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Dose Reconstruction
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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 Program Evaluation Report is required. Training required: As determined by the Task Manager. Initiated by Clark B. Barton.
02/17/2011	01	Revision to change modeling of intakes of type S plutonium to provide best-estimate intakes. Deleted previous underestimating intakes and instructions for dose reconstructors to perform case-specific intake modeling. Added 95th-percentile intake rates for all radionuclides. Constitutes a total rewrite or the document. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
04/13/2012	02	Revision to extend intake assignments for plutonium from 1990 to 2002 and add evaluation of tritium for 1981 through 2005. 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.
08/14/2018	03	Revision initiated to incorporate an evaluation of MHI absorption type for ^{238}Pu. Sections 4.1.2, 4.2.2, 4.3.2, 5.1.2, and Attachment A revised. 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	04	Revision initiated to include adding the potential and intake rates for type SS plutonium. No changes needed as a result of formal internal review. Incorporates formal NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.

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ACRONYMS AND ABBREVIATIONS

AMAD activity median aerodynamic diameter
AWE atomic weapons employer

Bq becquerel

d day
DOE U.S. Department of Energy
DTPA diethylene triamine pentaacetic acid

F fast (absorption type)

GM geometric mean
GSD geometric standard deviation

hr hour
HSPu heat-source plutonium
HTO tritiated water vapor

ICRP International Commission on Radiological Protection
IDOT Internal Dosimetry Tool
IMBA Integrated Modules for Bioassay Analysis
IREP Interactive RadioEpidemiological Program

m meter
M moderate (absorption type)
MESH Mound Environmental Safety and Health (database)
MHI Mound highly insoluble
mL milliliter

NIOSH National Institute for Occupational Safety and Health

ORAU Oak Ridge Associated Universities

pCi picocurie

S slow (absorption type)
SS super slow (absorption type)
SRDB Ref ID Site Research Database Reference Identification (number)

TIB technical information bulletin

USC *United States Code*

WGPu weapons-grade plutonium

yr year

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.

1.1 PURPOSE

Some employees at the Mound Plant 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 co-exposure 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 had the potential for unmonitored intakes of ^{210}Po, plutonium, or tritium.

1.2 SCOPE

ORAUT-OTIB-0019, *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 co-exposure results. ORAUT-PLAN-0014, *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 for the Mound Plant were obtained through the PORECON (Polonium Reconstruction) and PURECON (Plutonium Reconstruction) databases, which were created from logbooks and other original hard-copy records. Based on a spot check, this dataset coincides well with original Mound paper records. It is appropriate for use only at Mound. The databases are representative of worker bioassay results at Mound during a substantial part of the operating history at this site. PURECON data was used through 1990. Plutonium data after 1990 and tritium bioassay data were retrieved from the Mound Environmental Safety and Health (MESH) database.

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 facilitate 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-OTIB-0019 [ORAUT 2005] and its implementing procedure, ORAUT-PROC-0095, *Generating Summary Statistics for Coworker Bioassay Data* [ORAUT 2006]. The results were entered in the Integrated Modules for Bioassay Analysis (IMBA) or Internal Dosimetry Tool (IDOT) to obtain intake rates for assigning dose distributions.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 5.0.

2.0 DATA OVERVIEW

This section provides information on the general selection characteristics of the urinalysis data and the methods of analysis. Plutonium, ^{210}Po, and tritium are the radionuclides of interest, and significant numbers of monitoring records exist for them. More detailed radionuclide-specific information for ^{210}Po and ^{3}H nuclides is provided in Section 3.0.

2.1 DATA SELECTION

For all assessed nuclides, data were extracted from Mound-developed databases. Discussion of the creation and/or quality assurance testing of these databases can be found in MJW [2002]. Details of the specific datasets are discussed in the following sections.

Typically, the bioassay databases did not include incident information, so results associated with incidents were not explicitly excluded from the analyses. In general, the philosophy for the co-exposure studies is that if results are in line with other samples from the time, then they are representative of worker intakes regardless of whether they were associated with an identified incident. The exception is when a result is much larger than the next highest result (e.g., an order of magnitude or more; this was applied subjectively); such a result would be excluded as not representative of the exposure potential for the general workforce.

2.1.1 Polonium

The urine bioassay data were extracted from the verified PORECON_FINAL_COPY database [Mound no date a), dbo_SAMPLES table, BQ_DAY field. In this case, verified means the original PORECON database was created by Mound from information that was recorded on cards as well as from a review of the original chemistry logbooks from which the cards were created. Mound data entry clerks entered the data using double-entry methods. After that, data entry was reviewed by Mound health physicists.

Samples with PROBLEM_FLG = R or BQ_DAY = blank were not included in the statistical analysis [1]. Samples were excluded for the following reasons:

- 147 nonurine samples (blood and feces),
- 116 lost in processing,
- 182 no sample submitted (e.g., vacation, illness),
- 1,595 insufficient volume,
- 1,685 duplicates or recounts,
- 162 submitted too late,
- 36 contaminated samples,
- 79 marked as beta counts, and
- 56 with no result and blank or cryptic comment.

Note that in many of the above cases, there is no associated result and the bulleted item is the site's explanation of why the result is missing. This includes lost in processing, no sample submitted, insufficient volume, and submitted too late. The exclusion of recounts and duplicates was based on the site's entry of "R" in the problem flag field of a given result, indicating that the result should be rejected. These were primarily due to the collection of several individual spot samples in a 24-hour period when an intake was suspected. Each was analyzed and reported individually. This was a relatively frequent occurrence in some periods, and it was felt that too much weight would be put on a few samples if each result was included in the analysis.

2.1.2 Plutonium

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 [Mound no date b). 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 for 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 taken after diethylene triamine pentaacetic acid (DTPA) administration (chelation therapy), and samples that were analyzed for nuclides other than plutonium. There were 1,413 of 58,893 results marked with a problem flag. For the first quarter of 1983, 26 sample results were excluded because the comment field indicated that ^{239}Pu was added to the sample [2].

Samples were excluded for the following reasons:

- 57 were analyzed for radium, curium, or thorium rather than plutonium,
- 70 quality control samples,
- 2,307 DTPA (265 of which had a problem flag),
- 140 contaminated,
- 453 lost in processing (e.g., sample spilled, tracer not added, low recovery),
- 10 insufficient volume,
- 46 no result, no clear reason, and
- 137 with blank or cryptic comment.

Note that in some of the above cases, there is no associated result and the bulleted item is the site's explanation of why the result is missing. This includes lost in processing and submitted too late. There were far fewer duplicates and recounts than in PORECON, and they were not marked as such in the plutonium database. Because there were so few, it was assumed that their inclusion would have little effect on the outcome and they were not excluded from the analysis.

Plutonium urinalysis data beginning in 1991 were extracted from the MESH database. Samples were excluded because the s_reason field had a value of "S" or "N," or because the Comment field contained the following (or equivalents):

- "No cert,"
- "Baseline,"
- "Pre-job,"
- "New hire,"
- "Background,"
- "Do not verify," and
- "Re-work."

In addition, the comment field was evaluated using professional judgment for comments indicating records should not be used. Examples include "Wrong calcs. Don't use," "Void. Sample counted with wrong tracer," "Void - do not certify," "TH Contam - NO Cert," "test/learning sample," "Spectrum is ‘dirty’ - Recount,” “Nose wipe,” “sample ID switched, count results questionable,” and “low recovery--do not verify.”

2.1.3 Tritium

Tritium urinalysis data beginning in 1981 were also extracted from the MESH database. Samples with an SSN field value of Background, Spike 1, Spike 2, 999999999, or similar were excluded. No records were excluded on any other basis. The sampling date was based on the Sample Date if available and on the Read Date otherwise. Some samples had sample dates from before the creation of the MESH database but read dates that were consistent with the initiation of use of the MESH database and other bioassay data for that individual. For those samples, the read date was used instead of the sample date. The database contained 212,522 samples from 2,669 individuals.

It was not necessary to remove recounts and duplicates because ORAUT-OTIB-0011, *Technical Information Bulletin: Tritium Calculated and Missed Dose Estimates* [ORAUT 2004b), was used for the dose assessments. Sample times were taken into account. If multiple results had the same count date and time, the lower value was used to calculate the dose in the previous interval and the higher value was used in the subsequent interval.

2.2 ANALYSIS

This section describes the statistical analyses that were performed on the urine bioassay datasets described in Section 2.1 in preparation for intake assessments, which are described in Section 3.0. As noted in the previous section, ORAUT [2004b] was used for the tritium analysis because, due to the biokinetic and short retention time, dose assessments can easily be performed for each individual. This is not the case for other nuclides, so the bioassay data were first analyzed and then doses assessed as though the data came from a single individual. ORAUT-PROC-0095, *Generating Summary Statistics for Coworker Bioassay Data* [ORAUT 2006], was used in the generation of the geometric mean (GM) and geometric standard deviation (GSD) of the polonium and plutonium datasets. The 84th percentile of the data was also calculated but used only for the determination of the GSD; it was not used to assign intakes.

2.2.1 Polonium

Data were analyzed by calendar quarter from July 1944 through the end of 1970 and by year from 1971 through part of 1973. The analysis period was changed due to a decrease in the amount of available data. The results of samples that were reported 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 by Mound assuming a counting efficiency of 50% and a chemical recovery of 85%. They were normalized to a 24-hour 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 in accordance with the guidance in ORAUT-TKBS-0016-5, *Mound Site – Occupational Internal Dosimetry* [ORAUT 2017], which specifies a recovery efficiency of 10% (instead of 85%) for this period. A factor of 1.35 was applied to results from 1964 through 1973, again according to ORAUT-TKBS-0016-5, which specifies a recovery efficiency of 63% (instead of 85%) for this period.

A lognormal distribution was assumed for the urinary excretion data, and the 50th- and 84th-percentile excretion rates were calculated using the ORAUT-PROC-0095 method [ORAUT 2006]. These excretion rates are given in Table A-1. Bioassay data that were 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 with IMBA to calculate the intake rates.

2.2.2 Plutonium

Data were analyzed by year from 1956 through the end of 1961, by calendar quarter from 1962 through 1990, and by year from 1991 through 2002. The results from 1954 through 1960 were multiplied by a factor of 8.5, as specified in ORAUT-TKBS-0016-5 [ORAUT 2017]. 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 that was analyzed after June 1, 1981, were summed to create a total plutonium result for these samples. Most plutonium samples were 24-hour samples. Samples with no listed volume or more than 1,000 mL were assumed to be 24-hour samples. Samples with volumes less than 1,000 mL were normalized to a 24-hour sample assuming an excretion rate of 1,400 mL/d.

The MESH data contained results for both ^{238}Pu and ^{239}Pu. These results were summed to give a plutonium gross alpha concentration. Some samples were counted multiple times. The multiple results from samples with the same Laboratory Identification Number (denoted LIN) were averaged. All samples were assumed to represent a 24-hour sample, and the sampling date was based on the submit_date field.

A lognormal distribution was assumed for the urinary excretion data, and the 50th- and 84th-percentile excretion rates were calculated using the ORAUT-PROC-0095 method [ORAUT 2006]. These excretion rates are given in Table A-2. Bioassay data from 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.

2.2.3 Tritium

Tritium was evaluated differently than the other radionuclides in this co-exposure study. For tritium, the protocol in ORAUT-OTIB-0011 [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 nondetect, that result was excluded from the analysis because this was assumed to not be part of routine monitoring.
- Samples on the same date were ordered from lowest to highest.
- All dose was assigned as if it occurred on the bioassay date.
- Type 1 calculations were performed for samples separated by 40 or fewer days.
- Type 3 calculations were performed if there were no other samples within 90 days of a sample.
- Type 2 calculations were performed in all other situations.

The doses for a period were then plotted on a lognormal probability plot, and the typical parameters (GM, GSD, and R^2) 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. The plotting positions were calculated with the $i/n - 1/(2n)$ convention in ORAUT-PROC-0095 [ORAUT 2006].

3.0 INTAKE MODELING

This section discusses intake modeling assumptions, fitting, and materials for ^{210}Po and plutonium. Intake modeling and bioassay fitting was not performed for tritium because the methodology discussed above for tritium directly calculates individual doses.

The modeled material types were those that the International Commission on Radiological Protection (ICRP) has assigned to each element and that workers at Mound might have encountered as discussed in ORAUT [2017]. With the exception of a special-case type (MHI) for very insoluble plutonium, discussed in the plutonium sections, other material types are not addressed.

3.1 ASSUMPTIONS

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 [3].

3.1.1 Polonium

Each urinary excretion rate 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, urinalysis results were normalized as needed to 24-hour samples using 1,400 mL, which is the volume of urine that is excreted by Reference Man in a 24-hour period.

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 occurred 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.

3.1.2 Plutonium

All urinary excretion rates were modeled as normally distributed 24-hour 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 or IDOT for multiple chronic intakes of type M and type S plutonium, type MHI for ^{238}Pu only [NIOSH 2016], and type SS for ^{239}Pu only. This approach approximates a series of acute intakes with unknown intake dates.

3.2 BIOASSAY FITTING

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 an observable sustained change in the bioassay results. This fitting is subjective, but a general rule of thumb is to group results that are within about a factor of 2 of the average excretion rate of the group. This can vary if the data exhibit a general increasing or decreasing trend; in such cases, the fit that appears to most closely match the data is selected. By this method, the polonium and plutonium excretion data were divided into several chronic intake periods [5].

3.2.1 Polonium

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

3.2.2 Plutonium

The excretion data were modeled with IMBA for multiple chronic intakes of types M and S plutonium and type MHI for ^{238}Pu only [NIOSH 2016]. Plutonium data from 1956 through 2002 were fit as a series of chronic intakes.

3.3 MATERIAL TYPES

ORAUT-TKBS-0016-5 discusses Mound internal dosimetry data and includes guidance for the appropriate use of that information. It concludes that workers at Mound had the potential to receive intakes of polonium and plutonium [ORAUT 2017].

3.3.1 Polonium

Excretion data for the 50th- and 84th-percentile values of ^{210}Po for 1944 through 1973 are shown in Table A-1. Note that the third quarter of 1970 was omitted because of poor statistics [6]. The GM for this quarter was several orders of magnitude smaller than the other means, and the GSD exceeded 250. 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 [7].

3.3.2 Plutonium

Excretion data for the 50th- and 84th-percentile values of total plutonium for 1944 through 1973 are shown in Table A-2 [8]. Because plutonium of types S, M, MHI (applicable to ^{238}Pu only [NIOSH 2016]), or SS (applicable to ^{239}Pu only [ORAUT 2020]) 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 intake period was fit independently using only the bioassay results from that intake period. For a particular dose reconstruction, 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.

Plutonium urinalysis results were analyzed with IMBA or IDOT using types M, S, MHI, and SS materials to derive intake rates for 1956 to 2002.

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. Figure B-11 shows the 50th-percentile predicted excretion rates from all type M intakes. The solid lines in Figures B-12 to B-18 show the individual fits to the 84th-percentile excretion rates for type M materials. Figure B-19 shows the 84th-percentile predicted excretion rates from all type M intakes. The same intake periods were not applied for both percentiles because the values followed different patterns.

Plutonium Type S
The solid lines in Figures B-20 to B-25 show the individual fits to the 50th-percentile excretion rates for type S materials. Figure B-26 shows the 50th-percentile predicted excretion rates from all type S intakes. The solid lines in Figures B-27 to B-32 show the individual fits to the 84th-percentile excretion rates for type S materials [9]. Figure B-33 shows the 84th-percentile predicted excretion rates from all type S intakes.

Plutonium-238 Type MHI
The solid lines in Figures B-34 to B-39 show the individual fits to the 50th-percentile excretion rates for type MHI materials. Figure B-40 shows the 50th-percentile predicted excretion rates from all type MHI intakes. The solid lines in Figures B-41 to B-46 show the individual fits to the 84th-percentile excretion rates for type MHI materials [10]. Figure B-47 shows the 84th-percentile predicted excretion rates from all type MHI intakes.

Plutonium-239 Type SS
The solid lines in Figures B-48 to B-53 show the individual fits to the 50th-percentile excretion rates for type SS materials. Figure B-54 shows the 50th-percentile predicted excretion rates from all type SS intakes. The solid lines in Figures B-55 to B-60 show the individual fits to the 84th-percentile excretion rates for type S materials [11]. Figure B-61 shows the 84th-percentile predicted excretion rates from all type SS intakes.

4.0 ASSIGNING INTAKES AND DOSES

The derived intake rates were used to determine co-exposure doses to individuals. Worker-specific dates and information are used to calculate the doses. This section tabulates the derived intake rates and provides guidance for assigning doses. For tritium, the doses to assign are provided rather than intake rates.

The 50th- and 95th-percentile intake rates are presented in the tables. The GSD, as calculated from the ratio of the 50th- and 84th-percentile intake rates, is included with the 50th-percentile intake rate so that the full distribution can be assigned when appropriate. The 95th percentile was calculated based on the GM (50th percentile) and GSD of the distribution. Note that there is an exception to the use of the GSD calculated from the 50th- and 84th-percentile intake rates. A value of 3 is assigned in ORAUT-OTIB-0060, *Internal Dose Reconstruction* [ORAUT 2018], to account for the uncertainty in the bioassay measurements and biokinetic models, so a minimum value of 3 is assigned to the co-exposure intake rates. This includes the calculation of the 95th-percentile intake rate.

Workers with a significant potential for intake should be assigned doses at the 95th percentile with a constant distribution, while those with less potential should be assigned the full distribution (i.e., 50th percentile with a lognormal distribution). Section 3.3.5 of ORAUT [2018] contains additional guidance on which intake rate to assign. The lognormal distribution should be selected in the Interactive RadioEpidemiological Program (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 should be applied to all annual doses that are determined from the intake period.

Dose reconstructors should select the material type that is the most favorable to claimants. Refer to ORAUT [2017] for more information on determining the material type for assignment of dose.

4.1 POLONIUM

Five intake periods were fit to the derived 50th- and 84th-percentile polonium excretion data. Because many of the GSDs were relatively similar, they were combined and the largest value in a given period was assigned for simplicity [12].

The intake rates, GSDs, and periods to 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 with potential routine exposure should be calculated from the 50th-percentile intake rates by assuming the absorption type that results in the largest dose. Table 4-1 summarizes the derived polonium intake rates that produced the data-fitting results in Attachment B. Note that the results on the left hand side of Table

4-1 are in becquerels per day because the original data were recorded as such [13]. The values in picocuries per day are provided on the right hand side of the table.

Table 4-1. Derived polonium intake rates for types F and M ^{210}Po, 1944 to 1973.

Type F Po-210

Period	Type F 50th percentile (Bq/d)	Type F GSD	Type F 95th percentile (Bq/d)	Type F 50th percentile (pCi/d)	Type F GSD	Type F 95th percentile (pCi/d)
07/1944–03/1946	1,189.5	3.89	11,113	32,149	3.89	300,351
04/1946–03/1949	254.96	5.56	4,287	6,891	5.56	115,865
04/1949–03/1960	12.192	7.99	372	329.5	7.99	10,054
04/1960–03/1965	2.0696	6.70	47.3	55.94	6.7	1,278
04/1965–12/1973	0.10303	8.88	3.74	2.785	8.88	101.1

Type M Po-210

Period	Type M 50th percentile (Bq/d)	Type M GSD	Type M 95th percentile (Bq/d)	Type M 50th percentile (pCi/d)	Type M GSD	Type M 95th percentile (pCi/d)
07/1944–03/1946	4,097.6	3.9	38,444	110,746	3.9	1,039,027
04/1946–03/1949	800.19	5.8	14,422	21,627	5.8	389,784
04/1949–03/1960	39.851	8.0	1,219	1077	8	32,946
04/1960–03/1965	5.7883	6.2	116	156.4405405	6.2	3,135
04/1965–12/1973	0.34853	8.8	12.5	9.420	8.8	337.8

4.2 PLUTONIUM

Seven intake periods were fit to the derived 50th- and 84th-percentile plutonium excretion data for type M material. Five intake periods were fit to the derived 50th- and 84th-percentile plutonium excretion data for types S and SS material. Six intake periods were fit to the derived 50th- and 84th-percentile plutonium excretion data for type MHI ^{238}Pu. If the GSD was less than 3, the value was set to 3 to account for biological variation when determining dose [14].

The intake rates, GSDs, and applicable periods are given in Table A-5 for type M plutonium, Table A-6 for type S plutonium, Table A-7 for type MHI ^{238}Pu, and Table A-8 for type SS ^{239}Pu. In most cases, doses for individuals with potential routine exposure should be calculated from the 50th-percentile intake rates by assuming the absorption type that results in the largest probability of causation. Table 4-2 summarizes the derived plutonium intake rates that produced the data-fitting results in Attachment B. Note that the results in Table 4-2 are in picocuries per day because the original data were recorded as such [15]. If becquerels per day are preferred, multiply the Table 4-2 values by 0.037.

To calculate doses from plutonium, the intakes of total plutonium 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. For HSPu, absorption types M, S, and MHI should be considered. Determining the isotopic mix of WGPu is more complex. Table 4-3 lists three WGPu mixes aged 1, 3.2, and 10 years. These values are taken from the technical basis document [ORAUT 2017]. If the age of the isotopic mix is not known, the 10-year-aged material should be selected to be favorable to claimants in relation to the ingrowth of ^{241}Am from ^{241}Pu [16]. For WGPu, absorption types M, S, and SS intake rates should be evaluated.

Table 4-2. Derived plutonium intake rates for types M, S, MHI, and SS plutonium, 1956 to 2002.

Type M Pu

Period	50th percentile (pCi/d)	GSD	95th percentile (pCi/d)
1956–1957	750.98	3.00[a]	4,576
1958–1960	436.49	3.00[a]	2,659
1961–1967	12.141	5.42	196
1968–1969	12.141	11.69	693
1970–1977	2.2361	9.14	85.2
1978–1984	2.2361	5.82	40.5
1985–1997	0.4106	7.38	11.0
1998–2002	0.04092	12.31	2.54

Type S Pu

Period	50th percentile (pCi/d)	GSD	95th percentile (pCi/d)
1956–1957	27,150	3.00[a]	165,437
1958–1960	12,880	4.11	131,730
1961–1969	209.9	5.12	3,081
1970–1984	31.31	5.12	460
1985–1997	6.141	7.13	155
1998–2002	0.8638	12.32	53.7

Type MHI (Pu-238 only)

Period	50th percentile (pCi/d)	GSD	95th percentile (pCi/d)
1956–1957	2,161	3.00[a]	13,168
1958–1960	1,121	4.02	11,053
1961–1969	26.47	4.85	355.1
1970–1984	4.681	5.11	68.55
1985–1997	0.8675	7.30	22.80
1998–2002	0.09004	12.33	5.61

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

Type SS (Pu-239 only)

Period	50th percentile (pCi/d)	GSD	95th percentile (pCi/d)
1956–1957	99,300	3.00[a]	605,081
1958–1960	59,300	3.71	512,466
1961–1969	1,630	4.88	22,138
1970–1984	286	5.10	4,178
1985–1997	54.2	7.36	1,446
1998–2002	5.71	12.28	353.3

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

Table 4-3. Dose calculations for WGPu intakes.

Material age (yr)	% alpha activity Pu-239/240	% alpha activity Pu-238	% alpha activity Am-241	Beta activity (times $A_{Pu\text{-}239/240}$) 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

4.3 TRITIUM

Tritium doses rather than intake rates were calculated. Table 4-4 lists the tritium doses and GSDs to be used for each year of potential tritium exposure. These doses apply to exposure to tritiated water vapor (HTO), and do not apply to exposure to stable metal tritides. Refer to ORAUT [2017] for dose from stable metal tritides.

