ORAU TEAM
Dose Reconstruction
Project for NIOSH

Oak Ridge Associated Universities I Dade Moeller I MJW Technical Services

DOE Review Release 01/02/2014

Document Title:	Document Number:	ORAUT-OTIB-0081
Internal Coworker Dosimetry Data for the Savannah River Site	Revision:	02
	Effective Date:	12/16/2013
	Type of Document:	OTIB
	Supersedes:	Revision 01

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☐ New ☐ Total Rewrite ☒ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/08/2013	00	New technical information bulletin to provide internal coworker data for the Savannah River Site. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Matthew Arno.
04/01/2013	01	Revision initiated to correct the values provided in Tables 5-6, Type S uranium intake rates for 1968 through 2007, 5-10, changed end date from 2006 to 2007, A-3, plutonium bioassay data for 1955 through 2007, and A-8, neptunium bioassay data for 1991 through 2007. Incorporates formal internal review comments. No changes were made as a result of formal NIOSH review. No sections were deleted. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.
12/16/2013	02	Revision initiated to add dose reconstruction guidance for radionuclide assignment in response to an ABRWH request. Text added in Section 5.0 and a new Table 5-1 added. Intake rates for Cm and Cf added for the pre-1995 time period. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Matthew G. Arno.

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ACRONYMS AND ABBREVIATIONS

cm	centimeter
cpm	counts per minute
d	day
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DU	depleted uranium
EU	enriched uranium
g	gram
GSD	geometric standard deviation
HPRED	Health Protection Radiation Exposure Database
hr	hour
IA	Insufficient Amount
ICRP	International Commission on Radiological Protection Publication
ID	identification
IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
L	liter
LIP	Lost in Process
MDA	minimum detectable activity
MFP	mixed fission product
MFPG	mixed fission product - gamma
mL	milliliter
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH-Office of Compensation Analysis and Support Claims Tracking System
NT	natural uranium
OPOS	one-person, one-sample
ORAU	Oak Ridge Associated Universities
pCi	picocurie
QA	quality assurance
ROI	region of interest
SRS	Savannah River Site
TIB	technical information bulletin
U.S.C.	United States Code

WBC	whole-body count
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 in the event additional relevant information is obtained about the affected site(s). 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)].

ORAUT-OTIB-0019, *Analysis of Coworker Bioassay Data for Internal Dose Assignment* (ORAUT 2005a) describes the general process NIOSH uses to analyze bioassay data for the assignment of doses to individuals based on coworker results. ORAUT-PLAN-0014, *Coworker Data Exposure Profile Development* (ORAUT 2004a) describes the approach and processes to develop reasonable exposure profiles based on available dosimetric information for workers at DOE sites.

Bioassay results were obtained directly from the Savannah River Site (SRS) for 1991 through 2007. For the period before 1991, SRS does not have an electronic database of bioassay results. For years before 1991, the bioassay data in the NIOSH-Office of Compensation Analysis and Support Claims Tracking System (NOCTS) for SRS employees was used to develop a representative database of coworker bioassay data using the guidance of ORAUT-OTIB-0075, *Use of Claimant Datasets for Coworker Modeling* (ORAUT 2009).

A statistical analysis of the data was performed according to ORAUT-OTIB-0019 (ORAUT 2005a) 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) computer software to obtain intake rates for the assignment of dose distributions.

2.0 PURPOSE

Some employees at DOE sites were not monitored for potential intakes of radioactive material, or the records of such monitoring are incomplete or unavailable. In such cases, data from monitored coworkers can be used to assign an internal dose to address potential intakes of radioactive material. The purpose of this TIB is to provide monitored coworker information for calculating and assigning occupational internal doses to employees at SRS for whom no or insufficient monitoring records exist.

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

3.0 DATA OVERVIEW

This section provides information on the general selection characteristics of the data and methods of analysis. More detailed radionuclide-specific information is provided in Section 4.0.

3.1 BIOASSAY DATA SELECTION

Bioassay results were obtained directly from SRS in the form of an electronic database for 1991 through 2007. For the period before 1991, SRS does not have an electronic database of bioassay results. For years before 1991, the bioassay data in NOCTS for SRS employees were used to develop a representative database of coworker bioassay data (ORAUT 2009). In addition, neptunium and americium urinalysis bioassay data were obtained from SRS laboratory notebooks (DuPont 1961–1969, 1963–1970, 1969, 1969–1973, 1970–1973, 1973–1978, 1973–1979, 1978–1983, 1979–1980, 1980–1981a,b, 1981–1986, 1986–1989).

3.1.1 NOCTS Urinalysis Data

NOCTS data were used for this coworker study in the absence of a database of usable data from SRS for the period before 1991 as the best available compilation of data in a usable (i.e., electronic spreadsheet or database) form. The NOCTS database was queried on May 7, 2008, to generate a list of all claimants who worked at SRS before 1991. This list identified 1,421 individuals. Data for six additional individuals that became available during the data entry process were added for a total of 1,427 individuals. The NOCTS identification (ID) numbers of the specific individuals are listed in ORAUT (2011). The *in vitro* bioassay data for these individuals were entered in spreadsheets (some already existed in this form after the completion of dose reconstructions for those individuals) and subjected to a 100% verification review by a second person.

Records with results or units of "LIP" (Lost In Process) or "IA" (Insufficient Amount) were excluded from the evaluation because those records represent instances in which samples were collected but not analyzed. Records with units of per-unit-volume were adjusted to "per-1.5L" based on an assumed 1.5 L/d of urinary excretion. Volumes greater than 1 L were assumed to represent a full day's voiding and were not adjusted. Volumes less than or equal to 1 L were normalized to 1.5 L.

3.1.2 NOCTS Whole-Body Count Data

NOCTS whole-body count (WBC) data were used for ^{137}Cs and ^{237}Np analyses. WBC data were used for ^{237}Np only for the period during which urinalysis data were not available (i.e., 1970 to 1989). The NOCTS ID numbers of the specific individuals identified are listed in ORAUT (2011).

Cesium-137 Data

Cesium-137 results in nanocuries are commonly reported for WBCs in the NOCTS data. Some of the results are reported as a positive value, an uncensored value, a "<" value, or "<MDA" with a quantified count-specific minimum detectable activity (MDA) provided. Depending on the WBC reporting format, the MDA at the 95% confidence level is also available.

Neptunium-237 Data

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

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

$$nCi\ {}^{237}Np = 0.243 \times \left[\left({}^{131}I\ net\ cpm\right) - 0.389 \times \left({}^{40}K\ net\ cpm\right)\right] \qquad (3\text{-}1)$$

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

$$nCi\ {}^{237}Np = 0.243 \times (DIFF\ counts\ for\ 300\text{-}to\ 400\text{-}keV\ ROI) \qquad (3\text{-}2)$$

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

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

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

$$nCi\ {}^{237}Np = 0.211 \times ({}^{51}Cr\ DIFF\ counts) \times ({}^{51}Cr\ MDA\ nCi) \div ({}^{51}Cr\ MDA\ counts) \qquad (3\text{-}4)$$

3.1.3 Health Protection Radiation Exposure Database

In vitro data for 1991 through 2007 were obtained from the SRS Health Protection Radiation Exposure Database (HPRED) in the form of a text file named "NIOSH_SRS.txt." Review of the file revealed that it was in a fixed-width format. The text file was imported into a database according to the convention in Table 3-1. In a few instances, the field widths varied, which resulted in the first character of the "result" field at the end of the "isotope" field. The instances were manually corrected.

Table 3-1. SRS HPRED data import format.

No.	Field title	Start	Field width	Field type
1	OUO	1	18	Text
2	SSN	19	10	Long integer
3	Sort date	29	11	Text
4	Sort time	40	10	Text
5	Isotope	50	10	Text
6	Result	60	7	Double
7	Units	67	11	Text
8	Type	78	21	Text
9	Date received	99	11	Text
10	Time received	110	10	Text
11	Date added	120	11	Text
12	Time added	131	10	Text
13	Batch	141	10	Text
14	Sample #	151	7	Text
15	Activity	158	10	Text
16	Critical level	168	10	Text
17	Error	178	13	Text

From these data, the following records were excluded from further analysis:

- “Type” = “baseline”
- “Type” = “fecal” or any variation of the word fecal
- “Units” = “IA” but not “IA followup”
- “Type” = “QC”

Additional evaluation of the data resulted in modification as follows:

- If the “Sort date” field was blank or before January 1, 1990, the “Date received” was used instead.

- If the “Activity” field was blank, the “Result” field was used instead. Further, if the “Result” was positive (i.e., greater than zero), it was used as is; if the “Result” was negative, it was assumed to be a less-than value (i.e., “-1.5” was assumed to be “<1.5”) [1].

- Values with units of “per sample” were assumed to represent 24-hour samples.

- Records with units of per-unit-volume were adjusted to “per-1.5L” based on an assumed 1.5 L/d for urinary excretion.

3.1.4 Neptunium Logbook Data

Neptunium urinalysis bioassay data were obtained from SRS laboratory notebooks (DuPont 1961–1969, 1969) and from NOCTS records for years after 1969. The laboratory notebook data were transferred to a spreadsheet and subjected to a 100% verification review by a second person. Records with results or units of LIP or IA were excluded from the evaluation because those records represent instances in which samples were collected but not analyzed. It was assumed that all records are in units of dpm/1.5L. Many records were only partially legible, but contained enough information to infer the results; in particular, data indicated as “<0.0X” or “<0.XX” was assumed to be “<0.05”, a common reporting level. Similarly, results indicated as “<1” due to an illegible decimal place were changed to “<0.1,” the actual reporting level for the period.

3.1.5 Americium Logbook Data

The americium data from the logbooks were transferred to a spreadsheet and subjected to a quality assurance (QA) verification in accordance with MIL-STD-105E, *Sampling Procedures and Tables for Inspection by Attributes* (DOD 1989). A total of 315 out of 17,449 records were randomly picked and reviewed for accuracy of the data transcription. The first round of verification identified generic issues, which were corrected; a second round of verification indicated an acceptable error rate. In the second round, 15 errors were identified, 7 of which were classified as critical errors (i.e., errors that would affect subsequent data analysis). Seven errors of a sample of 315 records equates to a 1% error rate in the full data set. Per MIL-STD-105E, for a lot between 10,001 and 35,000 items, fewer than 8 errors results in lot acceptance based on the statistical variability of sampling. The errors that were identified during the QA process were corrected. In addition, other errors were discovered during subsequent statistical analyses of the data, usually as a result of identification of outliers in the dataset. The most common error was omission of the decimal due to legibility issues, resulting in higher than actual bioassay results. These corrections were made and documented before further analysis.

A single americium urine sample was commonly counted multiple times, usually twice but as many as 10 times was noted. The data in the logbooks consisted of one or more count rate results for each urine sample in units of dpm per disc, depending on how many times a sample was counted (this information was not used) and count-specific results in units of net dpm/1.5 L (this information was used). Further, a reported value for each sample, also in units of dpm/1.5 L, was usually provided. The result in dpm/1.5 L for each count of a sample was generally recorded as an uncensored value (i.e., the calculated result was recorded regardless of its value). In contrast, the “reported” values were generally censored (i.e., results less than some level, typically the detection or reporting limit were reported as a less-than result). Some dpm/1.5 L data that were less than zero were reported as zero.

Not all sample records included all this information, and in some instances the count-specific results were censored. If count-specific results were available, the valid results were averaged by the Oak Ridge Associated Universities (ORAU) Team to determine the sample result. This value was generally uncensored. If count-specific results were not available, the reported values were used, many of which were censored. Excluded samples included those marked as LIP, those marked “DTPA” to indicate chelation, or those that lacked sufficient identifying information (e.g., sample date or worker ID number).

Three sample results were excluded as false positives because the subsequent samples had no detected activity. In addition, all results for three individuals were excluded for an entire year due to an ingestion intake, a plutonium wound intake, and an incident that resulted in the highest assigned intake of ^{244}Cm in the history of SRS. These incidents and intakes were characterized by an extremely high number of bioassay results, many of which were orders of magnitude higher than the bioassay data for other individuals and were considered unrepresentative of the potential exposure to an unmonitored worker.

3.2 ANALYSIS

Bioassay data were analyzed by year or multiyear span, depending on the amount of data available for each radionuclide during a given period and the expected biokinetics of each radionuclide. A lognormal distribution was assumed. After the data were log-transformed, the 50th and 84th percentiles were determined for each period through the use of the method described in ORAUT-OTIB-0019 (ORAUT 2005a). A large fraction of the data for every radionuclide was entered as zero bioassay results. These zeros were retained in the analysis to rank the results.

In ORAUT-OTIB-0075 (ORAUT 2009), arguments are presented to support the practice of treating a claimant dataset as a simple random sample from the population of all monitored workers. One potential problem posed by using a claimant dataset is that workers who were involved in incidents usually submit more samples than workers who submit only routine (non-incident-related) samples. This is problematic because a small number of workers who were involved in incidents can dominate the claimant sample in a given year through the sheer number of submitted samples and because the samples in the dataset are no longer independent of each other. At SRS, the small population of workers subject to bioassay testing results in a similar problem. To compensate for the unequal number of samples submitted by workers, the "one-person, one-sample" (OPOS) technique was used, in which only one result was used for each person for each radionuclide for a given year. The OPOS statistic is calculated using the maximum possible mean methodology of ORAUT-RPRT-0053, *Analysis of Stratified Coworker Datasets* (ORAUT 2012).

3.3 TRITIUM

Claimant tritium urine bioassay data for 1954 to 1990 were obtained from the NOCTS dataset. This dataset contained 260,607 bioassay results for samples submitted by 1,520 workers between 1954 and 1990. Tritium urine bioassay data for all workers from 1991 to 2007 were obtained from the HPRED dataset. This dataset contained 881,561 bioassay results for samples submitted by 21,320 workers between 1991 and 2007. All bioassay results were reported in units of microcuries per liter.

3.4 PLUTONIUM

3.4.1 <u>NOCTS-Based Analysis</u>

NOCTS data were used for 1955 through 1990. Records with an isotope type identified in the "Pu" column of Table A-1 in Attachment A were tagged as plutonium data and used for this analysis. Records reporting gross plutonium results were assumed to be in units of dpm/1.5 L if no units were provided based on an examination of contemporaneous records. Isotope-specific results without units were assumed to be in units of dpm/1.0 L for the same reason. When isotopic data were reported, only the ^{239}Pu measurements were used and were corrected to be plutonium gross alpha equivalent assuming at 12% (fuel-grade) 10-year-aged plutonium mixture. Any records with mass units or in units of nanocuries or microcuries were assumed to be fecal samples and were excluded. Records within 60 days of chelation for an individual were also excluded.

3.4.2 <u>HPRED-Based Analysis</u>

HPRED was used for 1991 through 2007. HPRED records with an isotope type identified in the "Pu" column of Table A-2 in Attachment A were tagged as plutonium data and used for this analysis. Only the ^{239}Pu measurements were used. The results were converted to plutonium gross alpha data assuming a 12% (fuel-grade) 10-year-aged plutonium mixture for intake modeling.

3.5 URANIUM

3.5.1 <u>NOCTS-Based Analysis</u>

In the NOCTS data, uranium urinalysis results are recorded in units of both mass (micrograms) and activity (disintegrations per minute). For the coworker study, the mass-based measurements were converted to equivalent activity assuming natural uranium (0.683 pCi/g) through 1967 and depleted uranium (DU; 0.372 pCi/g) thereafter and merged with the activity-based data before statistical analysis. Records with an isotope type identified in the "U (all)" column of Table A-1 in Attachment A were tagged as uranium data and used for this analysis. Assumptions used to provide missing units and volumes were based on an examination of contemporaneous records:

- Designation of missing units:
  If the results field was “<5”, mass (µg) units were assumed
  If the results field was “<1”, activity (dpm) units were assumed
  If the results field was not “<5” or “<1”,
  - Activity (dpm) units were assumed if the Isotope =
    - EU (enriched uranium)
    - Eu
    - U234
    - U235
    - U238
  - Otherwise mass (micrograms) units were assumed

- Assembly of mass data:
  From the above selected records, records with mass units were selected, including:
  - ug/L
  - µg/L
  - ug/1.5L
  - µg/1.5L
  - ?g/L
  - ?g/1.5L
  - Those assigned mass units in the previous step

  From start of data through July 10, 1961, results were assumed to be “per liter” and converted to “per 1.5 liter” regardless of stated volume.

  From July 11, 1961, through December 31, 1990, all results were assumed to be “per 1.5 liter” regardless of stated volume.

- Assembly of activity data:
  Records with activity units were selected, including:
  - dpm/ 1.5 L
  - dpm/1.5L
  - dpm/1.5l
  - dpm/750ml
  - dpm/L
  - Records with missing units assigned activity units (A volume of 1.5 L was assumed for these records.)

3.5.2 HPRED-Based Analysis

HPRED was used for 1991 through 2007. HPRED records with an isotope type identified in the “U” column of Table A-2 in Attachment A were tagged as uranium data and used for this analysis. For mass-based uranium measurements, the specific activity of depleted uranium (0.372 pCi/g) was assumed based on ORAUT-TKBS-0003, *Savannah River Site* (ORAUT 2005b). If isotopic data were reported, the ^{234}U, ^{235}U, and ^{238}U results for the same person (“SSN” field) and date (using “Sort date” or “Date received” per the above instructions) were summed to yield a gross uranium activity. If all three measurements were based on the “Result” field rather than the “Activity” field and were negative (i.e., <MDA measurements), the sum was treated as a <MDA measurement; otherwise, it was treated as a real measurement. Nonisotopic measurements [EU, (NT)/DU] were assumed to represent all uranium present.

3.6 AMERICIUM, CURIUM, AND CALIFORNIUM

Bioassay techniques for americium, curium, and californium varied as a function of time at SRS. Of the techniques SRS used, the most significant feature is that differentiation between americium, curium, and californium was not possible until the use of alpha spectroscopy began in 1995. Before 1995, regardless of the notation placed in an individual's bioassay record, the analytical technique was the same. Therefore, americium, curium, and californium bioassay data are considered collectively before 1995 to determine excretion rates although separate intake rates are calculated. Beginning in 1995, each radionuclide was evaluated separately.

3.6.1 Logbook-Based Analysis

Americium logbook data were used for 1966 through 1989. Records reporting gross americium/ curium/californium results were assumed to be in units of dpm/1.5 L if no units were provided, based on an examination of contemporaneous records. Records with units of "per unit mass" were assumed to be fecal samples and excluded.

Examination of the data revealed occasions during which individuals were involved in incidents that resulted in large intakes and excretions. These data were judged to be unrepresentative of coworkers and were removed. The incidents were:

- One individual was involved in an incident on March 9, 1970. This person's bioassay data were excluded for the remainder of 1970.
- One individual was involved in an incident on March 16, 1972. This person's bioassay data were excluded for the remainder of 1972.
- One individual had a plutonium wound intake on May 8, 1986, which affected the americium bioassay results. This person's bioassay data were excluded for the remainder of 1986.
- Three individuals had false positive results, which were excluded.

3.6.2 HPRED-Based Analysis

HPRED data were used for 1991 through 2007. HPRED records with an isotope type identified in the "AmCmCf" column of Table A-2 in Attachment A were tagged as americium/curium/californium data and used for this analysis for 1991 through 1994. Beginning in 1995, each radionuclide was evaluated separately based on the isotope types identified in the "Am," "Cm," and "Cf" columns of Table A-2 and tagged as americium, curium, and californium, respectively.

3.7 NEPTUNIUM

For neptunium, the NOCTS urinalysis data contained insufficient data for a coworker model for the period before the era for which HPRED data were available. However, bioassay laboratory logbook data were found that provided results for 1961 through 1969 (DuPont 1961–1969, 1969). These data were assumed to be a complete dataset for this period.

NOCTS WBC data were used for 1970 through 1989.

For 1991 through 2007, HPRED data were used in the normal manner. HPRED records with an isotope type identified in the "Np" column of Table A-2 in Attachment A were tagged as neptunium data and used for this analysis for 1991 through 2007.

3.8 FISSION AND ACTIVATION PRODUCTS

Fission and activation products are evaluated in accordance with ORAUT-RPRT-0047, *Assignment of Fission and Activation Product Radionuclides for Non-Specific Bioassays at Savannah River Site – Comparison of Methods* (ORAUT 2013a) or subsequent revisions, using either ^{90}Sr or ^{137}Cs as the indicator radionuclide. The indicator radionuclide to be used varies as a function of time based on the available data. For the period before 1991, urinalysis bioassay of beta-emitting radionuclides was available for 1955 through 1965 and of gamma-emitting radionuclides for 1966 through 1989, referred to as mixed fission product (MFP) and mixed fission product - gamma (MFPG) data respectively. WBC results for ^{137}Cs were also available in this period. Starting in 1991, ^{90}Sr-specific urinalysis results from the HPRED data were available and were used as the preferred indicator radionuclide.

3.8.1 Strontium

NOCTS data were used for 1955 through 1965. Records with an isotope type identified in the "MFP" column of Table A-1 in Attachment A were tagged as MFP data and used for this analysis. If no units or sample volume were provided, results were assumed to be in units of dpm/750 mL for 1955 through 1959. For 1960 through 1965, the units were assumed to be dpm/500 mL if the result was "<30" or "<50" and dpm/1.5 L if the result was "<100," "<60," or positive.

HPRED data were used for 1991 and after. HPRED records with an isotope type identified in the "Sr" column of Table A-2 in Attachment A were tagged as strontium data and used for this analysis for 1991 through 2006.

3.8.2 Cesium-137

Cesium-137 was evaluated only for the period from 1961 through 1989 based on WBC data. For 1990, a limited amount of ^{137}Cs data was available due to a change in WBC methods, equipment, and reporting formats (use of the ABACOS system). The available data in a usable format for 1990 were inconsistent with the data for 1989 and potentially biased and were, therefore, not used. Uncensored data were used as is. Censored data or records for which an MDA but no result was provided were used as count-specific censoring levels. The MFPG data was evaluated but determined to be less sensitive than the WBC data and therefore was not used for this coworker study. Any contribution of fallout to ^{137}Cs whole-body burdens and calculated intake rates was ignored. After 1990, ^{90}Sr based on HPRED data was used to evaluate the intake of MFP.

3.8.3 Cobalt-60

Cobalt-60 was evaluated for 1955 through 1970. During this period, some workers handled pure or relatively pure ^{60}Co. The bioassay method used to monitor intakes from this work was MFP and MFPG analysis.

Cobalt-60 data were available in the form of MFP data for 1955 through 1965 and in the form of MFPG data from 1966 through 1970. Records with an isotope type identified in the "MFP" column of Table A-1 in Attachment A were tagged as MFP data and used for this analysis for 1955 through 1965. If no units or sample volume were provided, results were assumed to be in units of dpm/750 mL for 1955 through 1959. For 1960 through 1965, the units were assumed to be dpm/500 mL if the result was "<30" or "<50" and dpm/1.5 L if the result was "<100," "<60," or positive.

Records with an isotope type identified in the "MFPG" column of Table A-1 in Attachment A were tagged as MFPG data and used for this analysis for 1966 through 1970. All records were assumed to be in units of nCi/1.5 L. In addition, records with an isotope type identified in the "MFP" column of Table A-1 for 1966 through 1970 were tagged as MFPG data if the recorded units were nCi/1.5 L, or if there were no units given and the result was less than 30 and "FPIA Beta" was not recorded in the "Isotope" field. All the MFPG data were divided by 2 to account for the fact that ^{60}Co has two strong gamma rays emitted per disintegration.

3.9 THORIUM

The separation technique SRS used for americium, curium, and californium before 1990 also captured thorium (NIOSH 2012; Butler and Hall 1970; Taylor et al 1995). Therefore, the americium, curium, and californium bioassay data discussed above in Section 3.6.1 was also used to model thorium intakes for 1972 through 1989.

4.0 INTAKE MODELING

This section discusses intake modeling assumptions, intake fitting, and intake materials.

4.1 ASSUMPTIONS

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

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

For intake modeling purposes, all uranium activity was assumed to be ^{234}U. This assumption does not affect the fitting of the data for intake determination because all uranium isotopes have the same biokinetic behavior and the isotopes considered in this analysis all have long half-lives in relation to the assumed intake period. International Commission on Radiological Protection (ICRP) Publication 68 dose coefficients (also referred to as dose conversion factors) for ^{234}U are 7% to 31% larger than the dose coefficients for ^{235}U, ^{236}U, and ^{238}U (ICRP 1995). Therefore, the assumption that the intake is 100% ^{234}U provides a result that is favorable to claimants.

4.2 BIOASSAY FITTING

IMBA was used to fit the bioassay results to a series of inhalation intakes. Data from 1953 through 2007 were fit as a series of chronic intakes. The intake assumptions were based on observed patterns in the bioassay data. Periods with constant chronic intake rates were chosen by the selection of periods in which the bioassay results were similar. A new chronic intake period was started if the data indicated a significant sustained change in the bioassay results. By this method, the years from 1953 through 2007 were divided independently into multiple chronic intake periods for each radionuclide.

4.3 TRITIUM

Tritium was evaluated differently than the other radionuclides in this coworker study. The OPOS methodology was not used. For tritium, the protocol in *Technical Information Bulletin: Tritium Calculated and Missed Dose Estimates* (ORAUT 2004b) was used to calculate the dose for each individual with the following rules concerning the elapsed time between consecutive samples:

- If there was a single urine sample in a calendar year and it was a 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 after 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 [geometric mean, geometric standard deviation (GSD), and R^2] determined from a linear regression. Individuals that 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 $i/n - 1/(2n)$ convention specified in ORAUT-PROC-0095 (ORAUT 2006). Doses for 1954 to 1990 were calculated from the NOCTS dataset, which is considered a random sample of the complete dataset (ORAUT 2009). Doses for 1991 to 2001 were calculated from the HPRED dataset, which is considered a complete dataset.

4.4 PLUTONIUM

Because the plutonium isotopes at SRS have very long radiological half-lives, and because the material is retained in the body for long periods, excretion results are not independent. For example, an intake in the 1950s could contribute to urinary excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked at SRS for relatively short periods, each chronic intake was fit independently using only the bioassay results from the single intake period for type M and S solubilities. This method resulted in an overestimate of intakes for exposures that extended through multiple assumed intake periods. Only the results in the intake period were selected for use in the fitting of each period. Excluded results are shown in light gray or red in the figures in Attachment B; included results are shown in dark gray or blue. The results of the plutonium statistical analysis that was used to calculate the intakes are provided in Table A-3.

Plutonium Type M: The solid lines in Figures B-1 to B-4 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials. Figures B-5 and B-6 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes. Table B-1 lists the 50th- and 84th-percentile intake rates along with the associated GSDs determined from the plutonium urinalysis.

Plutonium Type S: The solid lines in Figures B-7 to B-10 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type S materials. The same intake periods were applied for both percentiles because the values followed a similar pattern. Figures B-11 and B-12 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type S intakes. Table B-2 lists the 50th- and 84th-percentile intake rates along with the associated GSDs determined from the plutonium urinalysis.

4.5 URANIUM

Because the uranium isotopes at SRS have very long radiological half-lives, and because the material is retained in the body for long periods for type S solubility, excretion results are not independent. For example, an intake in the 1950s could contribute to urinary excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked at SRS for relatively short periods, each chronic intake was fit independently using only the bioassay results from the single intake period for type S solubility. This method resulted in an overestimate of intakes for exposures that extended through multiple assumed intake periods. Only the results in the intake period were selected for use in the fitting of each period. Excluded results are shown in light gray or red in the figures in Attachment B; included results are shown in dark gray or blue. For type M and F solubility, this approach was not used.

