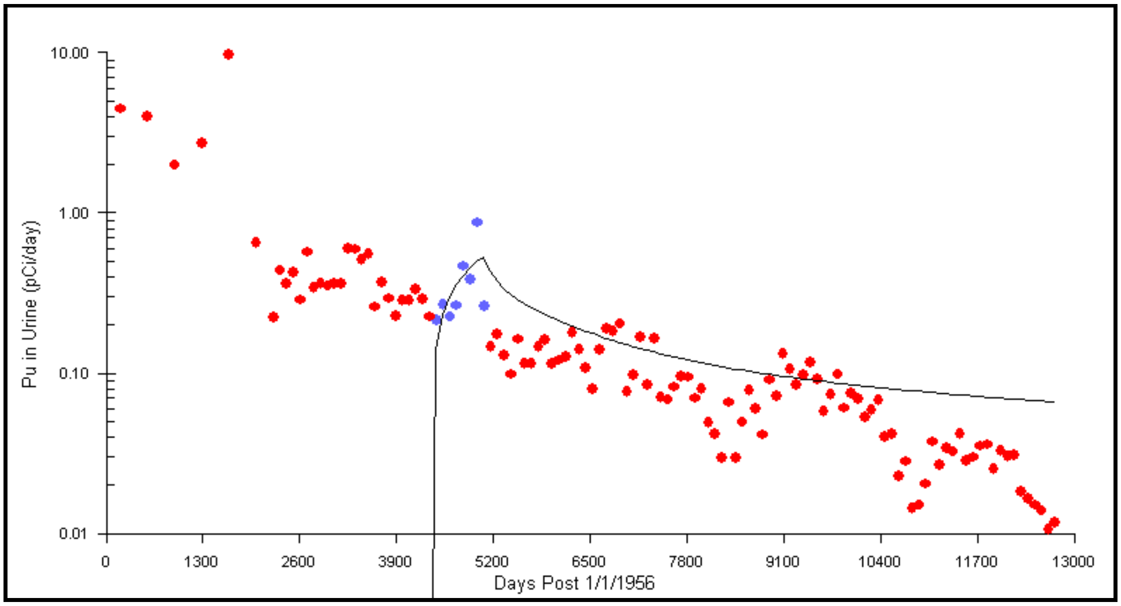

Figure B-13. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1968 to 1969.

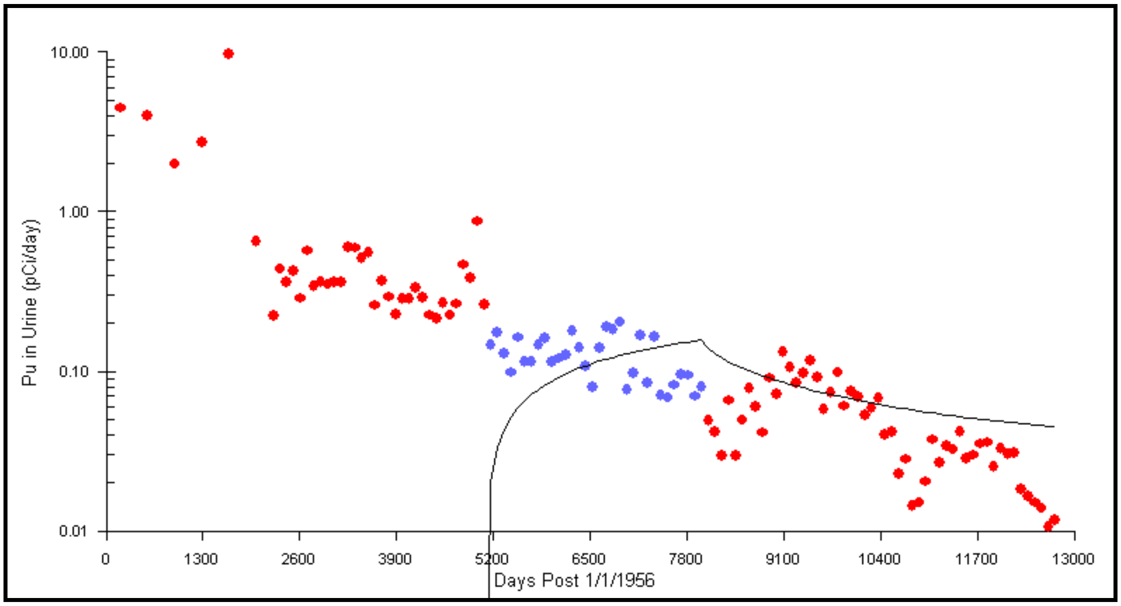

Figure B-14. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1970 to 1977.