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

Year	Dose	GSD
1981	0.001	5.88
1982	0.003	7.71
1983	0.002	8.22
1984	0.001	8.76
1985	0.001	8.69
1986	0.001	8.04
1987	0.001	7.26
1988	0.001	7.34
1989	0.0004	9.49
1990	0.0005	5.95
1991	0.0003	5.24
1992	0.0003	4.89
1993	0.0001	5.35
1994	0.0001	4.79
1995	0.0001	4.34
1996	0.0002	4.74
1997	0.0004	5.85
1998	0.0003	4.30
1999	0.0004	5.12
2000	0.0002	4.40
2001	0.0002	4.28
2002	0.0003	5.99
2003	0.0003	6.88
2004	0.0004	7.68
2005	0.0001	3.03

5.0 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).

Thomas LaBone previously served as a Site Expert for this document. As such, he was 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. Oak Ridge Associated Universities (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 cannot be used, because 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 DTPA 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.
Determinations were made in accordance with 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 about intakes at Mound that shows that the default values should not be used. See, for example, OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline* (NIOSH 2002), and ICRP Publication 66, *Human Respiratory Tract Model for Radiological Protection* (ICRP 1994).

[4] 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 one interval over another. In addition, the polonium results were recorded as activity per milliliter 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; therefore, the statistical parameters were converted to excretion per day before intake calculations were made using IMBA.

[5] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Determinations were made in accordance with ORAUT [2005]. The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist.

[6] Mahathy, Michael, and Lochamy, Joseph C. ORAU Team. Co-exposure Statistics Analyst and Senior Health Physicist. February 2007.
The table was compiled by Lochamy from data that was generated by Mahathy.

[7] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Attachment B figures were generated by LaBone from IMBA results.

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

[9] Arno, Matthew G. ORAU Team. Senior Health Physicist. February 2007.
Determinations were made in accordance with ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. Figures were generated by Arno from IMBA results.

[10] Arno, Matthew G. ORAU Team. Senior Health Physicist. February 2007.
Determinations were made in accordance with ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. Figures were generated by Arno from IMBA results.

[11] Arno, Matthew G. ORAU Team. Senior Health Physicist. February 2007.
Determinations were made in accordance with ORAUT (2005). The choice of intervals and resulting fits were peer reviewed by the Principal Internal Dosimetrist. Figures were generated by Arno from IMBA results.

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

[13] LaBone, Thomas R., Mahathy, Michael, and Lochamy, Joseph C. ORAU Team. Deputy Principal Internal Dosimetrist, Co-exposure Statistics Analyst, and Senior Health Physicist. February 2007.
Determinations were made by LaBone in accordance with ORAUT (2005). The table was compiled by Lochamy from data generated by Mahathy.

[14] LaBone, Thomas R. ORAU Team. Deputy Principal Internal Dosimetrist. February 2007.
Determinations were made in accordance with 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* (ORAUT 2018). It reflects the overall uncertainty that is associated with biokinetic modeling as well as usual radiochemical analysis, and it indicates that even though the spread in co-exposure excreta results for a given population (e.g., a year of excreta samples) can have a GSD of <3, the uncertainty of intakes that were determined using the biokinetic models is no less than 3.

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

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

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ORAUT [2018]. Internal dose reconstruction. ORAUT-OTIB-0060 Rev. 02. Oak Ridge, TN: Oak Ridge Associated Universities Team. April 20. [SRDB Ref ID: 171554]

ORAUT [2020]. Estimating doses for plutonium strongly retained in the lung. ORAUT-OTIB-0049 Rev. 02. Oak Ridge, TN: Oak Ridge Associated Universities Team. September 1. [SRDB Ref ID: 178329]

ATTACHMENT A
CO-EXPOSURE DATA TABLES

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CO-EXPOSURE DATA TABLES (continued)

Table A-1. 50th- and 84th-percentile urinary excretion rates of ^{210}Po, 1944 to 1973 (Bq/d).

Effective	50th percentile	84th percentile	Number of samples	Number of employees
08/15/1944	8.33E+01	5.07E+02	531	48
11/15/1944	8.89E+01	3.56E+02	618	59
02/15/1945	1.01E+02	2.97E+02	716	72
05/15/1945	1.39E+02	5.13E+02	887	162
08/15/1945	5.17E+01	2.03E+02	1,582	241
11/15/1945	5.45E+01	2.27E+02	1,917	272
02/15/1946	4.56E+01	1.99E+02	2,052	289
05/15/1946	8.63E+01	2.92E+02	937	205
08/15/1946	2.10E+01	1.04E+02	2,277	333
11/15/1946	1.88E+01	9.53E+01	2,162	324
02/15/1947	9.26E+00	6.78E+01	2,541	362
05/15/1947	1.01E+01	6.84E+01	2,520	396
08/15/1947	1.32E+01	8.68E+01	3,027	486
11/15/1947	2.16E+01	1.10E+02	3,578	500
02/15/1948	3.18E+01	1.71E+02	4,247	553
05/15/1948	2.62E+01	1.36E+02	3,540	560
08/15/1948	1.52E+01	8.99E+01	3,395	556
11/15/1948	1.90E+01	1.23E+02	3,482	476
02/15/1949	7.12E+00	7.36E+01	3,220	517
05/15/1949	2.88E+00	2.27E+01	4,342	803
08/15/1949	2.77E+00	2.02E+01	3,919	773
11/15/1949	2.29E+00	2.00E+01	4,818	796
02/15/1950	1.43E+00	1.39E+01	4,907	786
05/15/1950	7.55E−01	8.97E+00	4,490	750
08/15/1950	7.96E−01	7.03E+00	4,138	739
11/15/1950	6.05E−01	8.06E+00	4,281	728
02/15/1951	1.02E+00	7.32E+00	4,269	708
05/15/1951	1.30E+00	9.08E+00	4,258	729
08/15/1951	1.41E+00	8.73E+00	4,085	735
11/15/1951	1.10E+00	7.89E+00	4,578	745
02/15/1952	1.25E+00	6.68E+00	4,822	733
05/15/1952	9.10E−01	5.33E+00	4,450	761
08/15/1952	7.03E−01	4.84E+00	4,380	784
11/15/1952	1.18E+00	7.19E+00	4,616	759
02/15/1953	1.05E+00	7.53E+00	4,814	767
05/15/1953	9.60E−01	5.68E+00	2,541	582
08/15/1953	1.03E+00	4.51E+00	1,975	479
11/15/1953	4.56E−01	4.09E+00	1,555	420
02/15/1954	7.22E−01	6.44E+00	844	210
05/15/1954	1.47E+00	6.37E+00	690	184
08/15/1954	3.24E+00	9.88E+00	482	154
11/15/1954	1.41E+00	8.96E+00	576	131
02/15/1955	1.62E+00	5.72E+00	470	126
05/15/1955	5.26E−01	2.62E+00	418	96
08/15/1955	5.54E−01	3.90E+00	421	91
11/15/1955	9.41E−01	1.26E+01	432	88
02/15/1956	4.31E−01	7.80E+00	498	95
05/15/1956	8.55E−01	5.51E+00	424	75
08/15/1956	1.78E−01	2.44E+00	452	90
11/15/1956	6.41E−02	3.01E+00	551	106

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CO-EXPOSURE DATA TABLES (continued)

Effective	50th percentile	84th percentile	Number of samples	Number of employees
02/15/1957	2.98E−01	6.07E+00	562	111
05/15/1957	4.53E−02	2.09E+00	541	113
08/15/1957	4.34E−01	3.23E+00	569	97
11/15/1957	6.68E−01	6.92E+00	616	125
02/15/1958	9.75E−01	6.67E+00	716	145
05/15/1958	1.00E+00	1.20E+01	704	129
08/15/1958	6.22E−01	9.34E+00	577	123
11/15/1958	6.82E−01	8.50E+00	739	137
02/15/1959	1.37E+00	1.28E+01	751	138
05/15/1959	1.32E+00	7.19E+00	778	173
08/15/1959	9.35E−01	7.44E+00	703	169
11/15/1959	1.32E+00	1.08E+01	969	186
02/15/1960	6.88E−01	6.49E+00	1,142	215
05/15/1960	4.01E−01	4.16E+00	1,256	224
08/15/1960	5.34E−01	4.58E+00	1,266	231
11/15/1960	5.92E−01	4.91E+00	1,450	247
02/15/1961	6.98E−01	6.04E+00	1,498	244
05/15/1961	5.02E−01	3.75E+00	1,529	263
08/15/1961	4.12E−01	2.57E+00	1,553	259
11/15/1961	2.89E−01	2.33E+00	1,882	287
02/15/1962	2.51E−01	1.42E+00	2,016	293
05/15/1962	3.46E−01	1.98E+00	1,938	282
08/15/1962	4.88E−01	2.63E+00	1,760	293
11/15/1962	1.85E−01	1.80E+00	2,023	301
02/15/1963	2.09E−01	1.57E+00	1,721	287
05/15/1963	9.66E−02	7.90E−01	1,813	297
08/15/1963	9.01E−02	5.51E−01	2,158	336
11/15/1963	3.38E−01	1.66E+00	2,183	343
02/15/1964	4.71E−02	2.68E−01	2,114	317
05/15/1964	1.86E−02	1.56E−01	2,156	318
08/15/1964	4.43E−02	2.03E−01	2,030	319
11/15/1964	4.35E−02	2.00E−01	2,059	307
02/15/1965	3.60E−02	1.33E−01	2,185	319
05/15/1965	1.90E−02	6.91E−02	1,762	284
08/15/1965	3.27E−02	1.07E−01	1,506	288
11/15/1965	1.34E−02	7.85E−02	1,634	295
02/15/1966	8.63E−03	4.57E−02	1,798	287
05/15/1966	1.12E−02	5.53E−02	1,599	287
08/15/1966	1.53E−02	9.59E−02	1,605	305
11/15/1966	1.77E−02	8.22E−02	1,657	296
02/15/1967	2.11E−02	7.49E−02	1,901	315
05/15/1967	9.13E−03	4.15E−02	1,942	307
08/15/1967	2.00E−03	2.33E−02	1,757	317
11/15/1967	7.77E−04	2.24E−02	1,927	311
02/15/1968	4.09E−03	5.91E−02	1,702	288
05/15/1968	1.30E−02	9.17E−02	1,866	312
08/15/1968	2.19E−03	1.24E−01	1,555	267
11/15/1968	7.16E−03	9.72E−02	1,313	264
02/15/1969	1.87E−03	2.55E−02	1,286	248
05/15/1969	5.10E−03	2.35E−02	747	153
08/15/1969	1.14E−03	1.15E−02	582	135

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Effective	50th percentile	84th percentile	Number of samples	Number of employees
11/15/1969	3.99E−05	1.58E−03	572	116
02/15/1970	1.45E−03	9.66E−03	500	116
05/15/1970	1.37E−02	4.73E−02	272	88
11/15/1970	2.20E−02	6.67E−02	98	25
07/01/1971	5.96E−04	1.52E−02	353	56
07/01/1972	1.06E−02	2.40E−01	73	13
07/01/1973	4.38E−03	4.61E−01	30	3

Table A-2. 50th- and 84th-percentile urinary excretion rates of total plutonium, 1956 to 2002 (pCi/d).

Effective	50th percentile	84th percentile	Number of samples	Number of employees
07/01/1956	1.88E+00	4.49E+00	38	7
07/01/1957	2.26E+00	4.03E+00	86	19
07/01/1958	1.14E+00	2.00E+00	77	32
07/01/1959	1.53E+00	2.73E+00	99	32
07/01/1960	1.72E+00	9.81E+00	336	89
07/01/1961	8.01E−02	6.50E−01	792	178
02/15/1962	3.49E−02	2.25E−01	351	174
05/15/1962	7.15E−02	4.42E−01	338	169
08/15/1962	1.01E−01	3.63E−01	296	186
11/15/1962	1.06E−01	4.27E−01	390	205
02/15/1963	5.31E−02	2.88E−01	356	183
05/15/1963	7.53E−02	5.73E−01	553	317
08/15/1963	5.19E−02	3.41E−01	558	319
11/15/1963	7.01E−02	3.65E−01	535	327
02/15/1964	8.98E−02	3.53E−01	606	316
05/15/1964	1.19E−01	3.64E−01	674	408
08/15/1964	1.18E−01	3.62E−01	585	381
11/15/1964	1.59E−01	6.00E−01	755	443
02/15/1965	1.03E−01	5.95E−01	857	460
05/15/1965	1.07E−01	5.11E−01	835	492
08/15/1965	1.07E−01	5.58E−01	783	477
11/15/1965	5.56E−02	2.62E−01	723	474
02/15/1966	9.62E−02	3.70E−01	726	435
05/15/1966	7.11E−02	2.94E−01	897	578
08/15/1966	7.09E−02	2.29E−01	957	603
11/15/1966	8.56E−02	2.87E−01	954	567
02/15/1967	7.68E−02	2.87E−01	1,086	640
05/15/1967	8.63E−02	3.37E−01	791	515
08/15/1967	7.38E−02	2.91E−01	826	544
11/15/1967	4.86E−02	2.27E−01	911	550
02/15/1968	5.01E−02	2.17E−01	834	498
05/15/1968	7.91E−02	2.70E−01	769	476
08/15/1968	6.23E−02	2.26E−01	541	297
11/15/1968	4.47E−02	2.67E−01	670	363
02/15/1969	5.42E−02	4.69E−01	680	310
05/15/1969	5.14E−02	3.87E−01	674	351
08/15/1969	8.76E−02	8.74E−01	579	278
11/15/1969	4.45E−02	2.63E−01	489	246
02/15/1970	2.42E−02	1.47E−01	659	398
05/15/1970	3.27E−02	1.75E−01	632	370
08/15/1970	2.93E−02	1.31E−01	626	373

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CO-EXPOSURE DATA TABLES (continued)

Effective	50th percentile	84th percentile	Number of samples	Number of employees
11/15/1970	1.98E−02	9.93E−02	796	484
02/15/1971	2.90E−02	1.64E−01	608	399
05/15/1971	2.03E−02	1.16E−01	629	416
08/15/1971	2.21E−02	1.15E−01	484	339
11/15/1971	2.77E−02	1.46E−01	540	375
02/15/1972	2.83E−02	1.62E−01	708	392
05/15/1972	2.01E−02	1.15E−01	653	387
08/15/1972	2.05E−02	1.21E−01	685	389
11/15/1972	2.21E−02	1.27E−01	533	360
02/15/1973	3.80E−02	1.80E−01	517	376
05/15/1973	3.32E−02	1.40E−01	502	354
08/15/1973	2.29E−02	1.08E−01	535	387
11/15/1973	1.21E−02	8.04E−02	525	369
02/15/1974	3.65E−02	1.41E−01	545	364
05/15/1974	4.34E−02	1.91E−01	453	328
08/15/1974	3.70E−02	1.83E−01	532	366
11/15/1974	4.74E−02	2.06E−01	407	296
02/15/1975	1.10E−02	7.75E−02	510	339
05/15/1975	1.13E−02	9.84E−02	499	326
08/15/1975	3.49E−02	1.69E−01	199	153
11/15/1975	1.71E−02	8.51E−02	320	273
02/15/1976	3.49E−02	1.66E−01	283	195
05/15/1976	1.19E−02	7.15E−02	327	246
08/15/1976	1.46E−02	6.91E−02	261	204
11/15/1976	1.80E−02	8.28E−02	278	213
02/15/1977	2.13E−02	9.59E−02	347	250
05/15/1977	2.13E−02	9.50E−02	294	233
08/15/1977	1.15E−02	7.02E−02	350	268
11/15/1977	1.56E−02	8.01E−02	278	227
02/15/1978	7.79E−03	4.92E−02	370	294
05/15/1978	4.68E−03	4.20E−02	298	236
08/15/1978	4.44E−03	2.99E−02	371	297
11/15/1978	8.12E−03	6.62E−02	272	231
02/15/1979	2.78E−03	2.96E−02	385	326
05/15/1979	6.74E−03	5.00E−02	304	246
08/15/1979	1.80E−02	7.82E−02	293	260
11/15/1979	7.70E−03	6.01E−02	210	196
02/15/1980	6.84E−03	4.16E−02	334	287
05/15/1980	1.77E−02	9.15E−02	268	237
08/15/1980	1.80E−02	7.22E−02	294	255
11/15/1980	2.41E−02	1.33E−01	284	235
02/15/1981	2.22E−02	1.06E−01	346	284
05/15/1981	2.63E−02	8.57E−02	323	282
08/15/1981	2.02E−02	9.85E−02	274	243
11/15/1981	2.17E−02	1.17E−01	283	247
02/15/1982	1.89E−02	9.22E−02	301	249
05/15/1982	9.69E−03	5.85E−02	340	301
08/15/1982	1.23E−02	7.39E−02	279	244
11/15/1982	2.97E−02	9.91E−02	269	243
02/15/1983	1.24E−02	6.12E−02	243	205
05/15/1983	1.24E−02	7.51E−02	365	308

ATTACHMENT A
CO-EXPOSURE DATA TABLES (continued)

Effective	50th percentile	84th percentile	Number of samples	Number of employees
08/15/1983	1.08E−02	6.97E−02	290	252
11/15/1983	7.71E−03	5.37E−02	310	287
02/15/1984	9.94E−03	5.88E−02	289	250
05/15/1984	1.22E−02	6.80E−02	339	304
08/15/1984	7.50E−03	4.01E−02	316	263
11/15/1984	8.39E−03	4.20E−02	315	283
02/15/1985	2.49E−03	2.29E−02	325	284
05/15/1985	3.05E−03	2.84E−02	363	319
08/15/1985	1.12E−03	1.44E−02	368	300
11/15/1985	1.28E−03	1.51E−02	266	249
02/15/1986	2.25E−03	2.05E−02	359	292
05/15/1986	3.86E−03	3.76E−02	316	275
08/15/1986	3.09E−03	2.71E−02	318	280
11/15/1986	4.11E−03	3.44E−02	147	136
02/15/1987	6.20E−03	3.27E−02	239	232
05/15/1987	6.85E−03	4.20E−02	173	168
08/15/1987	4.05E−03	2.85E−02	205	201
11/15/1987	4.61E−03	3.01E−02	200	197
02/15/1988	5.23E−03	3.55E−02	189	185
05/15/1988	5.50E−03	3.60E−02	211	202
08/15/1988	3.47E−03	2.52E−02	183	179
11/15/1988	2.65E−03	3.32E−02	199	185
02/15/1989	3.17E−03	3.06E−02	178	164
05/15/1989	3.90E−03	3.11E−02	204	201
08/15/1989	1.88E−03	1.83E−02	235	183
11/15/1989	1.23E−03	1.66E−02	300	247
02/15/1990	1.16E−03	1.52E−02	340	283
05/15/1990	1.27E−03	1.40E−02	288	242
08/15/1990	6.78E−04	1.07E−02	411	360
11/15/1990	1.83E−03	1.18E−02	350	286
07/01/1991	2.83E−03	1.44E−02	1,612	712
07/01/1992	1.94E−03	1.08E−02	2,211	1,131
07/01/1993	1.07E−03	5.51E−03	2,108	915
07/01/1994	9.79E−04	4.55E−03	2,404	1,149
07/01/1995	1.64E−03	7.26E−03	1799	797
07/01/1996	2.18E−03	8.09E−03	678	255
07/01/1997	1.30E−03	6.60E−03	834	233
07/01/1998	3.18E−04	3.67E−03	847	205
07/01/1999	1.92E−04	2.77E−03	756	256
07/01/2000	2.02E−04	2.31E−03	1,033	329
07/01/2001	1.95E−04	2.26E−03	787	258
07/01/2002	1.32E−04	1.73E−03	577	321

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

Start	End	50th percentile	84th percentile	GSD
07/01/1944	03/31/1946	4,097.6	15,796	3.9
04/01/1946	03/31/1949	800.19	4,602.3	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

ATTACHMENT A
CO-EXPOSURE DATA TABLES (continued)

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

Start	End	50th percentile	84th percentile	GSD
07/01/1944	03/31/1946	1,189.5	4,628	3.89
04/01/1946	03/31/1949	254.96	1,416.8	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

Table A-5. Type M plutonium intake rates (pCi/d) and dates.

Start	End	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	12/31/1997	0.4106	3.03	7.38
01/01/1998	12/31/2002	0.04092	0.5039	12.31

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

Table A-6. Type S plutonium intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD
01/01/1956	12/31/1957	27,150	52,240	1.92[a]
01/01/1958	12/31/1960	12,880	53,000	4.11
01/01/1961	12/31/1969	209.9	1,301	4.91
01/01/1970	12/31/1984	31.31	160.2	5.12
01/01/1985	12/31/1997	6.141	43.77	7.13
01/01/1998	12/31/2002	0.8638	10.64	12.32

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

Table A-7. Type MHI ^{238}Pu intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD
01/01/1956	12/31/1957	2,161	4,143	1.92[a]
01/01/1958	12/31/1960	1,121	4,506	4.02
01/01/1961	12/31/1969	26.47	128.3	4.85
01/01/1970	12/31/1984	4.681	23.93	5.11
01/01/1985	12/31/1997	0.8675	6.329	7.30
01/01/1998	12/31/2002	0.09004	1.11	12.33

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

Table A-8. Type SS ^{238}Pu intake rates (pCi/d) and dates.

Start	End	50th percentile	84th percentile	GSD
01/01/1956	12/31/1957	99,300	198,000	1.99[a]
01/01/1958	12/31/1960	59,300	220,000	3.71
01/01/1961	12/31/1969	1,630	7,960	4.88
01/01/1970	12/31/1984	286	1,460	5.10
01/01/1985	12/31/1997	54.2	399	7.36
01/01/1998	12/31/2002	5.71	70.1	12.28

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

ATTACHMENT B
CO-EXPOSURE DATA FIGURES

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ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

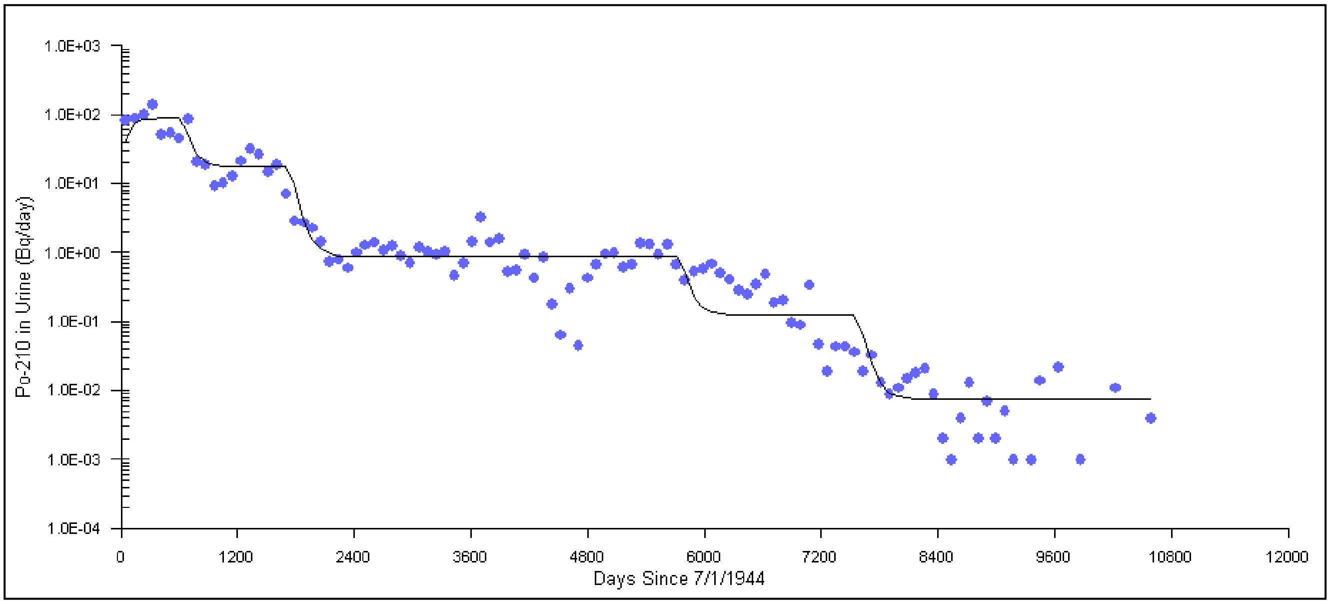

Figure B-1. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M ^{210}Po.