The 50th-percentile result for 1989 was excluded from the intake modeling due to the abnormally low result for that year in comparison with contemporaneous years. This action results in a slight increase in the calculated intake rate. The results of the uranium statistical analysis that were used to calculate the intakes are provided in Table A-4.

Uranium Type F: The solid lines in Figures B-13 and B-14 in Attachment B show the fit to the 50th- and 84th-percentile excretion rates, respectively, for type F materials. Table B-3 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the uranium urinalysis.

Uranium Type M: The solid lines in Figures B-15 and B-16 in Attachment B show the fit to the 50th- and 84th-percentile excretion rates, respectively, for type M materials. Table B-4 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the uranium urinalysis.

Uranium Type S: The solid lines in Figures B-17 to B-32 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type S materials. The same intake periods were applied for both percentiles because the values followed a similar pattern. Figures B-33 and B-34 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type S intakes. Table B-5 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the uranium urinalysis.

4.6 AMERICIUM, CURIUM, AND CALIFORNIUM

As for plutonium, americium, curium, and californium intake periods were independently fit using only the bioassay results from the single intake period. This method resulted in an overestimate of intakes for exposures that extended through multiple assumed intake periods. Only the results in the intake period were selected for use in the fitting of each period. Excluded results are shown in light gray or red in the figures in Attachment B; included results are shown in dark gray or blue. The results of the statistical analysis that was used to calculate the intakes are provided for americium in Table A-5, curium in Table A-6, and californium in Table A-7.

Americium Type M: The solid lines in Figures B-35 to B-42 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials. Figures B-43 and B-44 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes. Table B-6 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the americium urinalysis.

Curium Type M: The solid lines in Figures B-45 to B-52 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials. Figures B-53 and B-54 show the fit to the 50th- and 84th-percentile excretion rates, respectively, for type M materials. Table B-7 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the curium urinalysis.

Californium Type M: The solid lines in Figures B-55 to B-62 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials. Figures B-63 and B-64 show the fit to the 50th- and 84th-percentile excretion rates, respectively, for type M materials. Table B-8 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the californium urinalysis.

4.7 NEPTUNIUM

As for plutonium, neptunium intake periods were independently fit using only the bioassay results from the single intake period. This method resulted in an overestimate of intakes for exposures that extended through multiple assumed intake periods. Only the results in the intake period were selected for use in the fitting of each period. Excluded results are shown in light gray or red in the figures in Attachment B; included results are shown in dark gray or blue. The results of the neptunium statistical analysis that was used to calculate the intakes are provided in Tables A-8 and A-9. The intake rate for 1989 was extrapolated to 1990 as a measure that is favorable to claimants.

The solid lines in Figures B-65 to B-79 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for 1961 through 1989 and the combined fit for 1991 to 2007. The solid lines in Figures B-80 to B-83 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes. Table B-9 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the neptunium urinalysis for all years.

4.8 STRONTIUM

Strontium data, in the form of MFP data, were available for 1955 through 1965 and as ^{90}Sr data for 1991 through 2007. No strontium data were available for 1966 through 1990. These two periods were fit independently. The results of the strontium statistical analysis that was used to calculate the intakes are provided in Table A-10. The solid lines in Figures B-84 through B-87 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates, respectively, for type F strontium. Table B-10 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the strontium urinalysis. Because it was inconsistent with the contemporaneous results, 1996 was excluded from the fit. This results in a higher intake being assigned for 1996, which is favorable to the claimant.

4.9 CESIUM-137

The solid lines in Figures B-88 and B-89 in Attachment B show the fits to the 50th- and 84th-percentile whole-body burdens, respectively, for type F materials. Table B-11 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the ^{137}Cs WBCs. The results of the cesium statistical analysis that was used to calculate the intakes are provided in Table A-11.

4.10 COBALT-60

The solid lines in Figures B-90 and B-91 in Attachment B show the fits to the 50th- and 84th-percentile excretion rates, respectively, for type M materials. Table B-12 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the ^{60}Co type M excretion rates. The solid lines in Figures B-92 and B-93 in Attachment B show the fits to the 50th- and 84th-percentile excretion rates, respectively, for type S materials. Table B-13 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the ^{60}Co type S excretion rates. The results of the cobalt statistical analysis that was used to calculate the intakes are provided in Table A-12.

4.11 THORIUM

Thorium intake periods were fit in the same manner as americium with the exception that both solubility types M and S were evaluated. Intake periods were independently fit using only the bioassay results from the single intake period. This method resulted in an overestimate of intakes for exposures that extended through multiple assumed intake periods. Only the results in the intake period were selected for use in the fitting of each period. Excluded results are shown in light gray or red in the figures in Attachment B; included results are shown in dark gray or blue. The results of the americium statistical analysis that was used to calculate the thorium intakes are provided in Table A-5.

Thorium Type M: The solid lines in Figures B-94 to B-97 in Attachment B show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials. Figures B-98 and B-99 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes. Table B-14 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the thorium urinalysis.

Thorium Type S: The solid lines in Figures B-100 to B-103 in Attachment B show the fit to the 50th- and 84th-percentile excretion rates for type S materials, respectively. Figures B-104 and B-105 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type S intakes. Table B-15 lists the 50th- and 84th-percentile intake rates along with the associated GSDs from the thorium urinalysis.

5.0 ASSIGNMENT OF INTAKES AND DOSES

This section describes the derived intake rates and provides guidance for assigning doses. For the calculation of doses to individuals from bioassay data, a minimum GSD of 3 has been used to account for biological variation and uncertainty in the models. It was considered inappropriate to assign a value less than 3 for the coworker data. Therefore, a GSD of at least 3 was assigned for each intake period. The GSDs for different intake periods were conservatively adjusted for consistency between intake periods for calculational efficiency. The 95th-percentile values were based on the adjusted GSD for the intake period. The original GSDs are provided in the Attachment B tables for each element. For input into the Interactive RadioEpidemiological Program (IREP), dose reconstructors should use the adjusted GSDs in the tables in Section 5.0 when assigning the 50th-percentile intakes. For cases in which there is justification that the individual might have had larger intakes than the 50th-percentile intake rates, dose reconstructors should use the 95th-percentile intake rates input into IREP as a constant.

The following subsections list the intake rates that should be used for each radionuclide and the period of applicability of each intake rate except for tritium. For tritium, the actual dose that should be used is provided. Coworker intakes should be assigned for radionuclides that could have been present at the worker's location and for which the worker was not monitored. Table 5-1 lists the radionuclides potentially present at various SRS facilities or to which a worker who was assigned to a particular facility might have been exposed. Most radionuclides apply to the entire duration of the facility's existence; a few radionuclides apply to limited periods as noted in the table (ORAUT 2013b). The dosimeter codes applicable to various time periods are included to assist with determining a worker's work location.

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

Building/facility	Dosimeter Codes 1961-1972	Dosimeter Codes 1973-1990	Dosimeter Codes 1991-2003	Dosimeter Codes 2004-present	Radionuclides of concern
Reactors (R, P, L, K, C)	7A, 8A, 9A, 10A, 11A,	1C through 6C, 1K, 1P, 1L, 1R	C01, C02, C03, K01, L01, P01	LLL, NMM, SDD[a]	Tritium, fission products
F-Area unknown	1A	1F through 5F,	F, F01	235, CLB,	Plutonium mixture, uranium,

Building/facility	Dosimeter Codes 1961-1972	Dosimeter Codes 1973-1990	Dosimeter Codes 1991-2003	Dosimeter Codes 2004-present	Radionuclides of concern
facility		7F through 9F	through F05, F07 through F09	FBL, FCA	americium, neptunium, fission products
F-Area A-Line	1A	See F canyon	See F canyon	FCA	Uranium
221-F B-Line (FB and JB lines)	1A	1F through 5F, 7F through 9F	F, F01 through F05, F07 through F09	FBL	Plutonium mixture, americium
221-F Canyon	1A	1F through 5F, 7F through 9F	F, F01 through F05, F07 through F09	FBL, FCA,	Plutonium mixture, uranium, fission products, thorium (through 1966), neptunium
F-Area Outside Facilities	1B	9F	F09	FCA	Plutonium mixture, uranium, fission products
PuFF and PEF (235-F)	1A	5F, 8F	F05, F08	235	Plutonium mixture, americium, neptunium, thorium
235-F Vaults	1A	2F, 5F, 8F	2F, F05, F08	235	Plutonium mixture, uranium, neptunium, americium, curium, thorium
772-F and 772-1F Laboratories	1A	1A[b]	A01	CLB	Plutonium mixture, uranium, fission products, americium, tritium, neptunium
F/H Tank Farms, Effluent Treatment Facility (ETF), Cooling Water and Retention Basins		5F, 5H	F05, H05	ETP, FTF	Plutonium mixture, uranium, fission products, americium, neptunium
H-Area unknown facility	2A	1H through 6H	H01 through H06	299, HBL, HCA	Tritium, plutonium mixture, uranium, americium, fission products, neptunium
HB Line Facility	2A	6H	H06	HBL	Plutonium mixture, fission products, americium, neptunium, uranium[d]
H-Canyon and A-Line	2A	1H, 2H, 5H, 6H	H, H01, H02, H05, H06	HCA	Plutonium mixture, uranium, fission products, neptunium
221-H Area Outside Facilities	2A	9H	H09	HCA	Tritium, plutonium mixture, uranium, fission products, neptunium
232-H, HANM, HAOM, Tritium complex		6F, 4H	F06, H04, T	TEF, TRI	Tritium
300 M-Area, M area unknown facility	3A	3M	M03	SDD[a]	Uranium, thorium, plutonium mixture, neptunium, americium, curium (1964-65)
704-U, 704-B		1U, 6E, 7G	U, U01, E06, G07	No active codes	Fission products

Building/facility	**Dosimeter Codes 1961-1972**	**Dosimeter Codes 1973-1990**	**Dosimeter Codes 1991-2003**	**Dosimeter Codes 2004-present**	**Radionuclides of concern**
723-A, 773-A	5A, 6N	1A, 5A	A01, A02, A05,	SRTC	Plutonium mixture, americium, curium, californium, thorium (October 1972 and after), uranium, neptunium, fission products, tritium
735-A and 735-11A	6F	5D	A02, A03, A09, A16, B01	SRTC (apply 773-A intakes)	Environmental radionuclides, neptunium (1962)
776-A		1A, 15A	A01, A15	SRTC (apply 773-A intakes)	Plutonium mixture, americium, curium, californium, thorium, uranium, neptunium (1961–1988), fission products, tritium
777-M	5B	5B	A33	No active codes	Uranium, fission products, neptunium (through 1984)
CMX and TNX	5C	5C	T01	No active codes	Uranium
Central shops & Maintenance, Pittsburgh Testing Laboratory	6C, 6H, 6I, 6M, 6N, 6R, 12D, 12E, 12I	5J, 5W, 6B,6W, 7A, 7B, 7G, 7I, 7J, 7K, 7L, 7M, 7N, 7R, 7Q, 7W, 8A through 8C, 8H, through 8M, 8P, 8S, 8T, 1N	A12, A24, A25, A26, A27, A29, A34, J01, through J08, J12 through 41	No active codes	Plutonium mixture, uranium, fission products, tritium, americium, curium, neptunium, thorium
D-Area	4A	1D, 4D	D, D01, D04	SDD	Tritium
E-Area Solid Waste Disposal Facility (SWDF)	12A	12B, 4F, 3G, 8G	B12, G03, F04	SSS	Tritium, plutonium mixture, fission products, neptunium
New Special Recovery		See H-Area unknown facility	See H-Area unknown facility	MPF	Plutonium mixture, americium, uranium
Plutonium Storage Facility (PSF)		See H-Area unknown facility	See H-Area unknown facility	MPF	Plutonium mixture, americium, uranium
Receiving Basin for Off-Site Fuel (RBOF)	See H-Area unknown facility	See H-Area unknown facility	See H-Area unknown facility	RBO	Plutonium mixture
Resin Regeneration Facility (RRF)		See H-Area unknown facility	See H-Area unknown facility	RBO	Fission products
S-Area DWPF		1S, 2S, 1W, 2W	S01, S02	SWM	Plutonium mixture, fission products
Waste Certification Facility		3G	G03	SSS	Tritium, plutonium mixture, fission products
Z-Area		2Z	Z02	ZZZ	Tritium, fission products, plutonium mixture, all transuranic elements

Building/facility	Dosimeter Codes 1961-1972	Dosimeter Codes 1973-1990	Dosimeter Codes 1991-2003	Dosimeter Codes 2004-present	Radionuclides of concern
Not identifiable or unknown[c]		7Y, 8D, 8E, 000, missing	R01, Y01, missing	Blank, any code not already listed	Plutonium mixture, uranium, fission products, tritium, americium, curium, californium, neptunium, thorium

Note: Any code with X should not be included. These indicate off plant assignment.

a. Code SDD is used both for the reactors and 300-M area. If no other information regarding work location is available, the applicable radionuclides for both locations should be assigned.
b. Code 1A is used for both 772 and 773 prior to 1991. If no other information regarding work location is available, the applicable radionuclides for both locations should be assigned.
c. Unknown facility radionuclides should only be assigned if no information is available from any source regarding the worker's work location.
d. U-232/233 in Tables 5-8 through 5-10 should only be assigned for the HB Line for January 1, 1964 through September 30, 1972.

Coworker intakes of fission and activation products were based on application of ORAUT-RPRT-0047 (ORAUT 2013a) using ^{90}Sr or ^{137}Cs as indicator radionuclides. The ^{90}Sr data should be used for years for which it is available (1955 through 1965 and 1991 through 2006), and the ^{137}Cs data should be used for the remainder of the years.

5.1 TRITIUM

Table 5-2 lists the tritium doses and GSDs to be used for each year of potential tritium exposure.

Table 5-2. Tritium annual doses (rem) and GSDs.

Year	50th-percentile dose	GSD	95th-percentile dose	Year	50th-percentile dose	GSD	95th-percentile dose
1954	0.008	3.00	0.047	1981	0.017	3.00	0.105
1955	0.010	3.00	0.064	1982	0.015	3.00	0.092
1956	0.014	3.00	0.085	1983	0.012	3.00	0.076
1957	0.019	3.00	0.115	1984	0.013	3.00	0.081
1958	0.024	3.00	0.146	1985	0.014	3.00	0.083
1959	0.025	3.41	0.187	1986	0.007	3.26	0.051
1960	0.036	3.45	0.275	1987	0.007	3.35	0.050
1961	0.034	3.52	0.273	1988	0.006	3.12	0.041
1962	0.036	3.17	0.238	1989	0.005	3.00	0.029
1963	0.034	3.00	0.205	1990	0.005	3.00	0.029
1964	0.046	3.33	0.333	1991	0.003	3.00	0.019
1965	0.041	3.51	0.326	1992	0.003	3.00	0.015
1966	0.031	3.38	0.227	1993	0.002	3.00	0.014
1967	0.032	3.00	0.197	1994	0.003	3.00	0.017
1968	0.033	3.24	0.229	1995	0.003	3.00	0.016
1969	0.035	3.02	0.215	1996	0.003	3.00	0.017
1970	0.028	3.23	0.195	1997	0.003	3.00	0.018
1971	0.034	3.00	0.205	1998	0.003	3.00	0.017
1972	0.032	3.38	0.234	1999	0.003	3.00	0.016
1973	0.028	3.40	0.209	2000	0.003	3.00	0.017
1974	0.031	3.30	0.221	2001	0.002	3.00	0.015
1975	0.033	3.13	0.215	2002	0.003	3.00	0.016
1976	0.031	3.17	0.207	2003	0.003	3.00	0.016

Year	50th-percentile dose	GSD	95th-percentile dose		Year	50th-percentile dose	GSD	95th-percentile dose
1977	0.032	3.06	0.205		2004	0.002	3.00	0.015
1978	0.031	3.00	0.192		2005	0.002	3.00	0.012
1979	0.030	3.00	0.184		2006	0.001	3.00	0.008
1980	0.028	3.00	0.172		2007	0.002	3.00	0.010

5.2 PLUTONIUM

Tables 5-3 and 5-4 list the plutonium gross alpha intakes and associated GSDs to be used for each year of potential plutonium exposure.

Table 5-3. Type M plutonium gross alpha intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1955	12/31/1990	1.77	3.00	10.8
1/1/1991	12/31/2007	0.930	3.00	5.67

Table 5-4. Type S plutonium gross alpha intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1955	12/31/1990	20.69	3.00	126
1/1/1991	12/31/2007	13.6	3.00	82.9

5.3 URANIUM

Tables 5-5 to 5-7 list the uranium intakes and associated GSDs to be used for each year of potential uranium exposure. These intakes should be modeled as 100% ^{234}U. In Building 773-A from January 1, 1961 through September 30, 1972, and in Building 772-F and the HB-line from January 1, 1964 through September 30, 1972, ^{233}U production resulted in potential exposure to ^{233}U containing 8 ppm ^{232}U. For workers in those areas and time periods, use the intakes in Tables 5-8 through 5-10 [2].

Table 5-5. Type F ^{234}U intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1953	12/31/1953	15.15	3.00	92.3
1/1/1954	12/31/1954	6.762	3.00	41.2
1/1/1955	12/31/1956	3.489	3.00	21.3
1/1/1957	12/31/1967	1.407	3.35	10.3
1/1/1968	12/31/1980	0.686	4.27	7.48
1/1/1981	12/31/1990	1.559	3.00	9.5
1/1/1991	12/31/2000	0.8747	3.00	5.33
1/12001	12/31/2007	0.1384	3.00	0.843

Table 5-6. Type M ^{234}U intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1953	12/31/1953	73.3	3.00	447
1/1/1954	12/31/1954	20.78	3.00	127
1/1/1955	12/31/1956	13.08	3.00	79.7
1/1/1957	12/31/1967	5.623	3.40	42.2
1/1/1968	12/31/1980	2.731	4.34	30.5
1/1/1981	12/31/1990	6.473	3.00	39.4
1/1/1991	12/31/2000	3.575	3.00	21.8
1/1/2001	12/31/2007	0.4823	3.00	2.94

Table 5-7. Type S ^{234}U intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1953	12/31/1953	2,293	3.00	13,972
1/1/1954	12/31/1954	1,050	3.00	6,398
1/1/1955	12/31/1956	407.8	3.00	2,485
1/1/1957	12/31/1967	89.4	3.25	623
1/1/1968	12/31/1980	41.24	4.24	443
1/1/1981	12/31/1990	107.1	3.00	653
1/1/1991	12/31/2000	58.73	3.00	358
1/1/2001	12/31/2007	10.89	3.00	66.4

Table 5-8. Type F ^{233}U intake rates (dpm/d).

Start	End	50th percentile		GSD	95th percentile	
		U-232	U-233		U-232	U-233
1/1/1961	12/31/1967	0.024	1.383	3.35	0.18	10.12
1/1/1968	9/30/1972	0.012	0.674	4.27	0.13	7.35

Table 5-9. Type M ^{233}U intake rates (dpm/d).

Start	End	50th percentile		GSD	95th percentile	
		U-232	U-233		U-232	U-233
1/1/1961	12/31/1967	0.096	5.527	3.40	0.72	41.48
1/1/1968	9/30/1972	0.046	2.685	4.34	0.52	29.98

Table 5-10. Type S ^{233}U intake rates (dpm/d).

Start	End	50th percentile		GSD	95th percentile	
		U-232	U-233		U-232	U-233
1/1/1961	12/31/1967	1.52	87.88	3.25	10.6	612.4
1/1/1968	9/30/1972	0.70	40.54	4.24	7.5	435.5

5.4 AMERICIUM/CURIUM/CALIFORNIUM

Tables 5-11 to 5-13 list the americium, curium, and californium intakes and associated GSDs to be used for each year of potential americium, curium, and californium exposure. Before 1995, only one of americium, curium, or californium should be assigned because they are based on the same bioassay data. If no justification for using a specific radionuclide exists, then the most favorable to claimant one should be assigned. After 1994, the bioassay data for each radionuclide is a different dataset and one or more may be assigned as needed.

Table 5-11. Type M americium intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1963	12/31/1967	70.7	3.00	431
1/1/1968	12/31/1972	18.9	3.00	115
1/1/1973	12/31/1994	0.826	6.23	16.7
1/1/1995	12/31/2007	0.599	3.00	3.65

Table 5-12. Type M curium intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1963	12/31/1967	73.01	3.00	445
1/1/1968	12/31/1972	19.63	3.00	120
1/1/1973	12/31/1994	0.921	6.35	19.3
1/1/1995	12/31/2007	0.291	3.00	1.77

Table 5-13. Type M californium intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1963	12/31/1967	194.7	3.00	1186

1/1/1968	12/31/1972	53.88	3.00	328
1/1/1973	12/31/1994	3.01	6.62	67.5
1/1/1995	12/31/2007	1.55	3.00	9.45

5.5 NEPTUNIUM

Table 5-14 lists the neptunium intakes and associated GSDs to be used for each year of potential neptunium exposure.

Table 5-14. Type M neptunium intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1961	12/31/1963	0.528	3.02	3.24
1/1/1964	12/31/1964	0.528	12.37	33.0
1/1/1965	12/31/1965	4.84	3.00	29.5
1/1/1966	12/31/1967	4.84	3.08	30.9
1/1/1968	12/31/1969	1.79	3.21	12.2
1/1/1970	12/31/1974	93.5	3.00	570
1/1/1975	12/31/1979	38.7	4.25	418
1/1/1980	12/31/1990	2.90	5.46	47.2
1/1/1991	12/31/2007	0.336	3.00	2.05

5.6 FISSION/ACTIVATION PRODUCTS

Fission and activation products were evaluated in accordance with ORAUT-RPRT-0047 (ORAUT 2013a), using either ^{90}Sr or ^{137}Cs as the indicator radionuclide. The chosen indicator radionuclide varied as a function of time based on the available data. Strontium should be used for 1955 through 1965, ^{137}Cs for 1966 through 1989, and strontium again for 1991 through 2007. Cobalt-60 intake rates are also provided for workers potentially exposed to purified ^{60}Co (not as a part of a fission and activation product mixture).

5.6.1 Strontium

Table 5-15 lists the strontium intakes and associated GSDs to be used for each year of potential strontium exposure. For application of ORAUT-RPRT-0047 (ORAUT 2013a), the gross beta data (1955 through 1965) should be treated as chemically processed beta samples and the ^{90}Sr data should be treated as strontium-specific data.

Table 5-15. Type F strontium intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
Gross beta data				
1/1/1955	12/31/1962	58.93	3.00	359
1/1/1963	12/31/1964	168	3.00	1,024
1/1/1965	12/31/1965	349.9	3.00	2,132
Strontium-90 data				
1/1/1991	12/31/1993	0.0393	3.00	0.239
1/1/1994	12/31/1998	1.98	3.00	12.07
1/1/1999	12/31/2001	0.177	8.79	6.31
1/1/2002	12/312006	0.517	4.72	6.64

5.6.2 Cesium-137

Table 5-16 lists the ^{137}Cs intakes and associated GSDs to be used for each year of potential ^{137}Cs exposure. The intake rate calculated for 1979 through 1989 has been extended to include 1990 as a measure that is favorable to claimants because no data is available for 1990. Only the years for which ^{137}Cs should be used as the indicator radionuclide are included in Table 5-15.

Table 5-16. Type F ^{137}Cs intake rates (pCi/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1966	12/31/1967	224.1	3.00	1366
1/1/1968	12/31/1971	80.89	3.00	493
1/1/1972	12/31/1978	30.76	3.00	187
1/1/1979	12/31/1990	7.979	3.68	68.1

5.6.3 Cobalt-60

Tables 5-17 and 5-18 lists the ^{60}Co intakes and associated GSDs to be used for each year of potential ^{60}Co exposure.

Table 5-17. Type M ^{60}Co intake rates (pCi/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1955	12/31/1962	169.4	3.00	1,032
1/1/1963	12/31/1964	499.7	3.00	3,045
1/1/1965	12/31/1965	1,050	3.00	6,398
1/1/1966	12/31/1966	4,743	3.00	28,901
1/1/1967	12/31/1968	13,290	3.00	80,982
1/1/1969	12/31/1970	3,189	3.00	19,432

Table 5-18. Type S ^{60}Co intake rates (pCi/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1955	12/31/1962	667	3.00	4,064
1/1/1963	12/31/1964	2,004	3.00	12,211
1/1/1965	12/31/1965	4,221	3.00	25,721
1/1/1966	12/31/1966	18,150	3.00	110,596
1/1/1967	12/31/1968	53,580	3.00	326,488
1/1/1969	12/31/1970	11,680	3.00	71,172

5.7 THORIUM

Tables 5-19 and 5-20 list the ^{232}Th intake rates and associated GSDs to be used for each year of potential thorium exposure. Include intakes of ^{228}Th and ^{228}Ra with activities equal to the ^{232}Th intake rate.

Table 5-19. Type M ^{232}Th intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1972	12/31/1972	15.31	3.34	111.4
1/1/1973	12/31/1989	1.149	8.49	38.8

Table 5-20. Type S ^{232}Th intake rates (dpm/d).

Start	End	50th percentile	GSD	95th percentile
1/1/1972	12/31/1972	725.5	3.34	5,281
1/1/1973	12/31/1989	15.90	8.41	527.9

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

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

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This is based on communications with Tom LaBone indicating "<" values were recorded as negative results in the HPRED database.

[2] Mahathy, James M. Oak Ridge Associated Universities. Health Physicist. October 2013.
^{233}U was produced containing varying amounts of ^{232}U, most of which were in the 5-7 ppm range (DuPont 1965a, 1965b, 1984a, 1984b). Use of 8 ppm is a conservative estimate of ^{232}U content.