ATTACHMENT B
COWORKER DATA FIGURES
Page 8 of 10

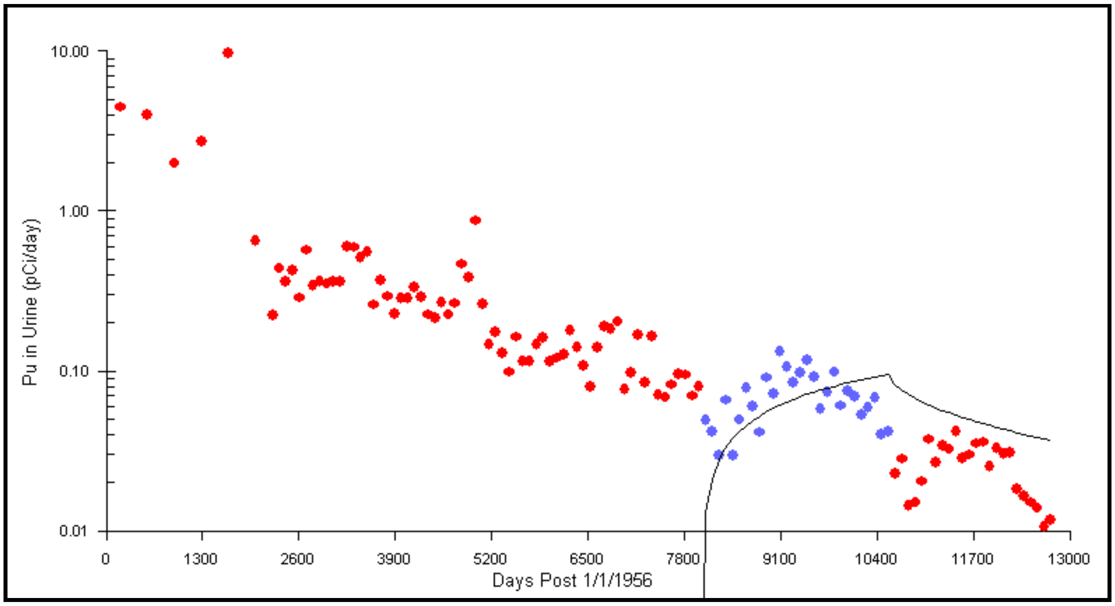

Figure B-15. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1978 to 1984.