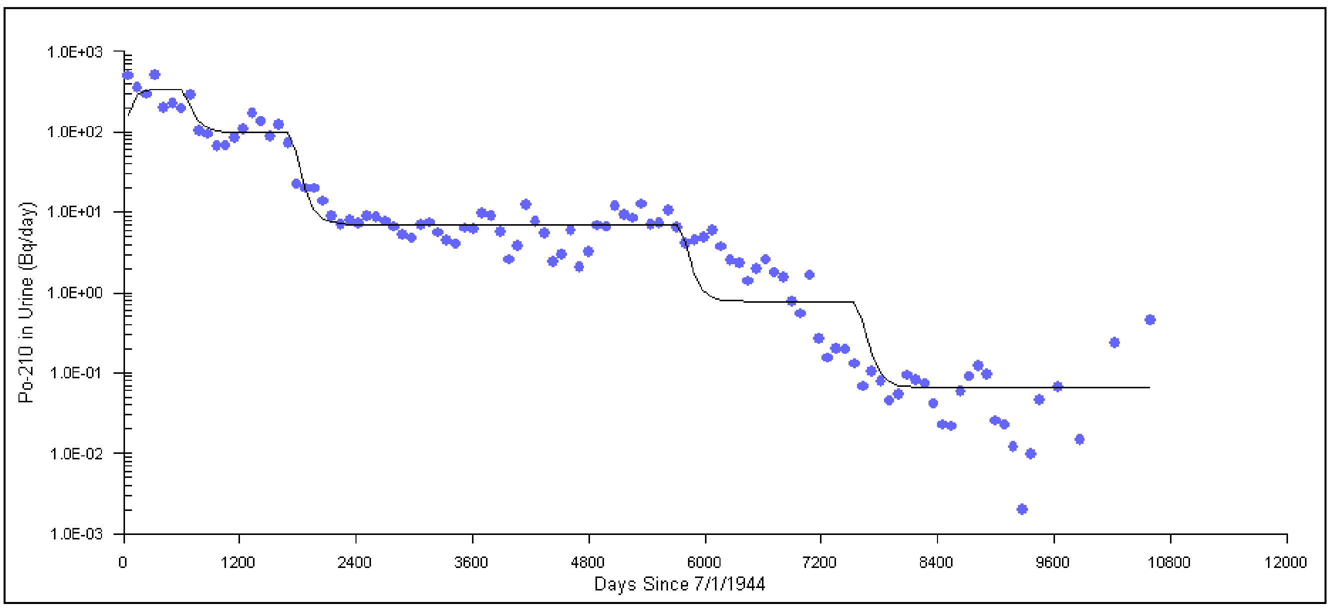

Figure B-2. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M ^{210}Po.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

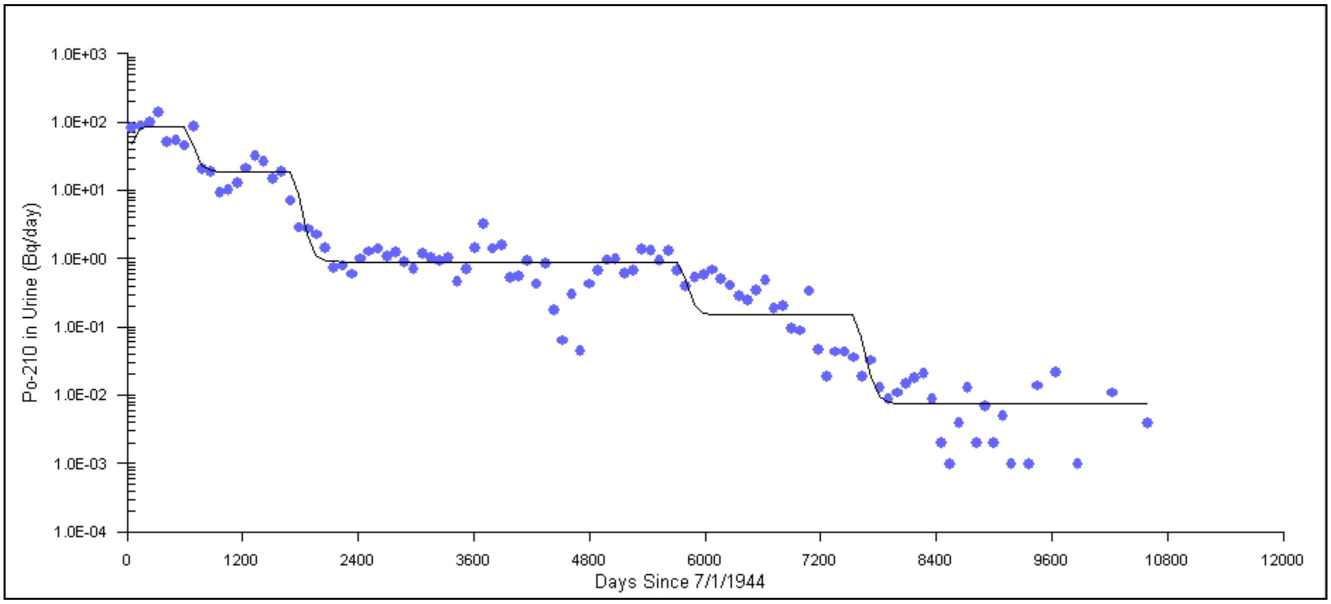

Figure B-3. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type F ^{210}Po.

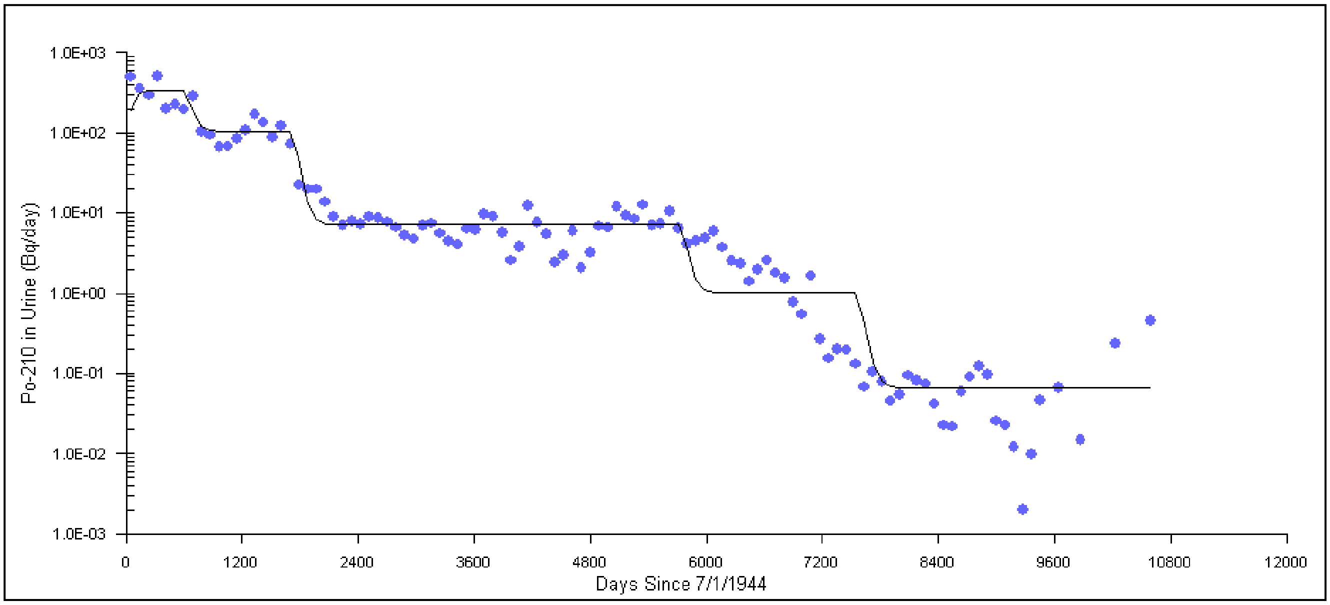

Figure B-4. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type F ^{210}Po.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

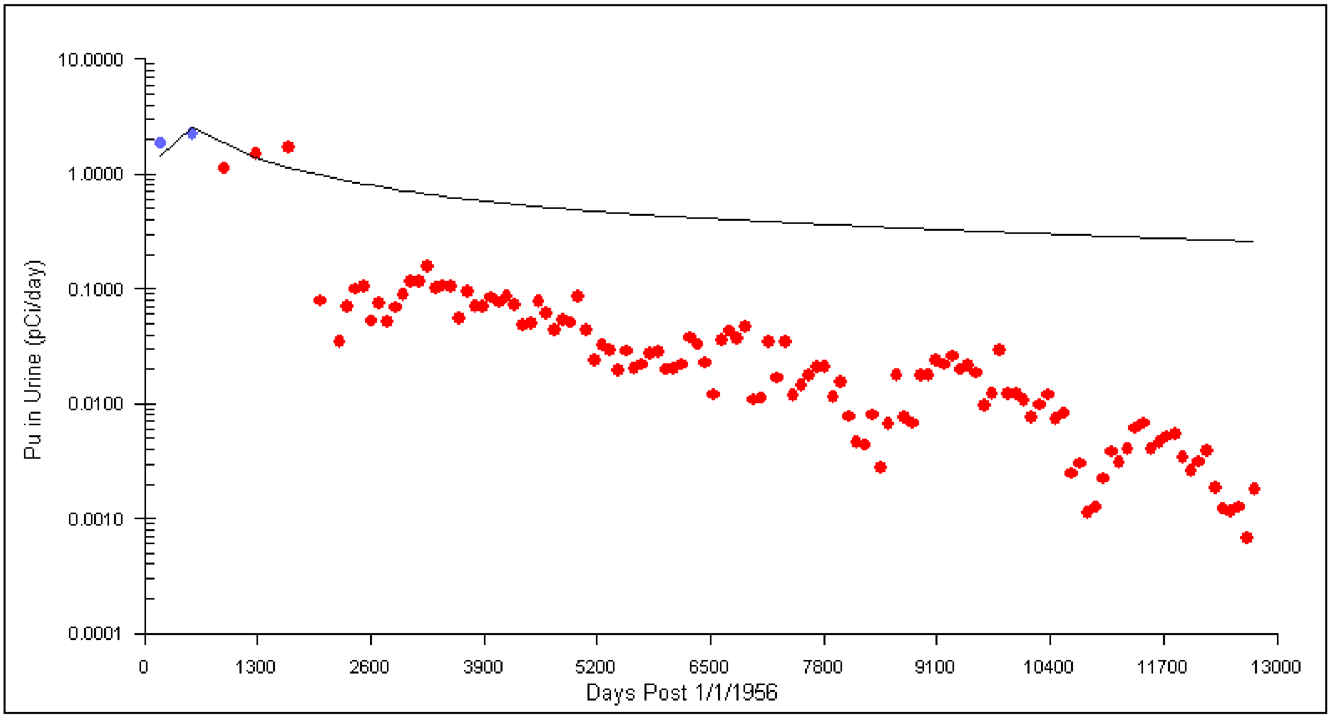

Figure B-5. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 1957.

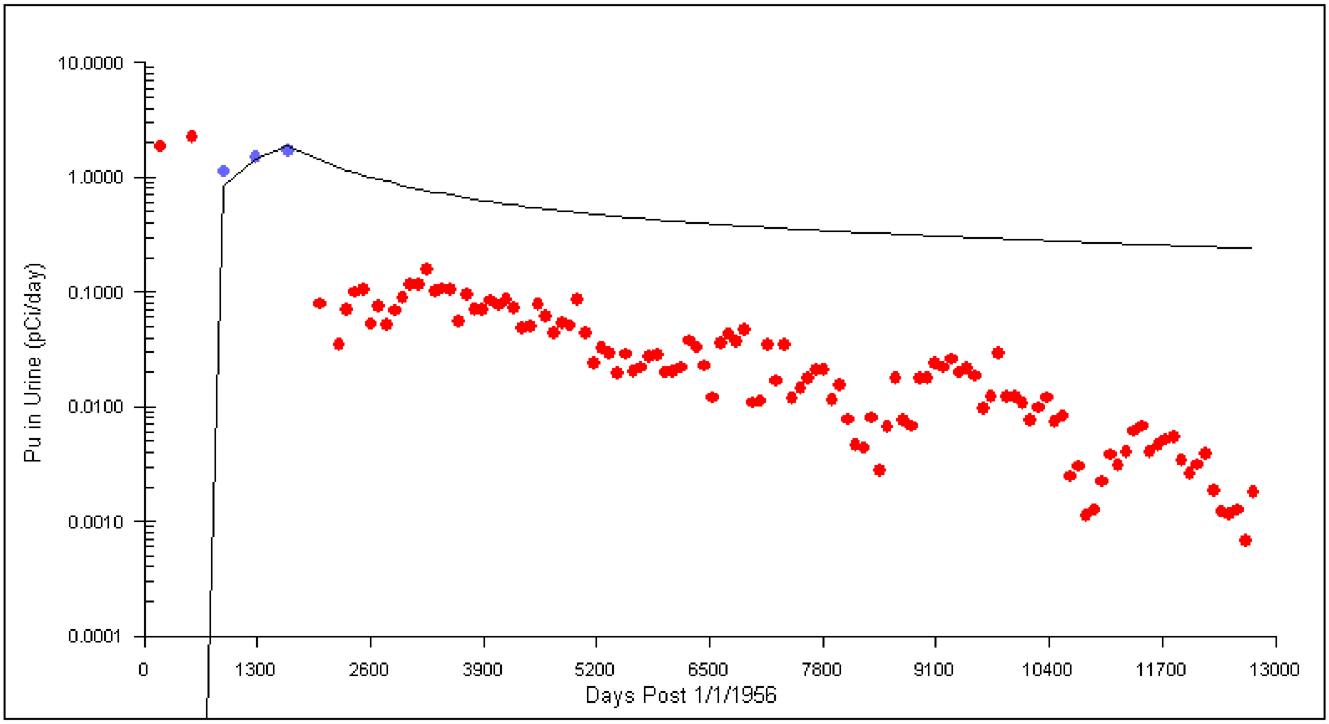

Figure B-6. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1958 to 1960.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

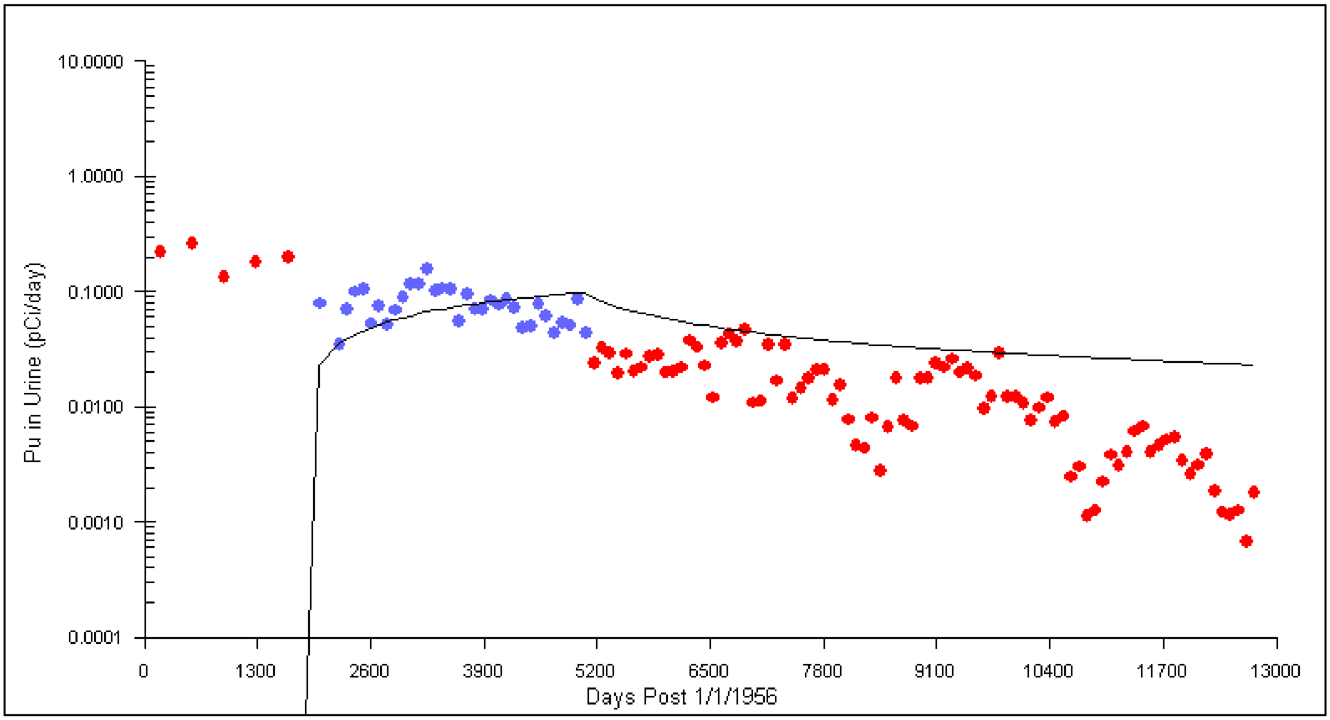

Figure B-7. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1961 to 1969.

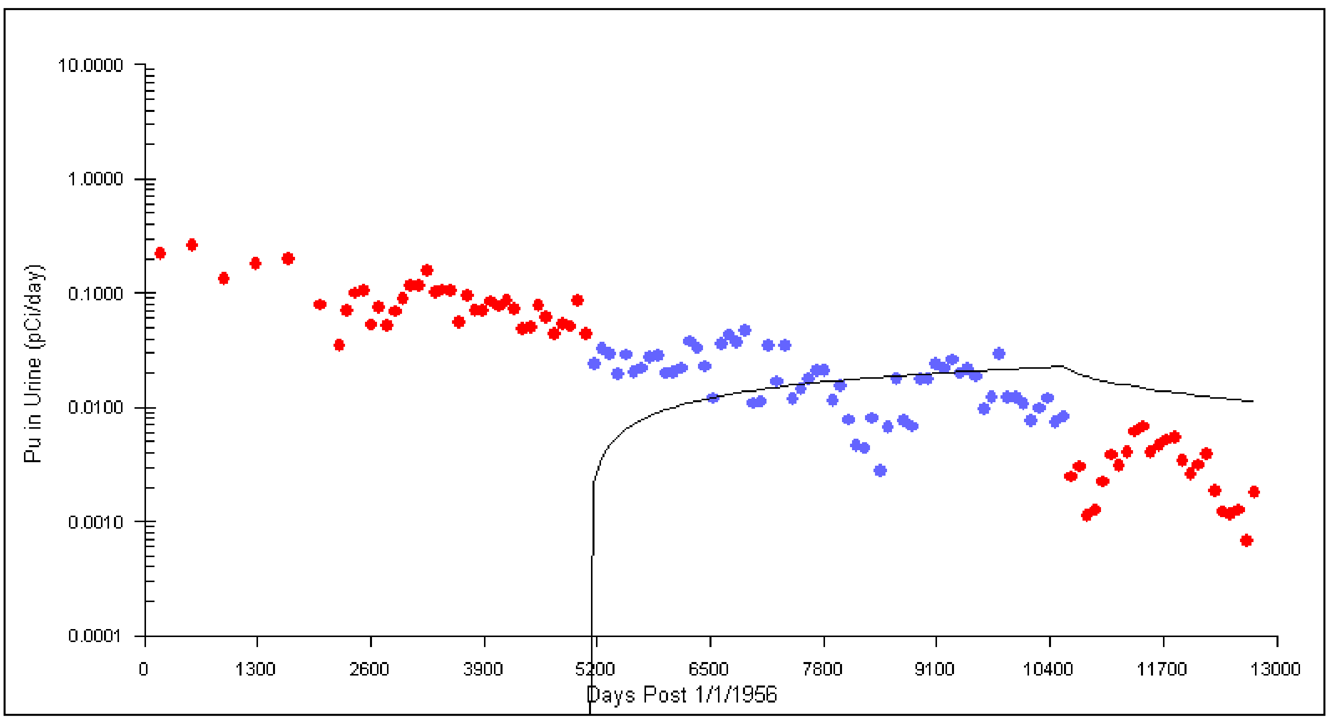

Figure B-8. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1970 to 1984.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

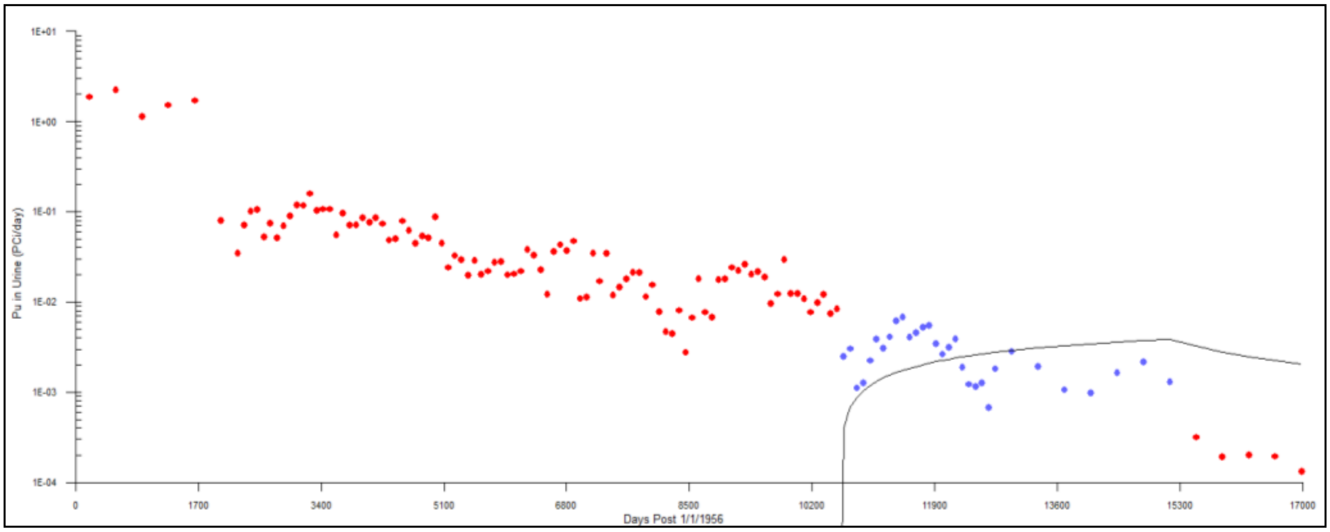

Figure B-9. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1985 to 1997.