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ATTACHMENT A
BIOASSAY DATA TYPES AND STATISTICAL ANALYSIS RESULTS

LIST OF TABLES

Table A-1. NOCTS radionuclide type matrix.[a]

No.	Nuclide	U (all)	Pu	Sr	Np	MFP
1	FP					X
2	Pu-238/239		X			
3	Sr90			X		
4	Pu		X			
5	Pu238					
6	Pu239		X			
7	U	X				
8	FPIA					X
9	IA					
10	IA beta					X
11	IA gamma					
12	Pu-239		X			
13	Pu 238					
14	Pu-238					
15	EU	X				
16	Pu238/239		X			
17	Am-Cm					
18	Am					
19	SP				X	
20	FP gamma					
21	Pu 239		X			
22	Eu	X				
23	AmCm					
24	Sr-90			X		
25	AmCmCf					
26	UR	X				
27	Ur	X				
28	Sp				X	
29	Pu-238/Pu-239		X			

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No.	Nuclide	U (all)	Pu	Sr	Np	MFP
30	Pu238-239		X			
31	Am					
32	LMF	X				
33	FP					X
34	F					
35						
36	Cf-252					
37	Am-241					
38	Cm-244					
39	U-234	X				
40	U-235	X				
41	U-238	X				
42	Np-237				X	
43	239		X			
44	238					
45	Np				X	
46	Po					
47	Pu-237					
48	Pu238/Pu239		X			
49	Th					
50	P					
51	TH					
52	Cr					
53	Fe					
54	IP					
55	NP				X	
56	Pu		X			
57	ENU	X				
58	Pu-241		X			
59	EnU	X				
60	M					
61	FPIA(PHA)					X
62	Sr			X		
63	Pu		X			
64	AC					
65	Cm244					
66	E					
67	Thorium					
68	Pm147					
69	Pu239		X			
70	Pu238					
71	Uranium	X				
72	FP					X
73	NT/ D U	X				
74	PU		X			
75	PP					
76	Pu 238/239		X			
77	FPIA					X
78	Pu 238/Pu 239		X			

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No.	Nuclide	U (all)	Pu	Sr	Np	MFP
79	Pu238/Pu-239		X			
80	FP(IA)					X
81	CM244					
82	PU238					
83	Sr 90			X		
84	FP-I					X
85	PU 239		X			
86	PU 238					
87	FP-IA					X
88	PU		X			
89	AM					
90	AM-CM					
91	FP (IA)					X
92	CM					
93	Pu 239/239		X			
94	PU238/239		X			
95	Fp					X
96	PU239		X			
97	Pu/Am		X			
98	Am 241					
99	AMCM					
100	AM					
101	H3					
102	D2O					
103	RU	X				
104	Pu-Am-Cm		X			
105	U 234	X				
106	U 235	X				
107	U 238	X				
108	IA-b					X
109	IA-g					
110	A					
111	PU 238/239		X			
112	AU	X				
113	FP (Np)					
114	AM CM					
115	FP/Pu		X			
116	PU238					
117	FU	X				
118	b g					X
119	SR90			X		
120	Pu241					
121	Cf					
122	Pu-239/240		X			
123	UO3	X				
124	PU239/AM		X			
125	FP & I131					X
126	FP-b					X
127	FP-g					

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No.	Nuclide	U (all)	Pu	Sr	Np	MFP
128	Pb					
129	IA					
130	Am241					
131	NT/D U	X				
132	Unat	X				
133	Cm-Am					
134	FPIA BETA					X
135	AMCM					
136	Am Cm					
137	PU vomitus					
138	PU241					
139	NT/DU	X				
140	U234	X				
141	U235	X				
142	U238	X				
143	Hg					
144	D20					
145	I-131					X
146	PU-238/239		X			
147	PU-238					
148	PU-239		X			
149	Lead					
150	Cm242					
151	AM-241					
152	Pu FP		X			
153	UF	X				
154	Pu240		X			
155	Pu242		X			
156	Pu243		X			
157	Pu244		X			
158	Pu245		X			
159	Pu246		X			
160	Pu247		X			
161	Pu248		X			
162	Pu249		X			
163	Pu251		X			
164	Pu252		X			
165	Pu250		X			
166	Cf252					
167	Merc					
168	Np237				X	
169	Iodine					
170	IA					X
171	g					
172	Pu238 & 239		X			
173	FL					
174	SR			X		
175	beta-gamma					X
176	alpha					

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No.	Nuclide	U (all)	Pu	Sr	Np	MFP
177	IAFP					X
178	Pu238, 239		X			
179	NT/ D U	X				
180	PU238/PU239		X			
181	CF252					
182	AM241					
183	NP237				X	
184	Am/Cm					
185	Mercury					
186	Cm					
187	Po-210					
188	Alpha					
189	I ACT					X
190	ID					
191	Ce144					
192	Zr95/Nb95					
193	Fluoride					
194	FPIA(131I)					X
195	R					
196	HG					
197	Am-CmCf					
198	NP-237				X	
199	GP					
200	PB					
201	Ru 106					
202	Ce 144					
203	Cm 244					
204	Pu		X			
205	Cm/Cf					
206	U	X				
207	Pu238					
208	Pu239		X			
209	PO210					
210	Po 210					
211	L.M.F.	X				
212	Beta					
213	Pu (3.00 Am)		X			
214	DU	X				
215	Pu-238-239		X			
216	FP/IA					X
217	Nat-U	X				
218	PU238-239		X			
219	Pa-231					
220	Th-231					
221	A					
222	Cm-Cf					
223	Am-Cm 244					
224	Cs 137					
225	Pu/FP		X			

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No.	Nuclide	U (all)	Pu	Sr	Np	MFP
226	NEU	X				
227	Pa 231					
228	Th 231					

a. Nuclide designations without an "X" were not used in the coworker study.

Table A-2. HPRED radionuclide type matrix.

No.	x	U	Pu	Am/Cm/Cf	Am	Cm	Cf	Sr	Np
1	H3								
2	U-234	X							
3	U-235	X							
4	U-238	X							
5	PU-238		X						
6	PU-239		X						
7	NP-237								X
8	AM-241			X	X				
9	CM-244			X		X			
10	CF-252			X			X		
11	SR90							X	
12	NT/DU	X							
13	Pu238		X						
14	Am241			X	X				
15	Pu239		X						
16	EU	X							
17	AmCmCf			X					
18	Sr90							X	
19	U234	X							
20	U235	X							
21	U238	X							
22	Np237								X
23	Cm242			X		X			
24	Cm244			X		X			
25	Cf252			X			X		

Table A-3. 50th- and 84th-percentile urinary excretion rates of plutonium gross alpha, 1955 to 2007 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1955	0.0273	0.068	203
7/1/1956	0.0106	0.050	314
7/1/1957	0.0263	0.056	312
7/1/1958	0.0371	0.061	286
7/1/1959	0.0307	0.085	337
7/1/1960	0.0188	0.080	350
7/1/1961	0.0074	0.028	367
7/1/1962	0.0430	0.073	398
7/1/1963	0.0049	0.028	338
7/1/1964	0.0134	0.054	327
7/1/1965	0.0295	0.060	414
7/1/1966	0.0291	0.064	376
7/1/1967	0.0240	0.068	355
7/1/1968	0.0147	0.053	384

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Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1969	0.0272	0.134	279
7/1/1970	0.0295	0.121	266
7/1/1971	0.0144	0.055	339
7/1/1972	0.0320	0.091	358
7/1/1973	0.0235	0.073	356
7/1/1974	0.0244	0.076	369
7/1/1975	0.0194	0.073	341
7/1/1976	0.0093	0.054	394
7/1/1977	0.0240	0.077	389
7/1/1978	0.0168	0.071	260
7/1/1979	0.0173	0.034	357
7/1/1980	0.0360	0.078	312
7/1/1981	0.0150	0.054	408
7/1/1982	0.0122	0.043	406
7/1/1983	0.0109	0.048	296
7/1/1984	0.0163	0.055	267
7/1/1985	0.0536	0.087	241
7/1/1986	0.0134	0.057	299
7/1/1987	0.0420	0.070	271
7/1/1988	0.0159	0.039	296
7/1/1989	0.0111	0.032	282
7/1/1990	0.0086	0.023	303
7/1/1991	2.39E-05	7.5E-04	8,694
7/1/1992	0.0006	0.0037	8,769
7/1/1993	0.0038	0.0121	6,604
7/1/1994	0.0076	0.0235	5,641
7/1/1995	0.0074	0.0237	5,257
7/1/1996	0.0087	0.0250	4,994
7/1/1997	0.0076	0.0263	4,919
7/1/1998	0.0088	0.0296	4,938
7/1/1999	0.0091	0.0258	4,322
7/1/2000	0.0086	0.0222	3,076
7/1/2001	0.0080	0.0205	2,734
7/1/2002	0.0093	0.0228	2,687
7/1/2003	0.0089	0.0229	2,545
7/1/2004	0.0075	0.0180	2,277
7/1/2005	0.0091	0.0223	2,477
7/1/2006	0.0083	0.0209	2,218
7/1/2007	0.0085	0.0213	2,077

Table A-4. 50th- and 84th-percentile urinary excretion rates of uranium, 1953 to 2007 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1953	4.076	7.573	31
7/1/1954	1.867	3.021	93
7/1/1955	0.9926	1.648	277
7/1/1956	0.9515	1.296	390
7/1/1957	0.392	1.370	207
7/1/1958	0.3738	1.388	151
7/1/1959	0.2422	0.807	201

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Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1960	0.2772	0.844	252
7/1/1961	0.1476	0.744	220
7/1/1962	0.3962	1.337	243
7/1/1963	0.7477	1.957	260
7/1/1964	0.7036	1.945	271
7/1/1965	0.4095	1.489	251
7/1/1966	0.4085	1.472	210
7/1/1967	0.3055	1.113	198
7/1/1968	0.1094	0.554	219
7/1/1969	0.1166	0.771	180
7/1/1970	0.09433	0.933	177
7/1/1971	0.1265	0.854	212
7/1/1972	0.1264	0.869	222
7/1/1973	0.1081	0.782	222
7/1/1974	0.1402	0.796	201
7/1/1975	0.2212	0.999	219
7/1/1976	0.3098	0.781	189
7/1/1977	0.1775	0.803	114
7/1/1978	0.4689	1.004	99
7/1/1979	0.3177	0.942	107
7/1/1980	0.2537	0.698	79
7/1/1981	0.07588	0.474	90
7/1/1982	0.3631	1.431	86
7/1/1983	0.7964	2.181	86
7/1/1984	0.2588	1.408	64
7/1/1985	0.4568	1.447	93
7/1/1986	0.08252	0.340	82
7/1/1987	0.6084	1.009	80
7/1/1988	0.2133	0.940	67
7/1/1989	0.02113	0.179	87
7/1/1990	1.048	1.202	36
7/1/1991	0.09117	0.344	2,349
7/1/1992	0.07548	0.274	2,842
7/1/1993	0.3592	0.698	2,952
7/1/1994	0.3419	0.873	2,511
7/1/1995	0.2393	0.569	2,401
7/1/1996	0.3281	0.748	2,193
7/1/1997	0.3409	0.724	2,045
7/1/1998	0.2581	0.573	2,267
7/1/1999	0.2207	0.589	2,116
7/1/2000	0.2388	0.665	1,597
7/1/2001	0.09381	0.422	1,410
7/1/2002	0.03714	0.086	1,411
7/1/2003	0.03625	0.088	1,300
7/1/2004	0.03338	0.080	1,291
7/1/2005	0.03486	0.080	1,473
7/1/2006	0.04674	0.092	1,093
7/1/2007	0.04698	0.091	914

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Table A-5. 50th- and 84th-percentile urinary excretion rates of americium, 1963 to 2007 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1963	0.8360	1.296	43
7/1/1965	0.3360	0.769	126
7/1/1966	0.8282	2.027	155
7/1/1967	0.9520	1.476	227
7/1/1968	0.2527	0.627	364
7/1/1969	0.3065	0.890	379
7/1/1970	0.2320	0.517	567
7/1/1971	0.1693	0.419	663
7/1/1972	0.0721	0.241	650
7/1/1973	0.0082	0.064	644
7/1/1974	0.0093	0.096	456
7/1/1975	0.0102	0.075	467
7/1/1976	0.0130	0.081	450
7/1/1977	0.0037	0.042	383
7/1/1978	0.0258	0.257	228
7/1/1979	0.0249	0.270	322
7/1/1980	0.0096	0.070	230
7/1/1981	0.0028	0.016	267
7/1/1982	0.0021	0.008	307
7/1/1983	0.0054	0.045	303
7/1/1984	0.0063	0.069	275
7/1/1985	0.0119	0.120	259
7/1/1986	0.0035	0.040	273
7/1/1987	0.0175	0.088	305
7/1/1988	0.0185	0.141	288
7/1/1991	0.0180	0.0568	570
7/1/1992	0.0232	0.0608	373
7/1/1993	0.0156	0.0649	208
7/1/1994	0.0315	0.0951	180
7/1/1995	0.0124	0.0351	226
7/1/1996	0.0118	0.0362	271
7/1/1997	0.0113	0.0302	401
7/1/1998	0.0120	0.0286	681
7/1/1999	0.0121	0.0276	1,499
7/1/2000	0.0111	0.0237	2,130
7/1/2001	0.0094	0.0214	2,305
7/1/2002	0.0082	0.0210	2,473
7/1/2003	0.0072	0.0185	2,313
7/1/2004	0.0060	0.0159	1,985
7/1/2005	0.0058	0.0153	2,242
7/1/2006	0.0058	0.0164	2,103
7/1/2007	0.0062	0.0165	2,030

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Table A-6. 50th- and 84th-percentile urinary excretion rates of curium, 1963 to 2007 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1963	0.8360	1.296	43
7/1/1965	0.3360	0.769	126
7/1/1966	0.8282	2.027	155
7/1/1967	0.9520	1.476	227
7/1/1968	0.2527	0.627	364
7/1/1969	0.3065	0.890	379
7/1/1970	0.2320	0.517	567
7/1/1971	0.1693	0.419	663
7/1/1972	0.0721	0.241	650
7/1/1973	0.0082	0.064	644
7/1/1974	0.0093	0.096	456
7/1/1975	0.0102	0.075	467
7/1/1976	0.0130	0.081	450
7/1/1977	0.0037	0.042	383
7/1/1978	0.0258	0.257	228
7/1/1979	0.0249	0.270	322
7/1/1980	0.0096	0.070	230
7/1/1981	0.0028	0.016	267
7/1/1982	0.0021	0.008	307
7/1/1983	0.0054	0.045	303
7/1/1984	0.0063	0.069	275
7/1/1985	0.0119	0.120	259
7/1/1986	0.0035	0.040	273
7/1/1987	0.0175	0.088	305
7/1/1988	0.0185	0.141	288
7/1/1991	0.0180	0.0568	570
7/1/1992	0.0232	0.0608	373
7/1/1993	0.0156	0.0649	208
7/1/1994	0.0315	0.0951	180
7/1/1995	0.00204	0.00651	226
7/1/1996	0.00391	0.00826	271
7/1/1997	0.00710	0.01316	401
7/1/1998	0.00691	0.01350	681
7/1/1999	0.00266	0.00637	1,499
7/1/2000	0.00093	0.00291	2,130
7/1/2001	0.00164	0.00503	2,305
7/1/2002	0.00382	0.00893	2,473
7/1/2003	0.00355	0.00861	2,313
7/1/2004	0.00394	0.00951	1,984
7/1/2005	0.00458	0.01001	2,242
7/1/2006	0.00475	0.01053	2,103
7/1/2007	0.00390	0.00939	2,030

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Table A-7. 50th- and 84th-percentile urinary excretion rates of californium, 1963 to 2007 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1963	0.8360	1.296	43
7/1/1965	0.3360	0.769	126
7/1/1966	0.8282	2.027	155
7/1/1967	0.9520	1.476	227
7/1/1968	0.2527	0.627	364
7/1/1969	0.3065	0.890	379
7/1/1970	0.2320	0.517	567
7/1/1971	0.1693	0.419	663
7/1/1972	0.0721	0.241	650
7/1/1973	0.0082	0.064	644
7/1/1974	0.0093	0.096	456
7/1/1975	0.0102	0.075	467
7/1/1976	0.0130	0.081	450
7/1/1977	0.0037	0.042	383
7/1/1978	0.0258	0.257	228
7/1/1979	0.0249	0.270	322
7/1/1980	0.0096	0.070	230
7/1/1981	0.0028	0.016	267
7/1/1982	0.0021	0.008	307
7/1/1983	0.0054	0.045	303
7/1/1984	0.0063	0.069	275
7/1/1985	0.0119	0.120	259
7/1/1986	0.0035	0.040	273
7/1/1987	0.0175	0.088	305
7/1/1988	0.0185	0.141	288
7/1/1991	0.0180	0.0568	570
7/1/1992	0.0232	0.0608	373
7/1/1993	0.0156	0.0649	208
7/1/1994	0.0315	0.0951	180
7/1/1995	0.00469	0.0144	226
7/1/1996	0.00508	0.0146	271
7/1/1997	0.00684	0.0197	401
7/1/1998	0.00834	0.0215	681
7/1/1999	0.00648	0.0156	1,499
7/1/2000	0.00501	0.0123	2,130
7/1/2001	0.00346	0.0086	2,305
7/1/2002	0.00444	0.0112	2,473
7/1/2003	0.00662	0.0171	2,313
7/1/2004	0.00852	0.0206	1,984
7/1/2005	0.00848	0.0187	2,242
7/1/2006	0.00791	0.0180	2,103
7/1/2007	0.00844	0.0183	2,030

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Table A-8. 50th- and 84th-percentile urinary excretion rates of neptunium, 1961 to 1969 and 1991 to 2007 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1961	0.0216	0.0470	312
7/1/1962	0.0049	0.0291	933
7/1/1963	0.0057	0.0356	459
7/1/1964	0.0201	0.1078	48
7/1/1965	0.0835	0.1625	48
7/1/1966	0.1215	0.3365	32
7/1/1967	0.1205	0.3010	42
7/1/1968	0.0264	0.1401	68
7/1/1969	0.0470	0.1074	29
7/1/1991	0.0131	0.0422	89
7/1/1992	0.0049	0.0195	196
7/1/1993	0.0046	0.0283	266
7/1/1994	0.0150	0.0582	274
7/1/1995	0.0129	0.0385	249
7/1/1996	0.0126	0.0422	253
7/1/1997	0.0116	0.0333	447
7/1/1998	0.0107	0.0327	662
7/1/1999	0.0136	0.0379	825
7/1/2000	0.0128	0.0304	1,026
7/1/2001	0.0117	0.0257	981
7/1/2002	0.0123	0.0264	997
7/1/2003	0.0092	0.0199	971
7/1/2004	0.0086	0.0195	910
7/1/2005	0.0090	0.0199	1,081
7/1/2006	0.0110	0.0234	1,101
7/1/2007	0.0113	0.0248	1,111

Table A-9. 50th- and 84th-percentile whole body burdens of neptunium, 1971 to 1989 (dpm).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1971	8,026	14,580	42
7/1/1973	4,909	11,512	47
7/1/1974	3,506	10,181	68
7/1/1975	1,155	5,307	85
7/1/1976	3,370	7,535	13
7/1/1977	1,036	5,729	54
7/1/1978	2,317	9,710	92
7/1/1979	1,351	7,717	67
7/1/1980	210	873	106
7/1/1981	150	1,013	122
7/1/1982	193	852	118
7/1/1983	244	1,024	106
7/1/1984	189	1,161	117
7/1/1985	66	693	75
7/1/1986	235	1,265	78
7/1/1987	477	2,299	96
7/1/1988	288	1,592	90
7/1/1989	186	1,162	86

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Table A-10. 50th- and 84th-percentile urinary excretion rates of strontium, 1955 to 1965 and 1991 to 2006 (dpm/d).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1955	17.92	33.05	209
7/1/1956	11.37	40.88	285
7/1/1957	12.99	40.06	177
7/1/1958	15.82	44.47	136
7/1/1959	7.88	44.99	191
7/1/1960	25.44	45.26	276
7/1/1961	7.86	20.78	329
7/1/1962	11.38	41.71	391
7/1/1963	35.95	66.57	328
7/1/1964	41.48	66.46	319
7/1/1965	79.70	97.09	314
7/1/1991	0.00529	0.022	3,105
7/1/1992	0.01121	0.013	4,352
7/1/1993	0.005932	0.027	3,711
7/1/1994	0.4736	1.175	3,496
7/1/1995	0.6499	1.287	3,500
7/1/1996	0.02397	0.187	3,445
7/1/1997	0.4553	1.495	3,252
7/1/1998	0.2543	1.163	3,841
7/1/1999	0.08286	0.570	3,600
7/1/2000	0.04699	0.311	2,067
7/1/2001	0.06374	0.384	1,537
7/1/2002	0.1224	0.630	1,274
7/1/2003	0.127	0.611	1,118
7/1/2004	0.0987	0.481	1,001
7/1/2005	0.1327	0.594	1,267
7/1/2006	0.1734	0.703	1,174

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Table A-11. 50th- and 84th-percentile whole body burdens of cesium, 1961 to 1989 (pCi).

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1961	4,863	6,337	36
7/1/1962	5,508	8,699	52
7/1/1963	9,692	13,046	27
1/1/1966	15,400	20,361	19
1/1/1970	5,564	9,777	29
7/1/1972	3,457	4,785	32
7/1/1973	2,748	4,348	46
7/1/1974	2,344	4,014	70
7/1/1975	2,037	5,003	87
7/1/1976	1,914	4,126	60
7/1/1977	1,898	4,215	81
7/1/1978	1,749	4,476	94
7/1/1979	948	2,750	94
7/1/1980	600	1,909	109
7/1/1981	556	1,792	120
7/1/1982	468	1,560	119
7/1/1983	343	1,244	113
7/1/1984	397	1,343	115
7/1/1985	385	1,247	78
7/1/1986	1,082	4,014	117
7/1/1987	534	2,048	110
7/1/1988	618	2,701	110
7/1/1989	628	2,412	95

Table A-12. 50th- and 84th-percentile urinary excretion rates of ^{60}Co, 1955 to 1970.

Effective bioassay date	50th percentile	84th percentile	No. of employees
7/1/1955	17.92	33.05	209
7/1/1956	11.37	40.88	285
7/1/1957	12.99	40.06	177
7/1/1958	15.82	44.47	136
7/1/1959	7.88	44.99	191
7/1/1960	25.44	45.26	276
7/1/1961	7.86	20.78	329
7/1/1962	11.38	41.71	391
7/1/1963	35.95	66.57	328
7/1/1964	41.48	66.46	319
7/1/1965	79.70	97.09	314
7/1/1966	330	511	356
7/1/1967	1,131	1,753	436
7/1/1968	945	1,465	494
7/1/1969	355	551	429
7/1/1970	317	491	471

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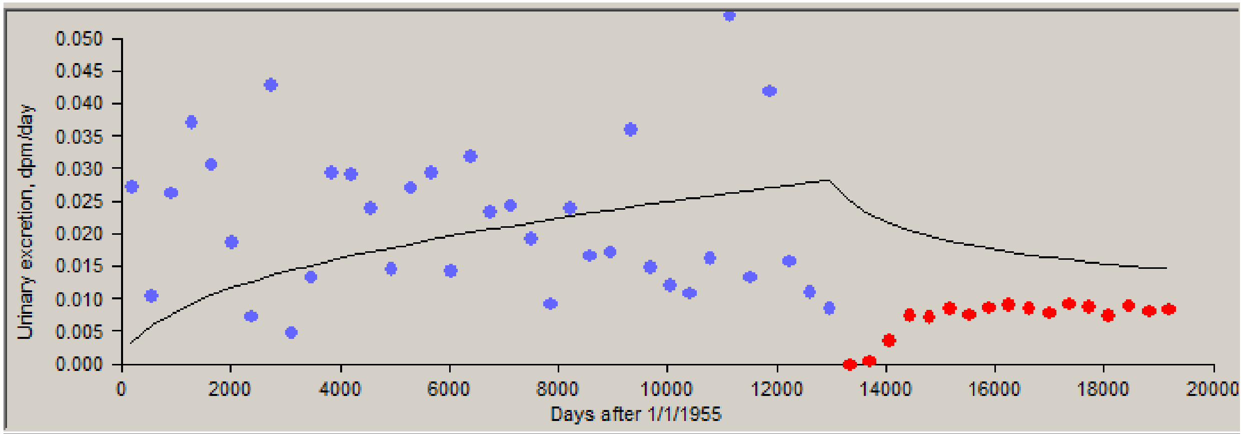

Figure B-1. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 50th percentile, 1955–1990, type M.

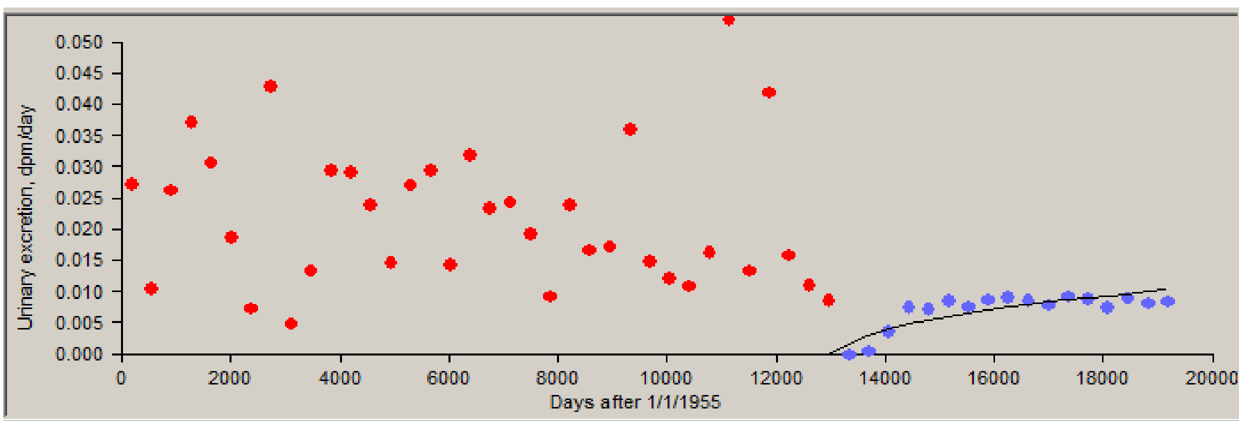

Figure B-2. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 50th percentile, 1991–2007, type M.

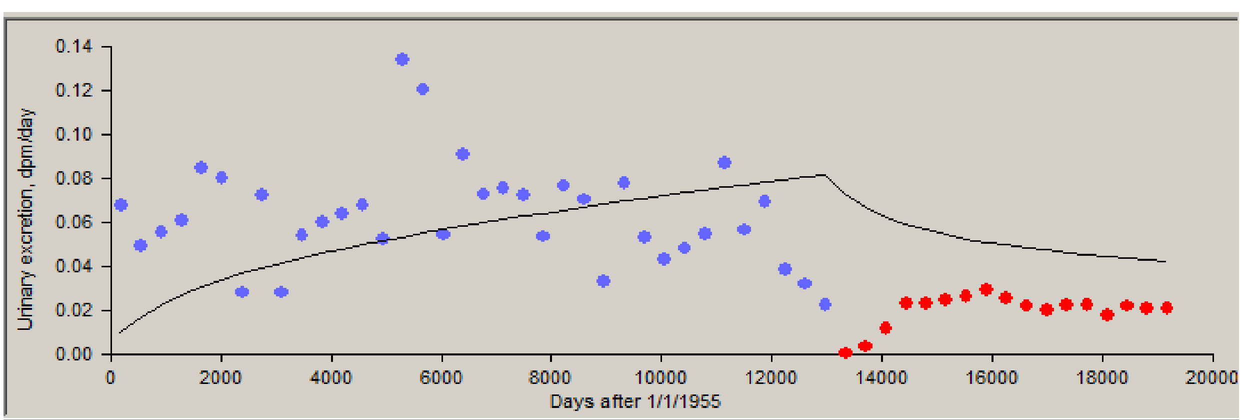

Figure B-3. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 84th percentile, 1955–1990, type M.