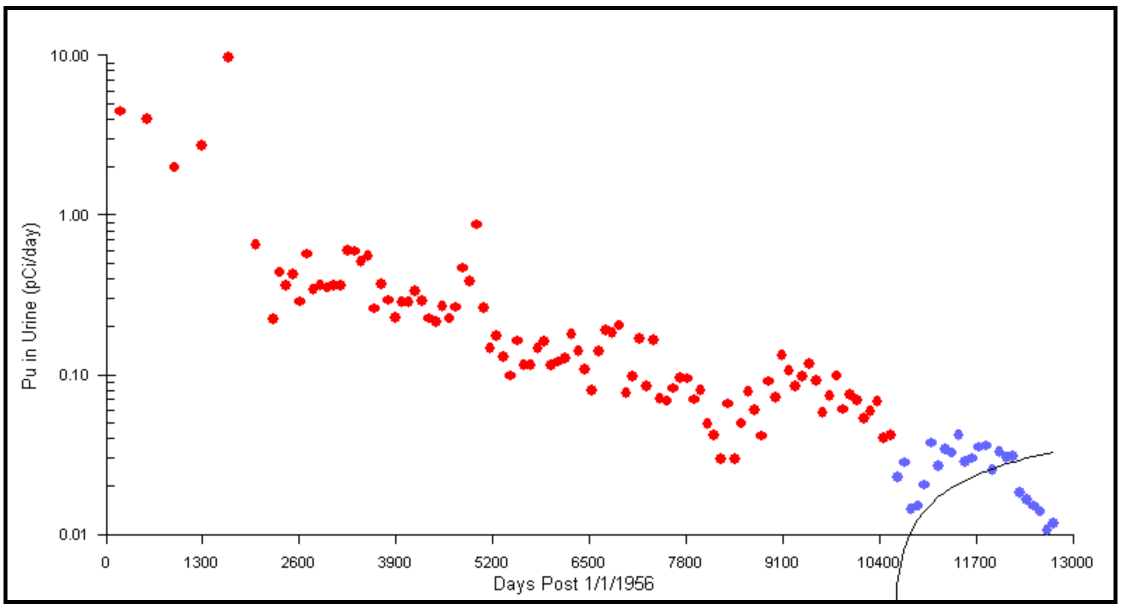

Figure B-16. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1985 to 1990.

ATTACHMENT B
COWORKER DATA FIGURES
Page 9 of 10

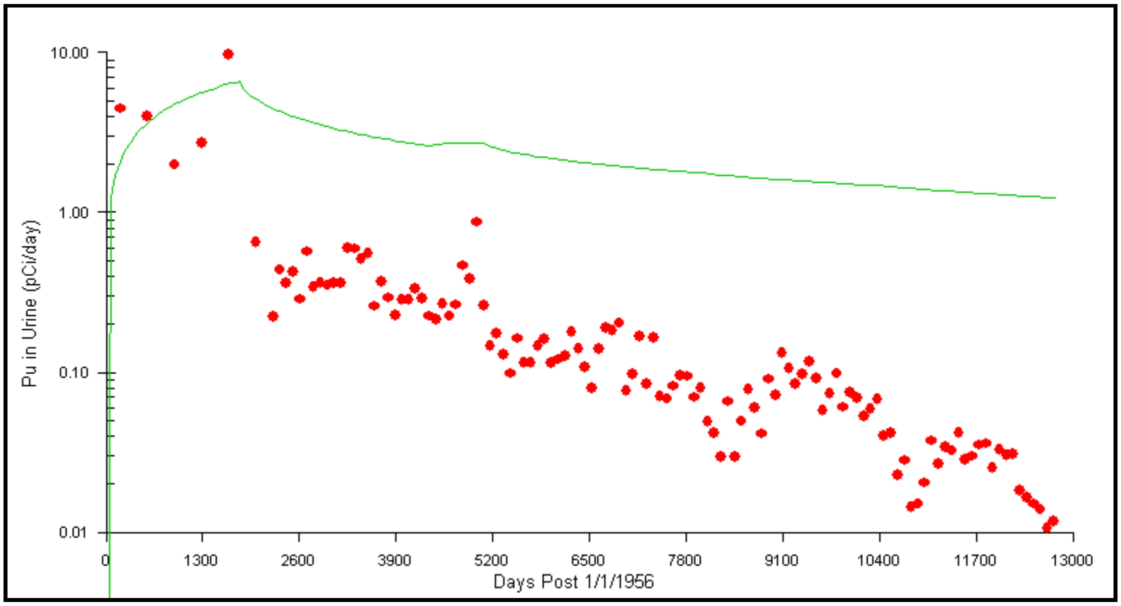

Figure B-17. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 1990.