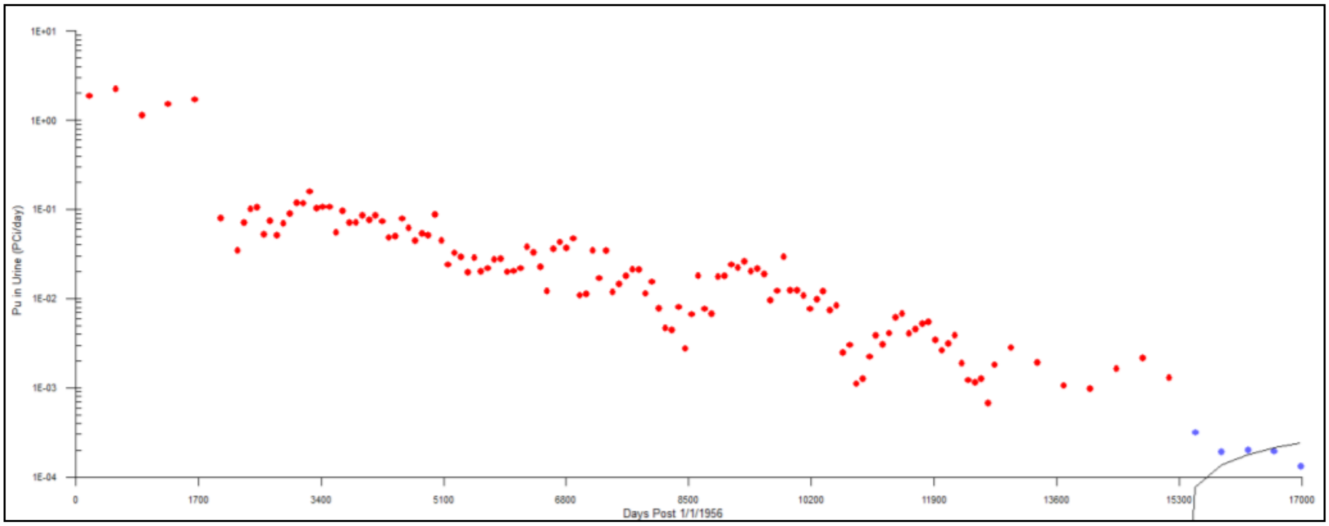

Figure B-10. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1998 to 2002.

ATTACHMENT B
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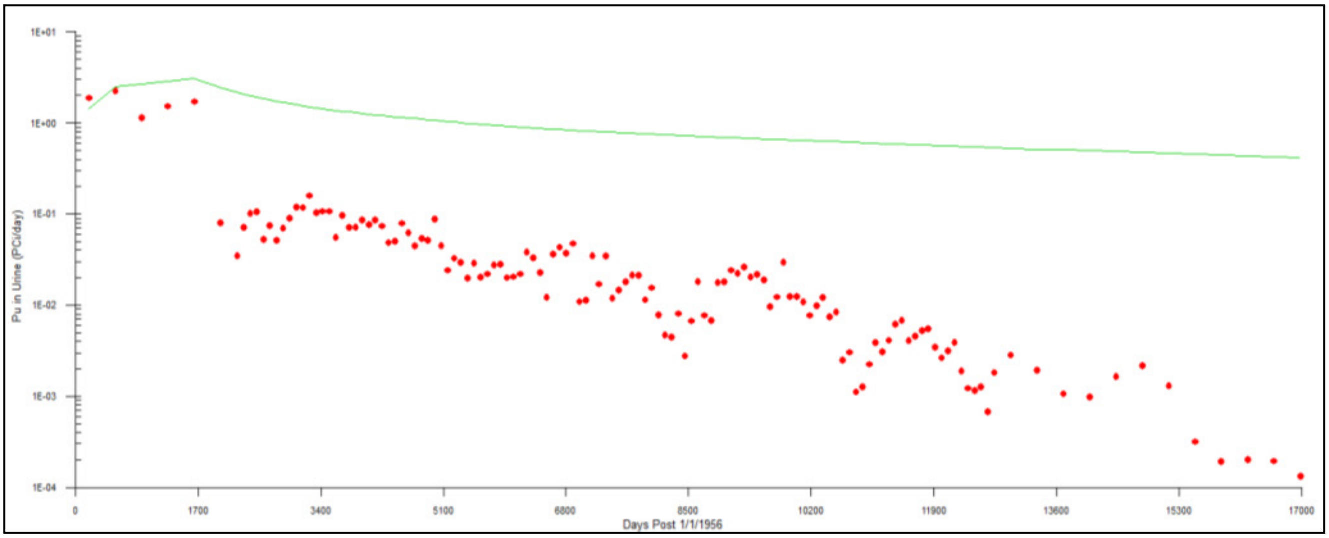

Figure B-11. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 2002.

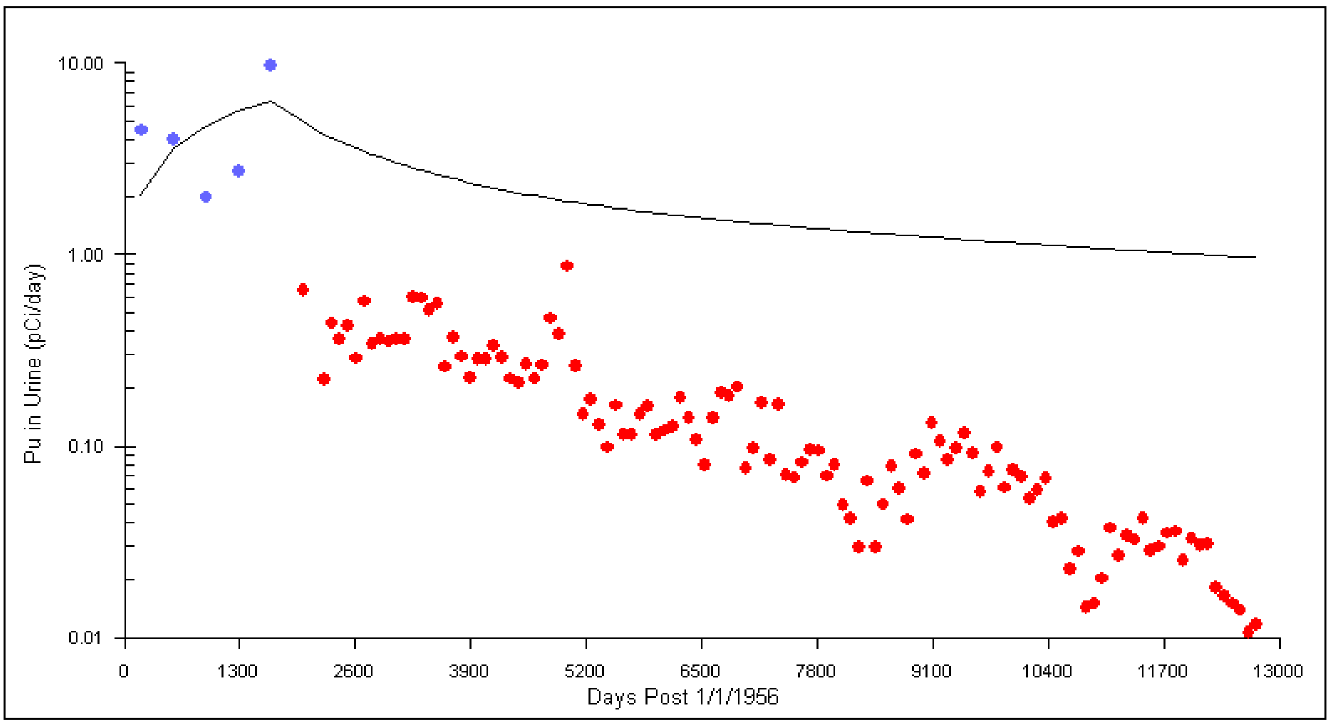

Figure B-12. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 1960.

ATTACHMENT B
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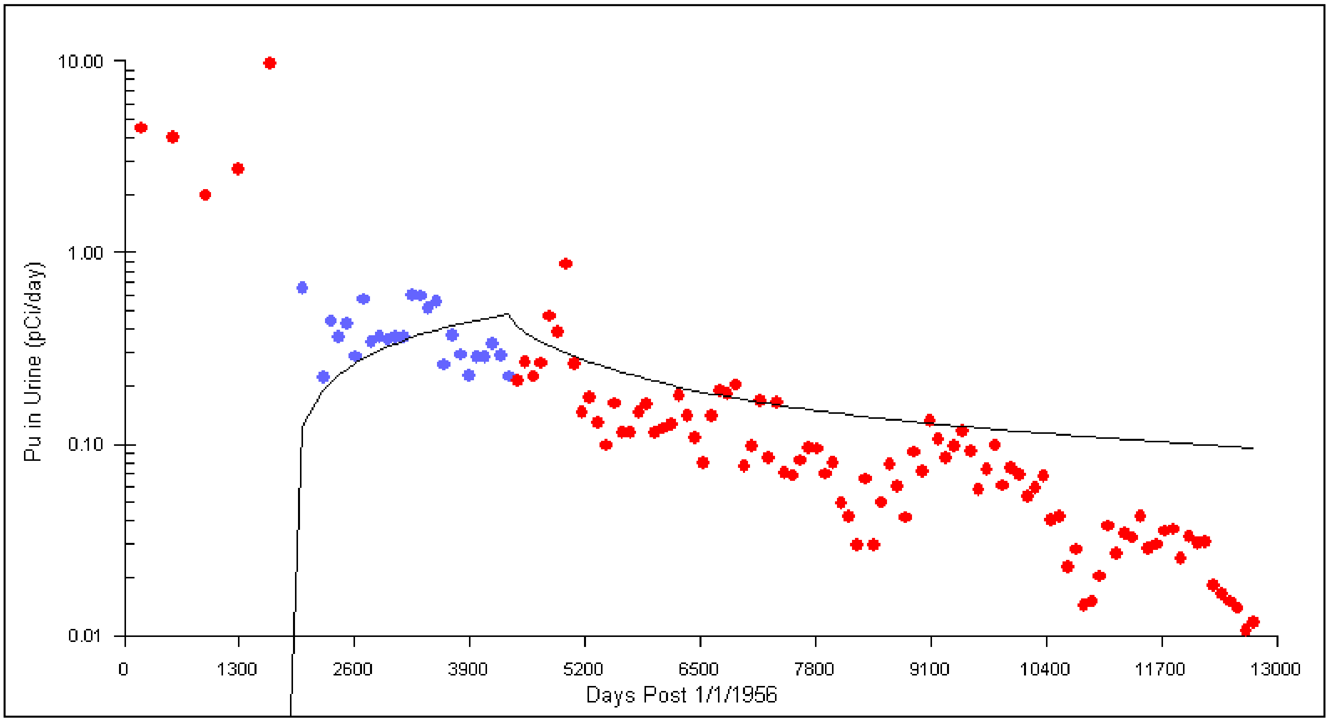

Figure B-13. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1961 to 1967.

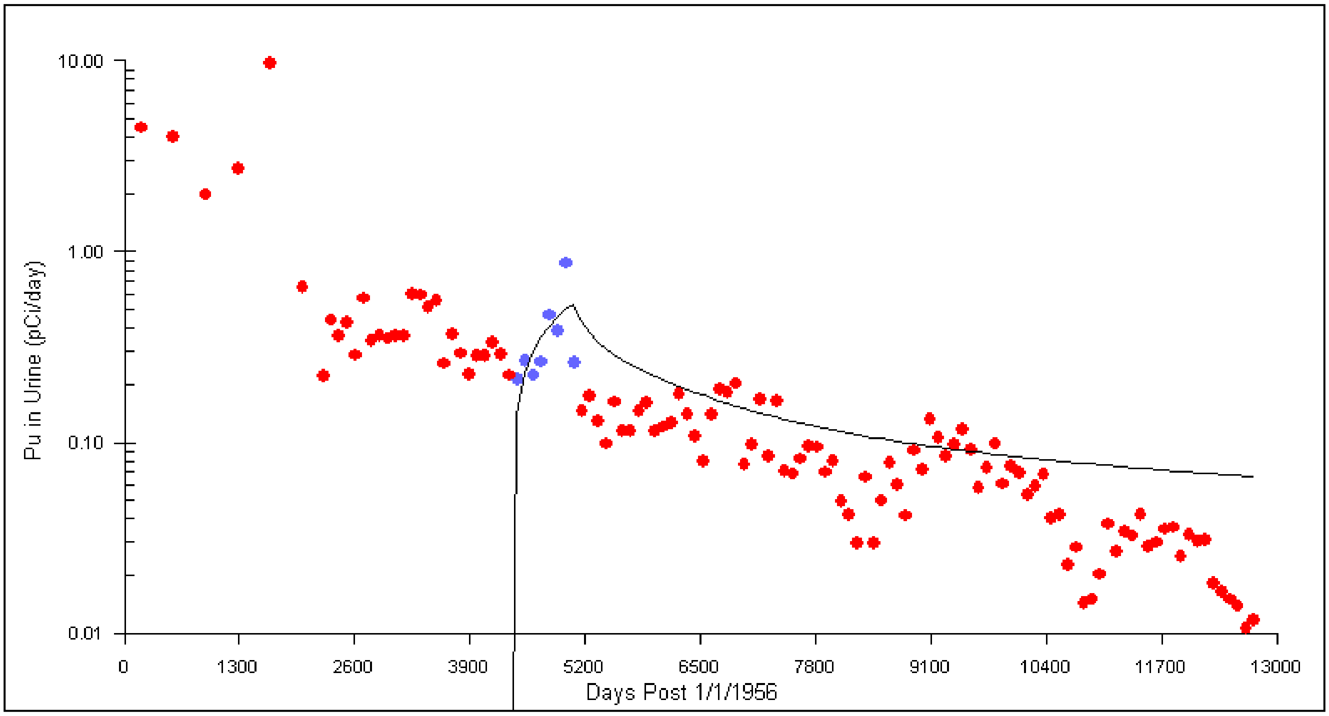

Figure B-14. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1968 to 1969.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

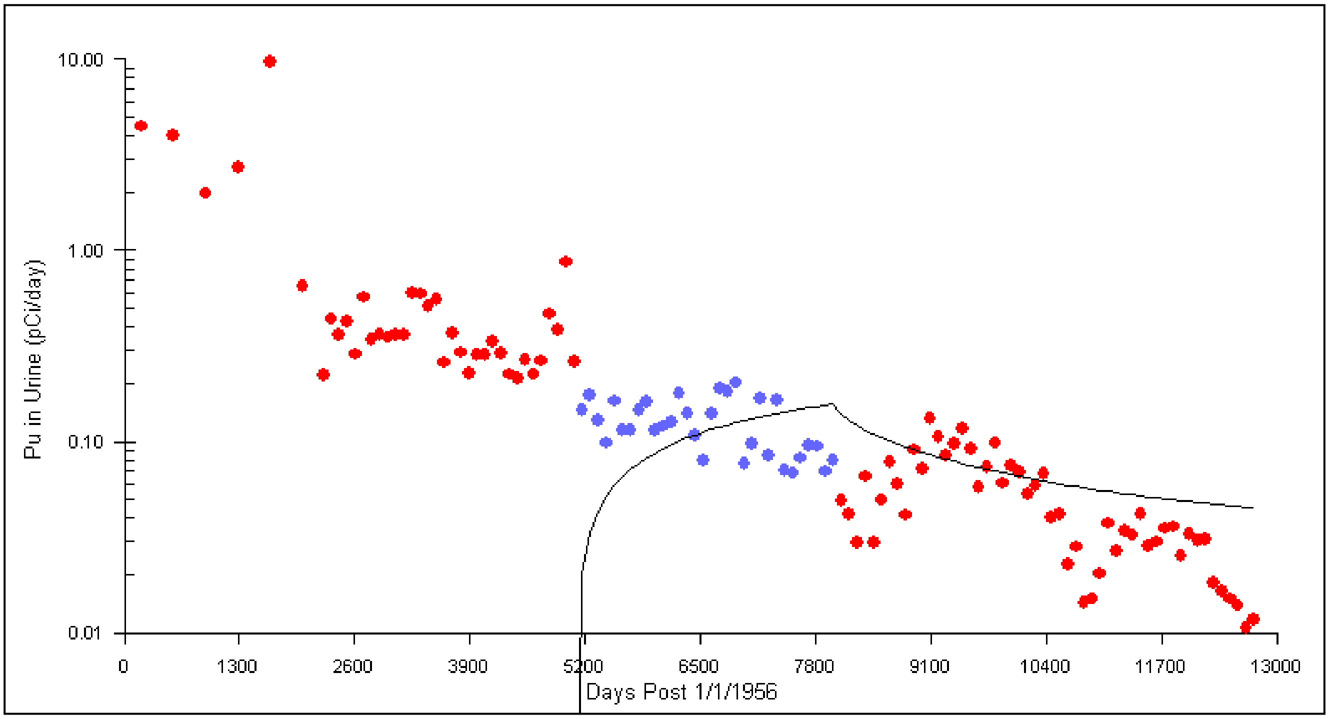

Figure B-15. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1970 to 1977.

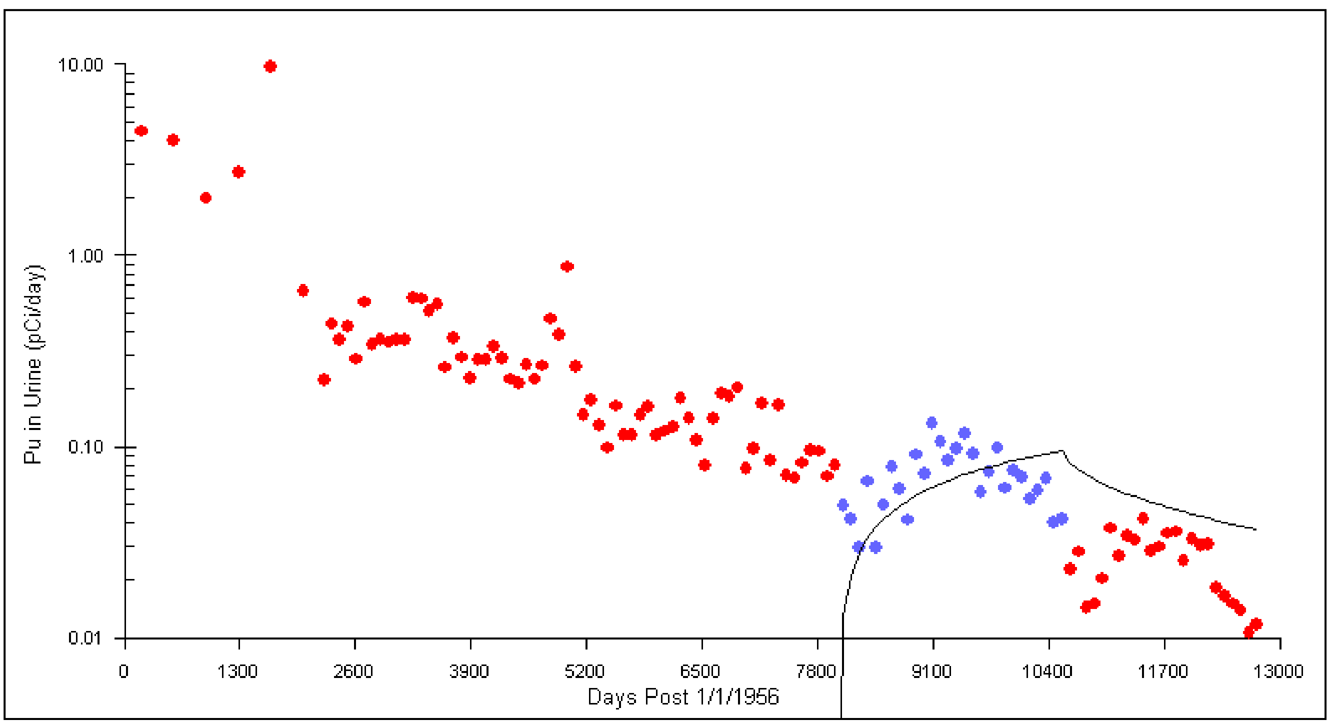

Figure B-16. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1978 to 1984.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

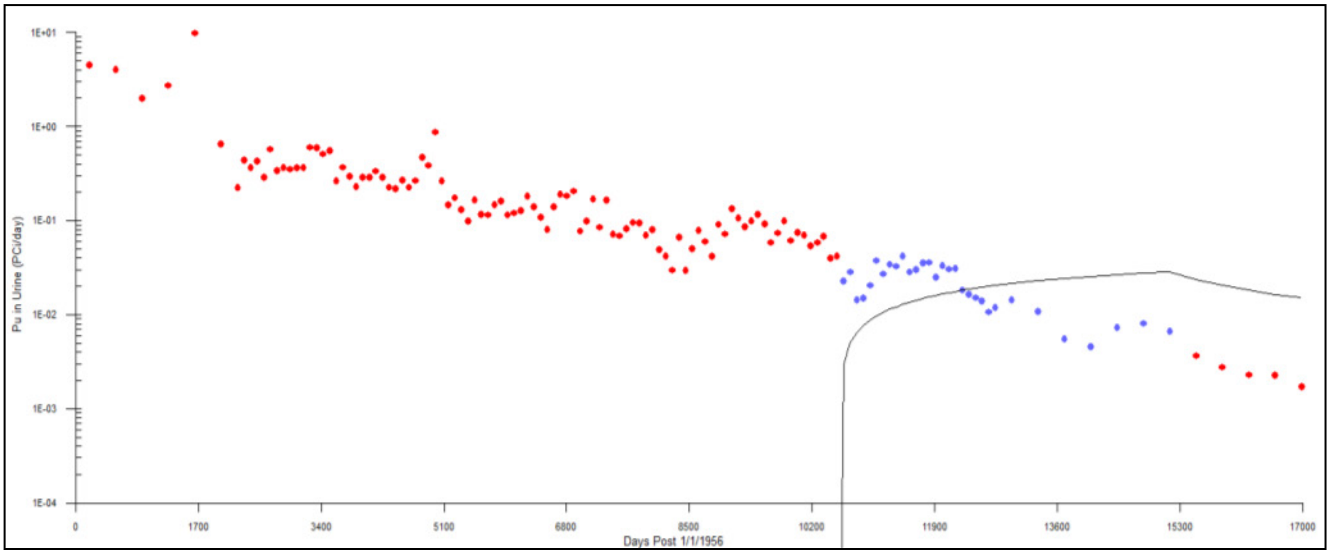

Figure B-17. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1985 to 1997.