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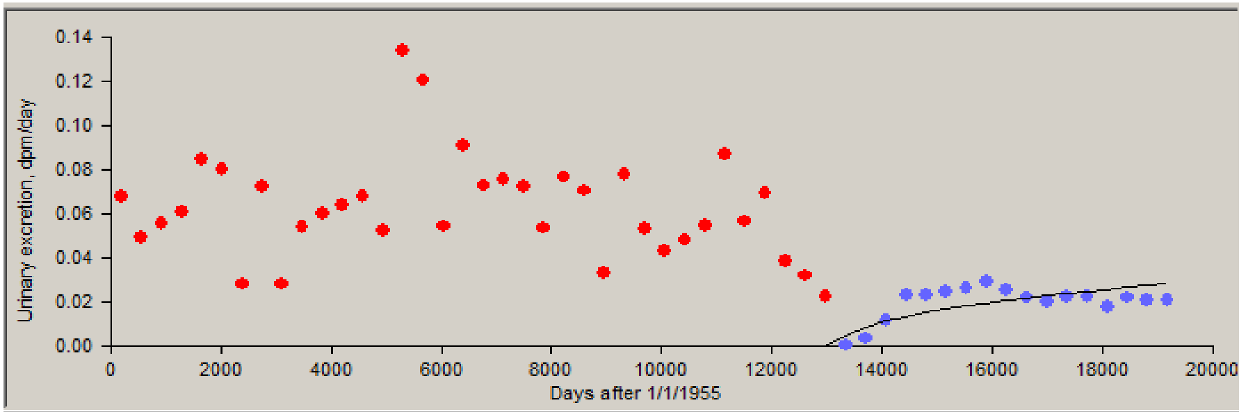

Figure B-4. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 84th percentile, 1991–2007, type M.

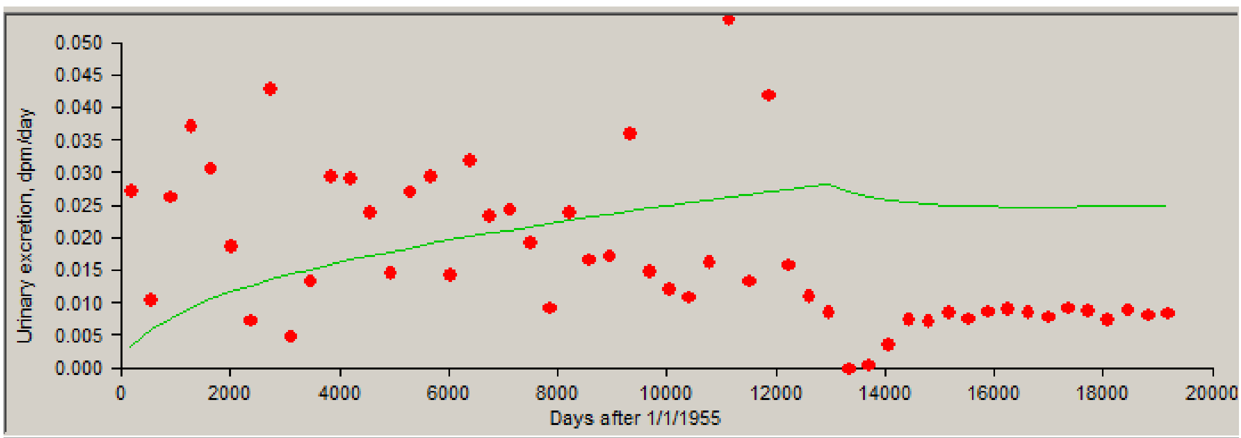

Figure B-5. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 50th percentile, all intake periods, type M.

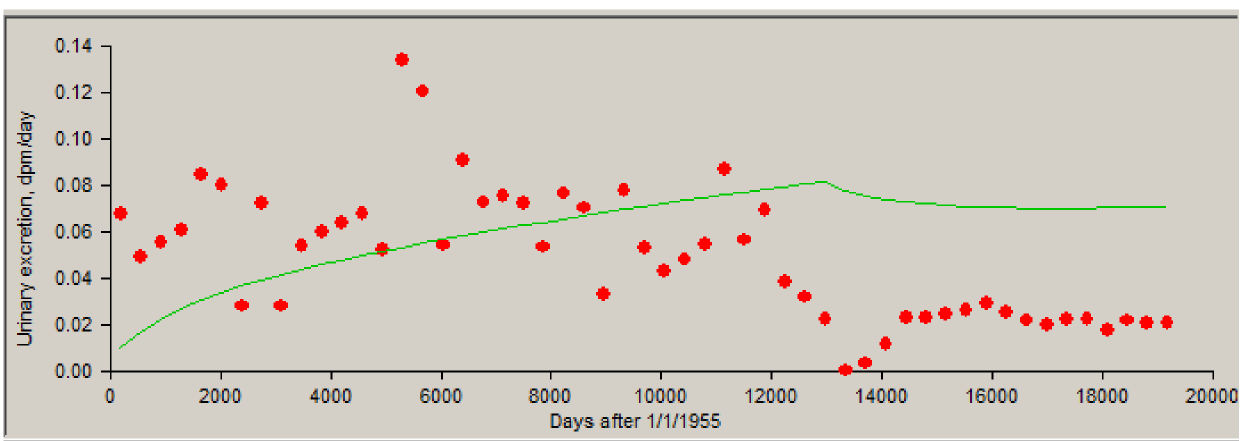

Figure B-6. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 84th percentile, all intake periods, type M.

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Table B-1. Summary of plutonium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1955–1990	1.77	5.103	2.88	3.00	10.8
1991–2007	0.930	2.542	2.73	3.00	5.67

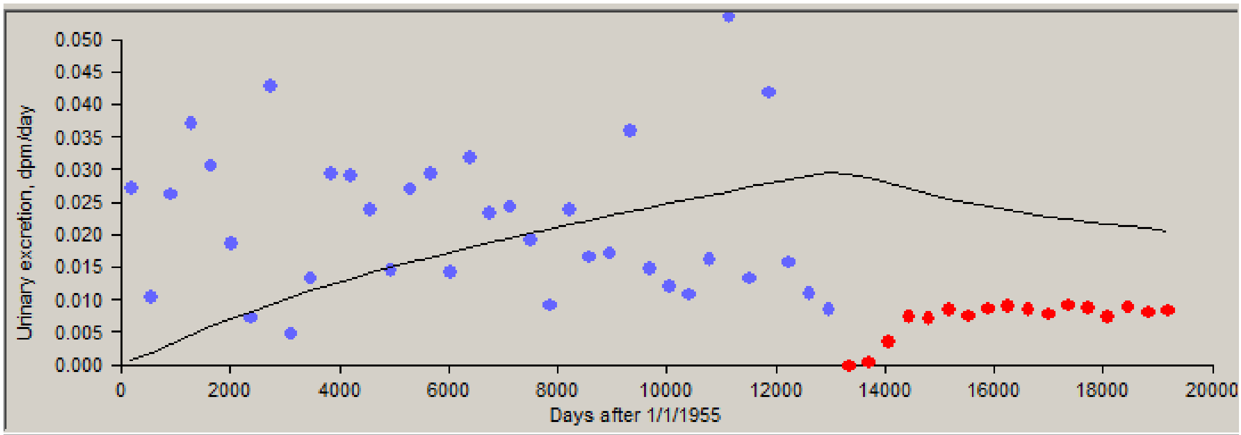

Figure B-7. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 50th percentile, 1955–1990, type S.

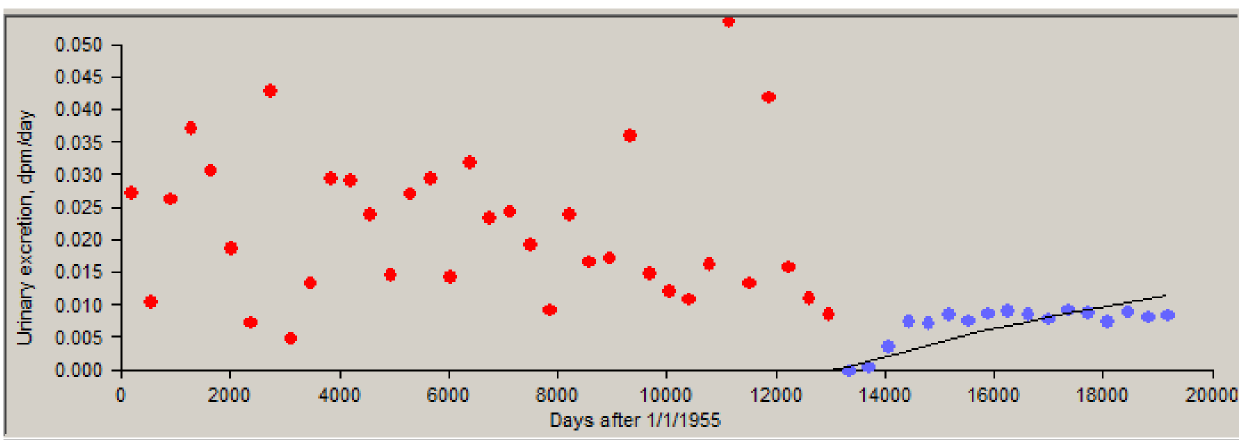

Figure B-8. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 50th percentile, 1991–2007, type S.

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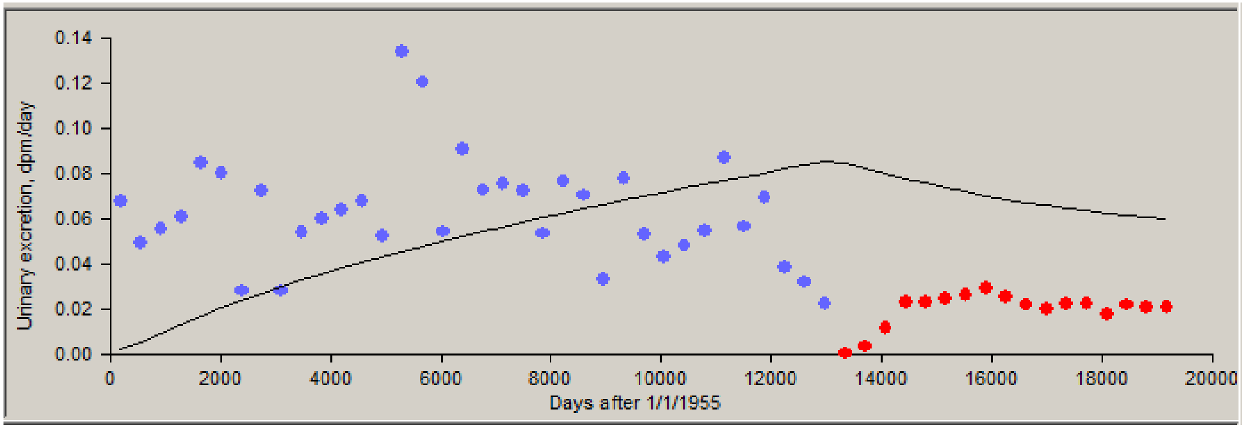

Figure B-9. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 84th percentile, 1955–1990, type S.

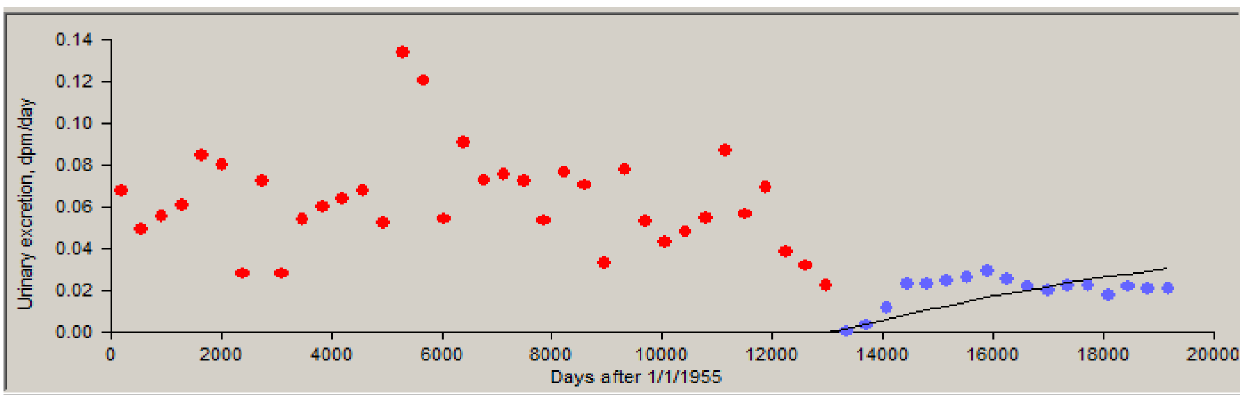

Figure B-10. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 84th percentile, 1991–2007, type S.

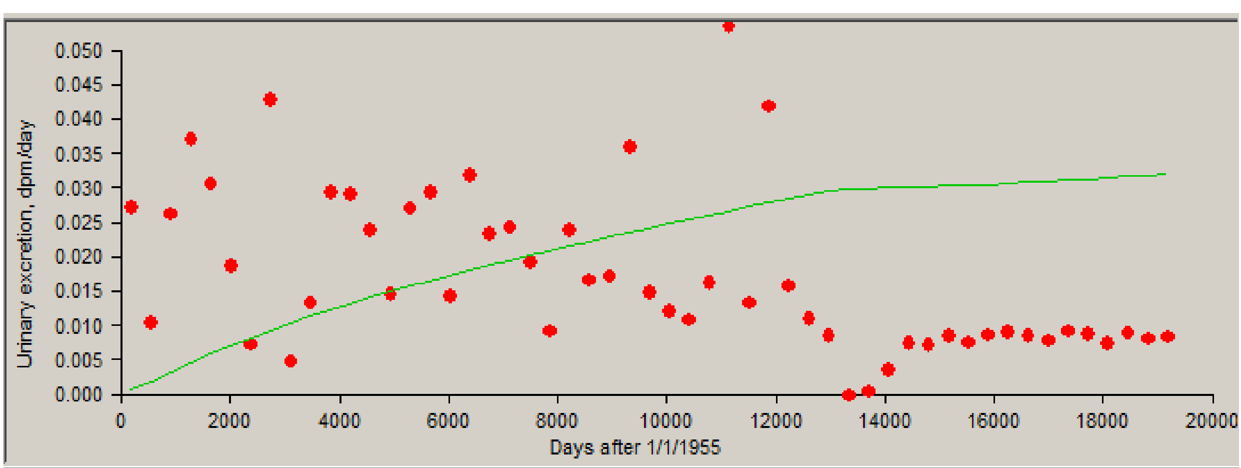

Figure B-11. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 50th percentile, all intake periods, type S.

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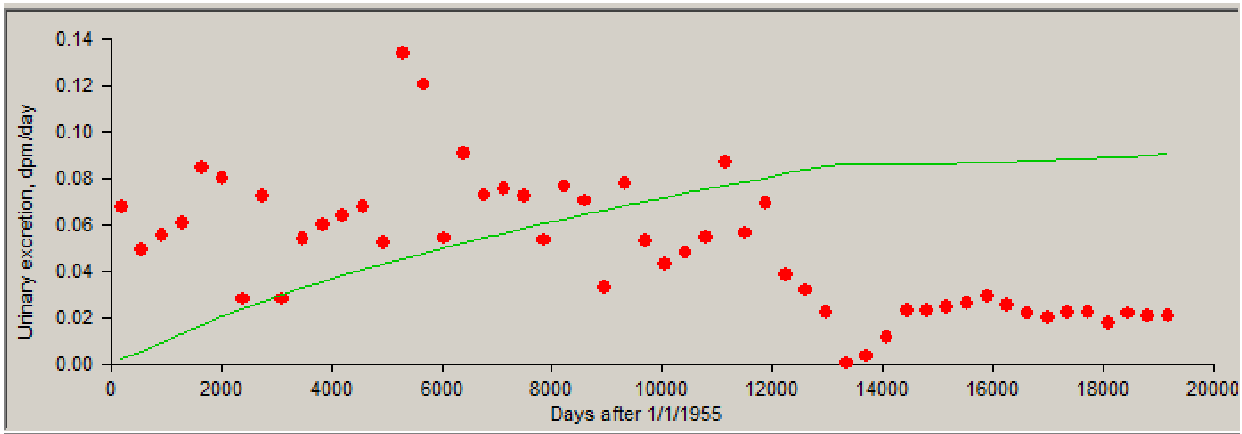

Figure B-12. Predicted plutonium bioassay results calculated using IMBA-derived plutonium intake rates (line) compared with bioassay results (dots), 84th percentile, all intake periods, type S.

Table B-2. Summary of plutonium type S intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1955–1990	20.69	59.53	2.88	3.00	126
1991–2007	13.6	36.57	2.69	3.00	82.9

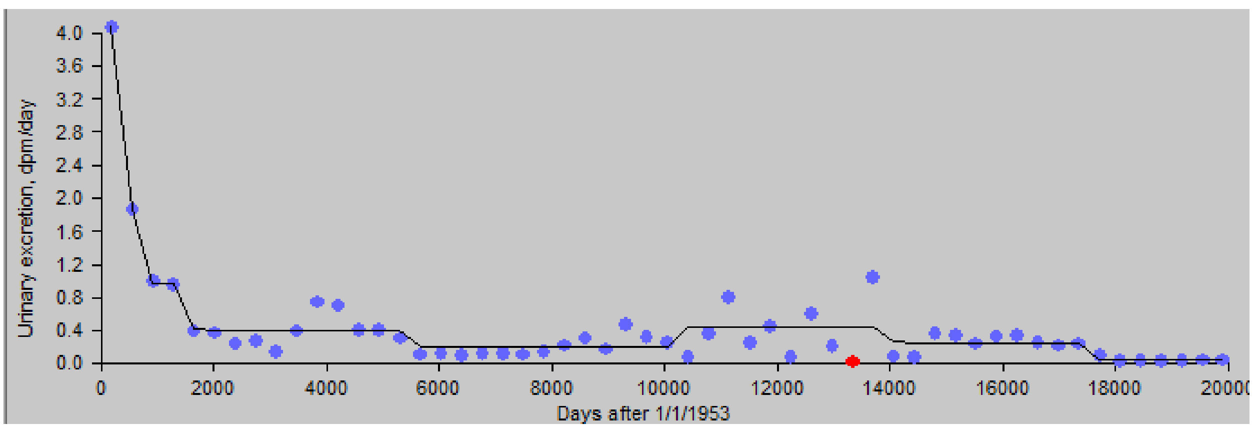

Figure B-13. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, type F.

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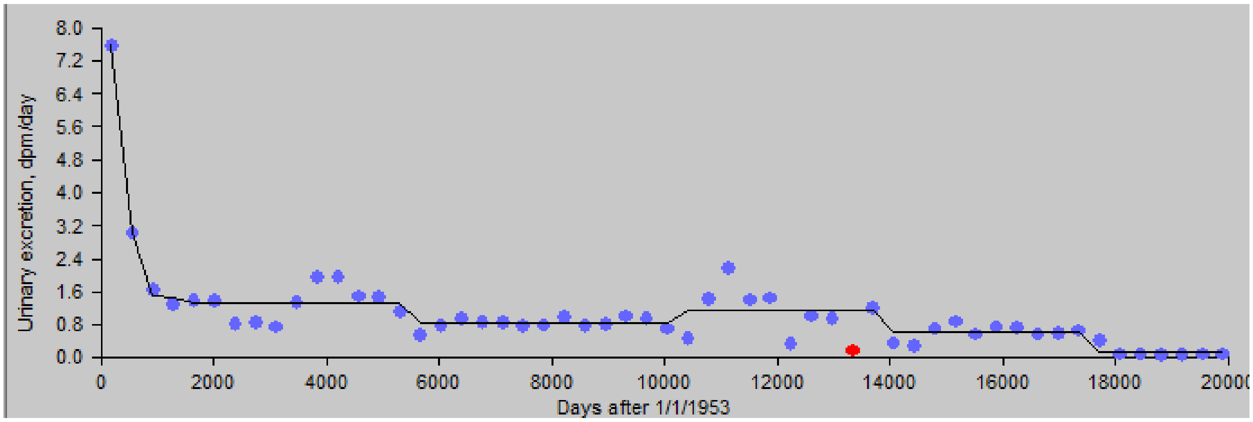

Figure B-14. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, type F.

Table B-3. Summary of uranium type F intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1953	15.15	28.15	1.86	3.00	92.3
1954	6.762	10.9	1.61	3.00	41.2
1955–1956	3.489	5.258	1.51	3.00	21.3
1957–1967	1.407	4.707	3.35	3.35	10.3
1968–1980	0.686	2.931	4.27	4.27	7.48
1981–1990	1.559	4.144	2.66	3.00	9.50
1991–2000	0.8747	2.113	2.42	3.00	5.33
2001–2007	0.1384	0.4005	2.89	3.00	0.843

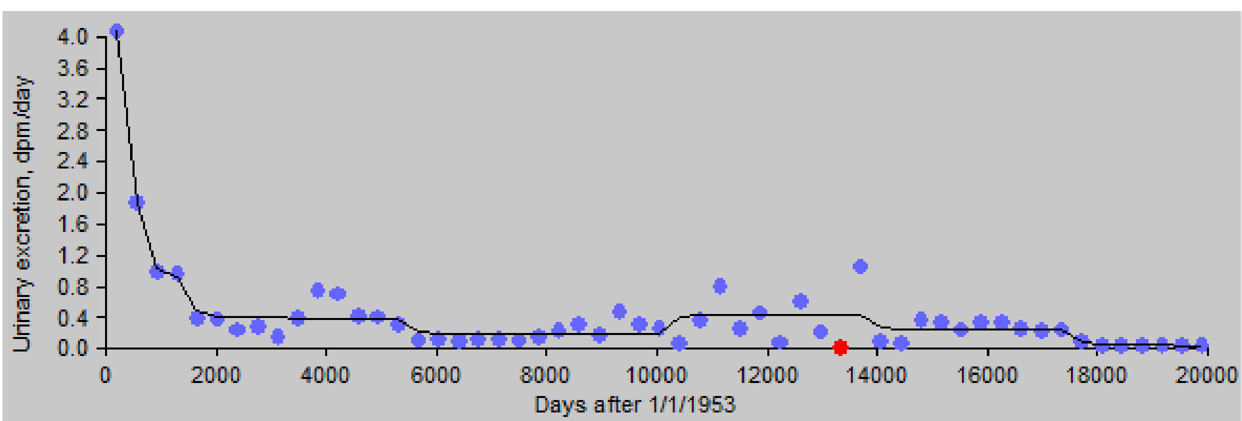

Figure B-15. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, type M.

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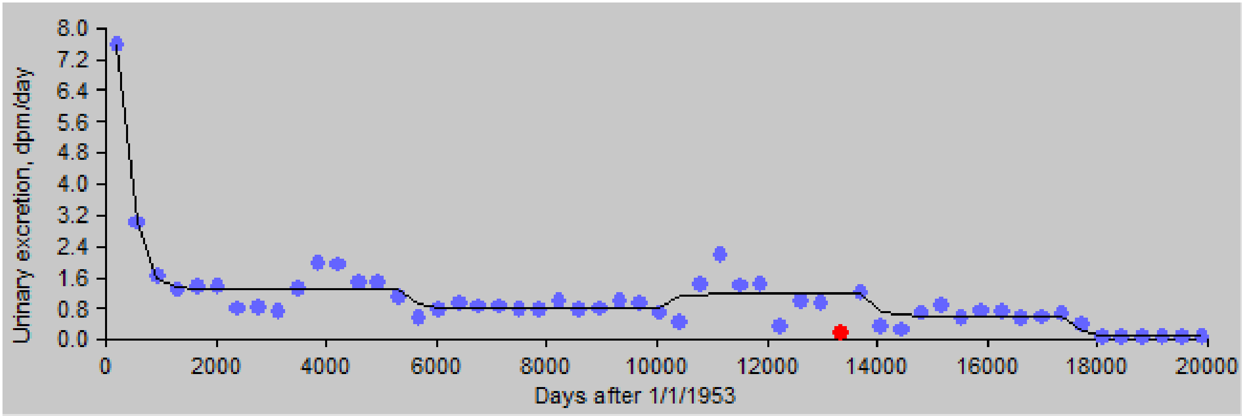

Figure B-16. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, type M.

Table B-4. Summary of uranium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1953	73.3	136.2	1.86	3.00	447
1954	20.78	30.95	1.49	3.00	127
1955–1956	13.08	19.61	1.50	3.00	79.7
1957–1967	5.623	19.14	3.40	3.40	42.2
1968–1980	2.731	11.84	4.34	4.34	30.5
1981–1990	6.473	17.07	2.64	3.00	39.4
1991–2000	3.575	8.621	2.41	3.00	21.8
2001–2007	0.4823	1.386	2.87	3.00	2.94

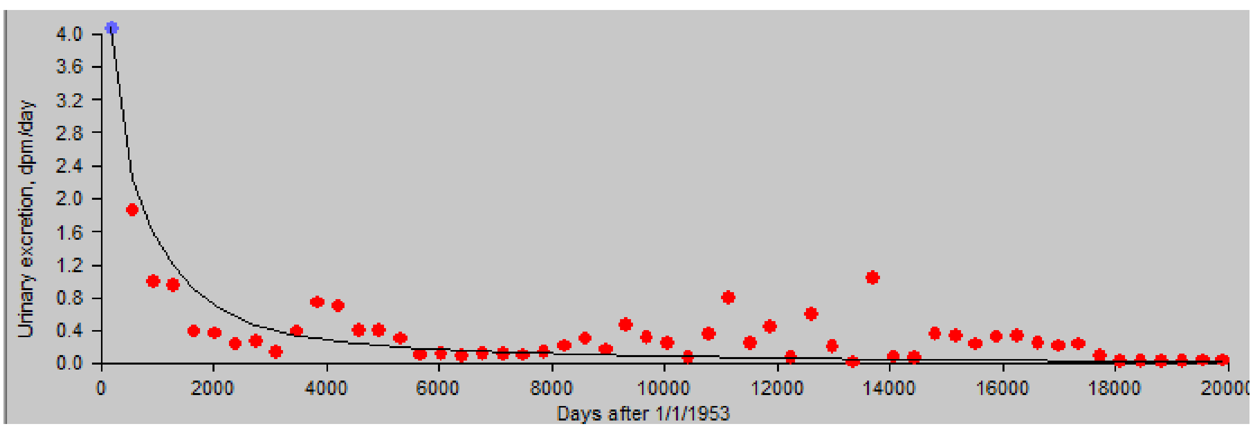

Figure B-17. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1953, type S.

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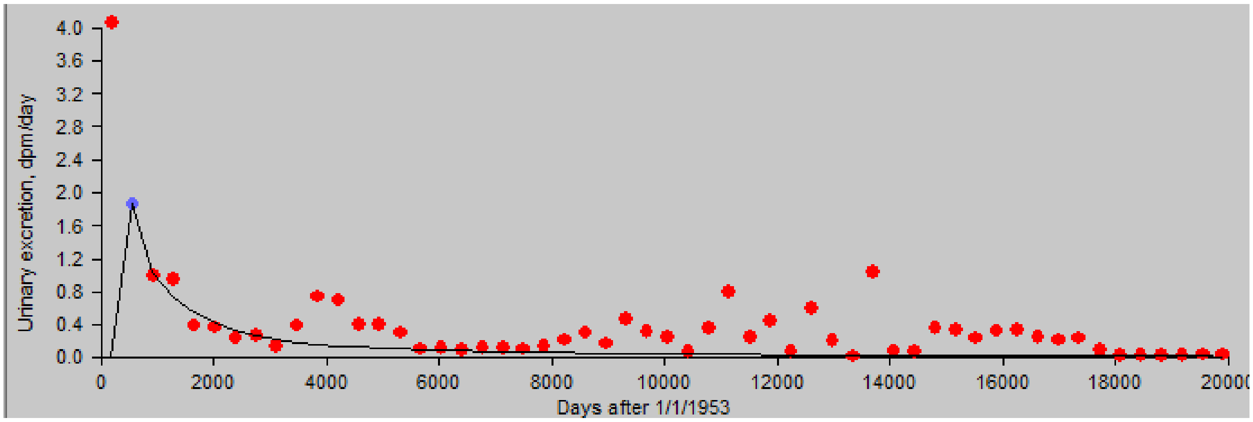

Figure B-18. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1954, type S.