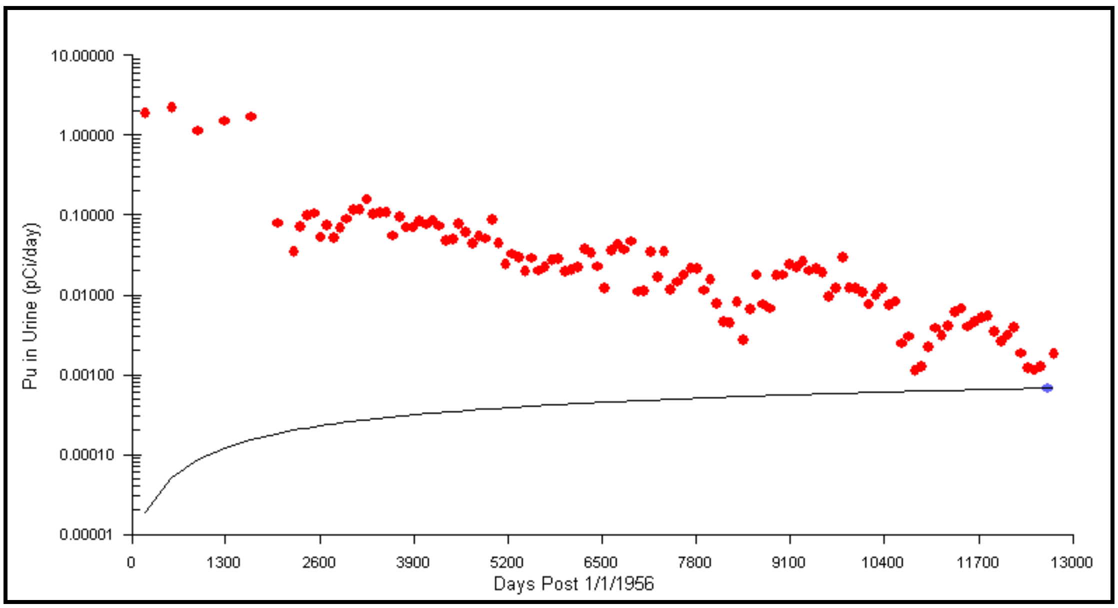

Figure B-18. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1956 to 1990.

ATTACHMENT B
COWORKER DATA FIGURES
Page 10 of 10

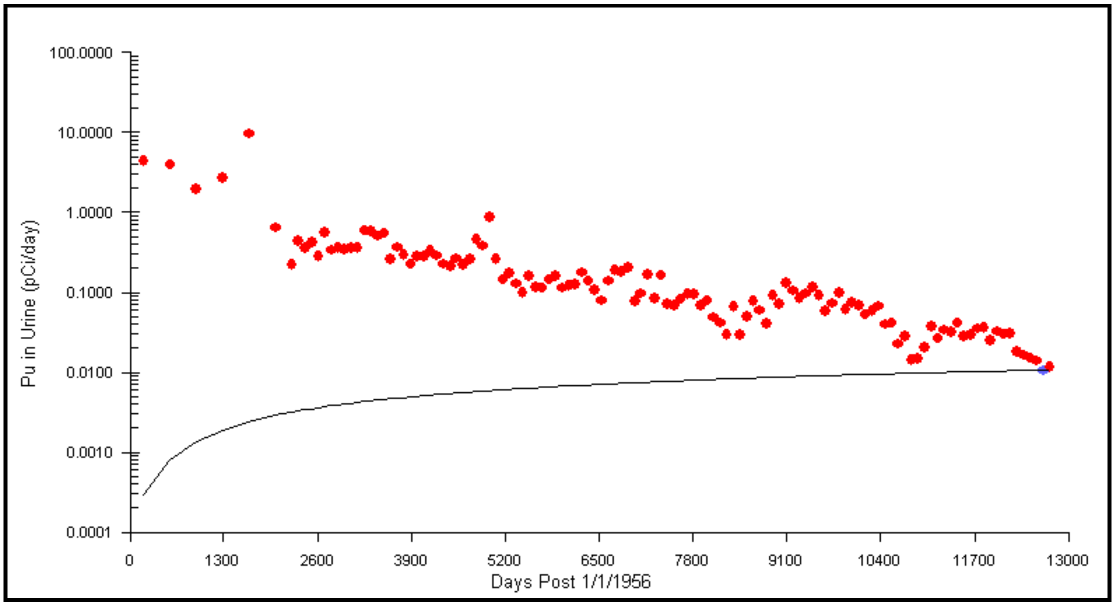

Figure B-19. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1956 to 1990.