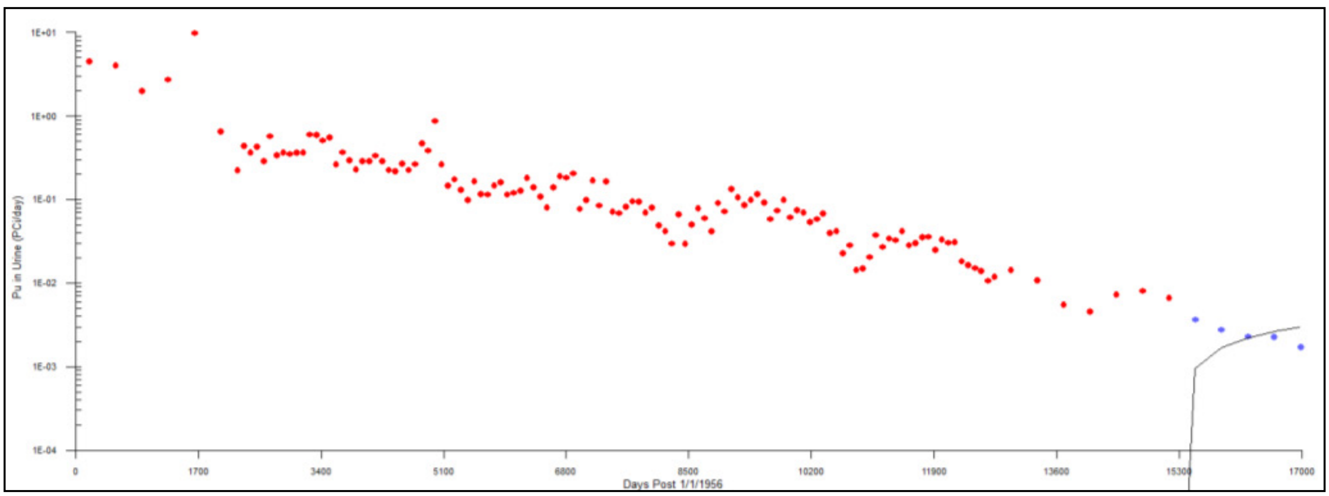

Figure B-18. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1998 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

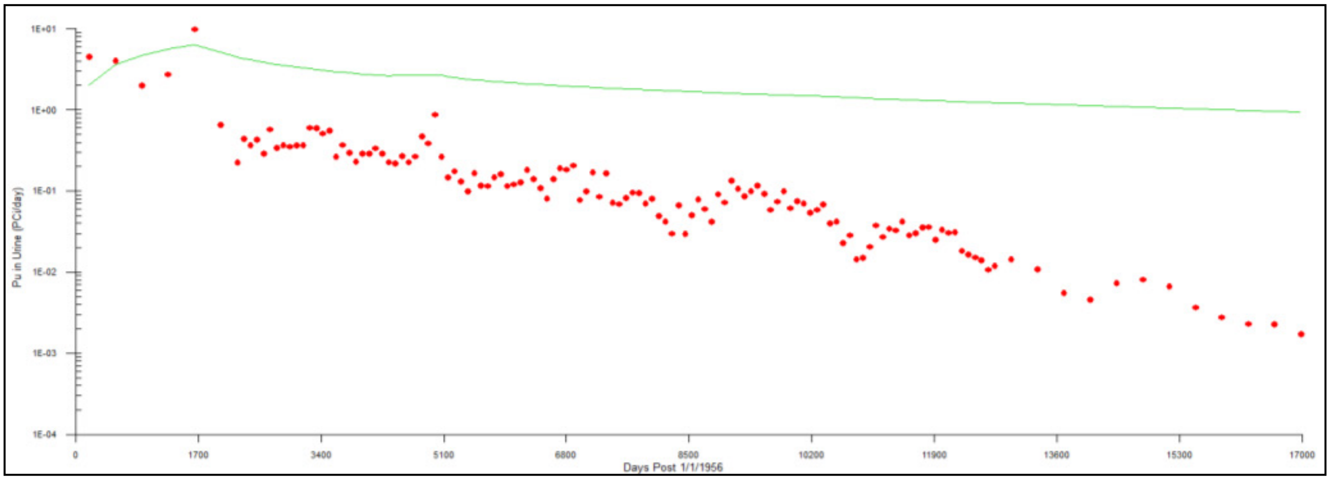

Figure B-19. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming inhalation intakes of type M plutonium, 1956 to 2002.

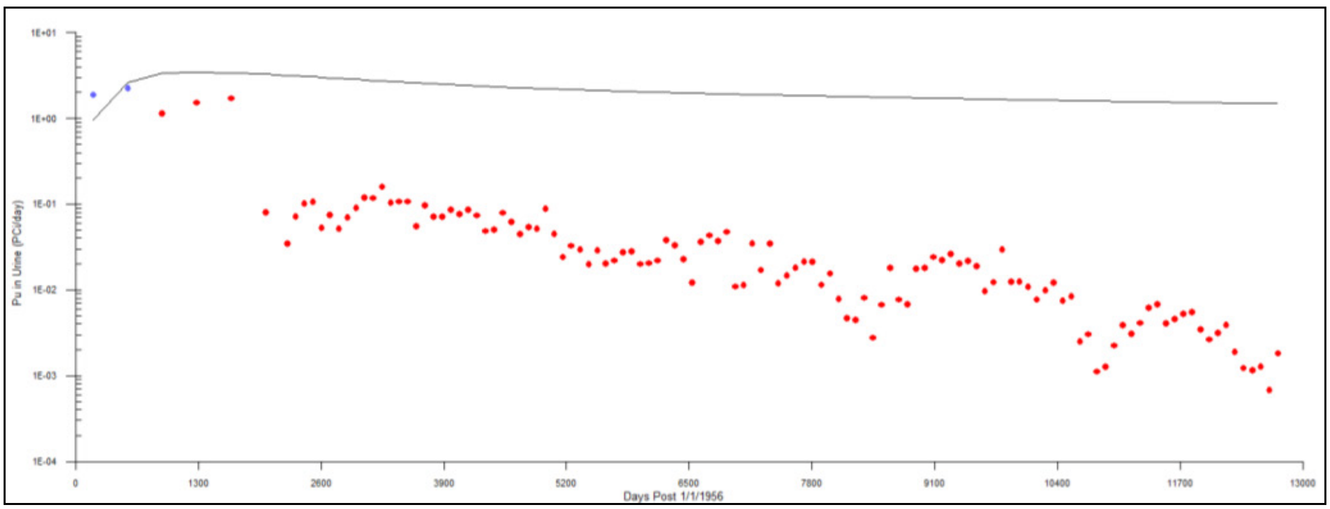

Figure B-20. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1956 to 1957.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

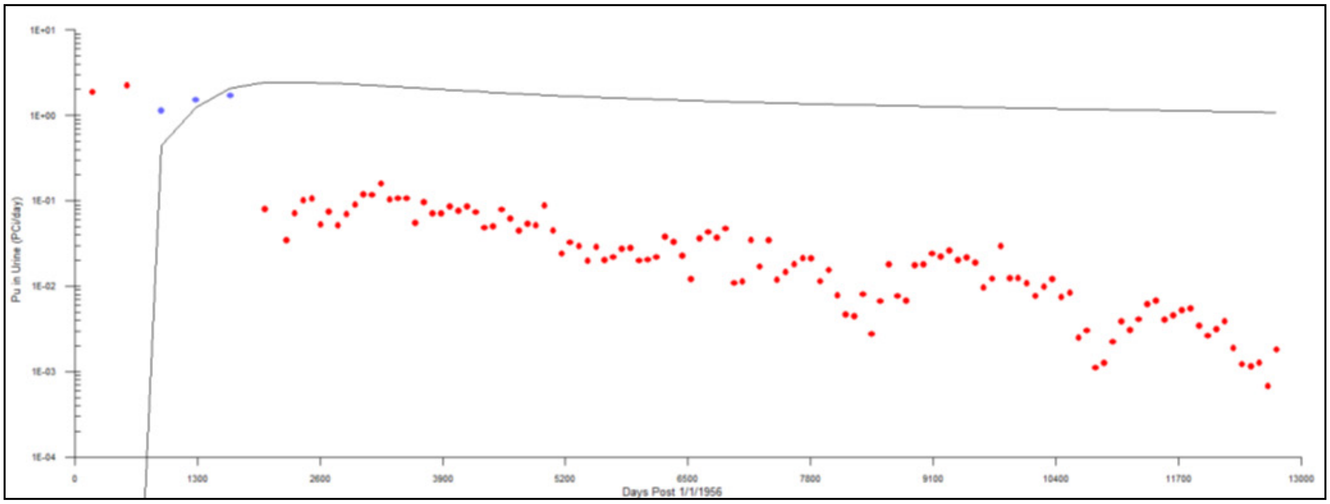

Figure B-21. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1958 to 1960.

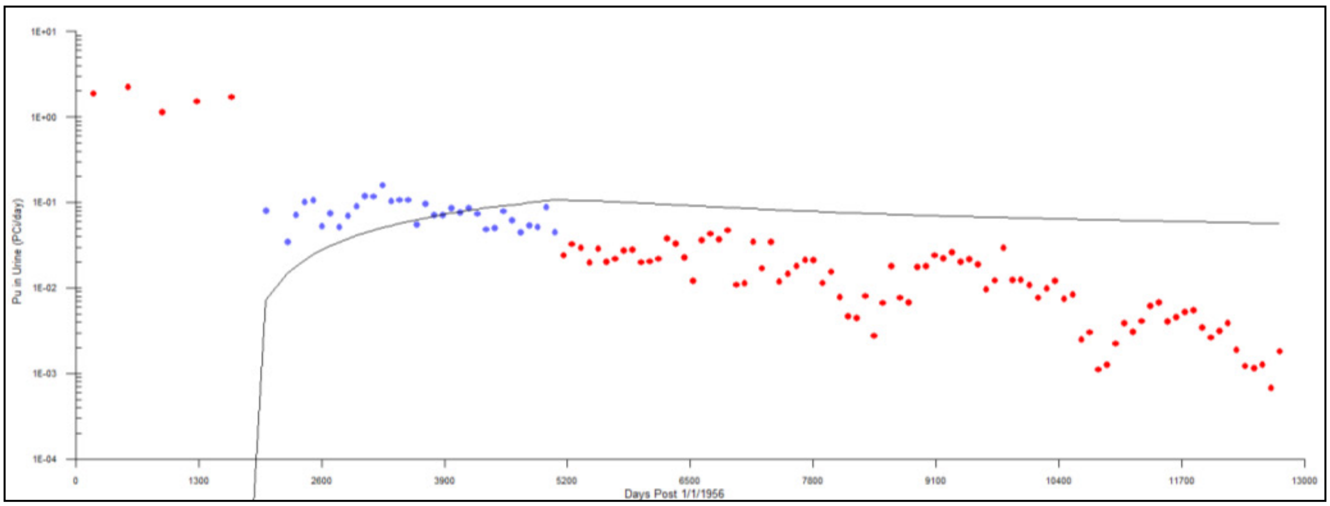

Figure B-22. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1961 to 1969.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

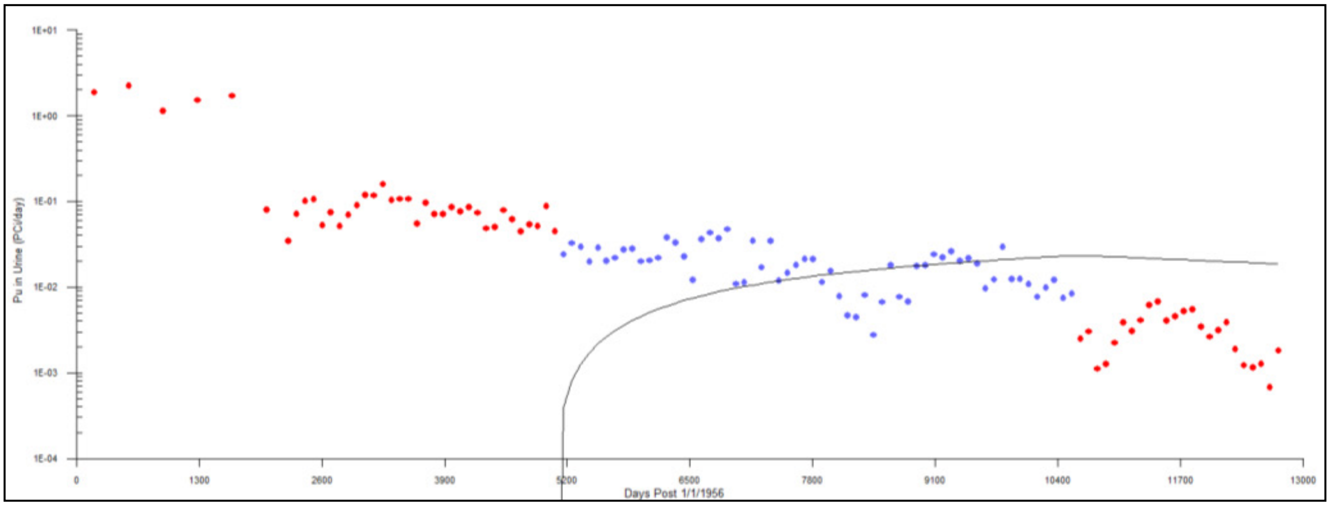

Figure B-23. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1970 to 1984.

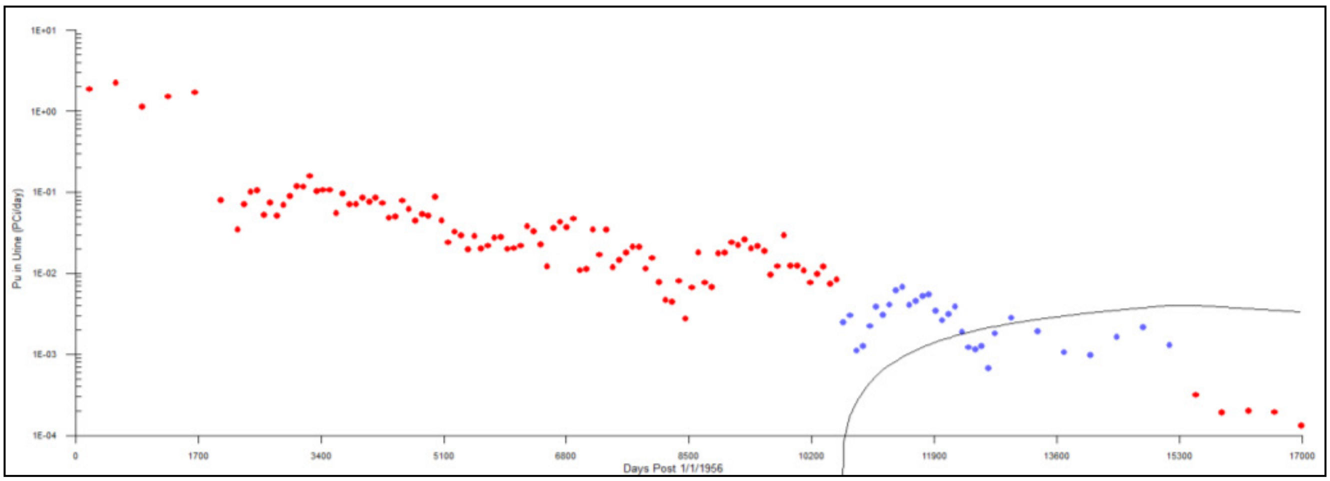

Figure B-24. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1985 to 1997.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

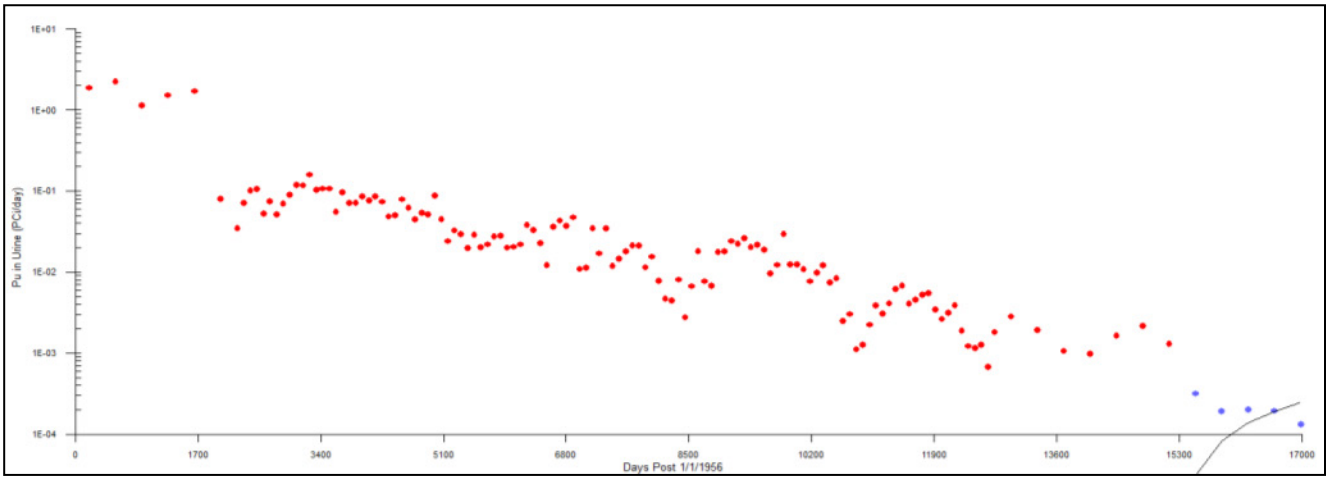

Figure B-25. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1998 to 2002.

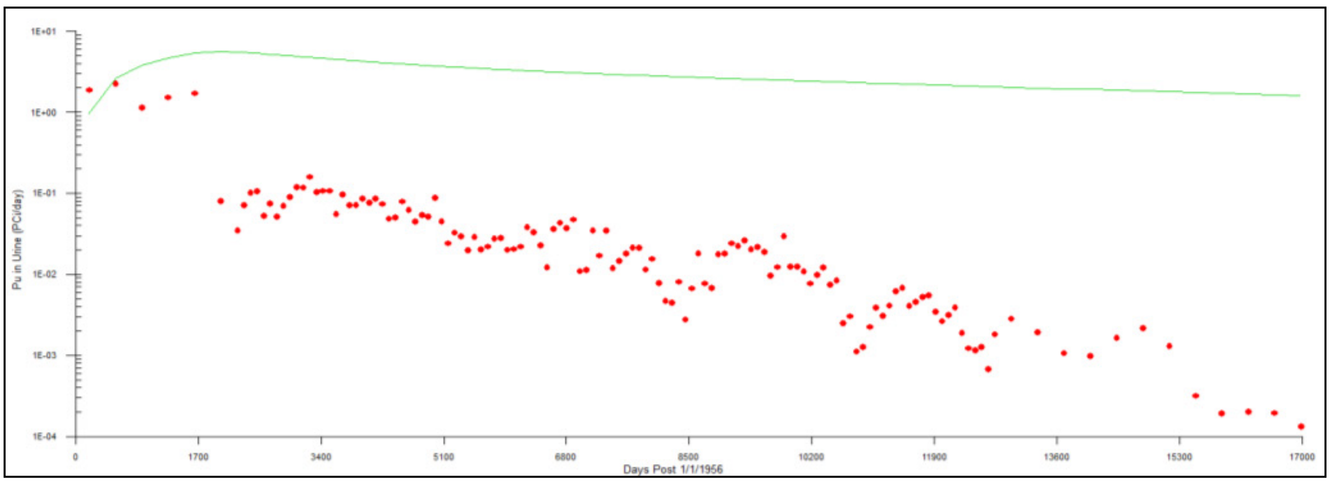

Figure B-26. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1956 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

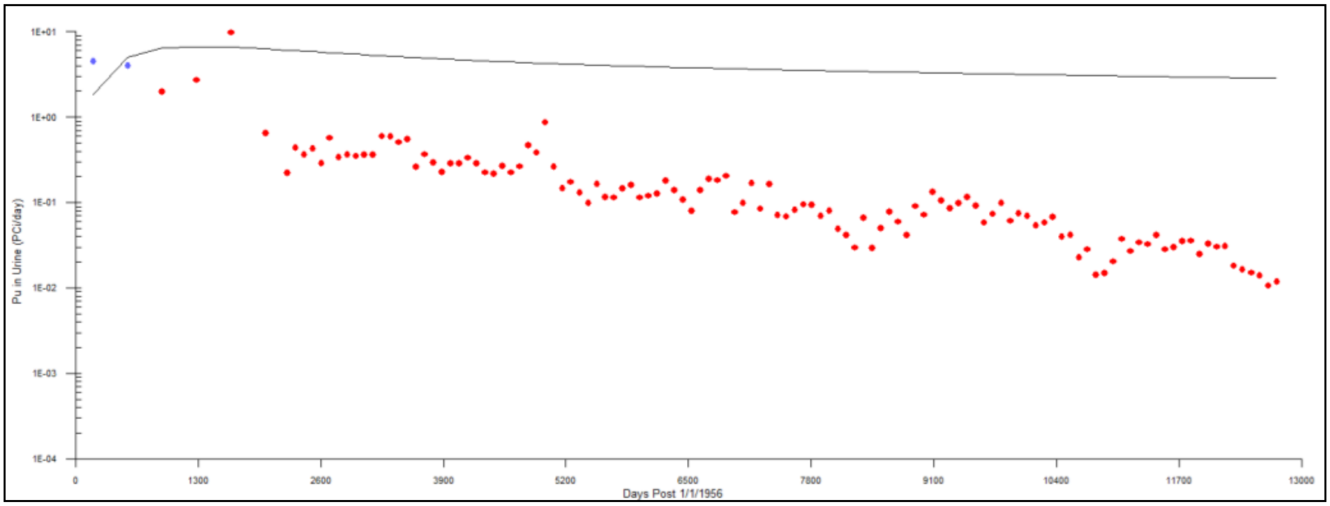

Figure B-27. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1956 to 1957.

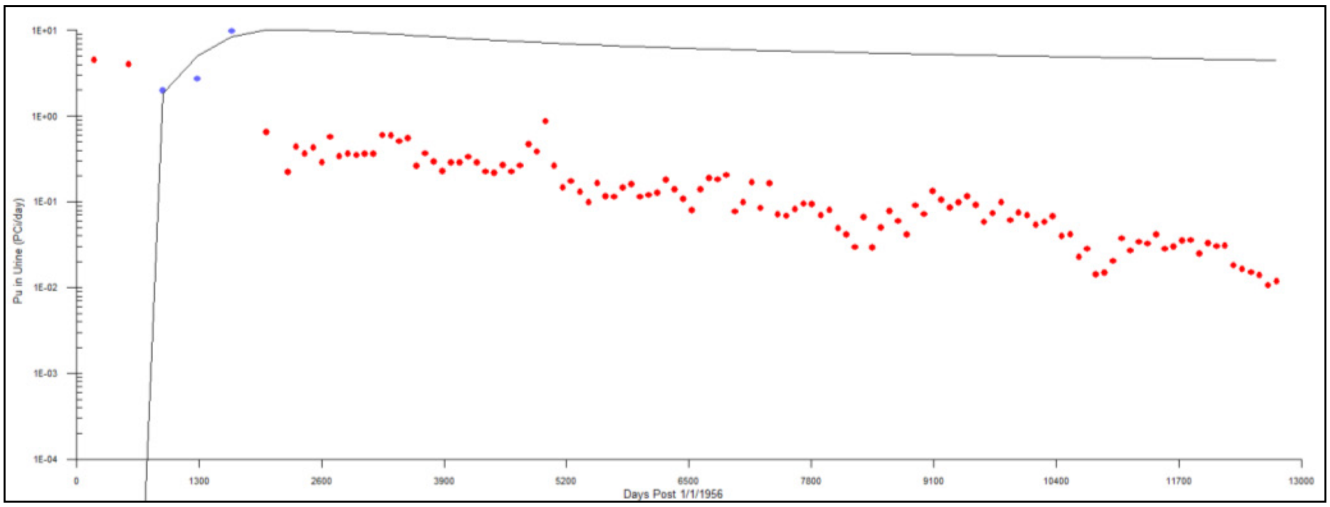

Figure B-28. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1958 to 1960.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

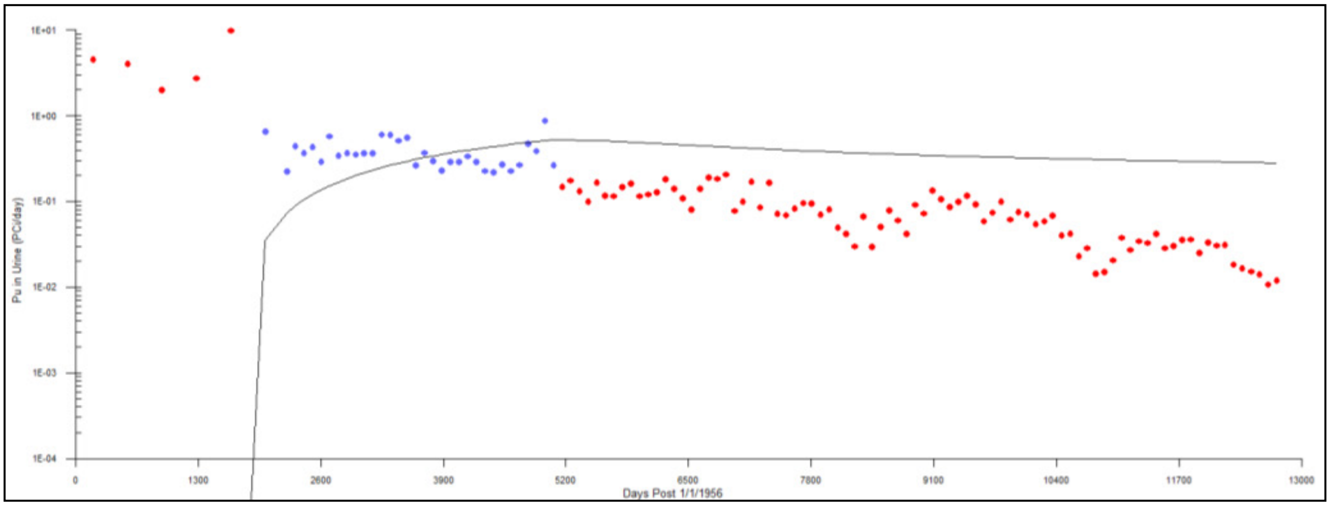

Figure B-29. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1961 to 1969.