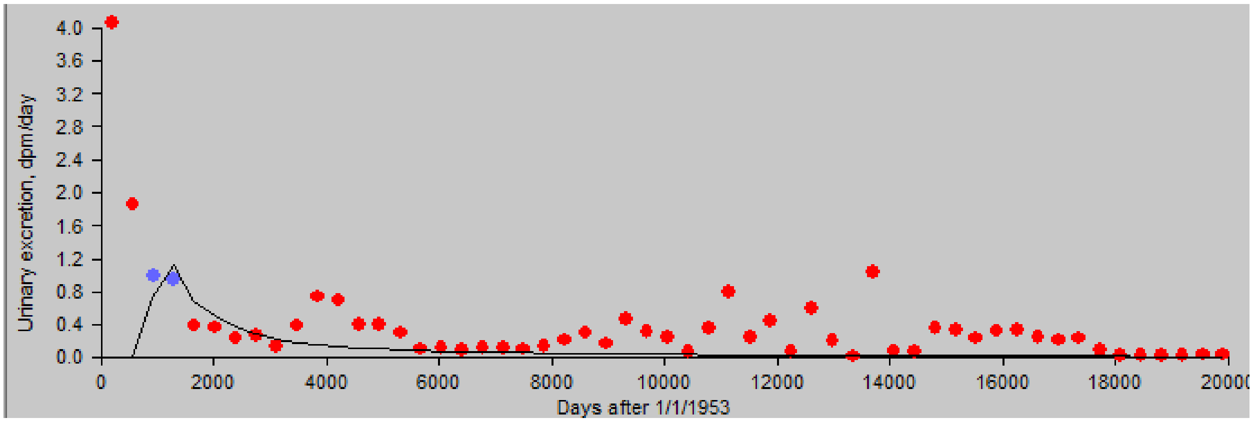

Figure B-19. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1955–1956, type S.

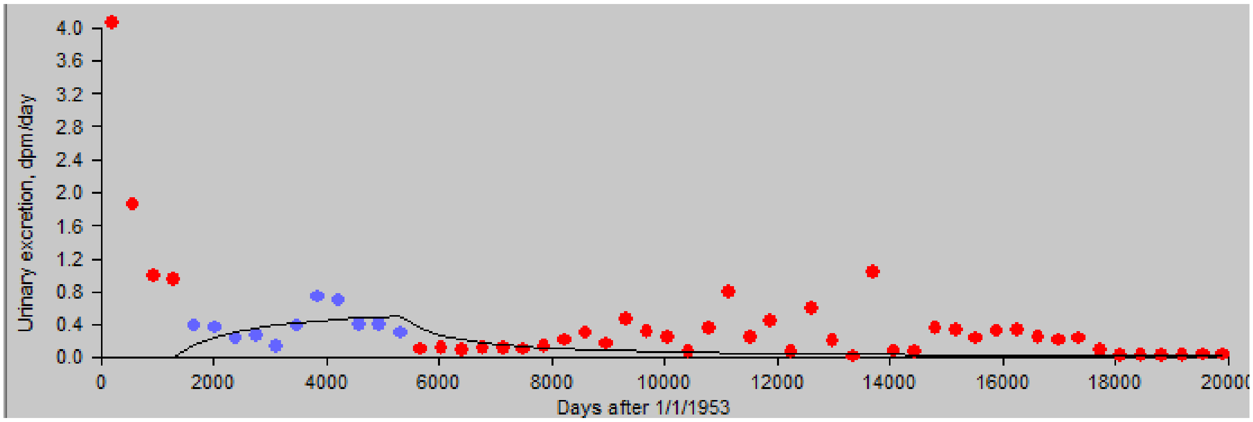

Figure B-20. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1957–1967, type S.

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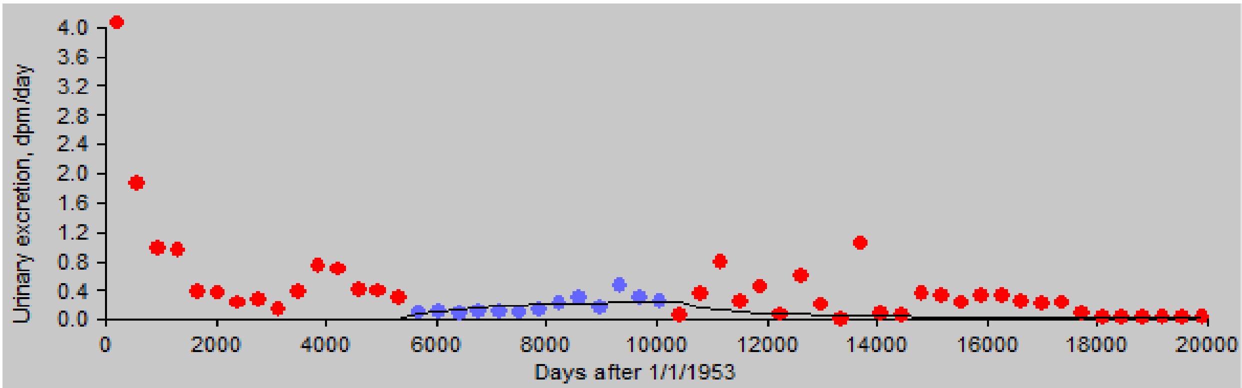

Figure B-21. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1968–1980, type S.

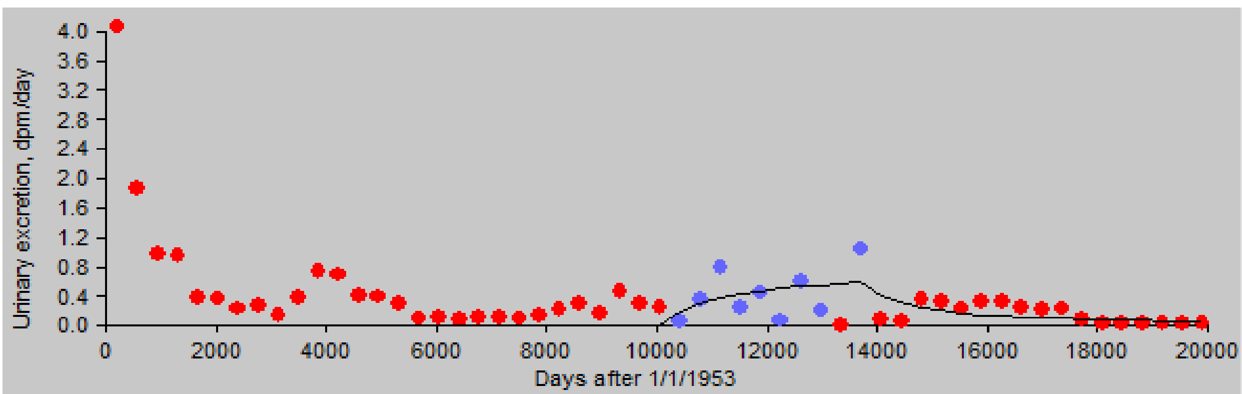

Figure B-22. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1981–1990, type S.

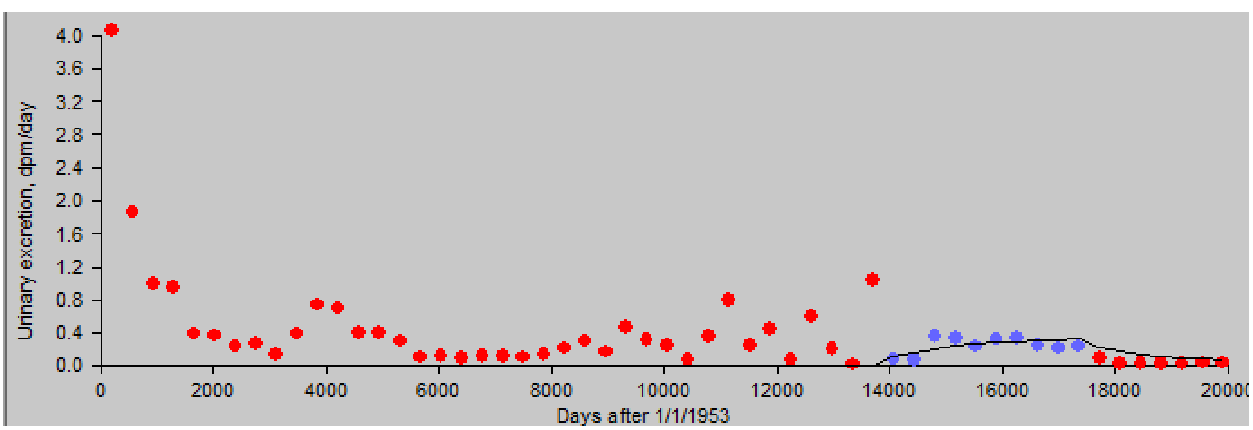

Figure B-23. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 1991–2000, type S.

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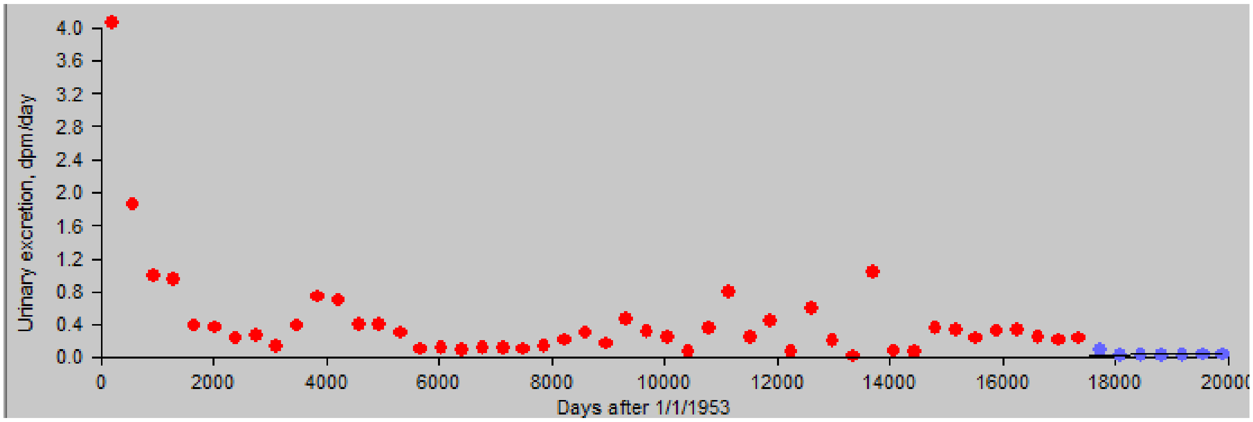

Figure B-24. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, 2001–2007, type S.

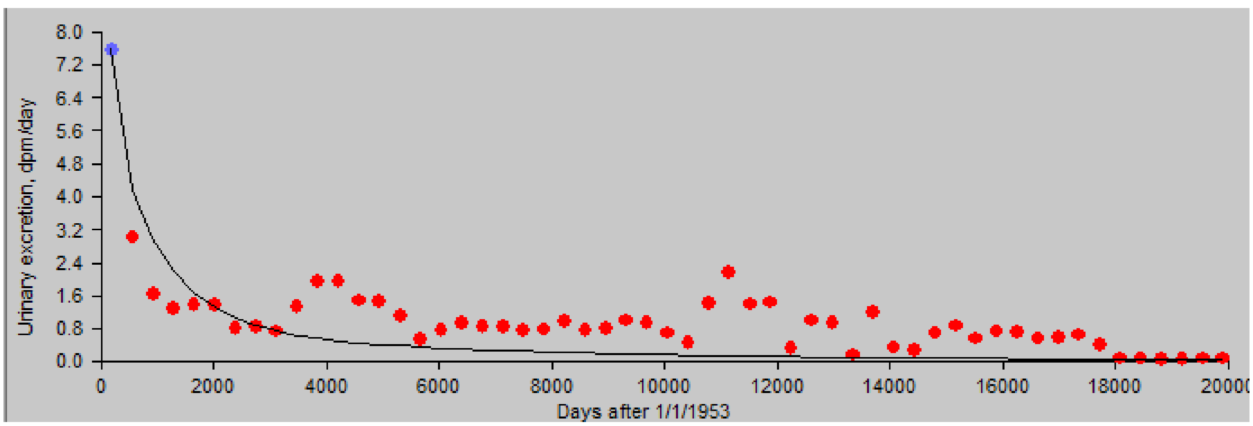

Figure B-25. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1953, type S.

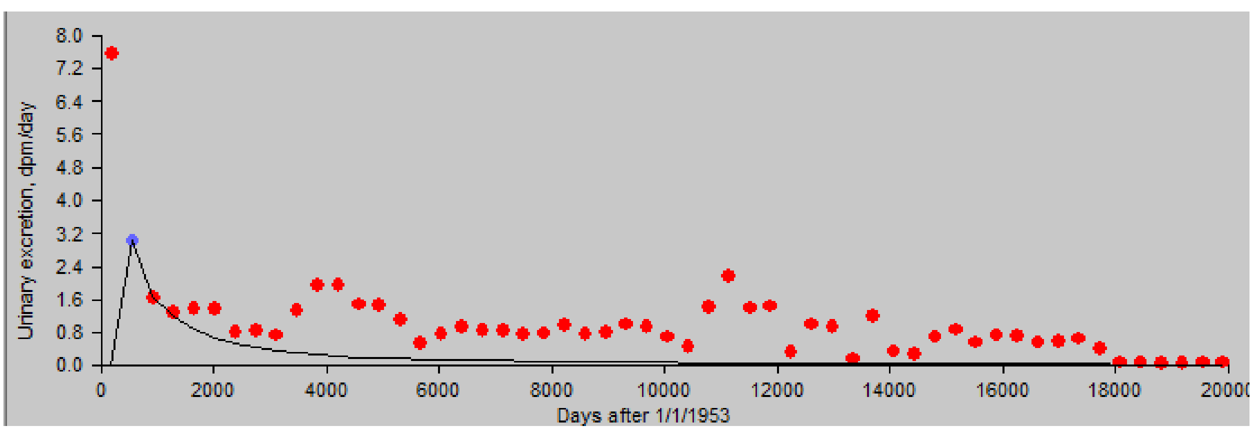

Figure B-26. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1954, type S.

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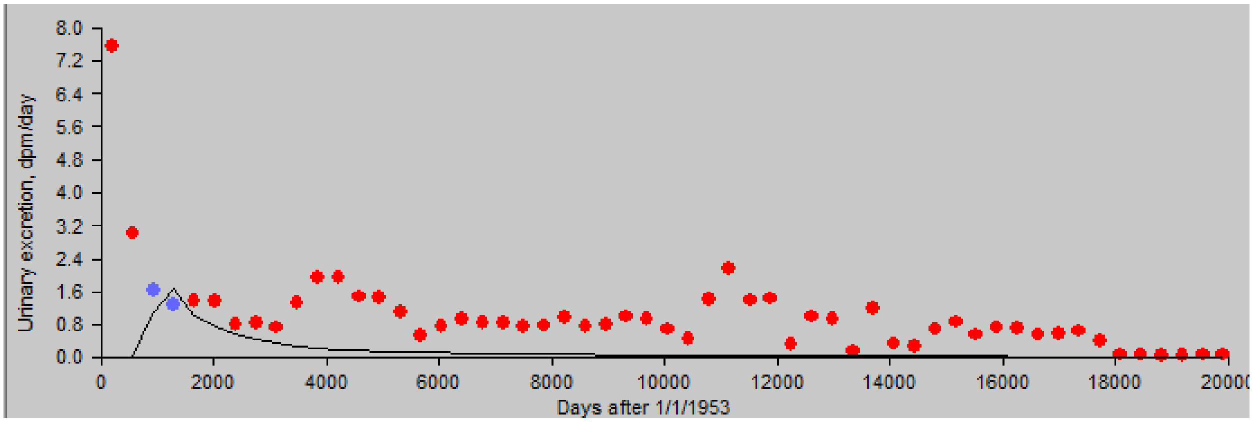

Figure B-27. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1955–1956, type S.

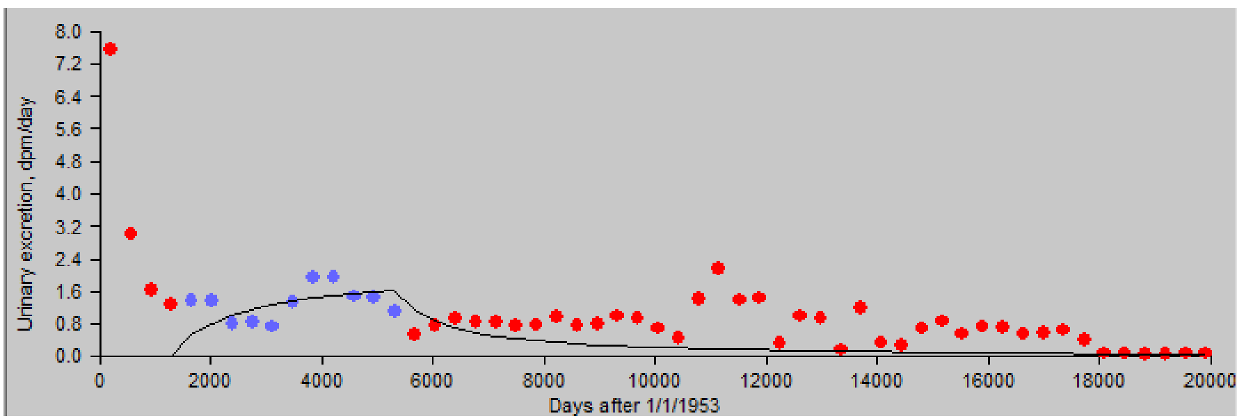

Figure B-28. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1957–1967, type S.

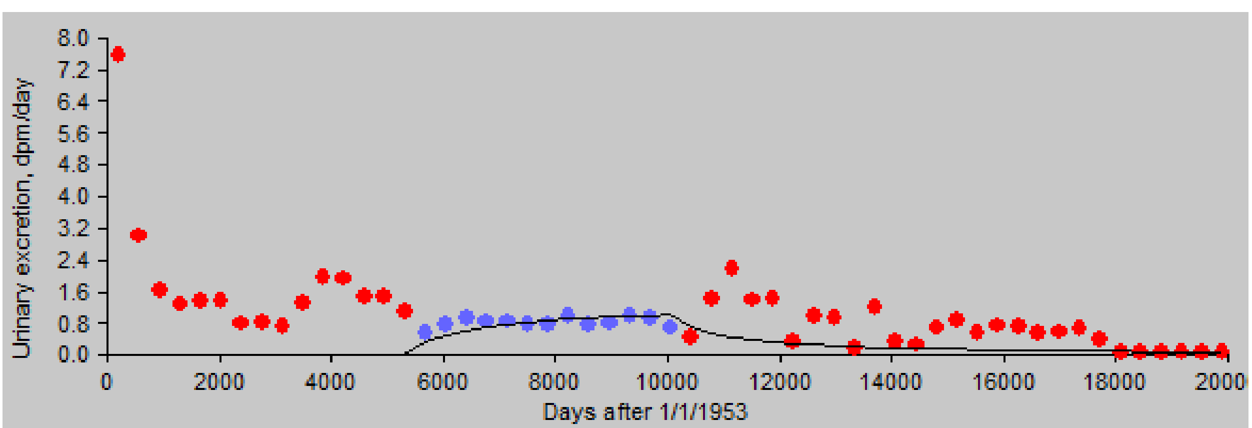

Figure B-29. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1968–1980, type S.

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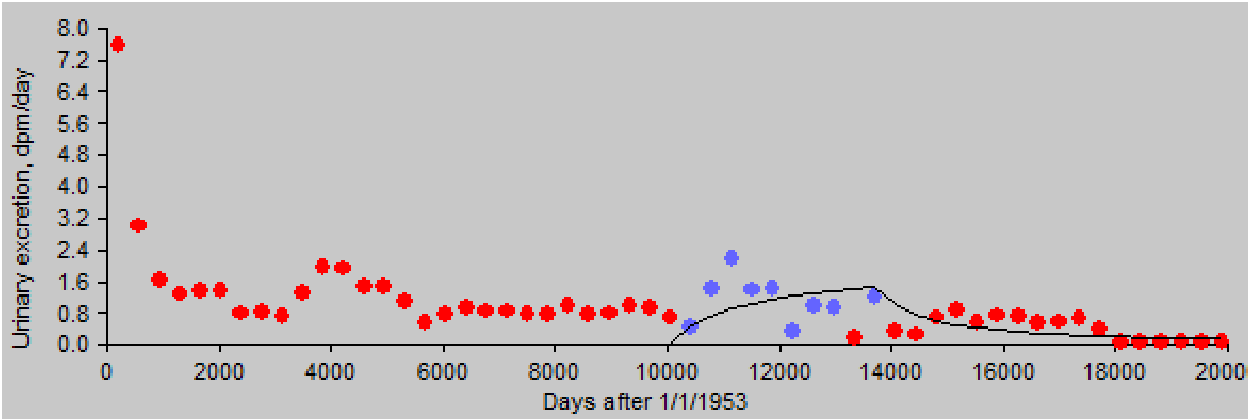

Figure B-30. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1981–1990, type S.

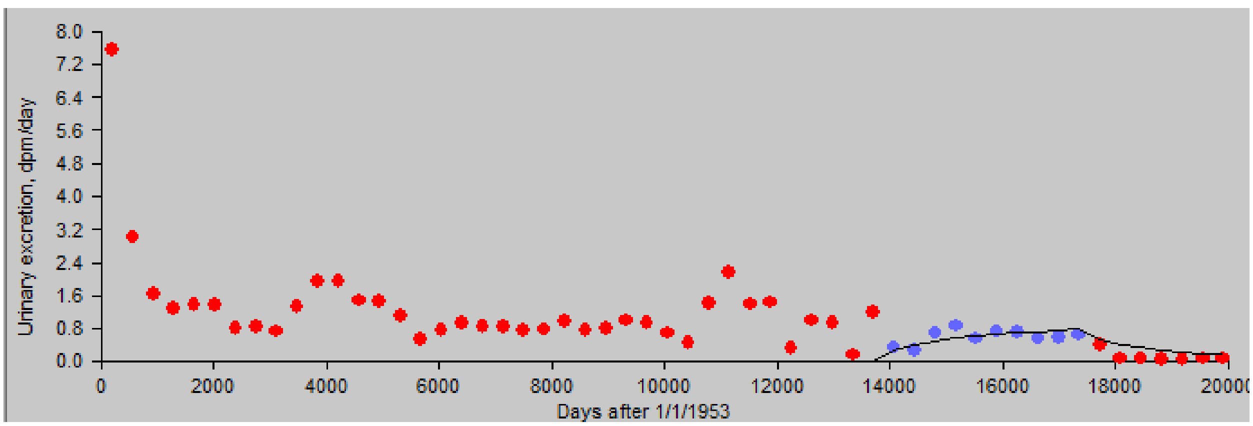

Figure B-31. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 1991–2000, type S.

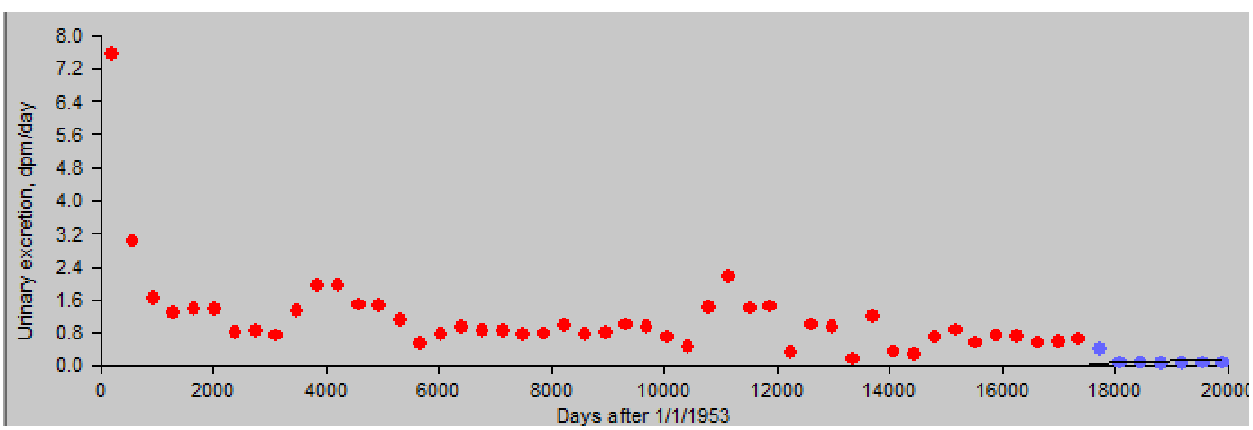

Figure B-32. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, 2001–2007, type S.

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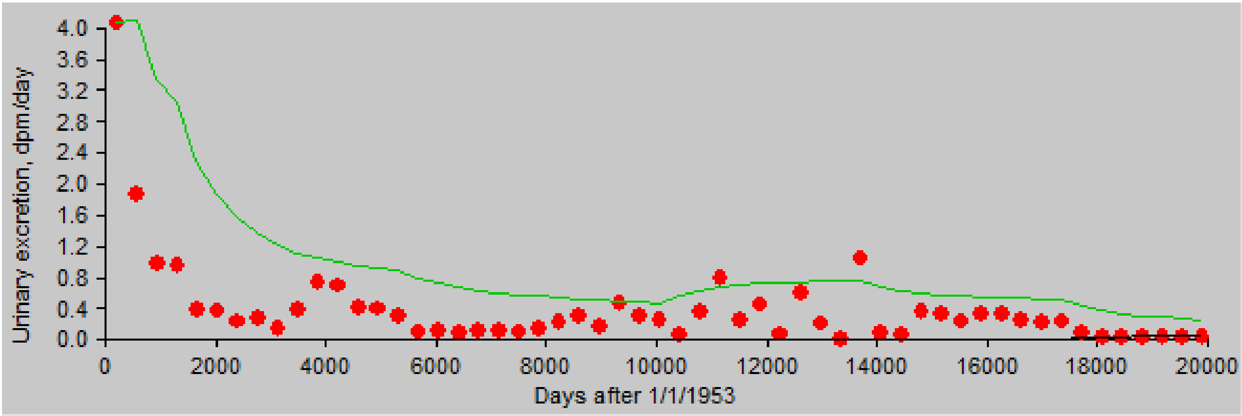

Figure B-33. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 50th percentile, all intake periods, type S.

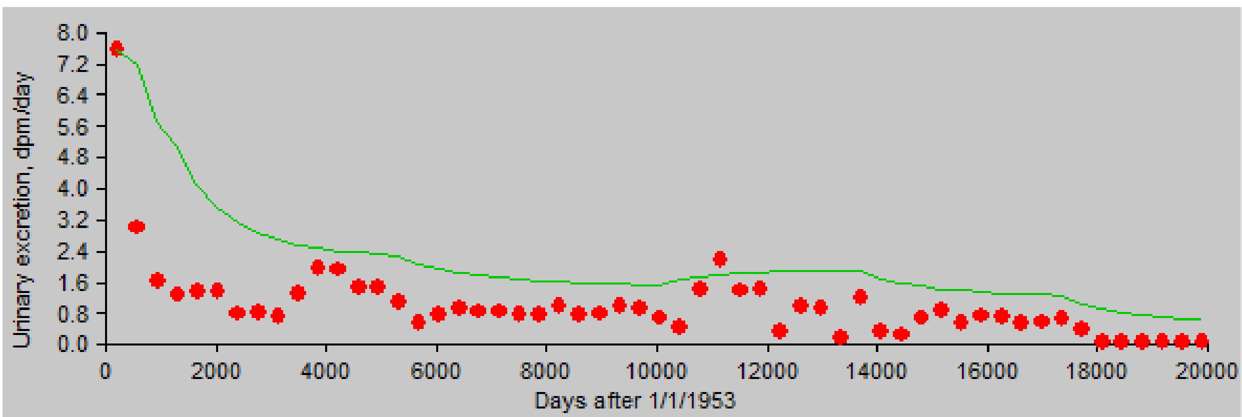

Figure B-34. Predicted uranium bioassay results calculated using IMBA-derived uranium intake rates (line) compared with bioassay results (dots), 84th percentile, all intake periods, type S.

Table B-5. Summary of uranium type S intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1953	2,293	4,261	1.86	3.00	13,972
1954	1,050	1,700	1.62	3.00	6,398
1955–1956	407.8	604.4	1.48	3.00	2,485
1957–1967	89.38	290.9	3.25	3.25	623
1968–1980	41.24	174.7	4.24	4.24	443
1981–1990	107.1	264.2	2.47	3.00	653
1991–2000	58.73	141.1	2.40	3.00	358
2001–2007	10.89	27.35	2.51	3.00	66.4

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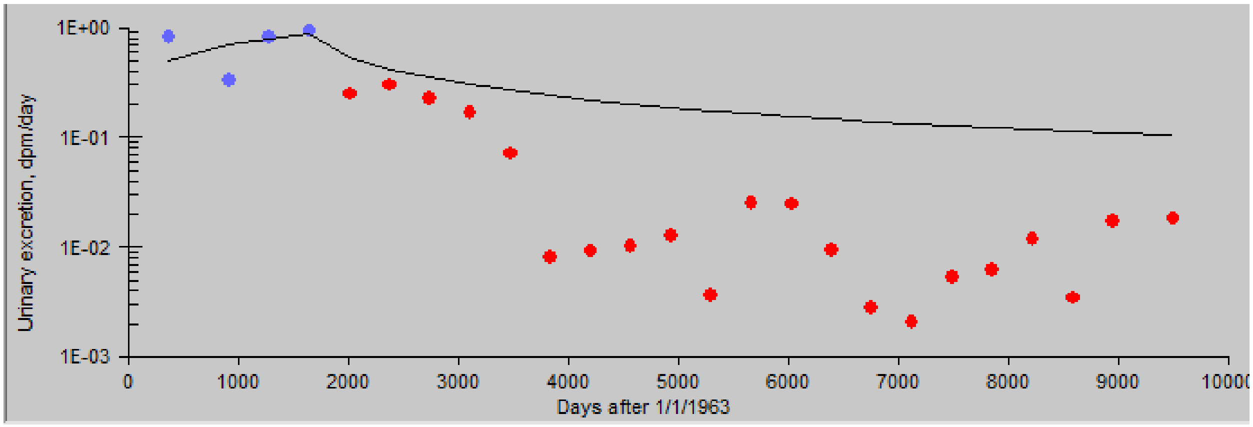

Figure B-35. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 50th percentile, 1963–1967, type M.

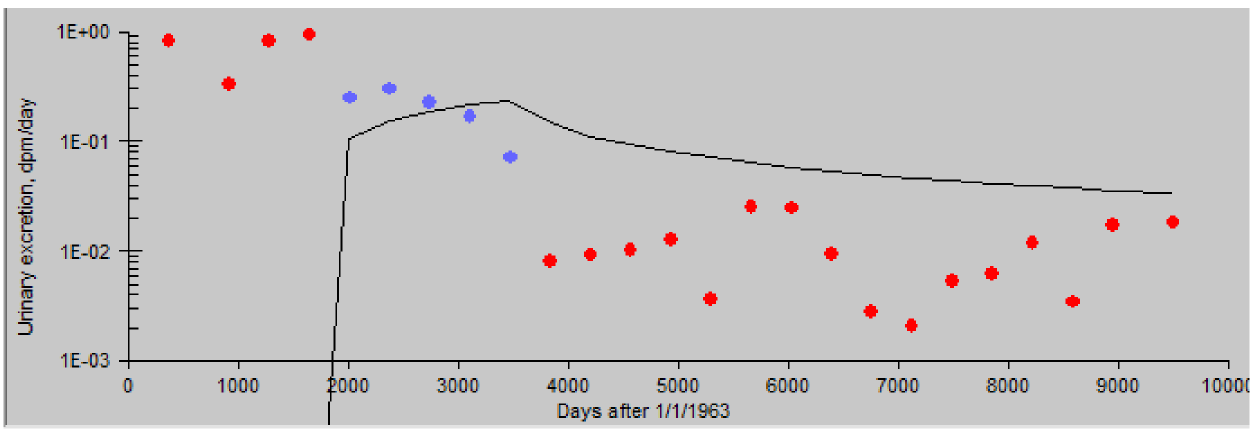

Figure B-36. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 50th percentile, 1968–1972, type M.

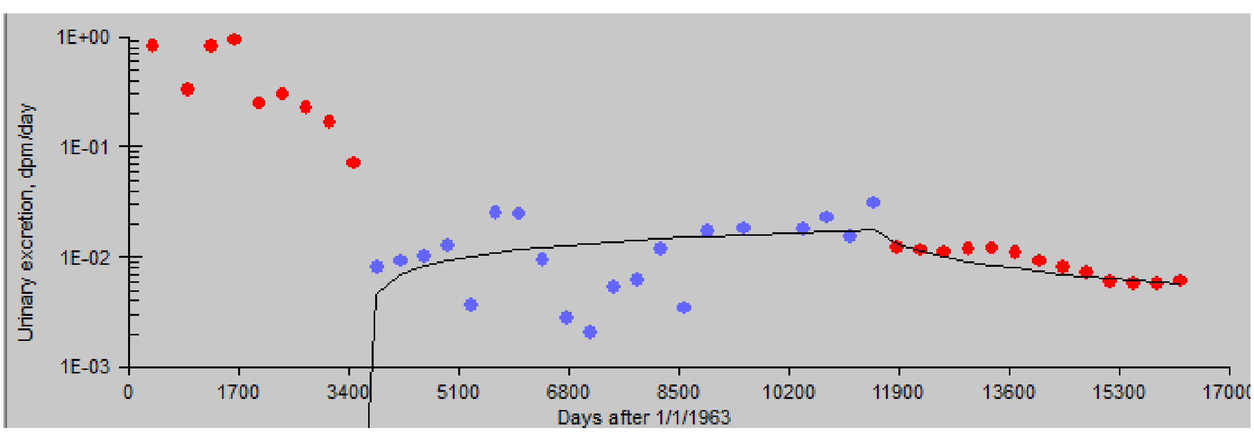

Figure B-37. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 50th percentile, 1973–1994, type M.

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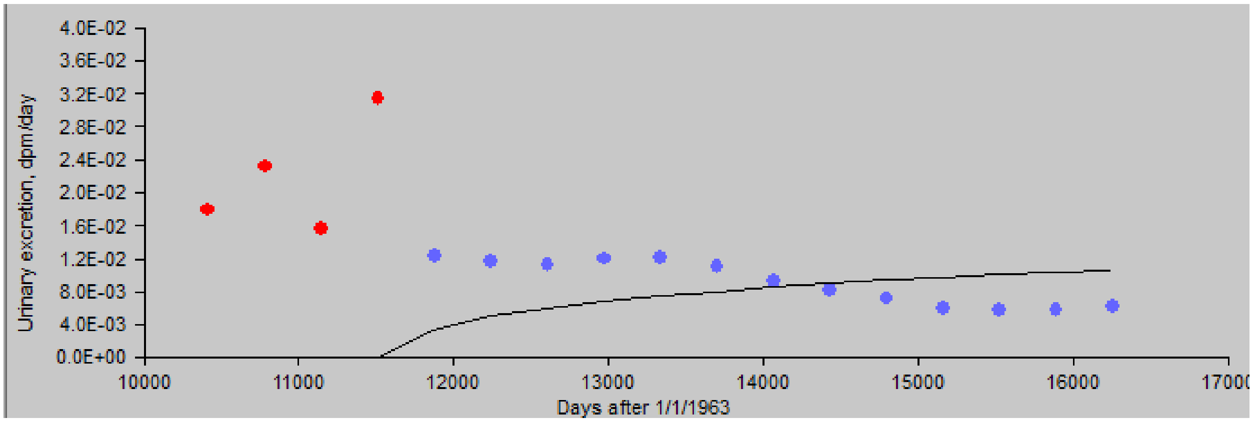

Figure B-38. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 50th percentile, 1995–2007, type M.

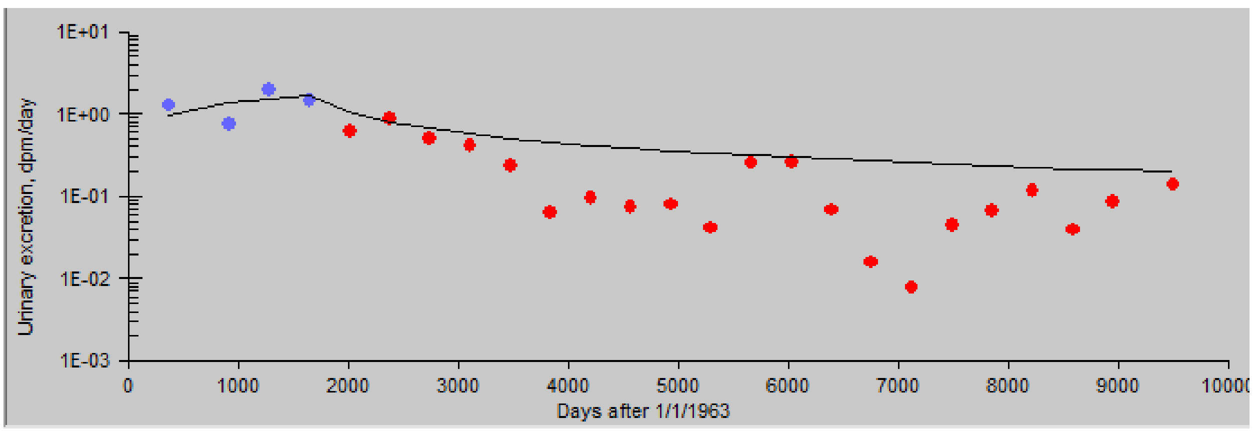

Figure B-39. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 84th percentile, 1963–1967, type M.

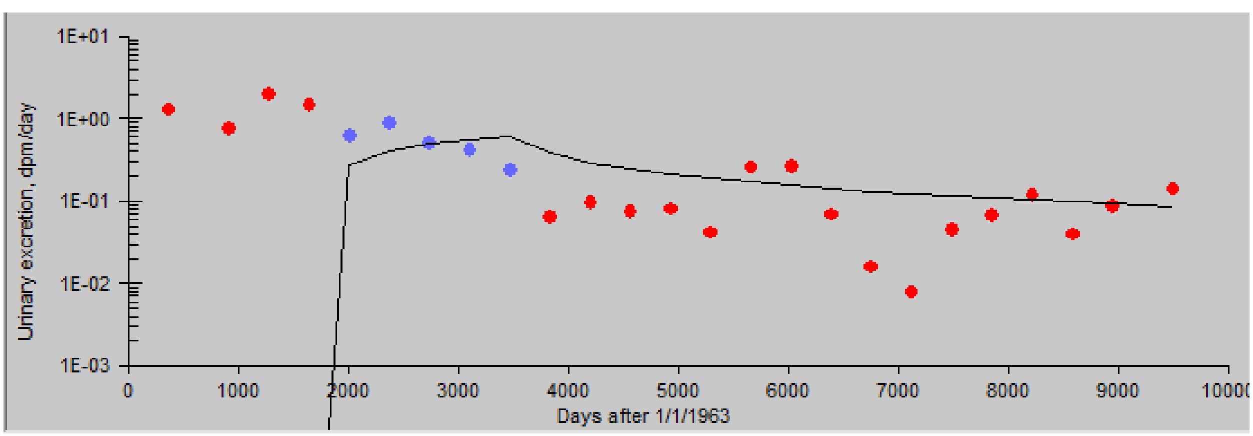

Figure B-40. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 84th percentile, 1968–1972, type M.

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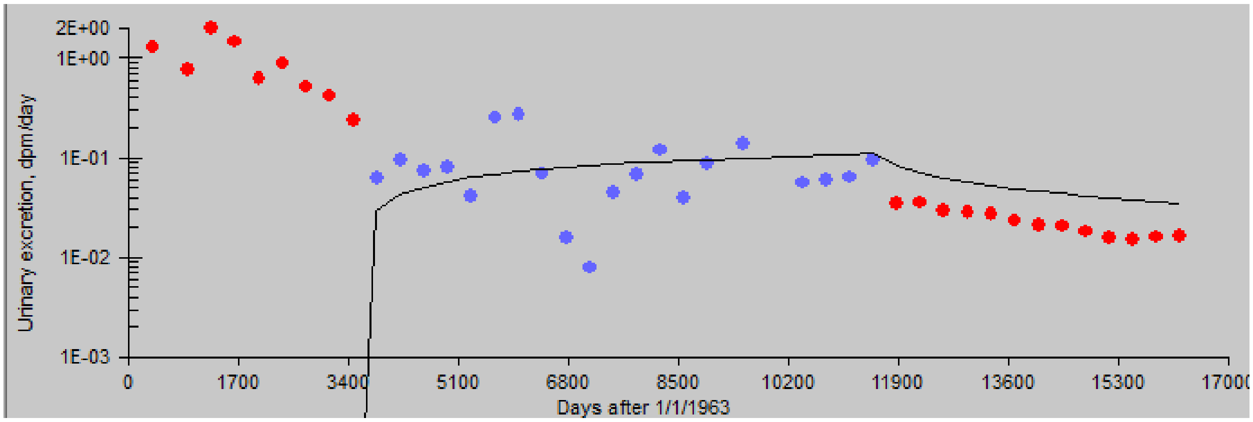

Figure B-41. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 84th percentile, 1973–1994, type M.

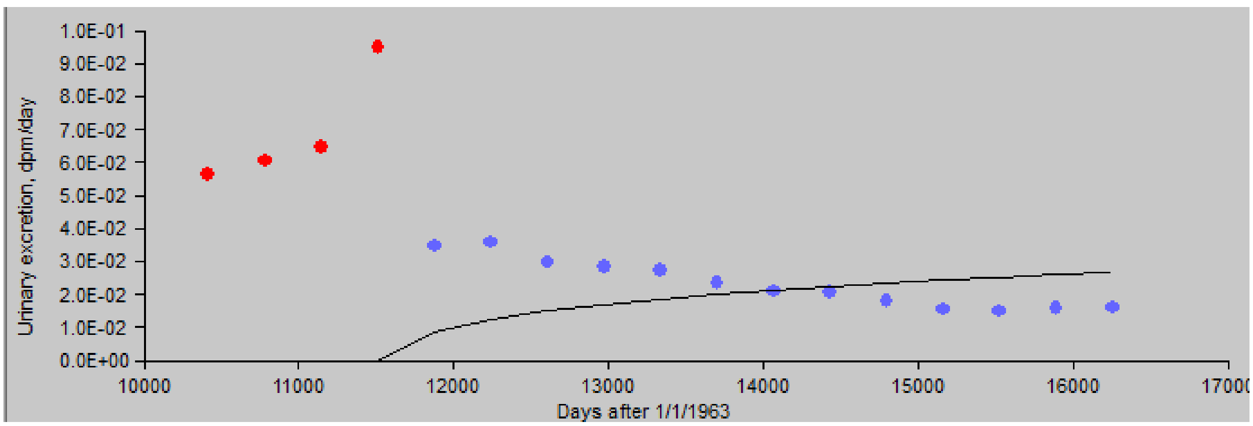

Figure B-42. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 84th percentile, 1995–2007, type M.

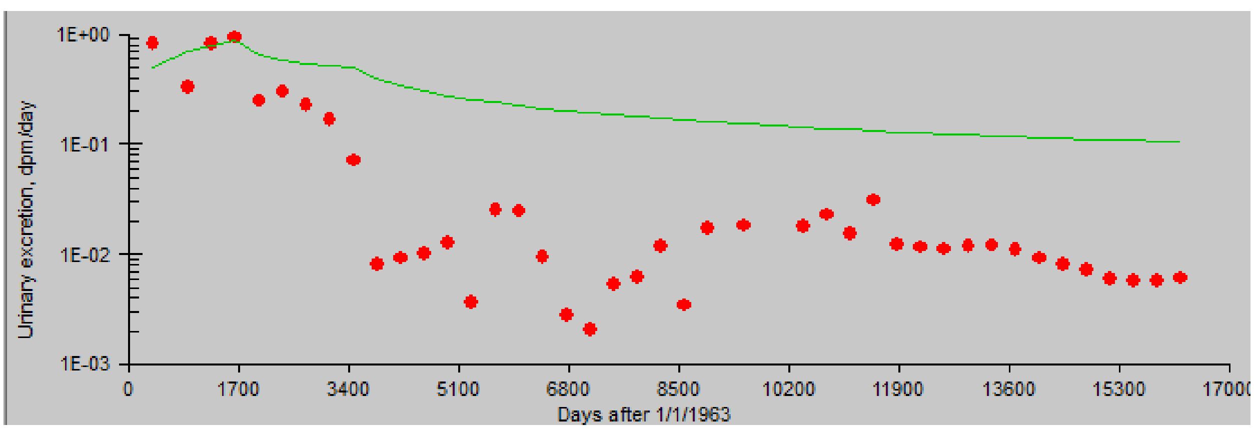

Figure B-43. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 50th percentile, all intake periods, type M.

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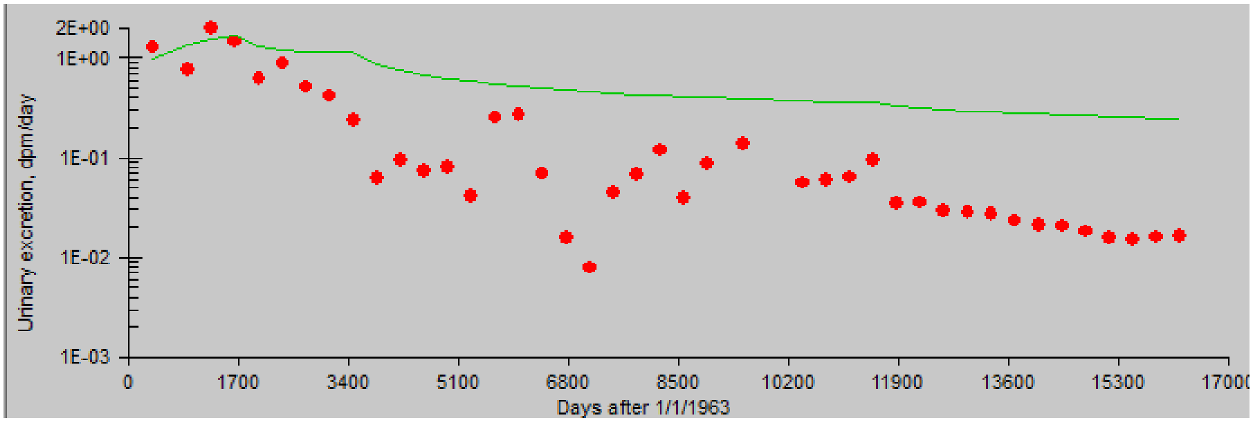

Figure B-44. Predicted americium bioassay results calculated using IMBA-derived americium intake rates (line) compared with bioassay results (dots), 84th percentile, all intake periods, type M.

Table B-6. Summary of americium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1963–1967	70.7	134.8	1.91	3.00	431
1968–1972	18.9	49.53	2.62	3.00	115
1973–1994	0.826	5.142	6.23	6.23	16.7
1995–2007	0.599	1.523	2.54	3.00	3.65

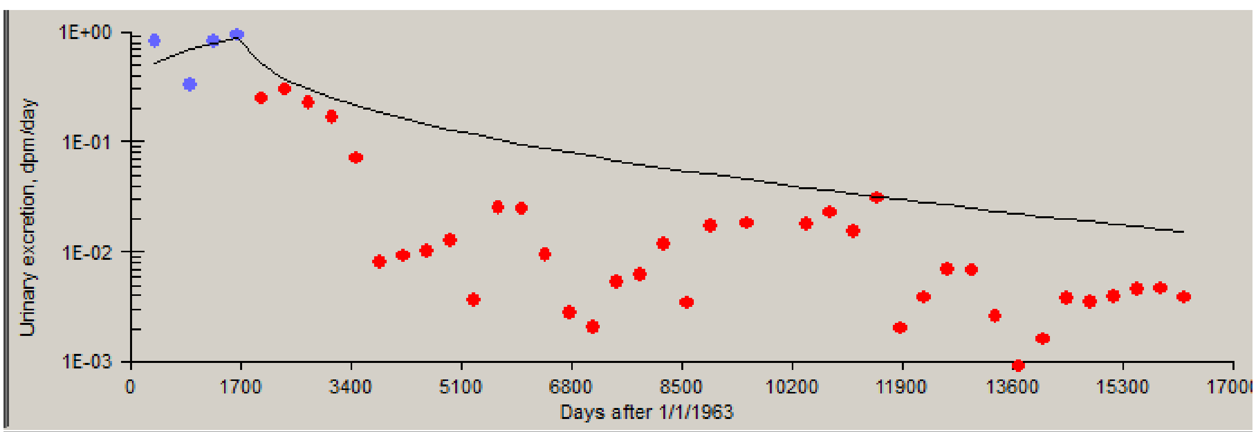

Figure B-45. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 50th percentile, 1963–1967, type M.

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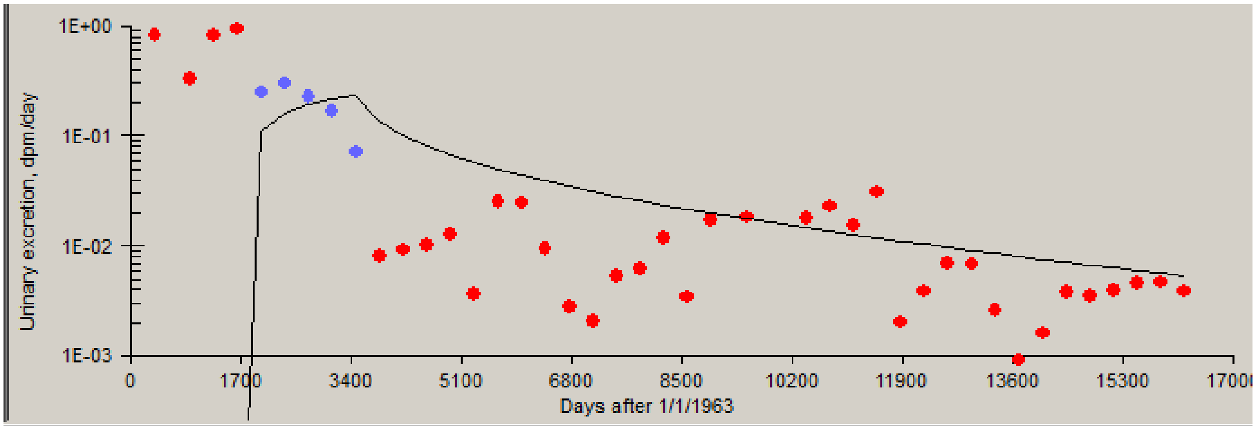

Figure B-46. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 50th percentile, 1968–1972, type M.

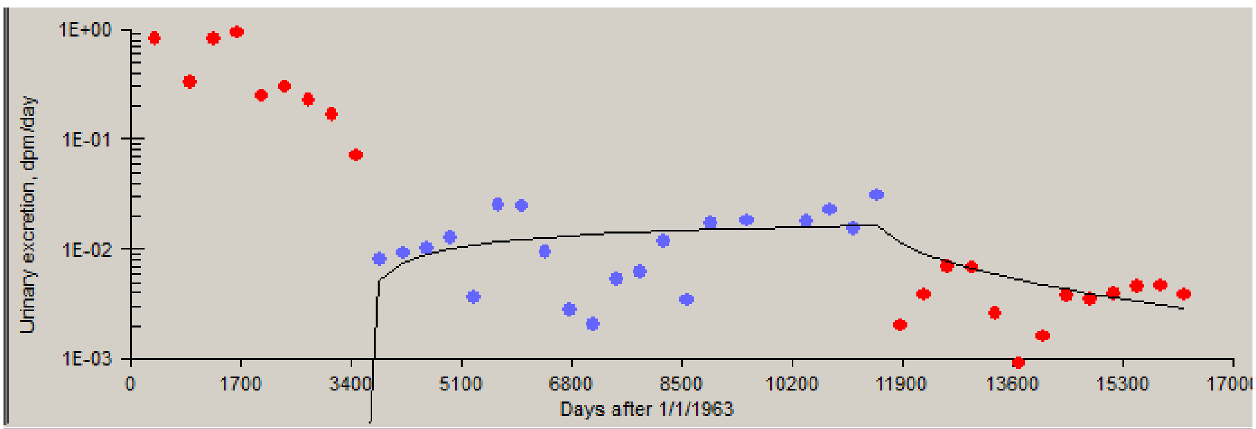

Figure B-47. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 50th percentile, 1973–1994, type M.

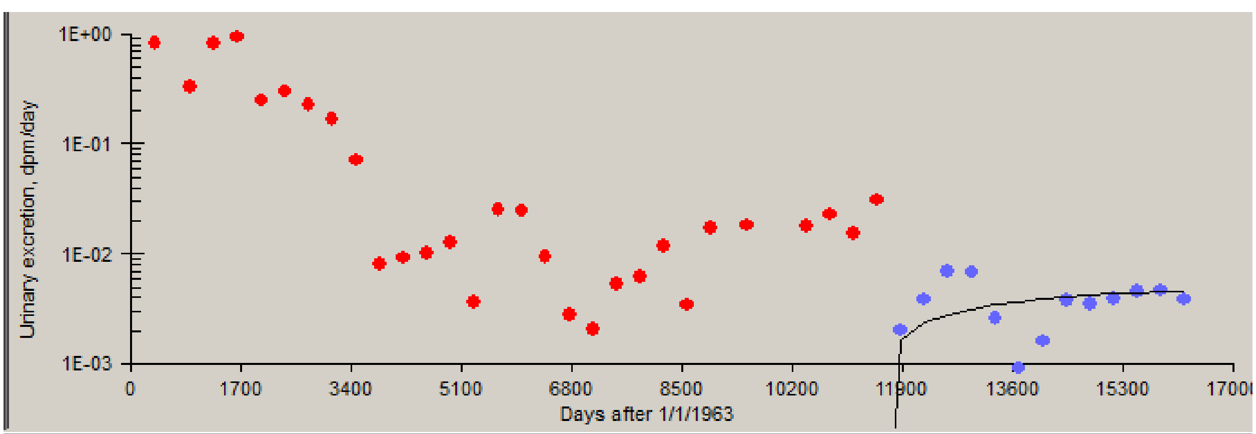

Figure B-48. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 50th percentile, 1995–2007, type M.