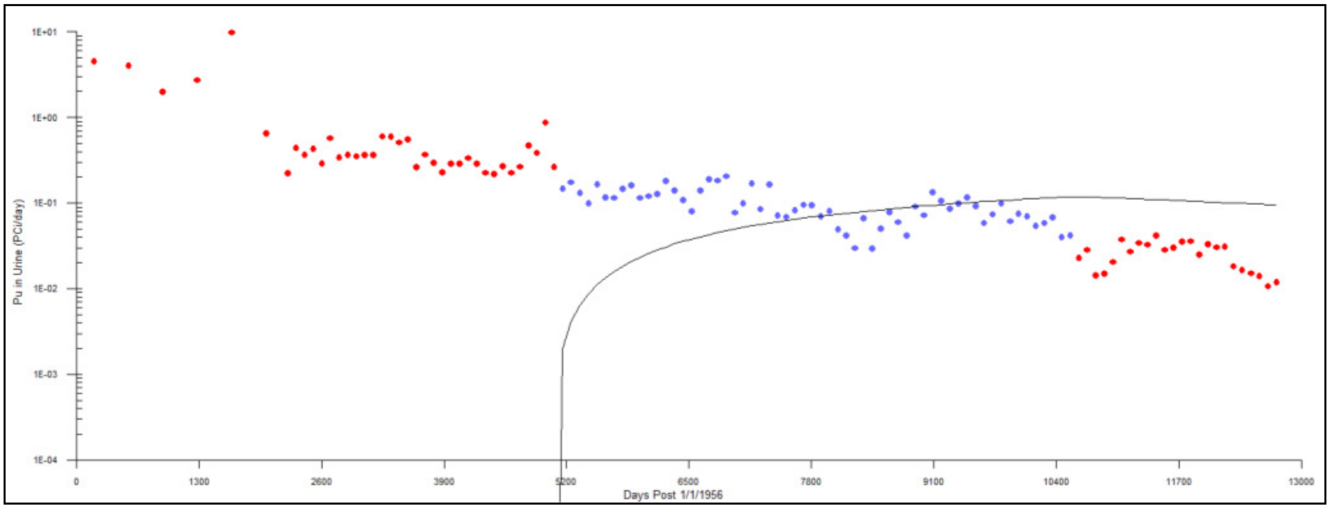

Figure B-30. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1970 to 1984.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

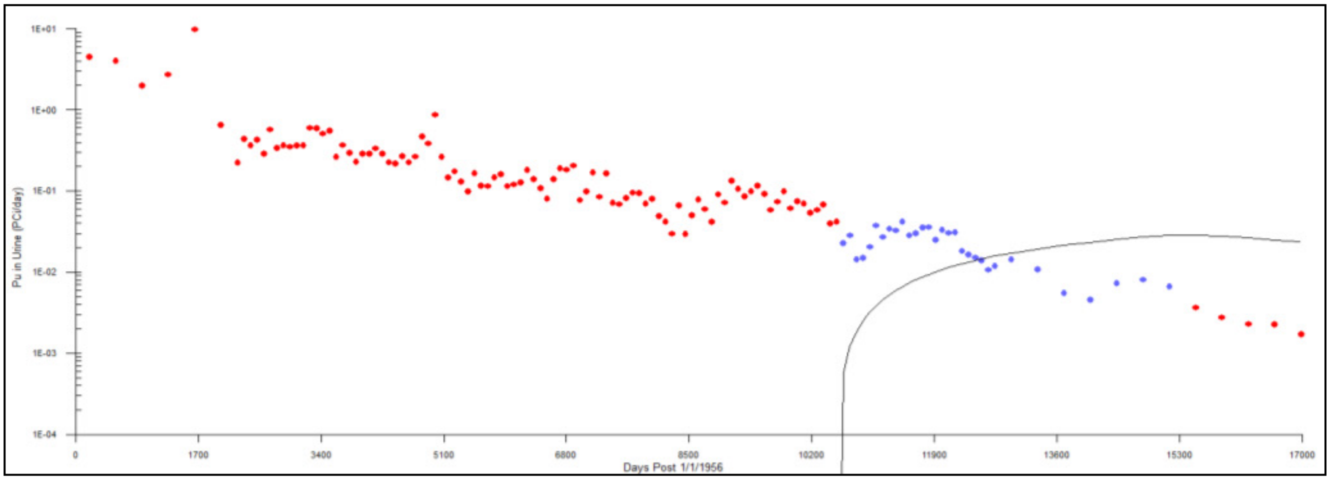

Figure B-31. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1985 to 1997.

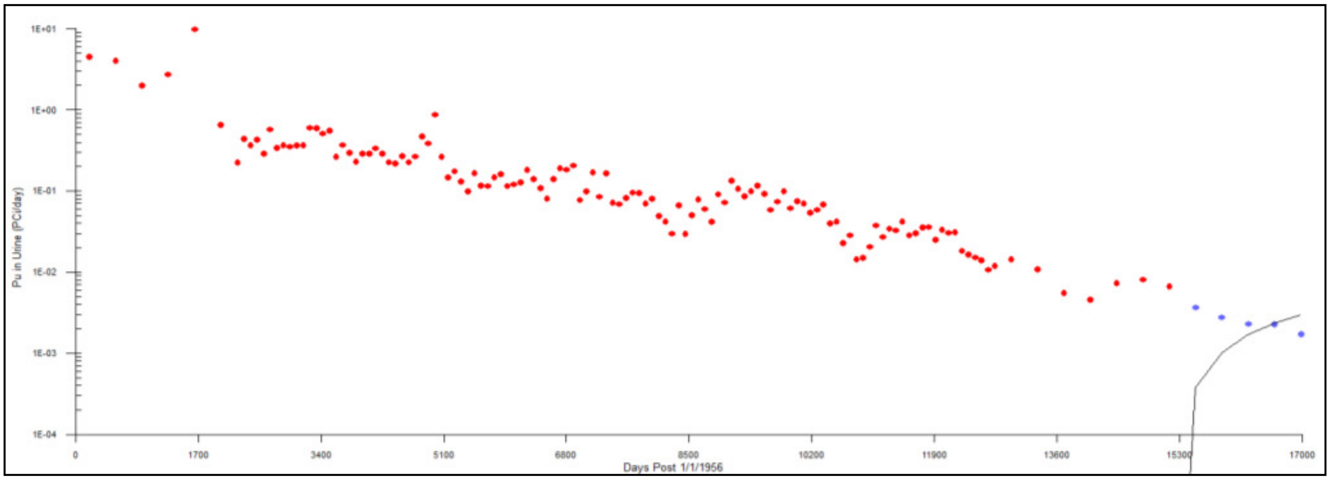

Figure B-32. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1998 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

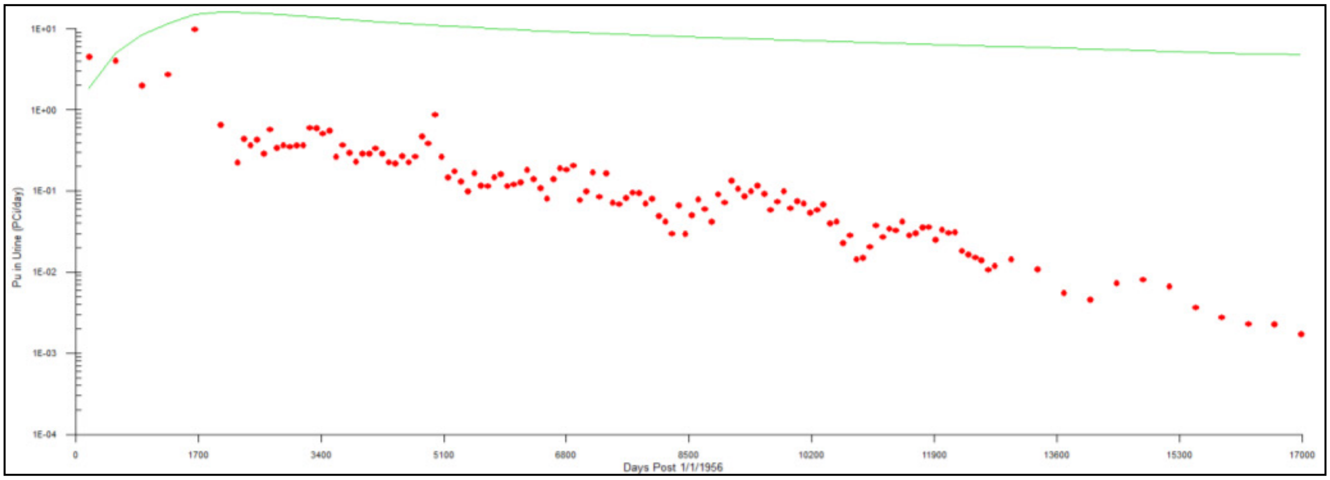

Figure B-33. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type S plutonium, 1956 to 2002.

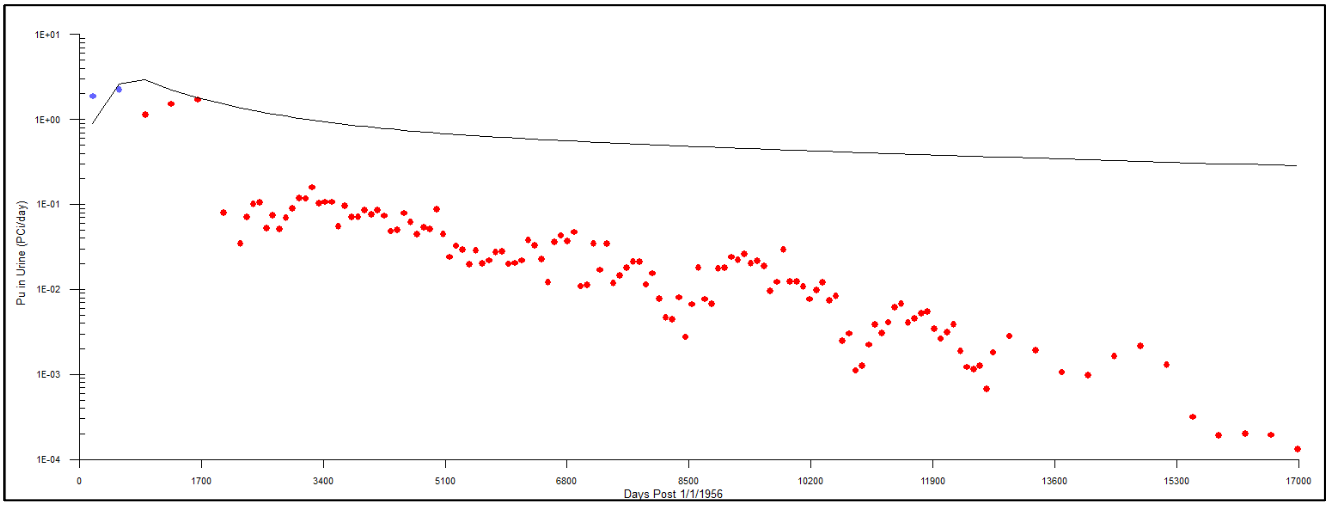

Figure B-34. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1956 to 1957.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

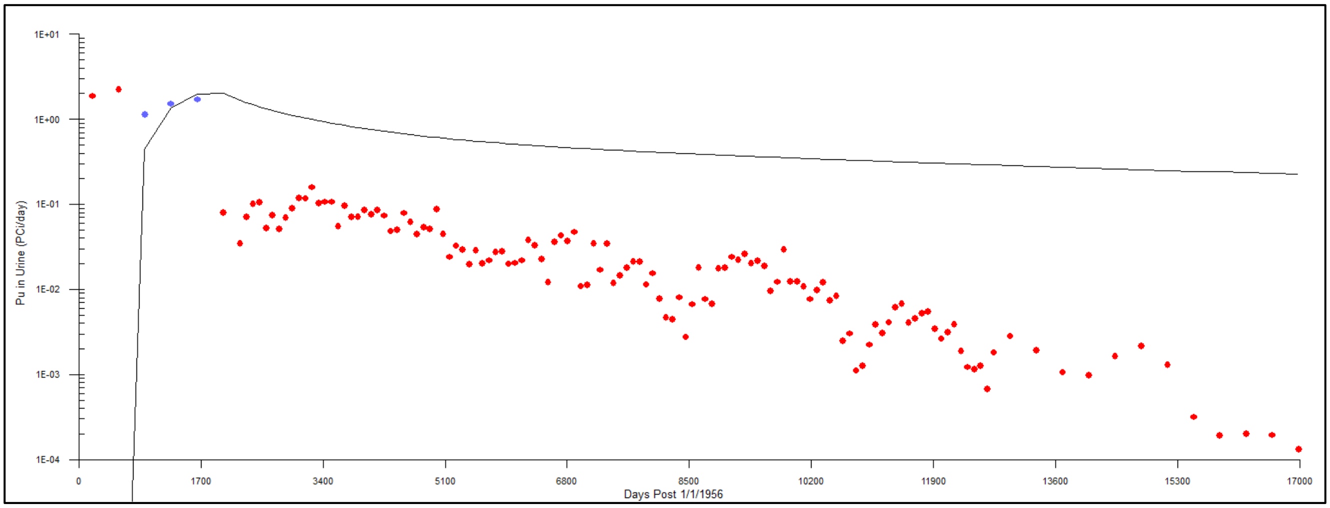

Figure B-35. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1958 to 1960.

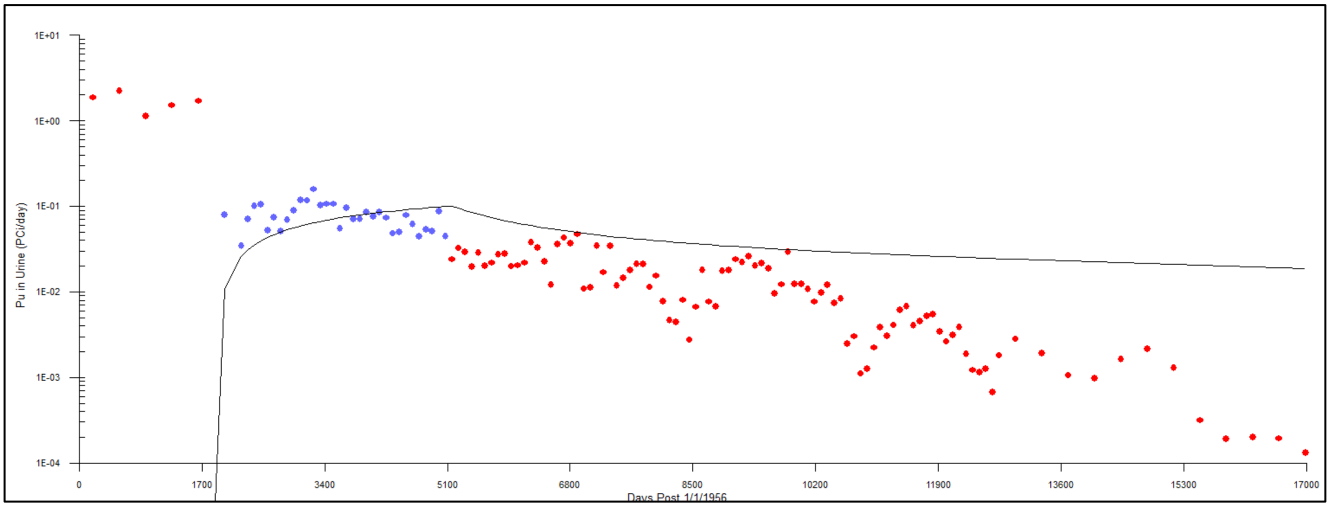

Figure B-36. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1961 to 1969.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

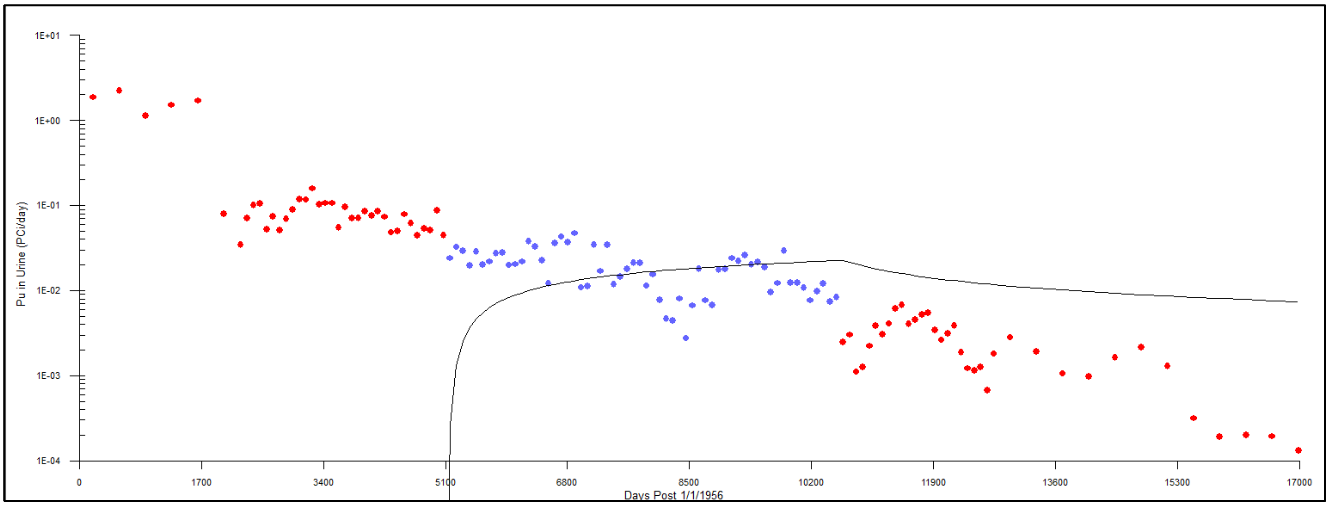

Figure B-37. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1970 to 1984.

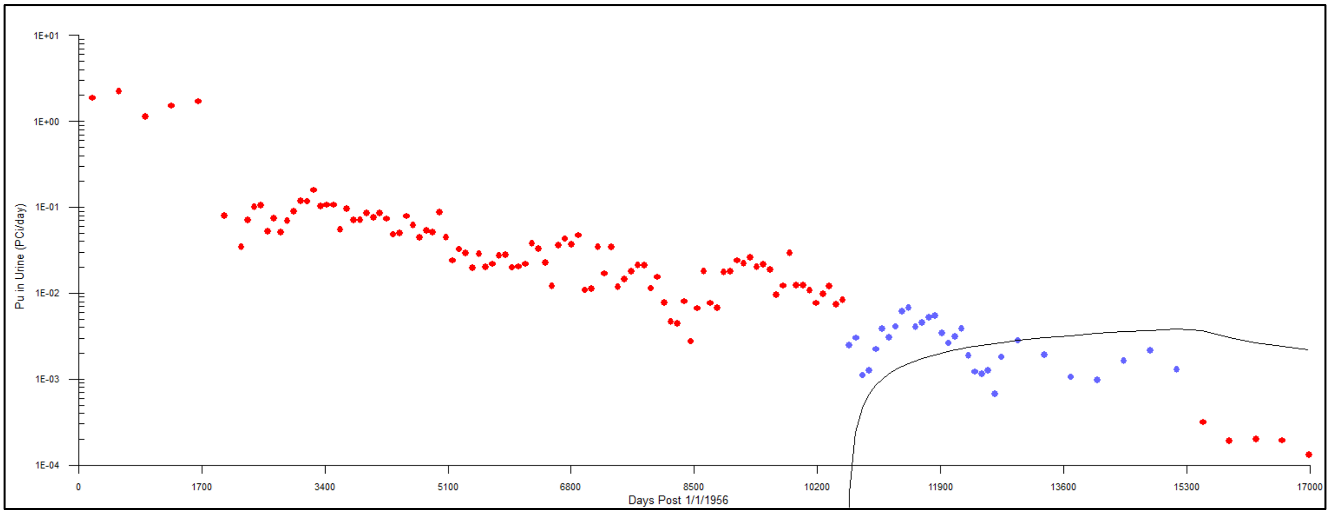

Figure B-38. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1985 to 1997.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

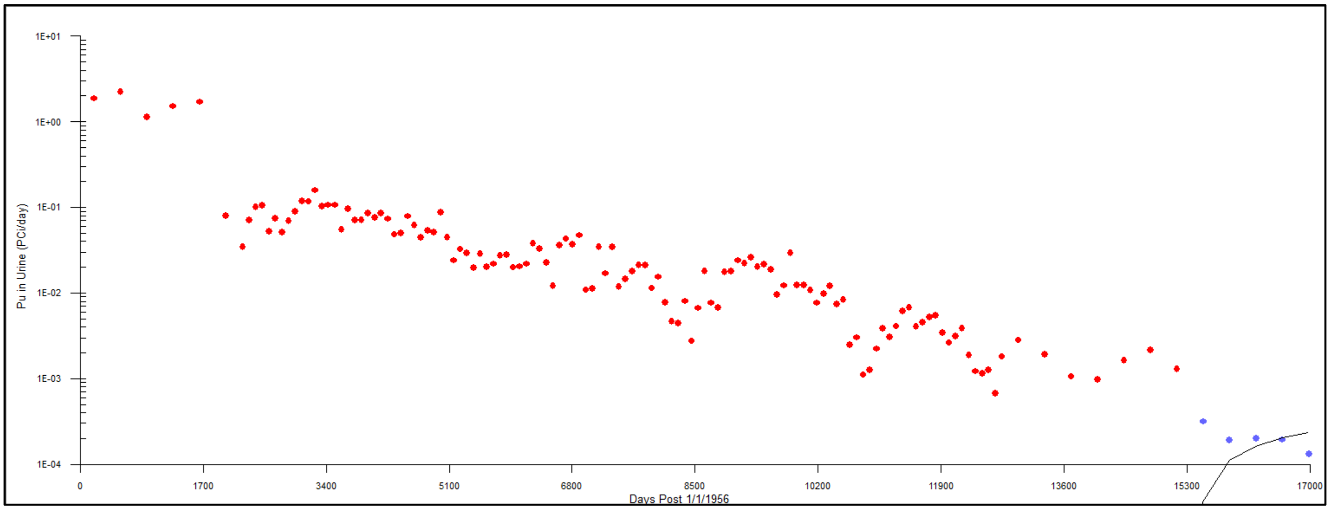

Figure B-39. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1998 to 2002.