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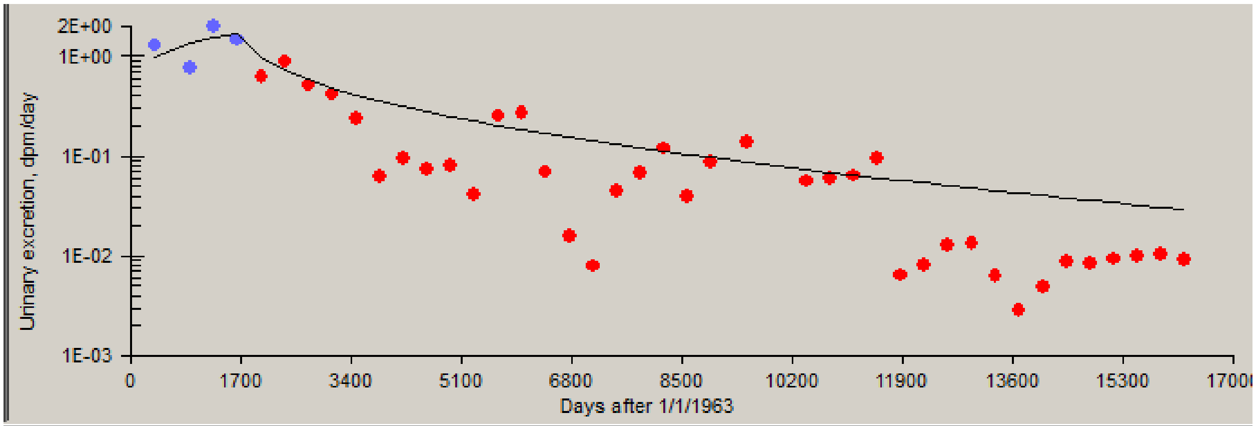

Figure B-49. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 84th percentile, 1963–1967, type M.

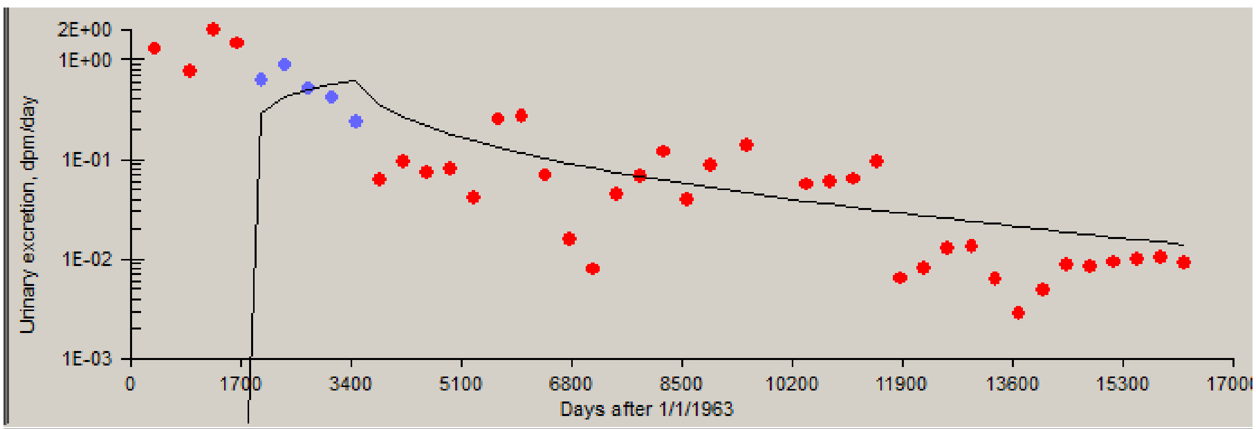

Figure B-50. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 84th percentile, 1968–1972, type M.

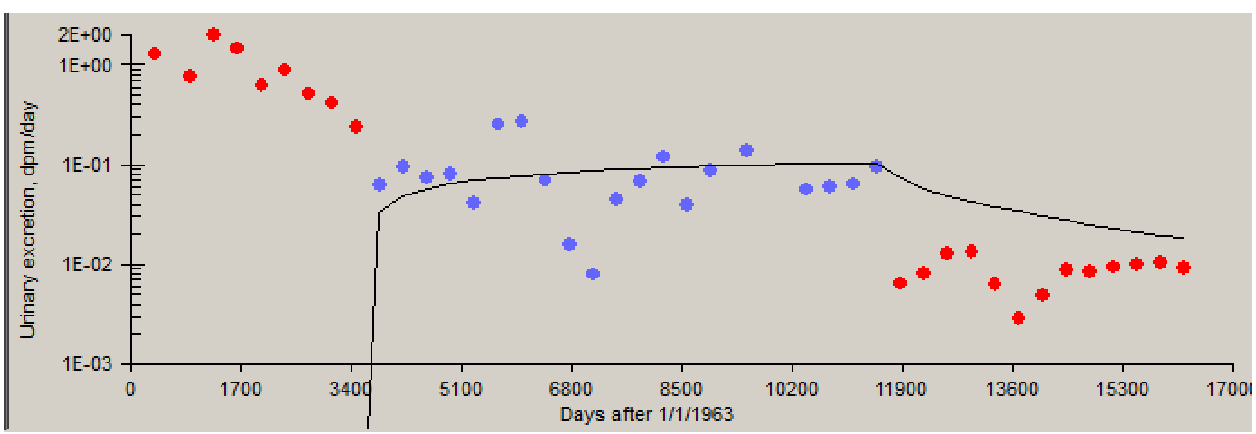

Figure B-51. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 84th percentile, 1973–1994, type M.

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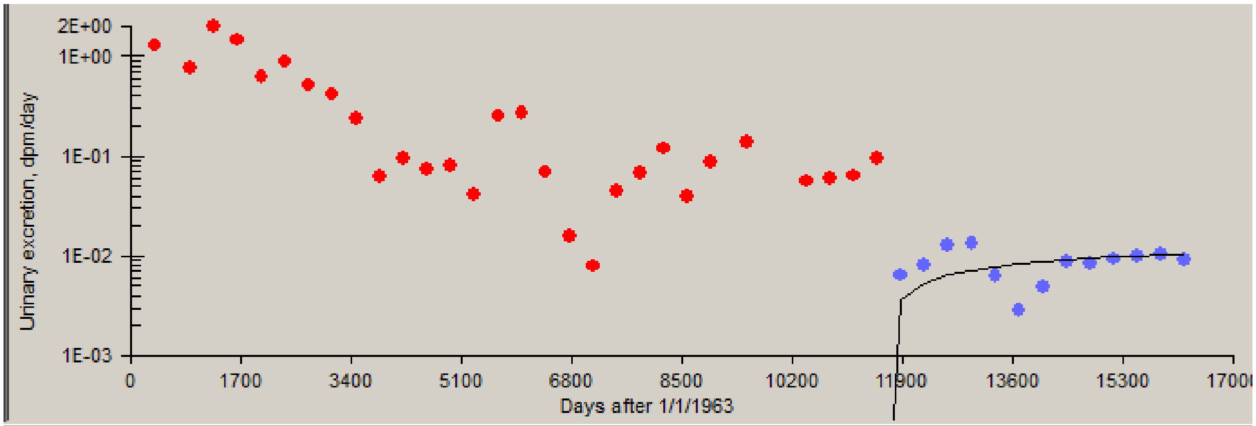

Figure B-52. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 84th percentile, 1995–2007, type M.

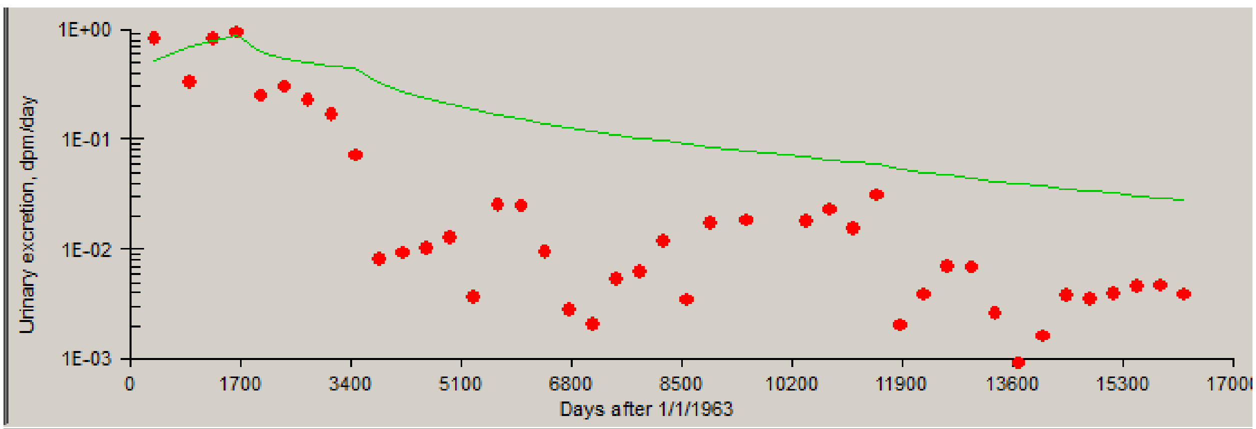

Figure B-53. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 50th percentile, all intake periods, type M.

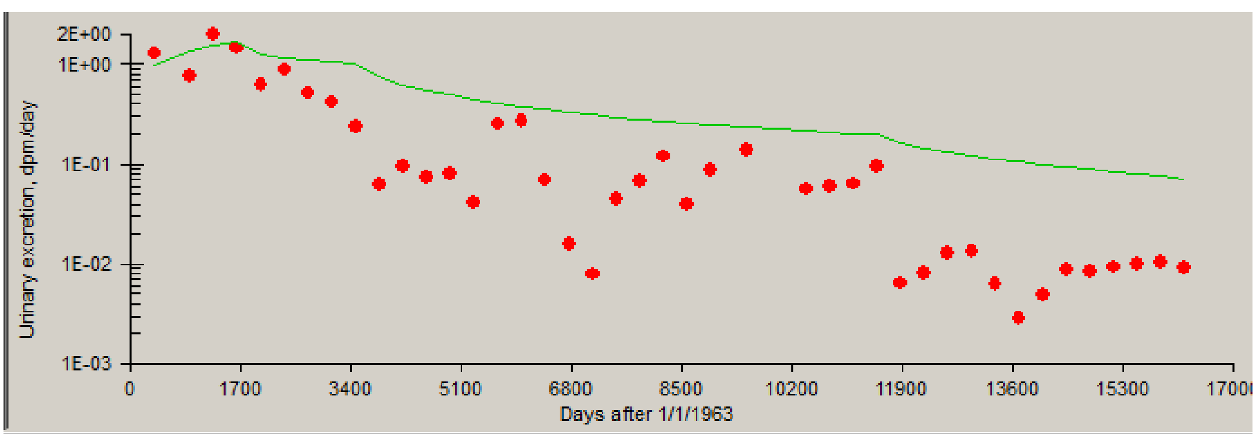

Figure B-54. Predicted curium bioassay results calculated using IMBA-derived curium intake rates (line) compared with bioassay results (dots), 84th percentile, all intake periods, type M.

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Table B-7. Summary of curium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1963–1967	73.01	139.2	1.91	3.00	444.9
1968–1972	19.63	51.4	2.62	3.00	119.6
1973–1994	0.921	5.852	6.35	6.35	19.3
1995–2007	0.291	0.6621	2.28	3.00	1.77

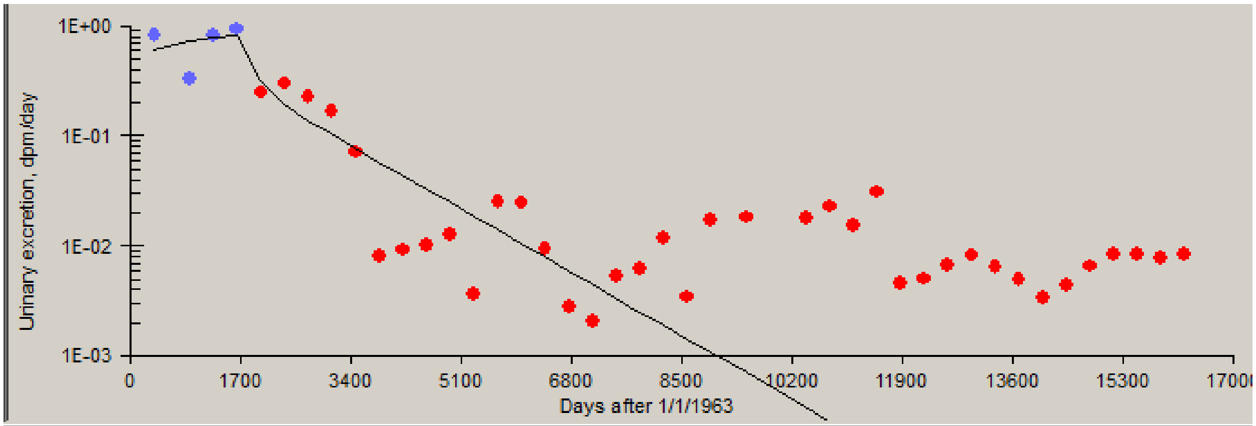

Figure B-55. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 50th percentile, 1963–1967, type M.

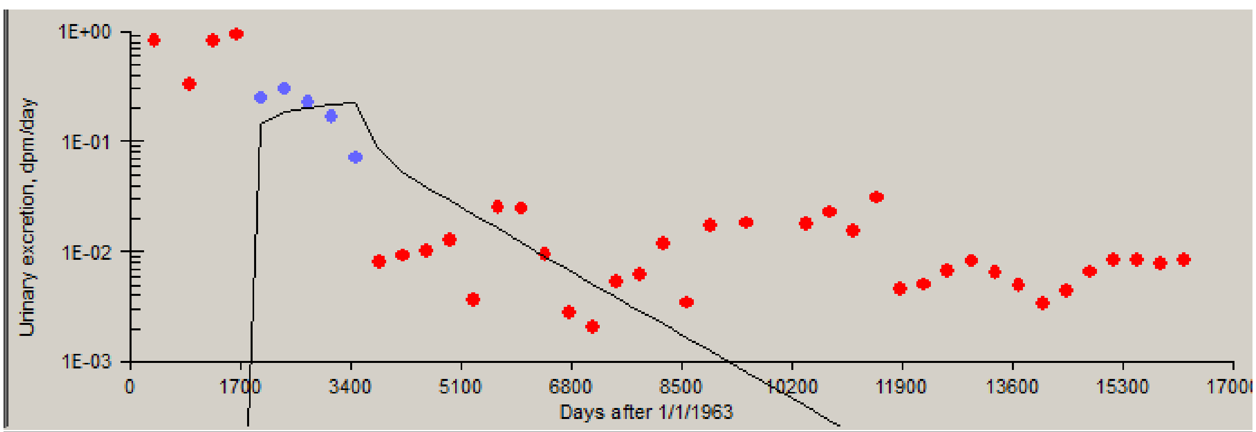

Figure B-56. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 50th percentile, 1968–1972, type M.

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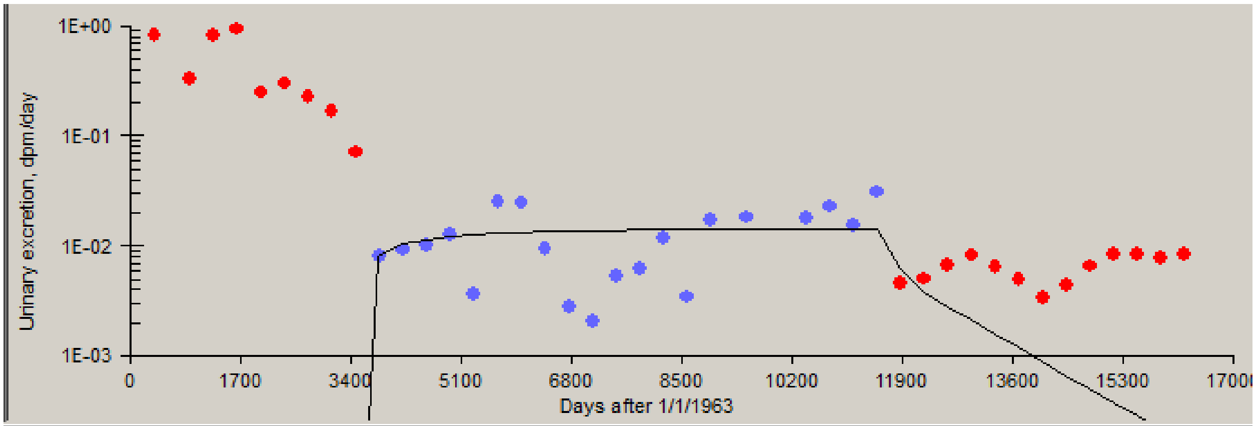

Figure B-57. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 50th percentile, 1973–1994, type M.

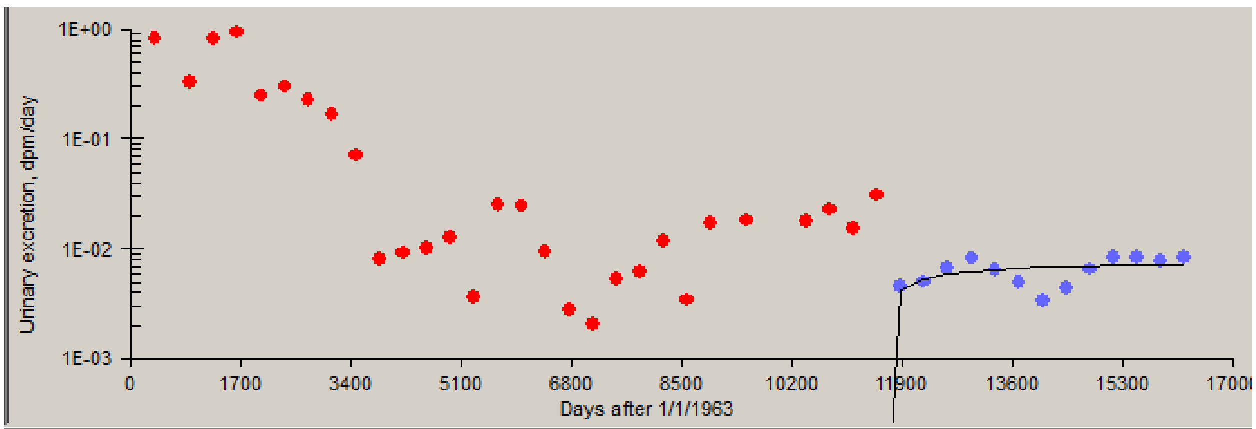

Figure B-58. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 50th percentile, 1995–2007, type M.

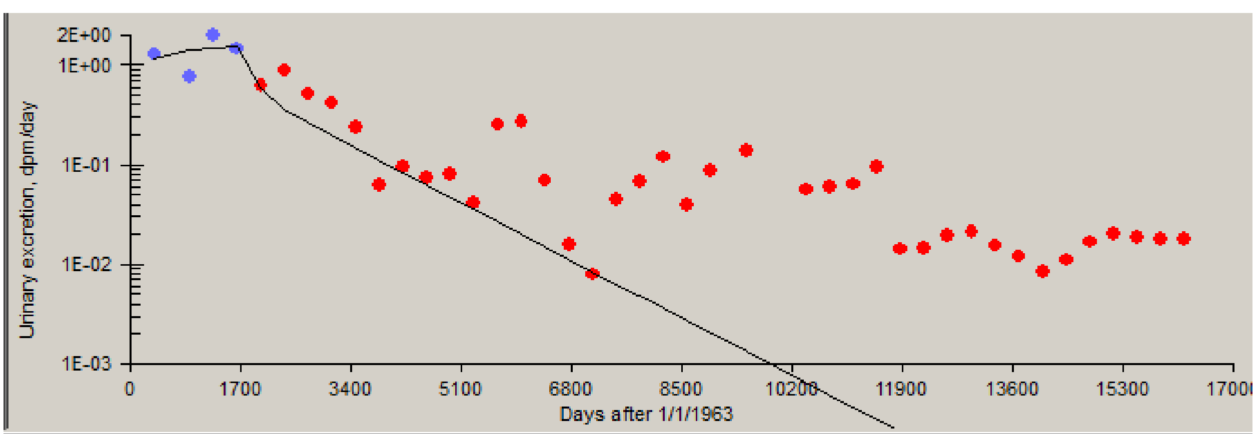

Figure B-59. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 84th percentile, 1963–1967, type M.

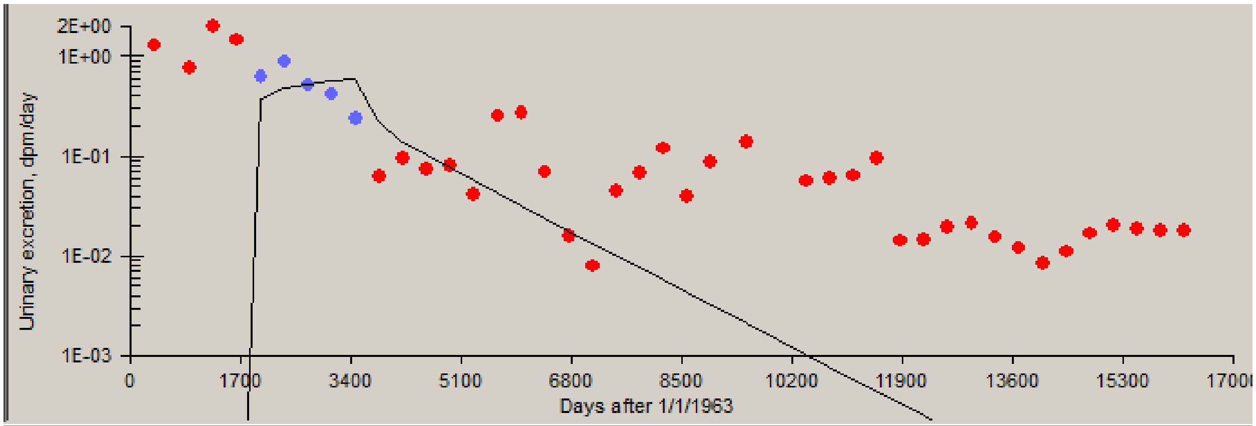

Figure B-60. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 84th percentile, 1968–1972, type M.

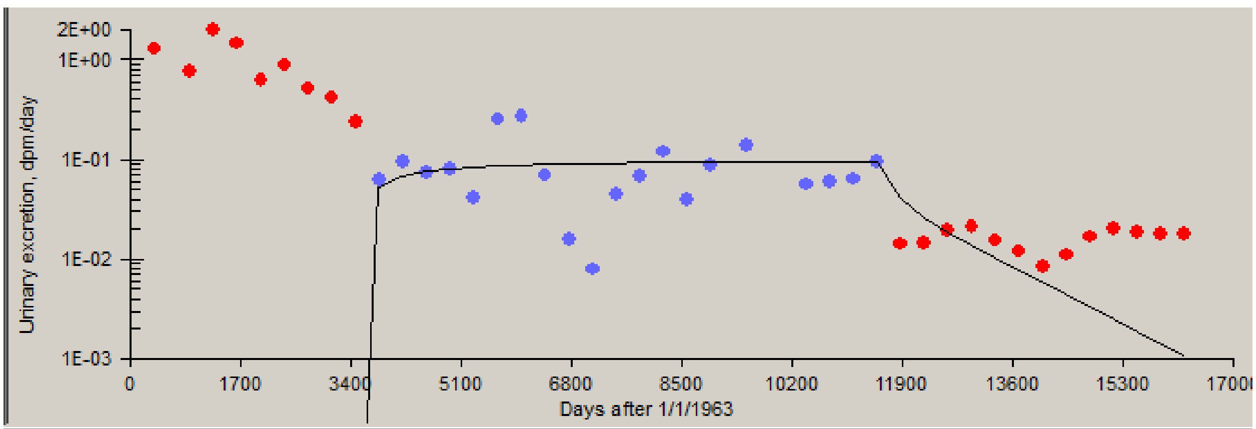

Figure B-61. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 84th percentile, 1973–1994, type M.

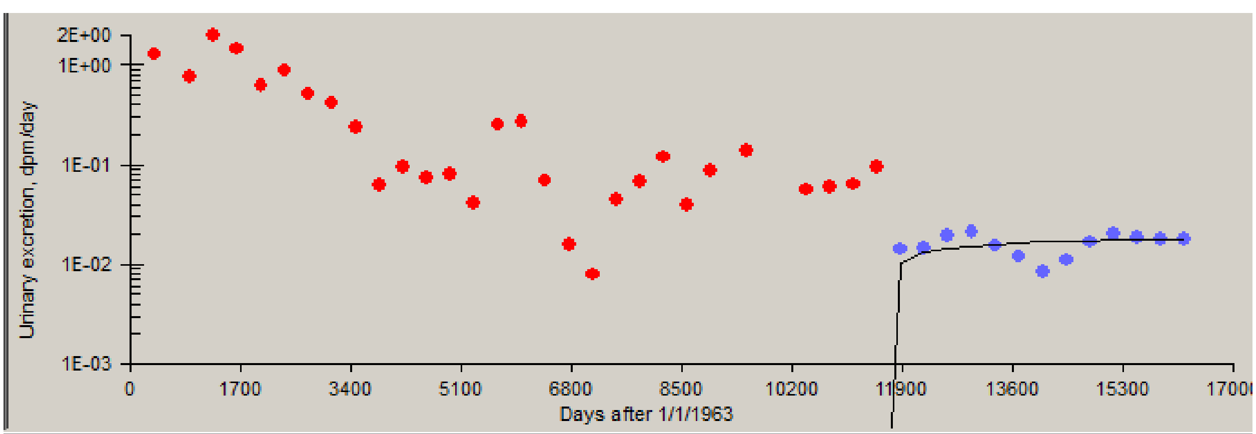

Figure B-62. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 84th percentile, 1995–2007, type M.

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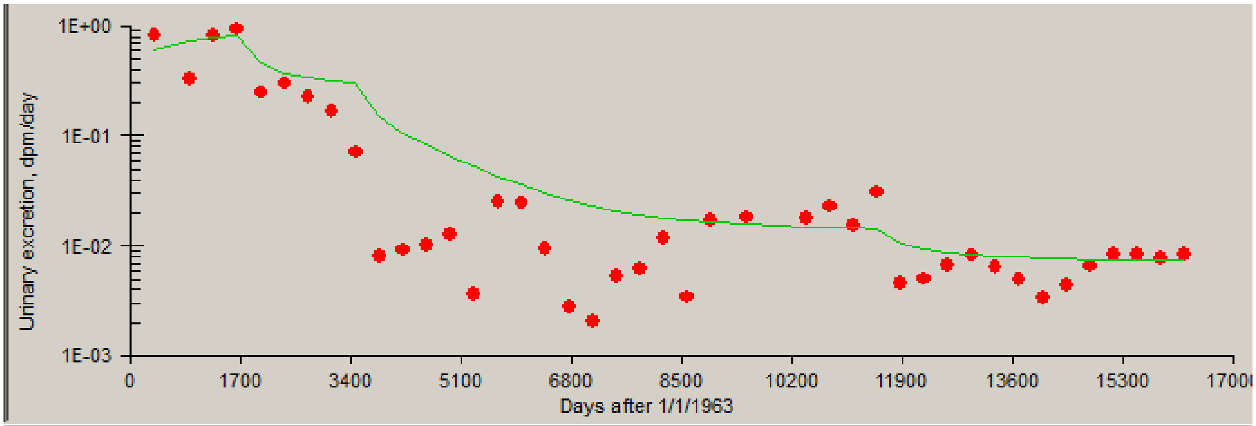

Figure B-63. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 50th percentile, all intake periods, type M.