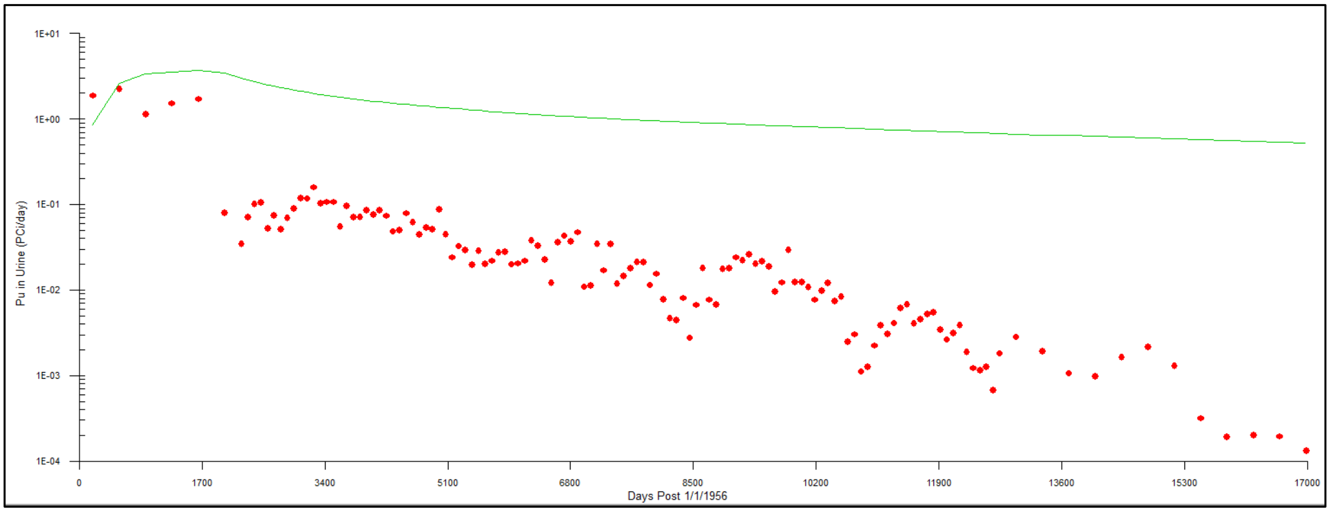

Figure B-40. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1956 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

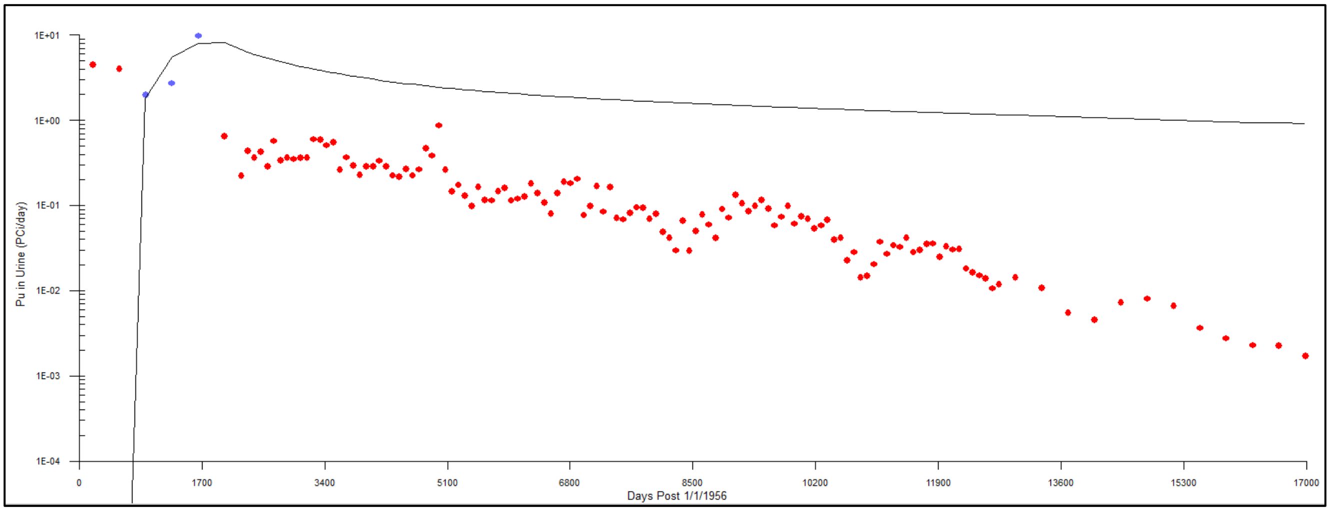

Figure B-41. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1956 to 1957.

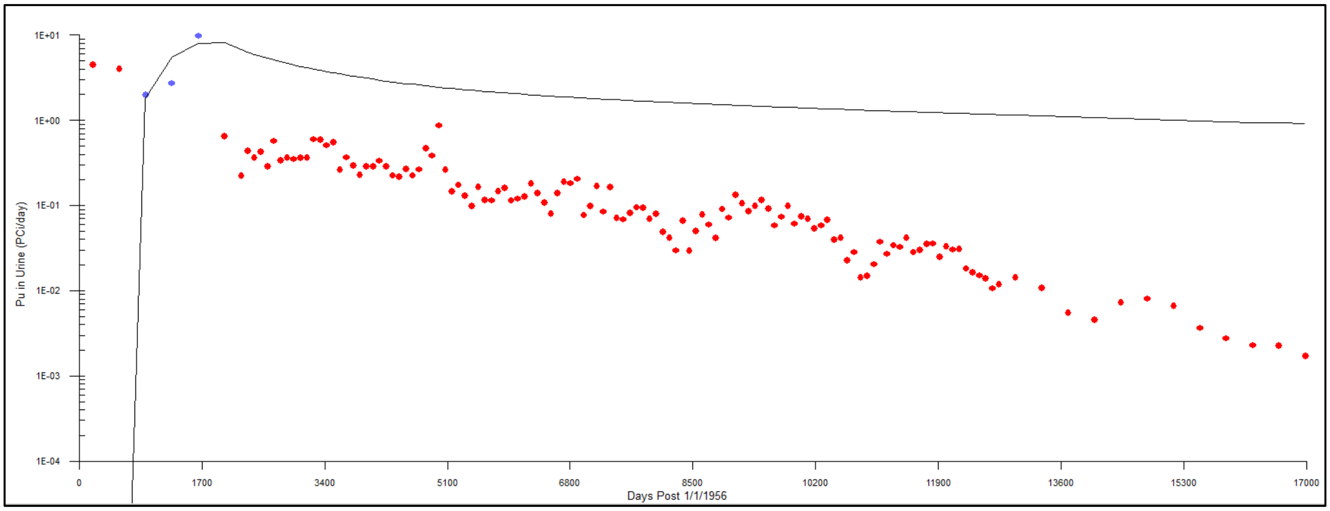

Figure B-42. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1958 to 1960.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

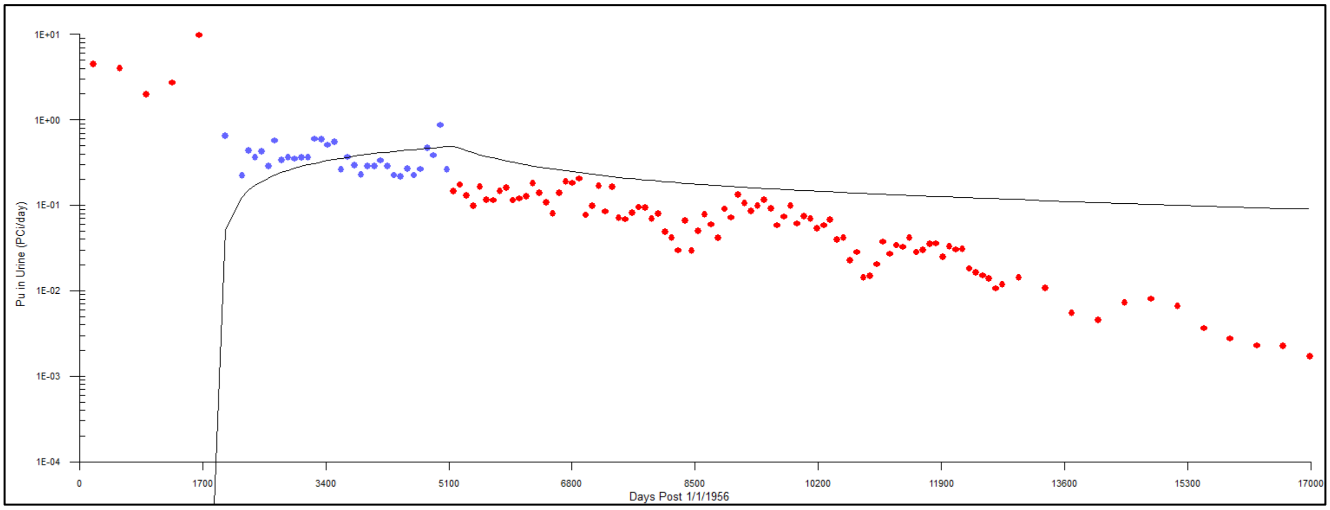

Figure B-43. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1961 to 1969.

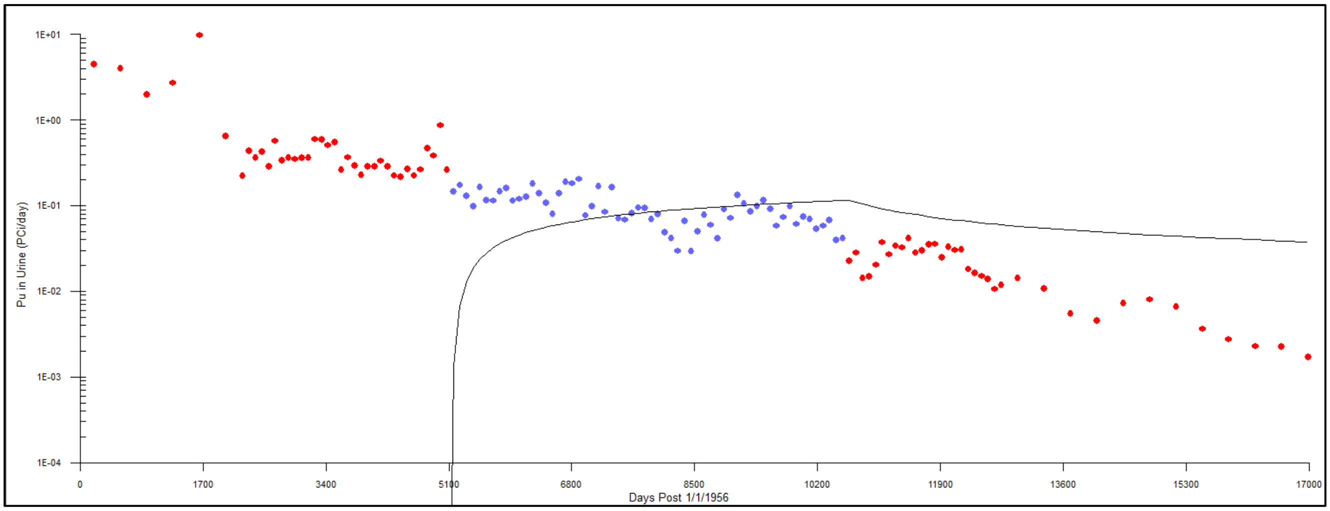

Figure B-44. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1970 to 1984.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

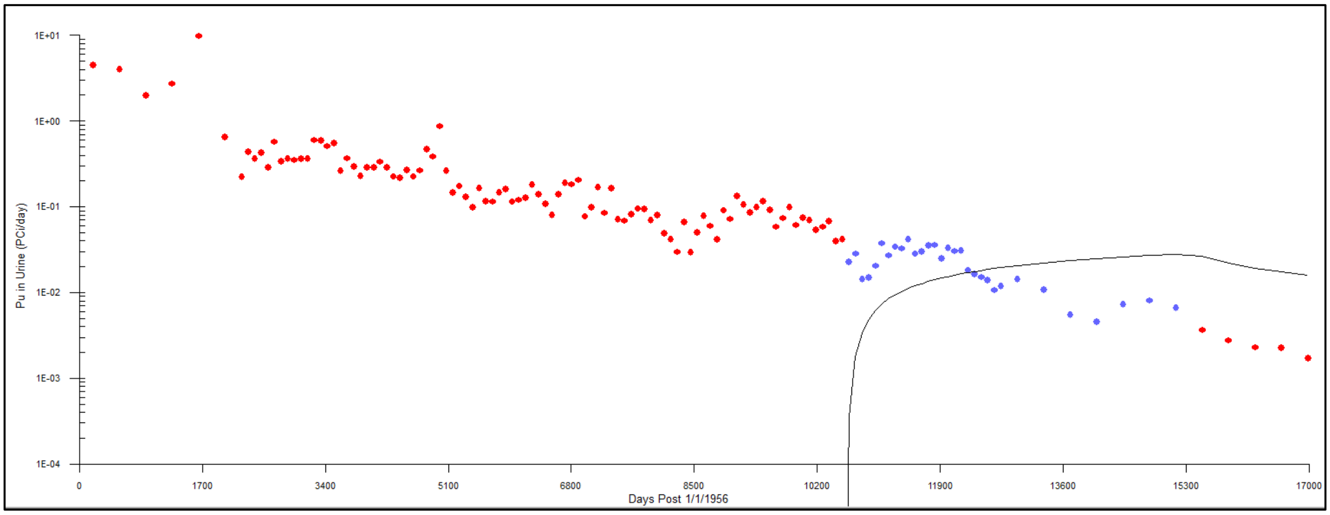

Figure B-45. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1985 to 1997.

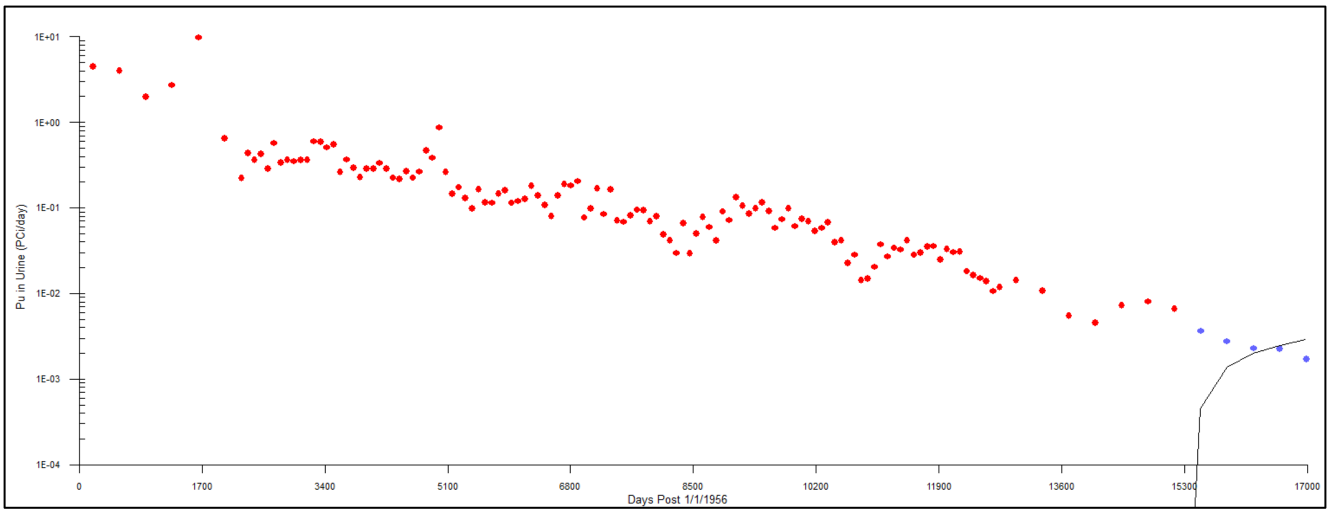

Figure B-46. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1998 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

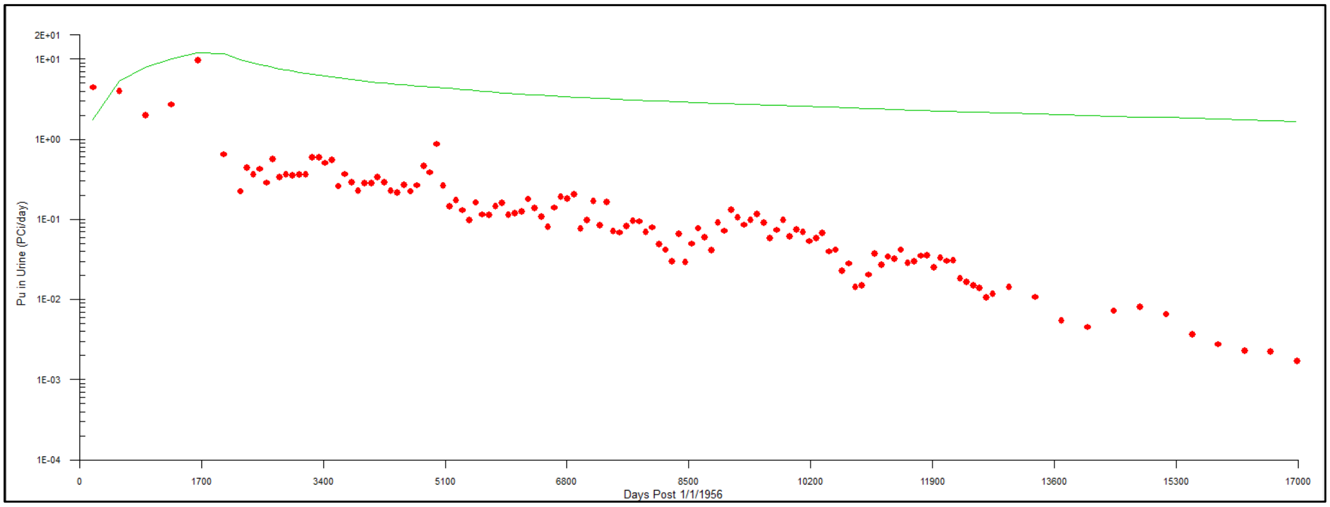

Figure B-47. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type MHI ^{238}Pu, 1956 to 2002.

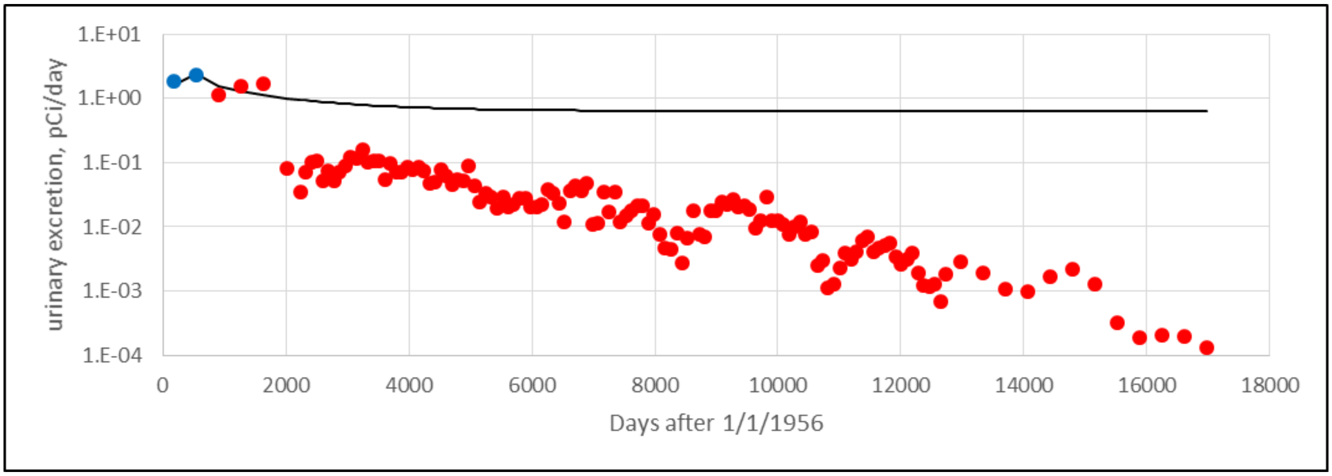

Figure B-48. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1956 to 1957.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

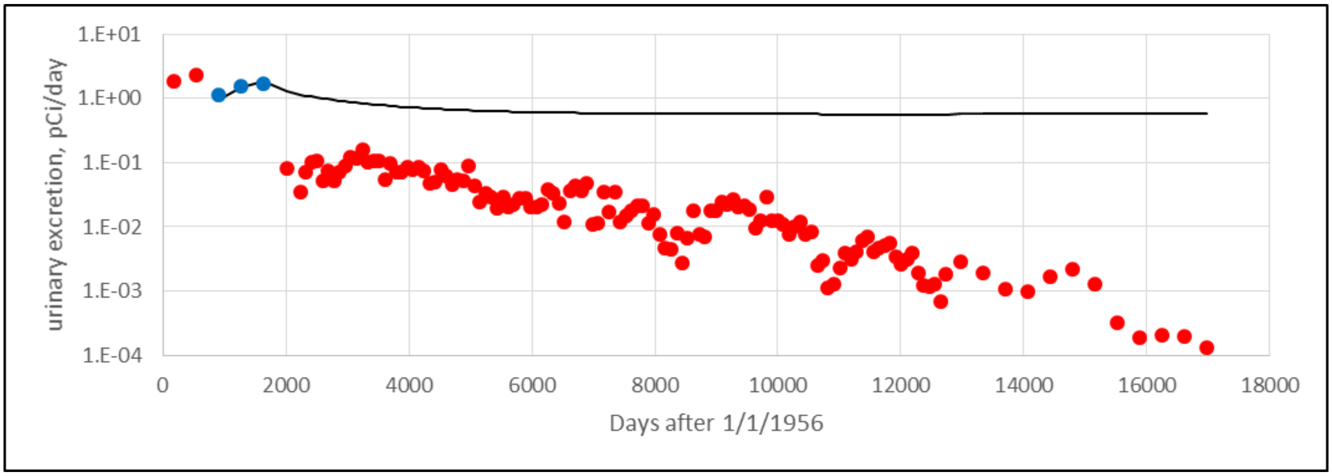

Figure B-49. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1958 to 1960.

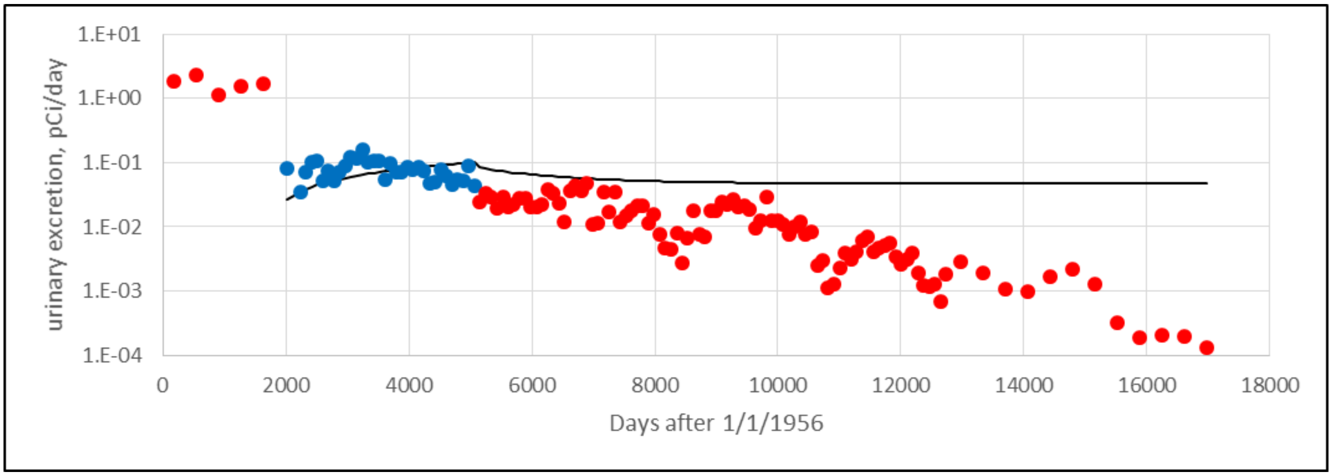

Figure B-50. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1961 to 1969.

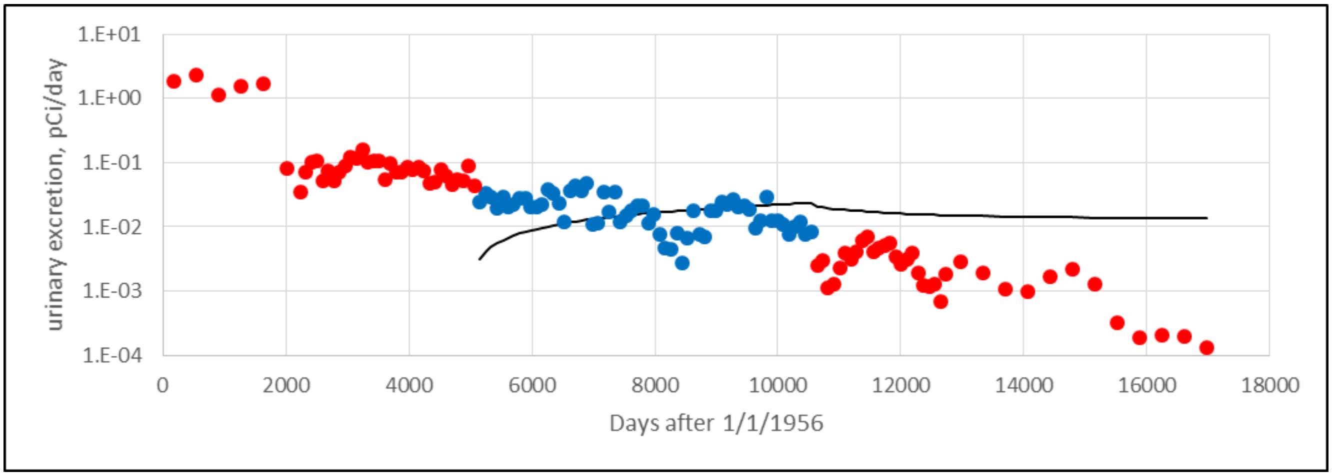

Figure B-51. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1970 to 1984.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

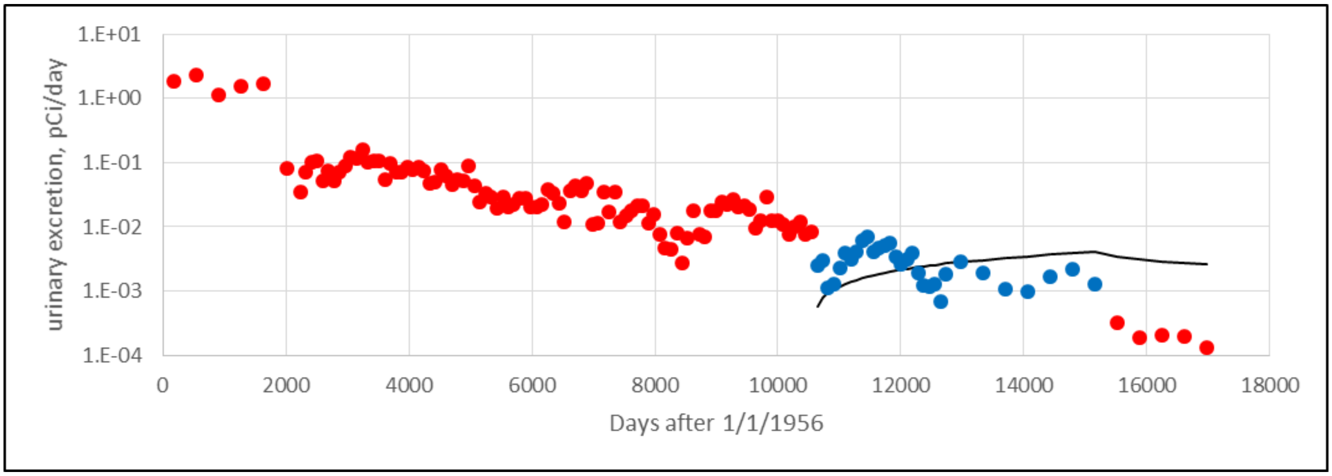

Figure B-52. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1985 to 1997.

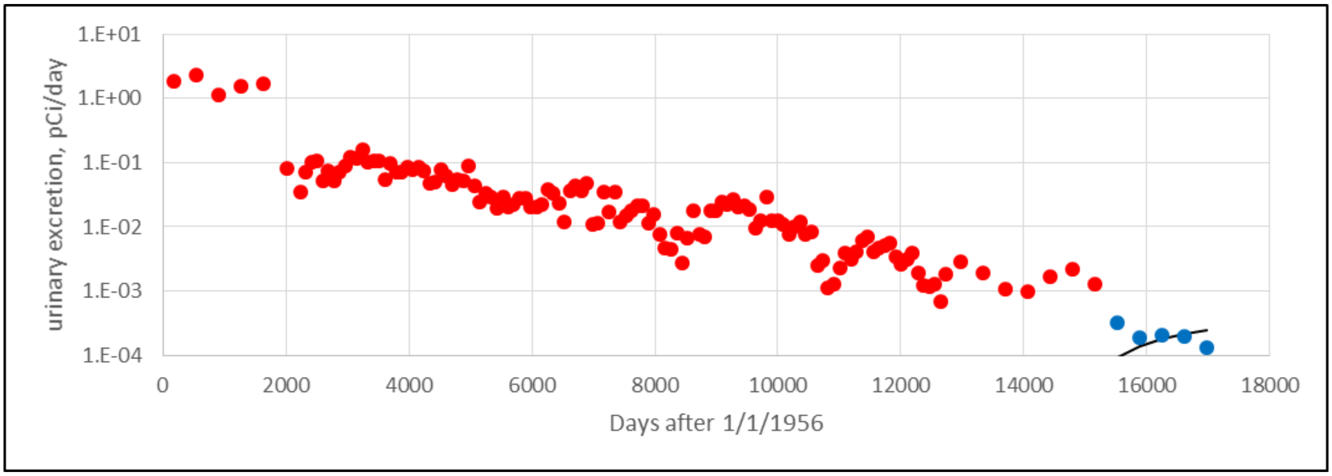

Figure B-53. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1998 to 2002.

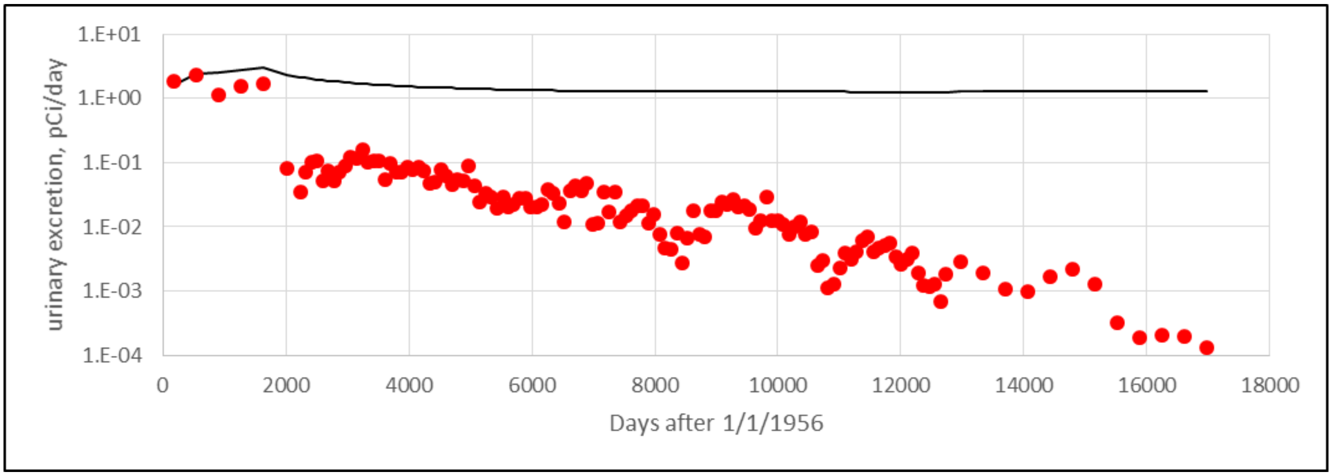

Figure B-54. Predicted (line) and observed (dots) 50th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1956 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

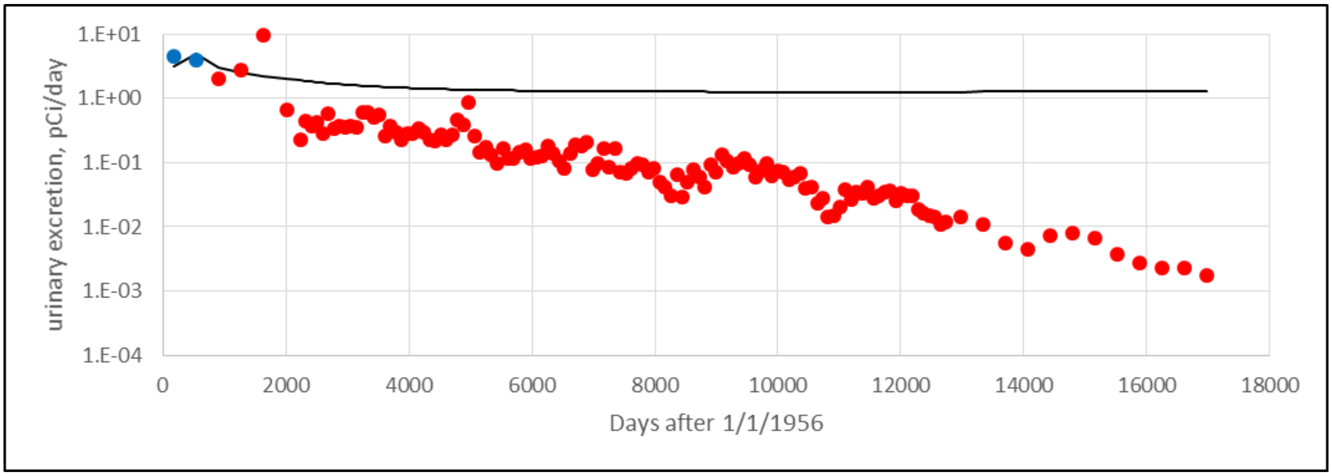

Figure B-55. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1956 to 1957.

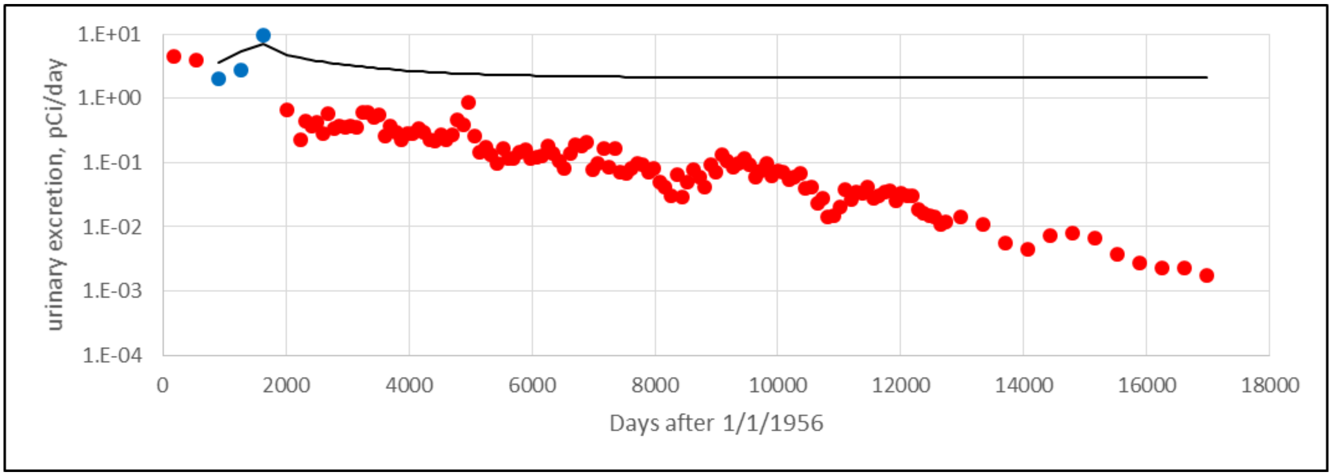

Figure B-56. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1958 to 1960.

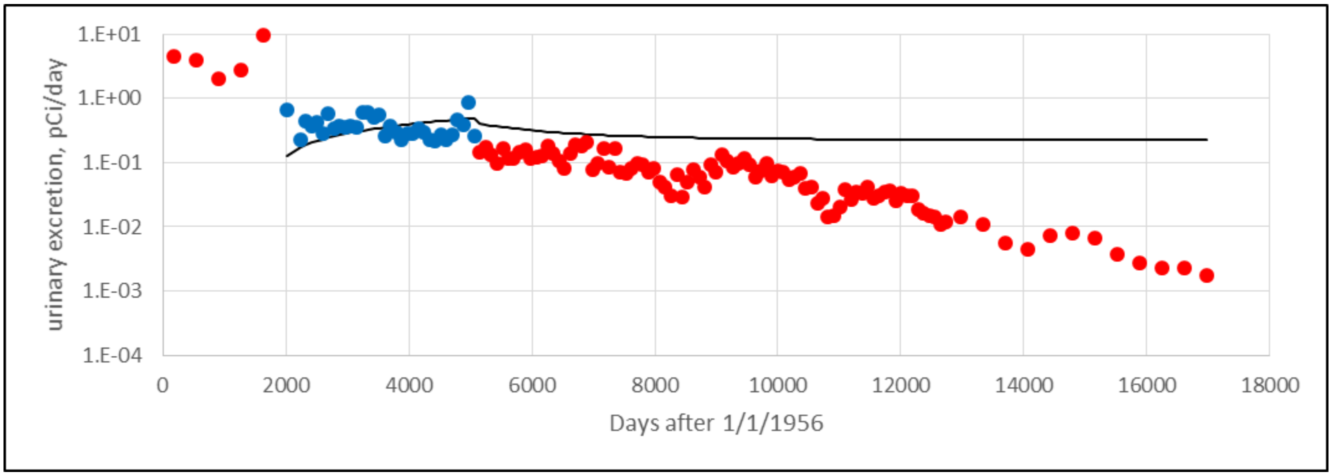

Figure B-57. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1961 to 1969.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

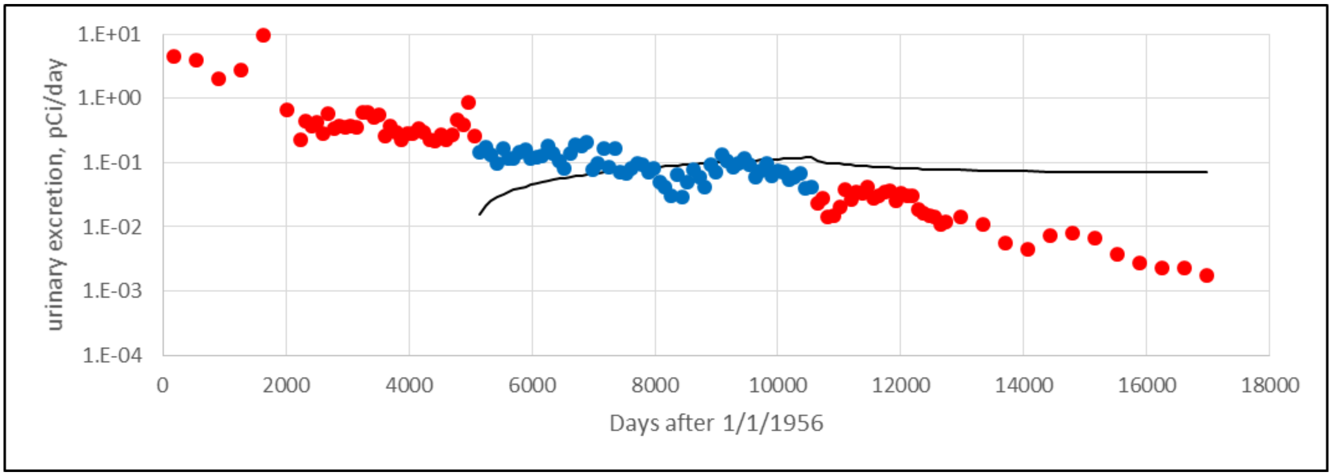

Figure B-58. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1970 to 1984.

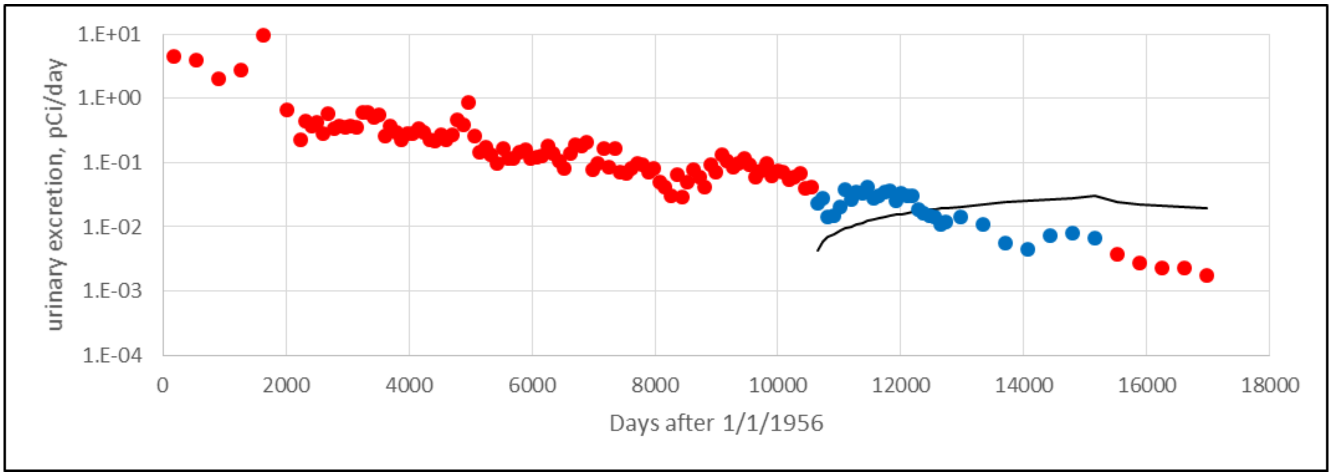

Figure B-59. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1985 to 1997.

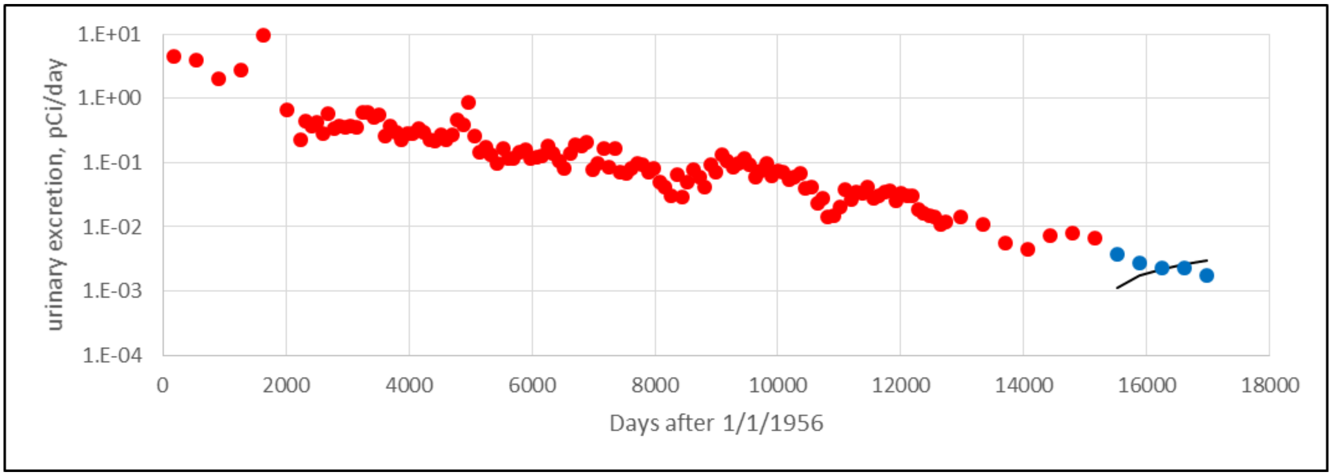

Figure B-60. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1998 to 2002.

ATTACHMENT B
CO-EXPOSURE DATA FIGURES (continued)

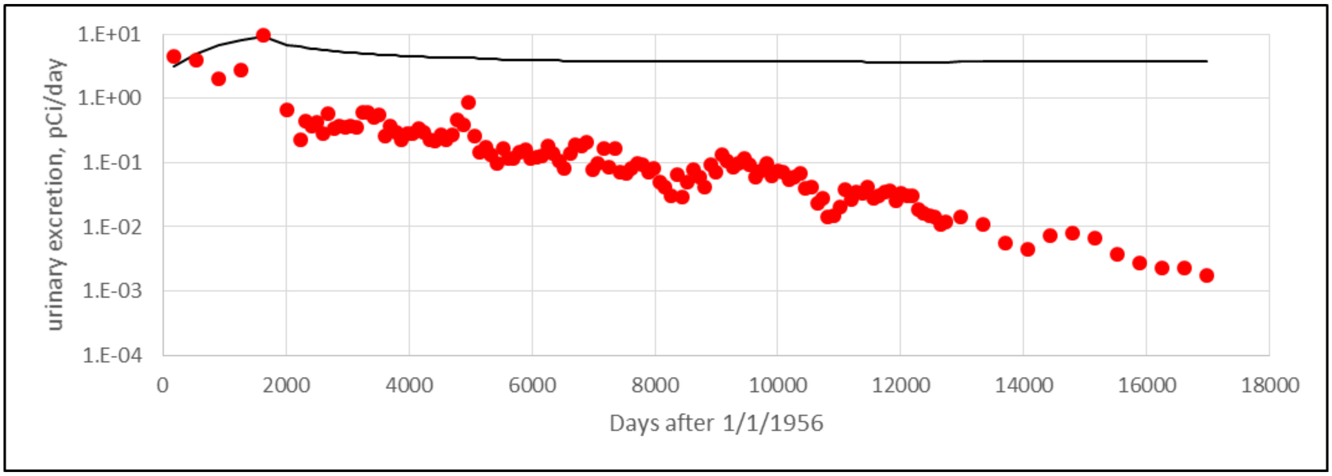

Figure B-61. Predicted (line) and observed (dots) 84th-percentile urinary excretion assuming a single chronic inhalation intake of type SS plutonium, 1956 to 2002.