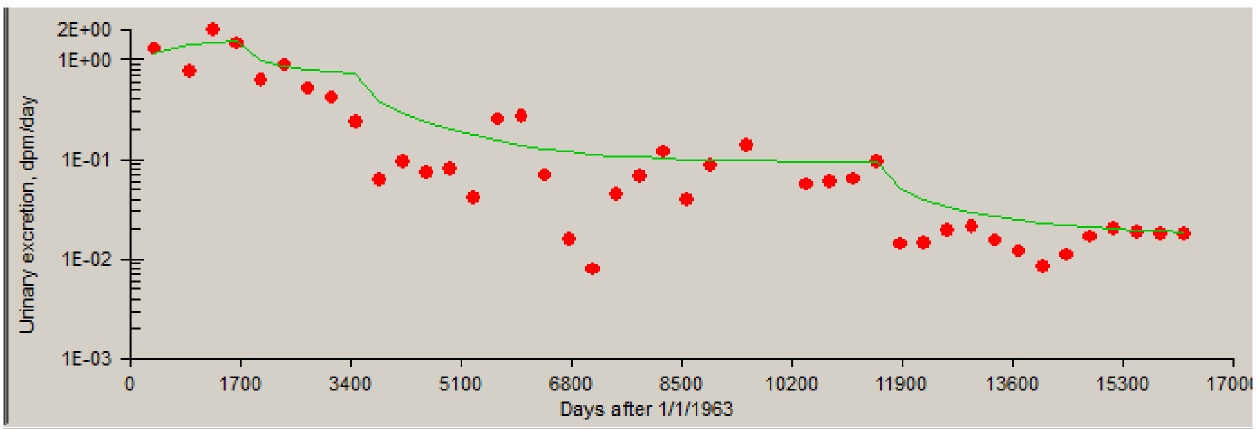

Figure B-64. Predicted californium bioassay results calculated using IMBA-derived californium intake rates (line) compared with bioassay results (dots), 84th percentile, all intake periods, type M.

Table B-8. Summary of californium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1963–1967	194.7	369.8	1.90	3.00	1,186
1968–1972	53.88	140.9	2.62	3.00	328.3
1973–1994	3.012	19.94	6.62	6.62	67.5
1995–2007	1.551	3.827	2.47	3.00	9.45

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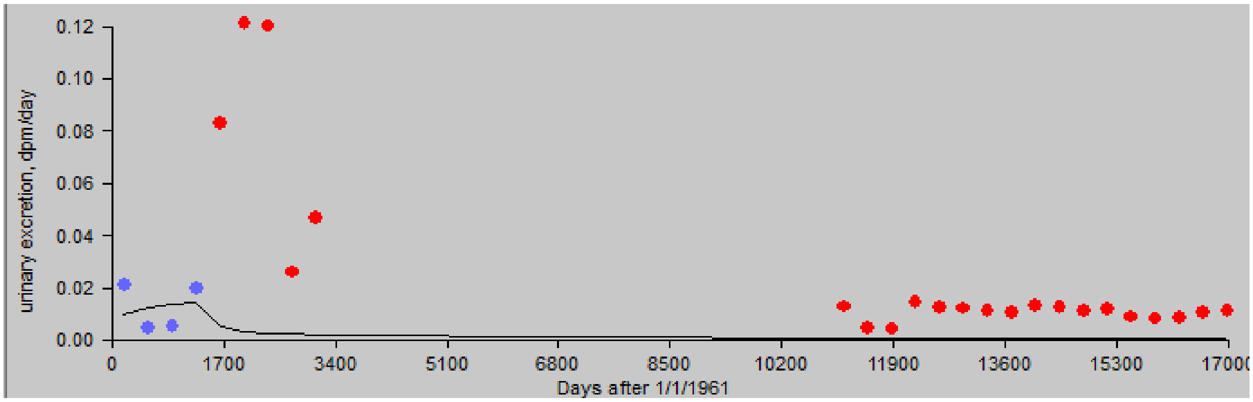

Figure B-65. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1961–1964, type M.

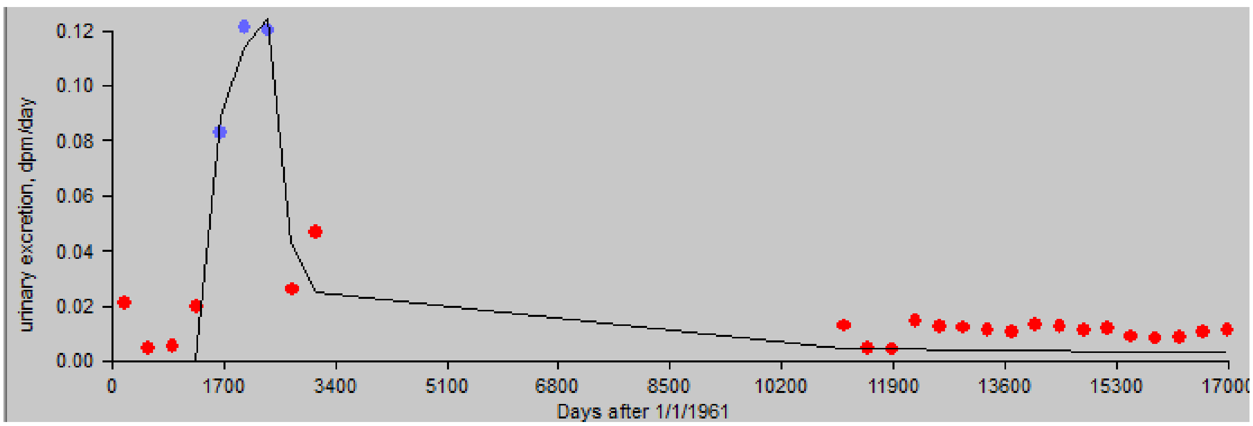

Figure B-66. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1965–1967, type M.

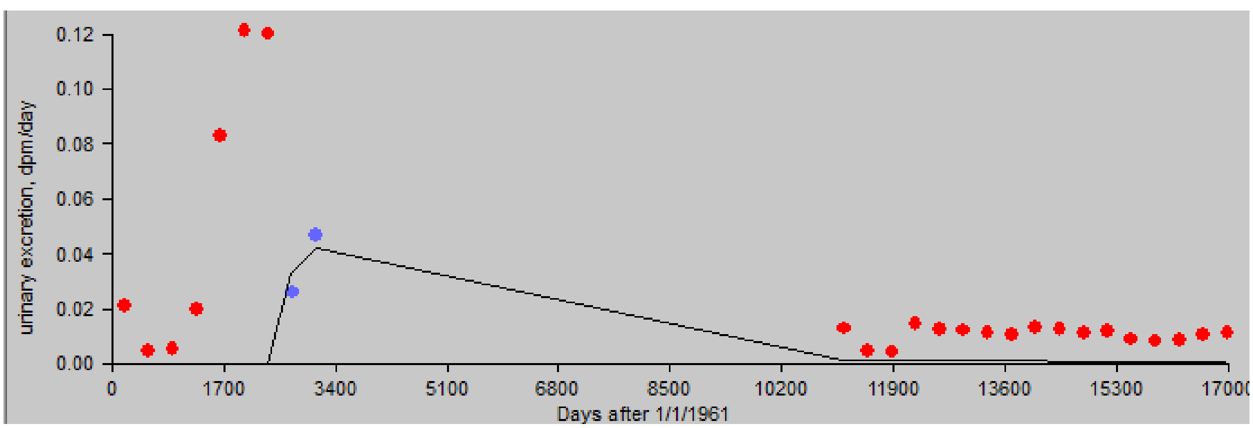

Figure B-67. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1968–1969, type M.

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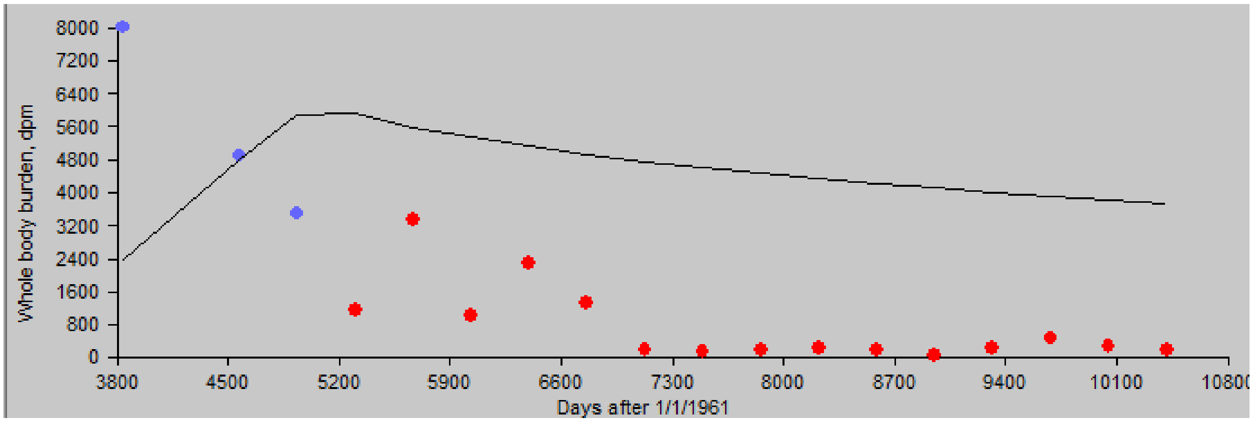

Figure B-68. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1970–1974, type M.

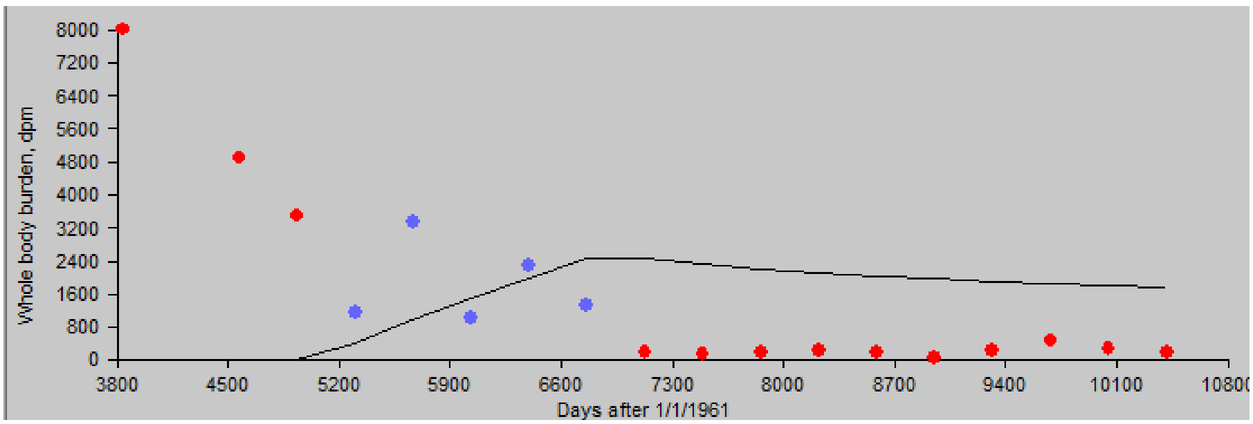

Figure B-69. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1975–1979, type M.

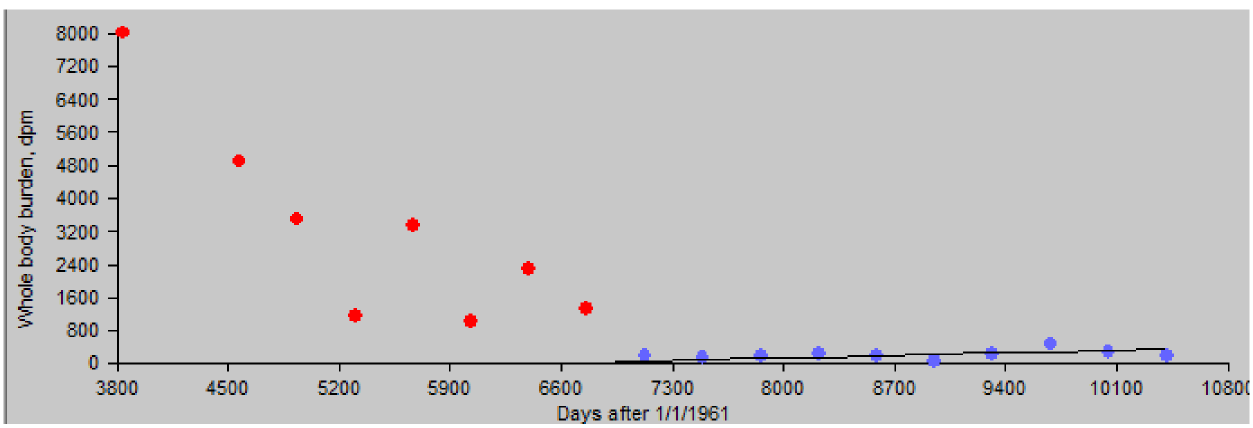

Figure B-70. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1980–1990, type M.

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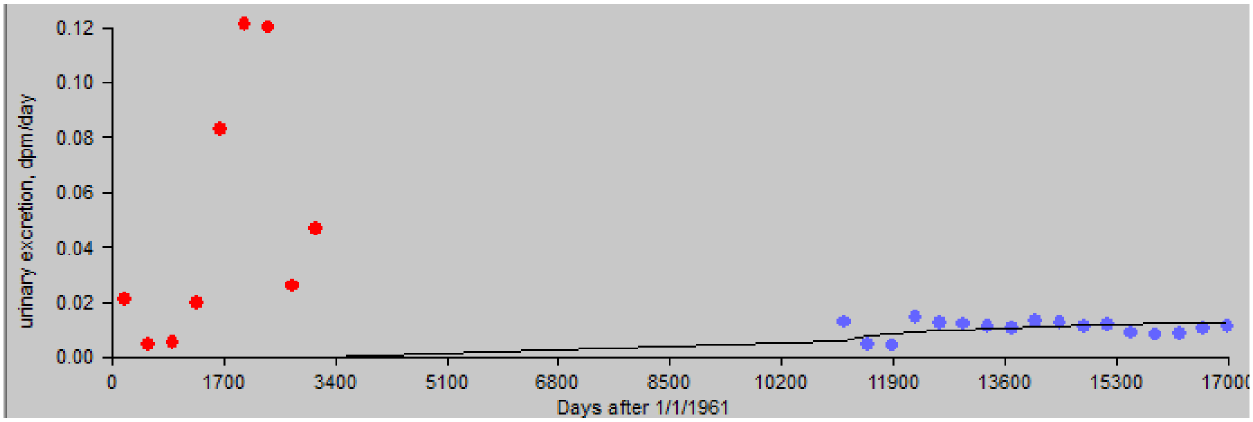

Figure B-71. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1991–2007, type M.

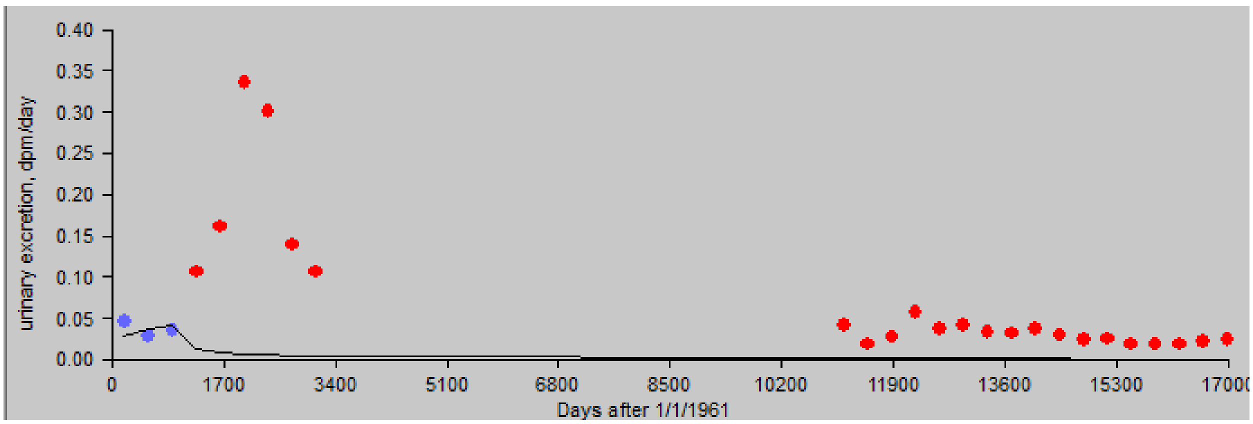

Figure B-72. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1961–1963, type M.

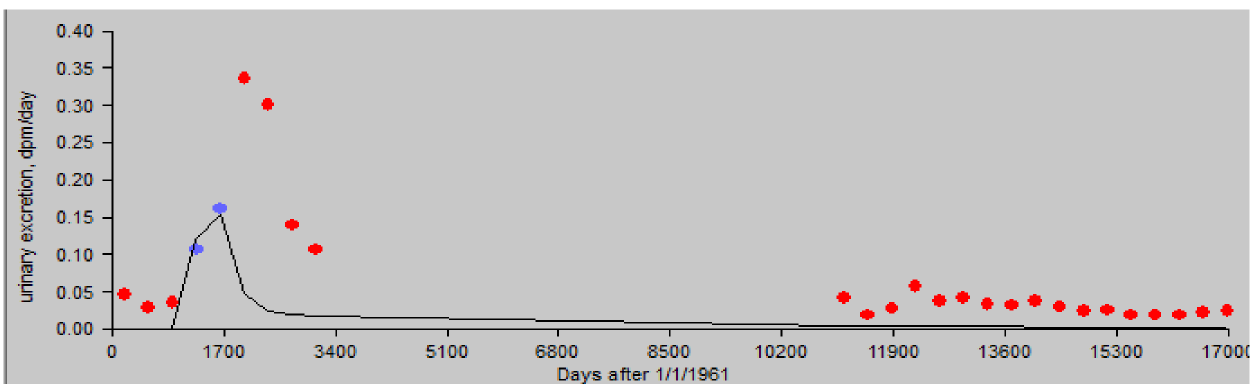

Figure B-73. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1964–1965, type M.

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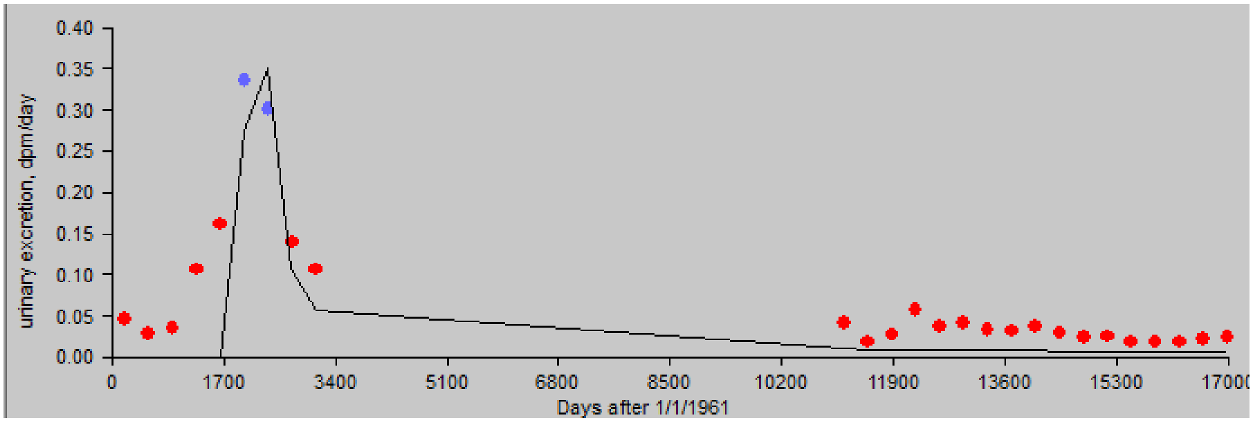

Figure B-74. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1966–1967, type M.

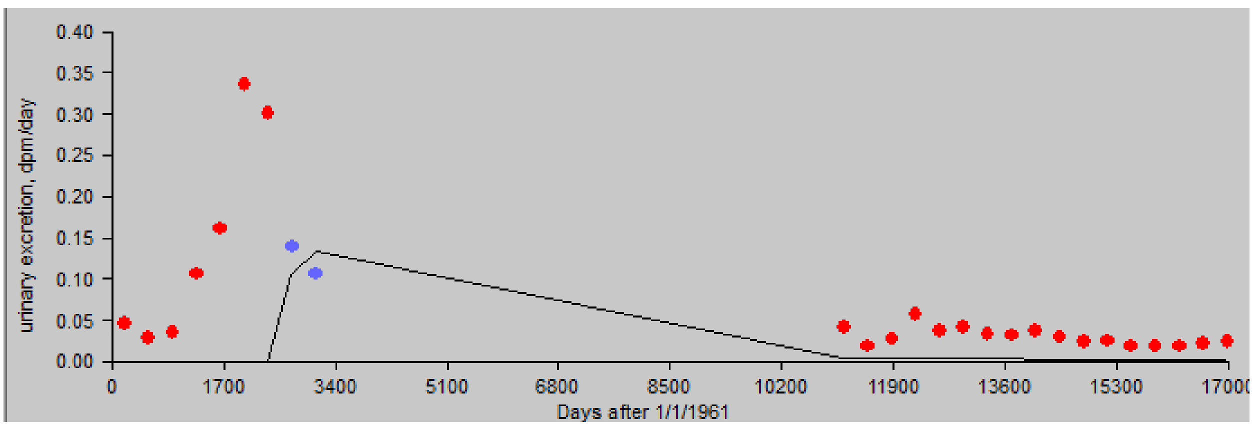

Figure B-75. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1968–1969, type M.

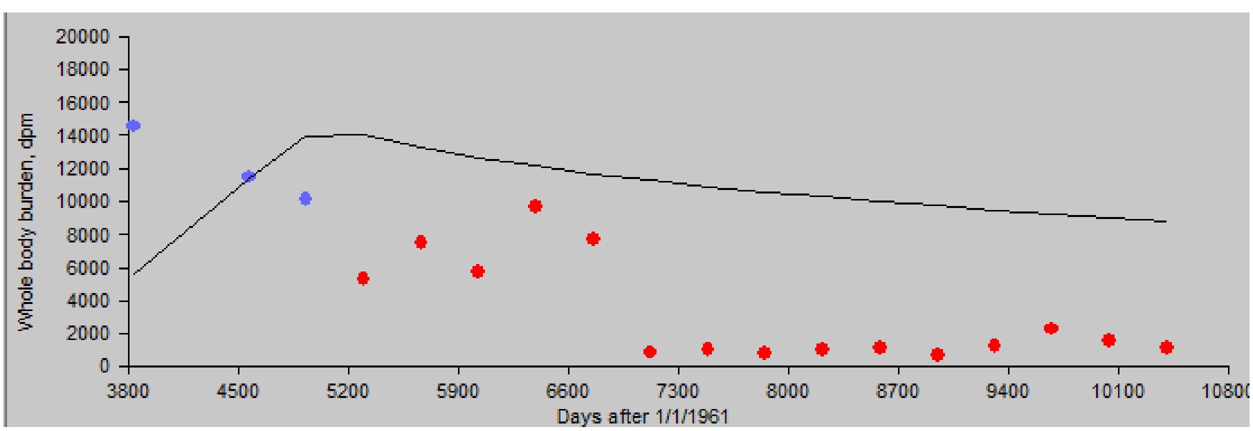

Figure B-76. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1970–1974, type M.

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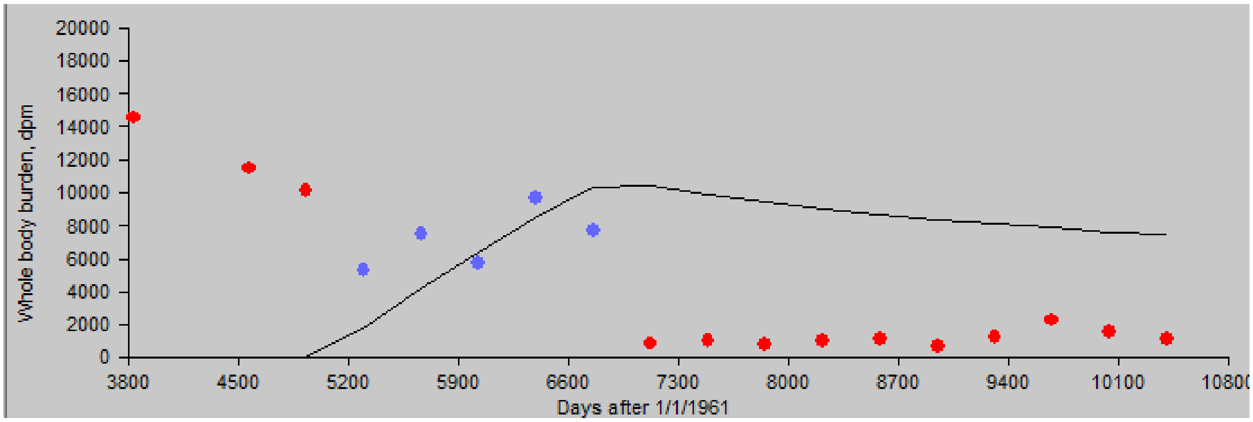

Figure B-77. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1975–1979, type M.

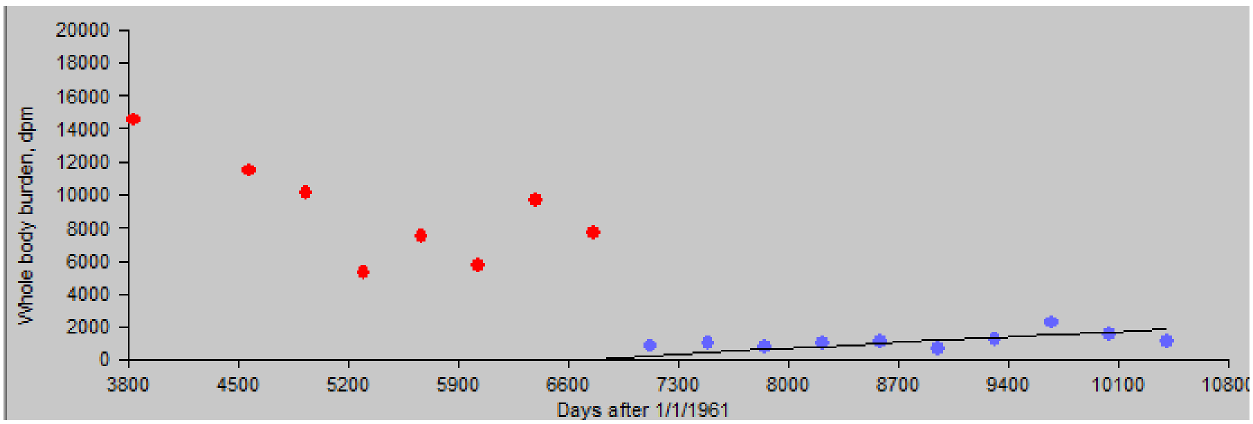

Figure B-78. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1980–1990, type M.

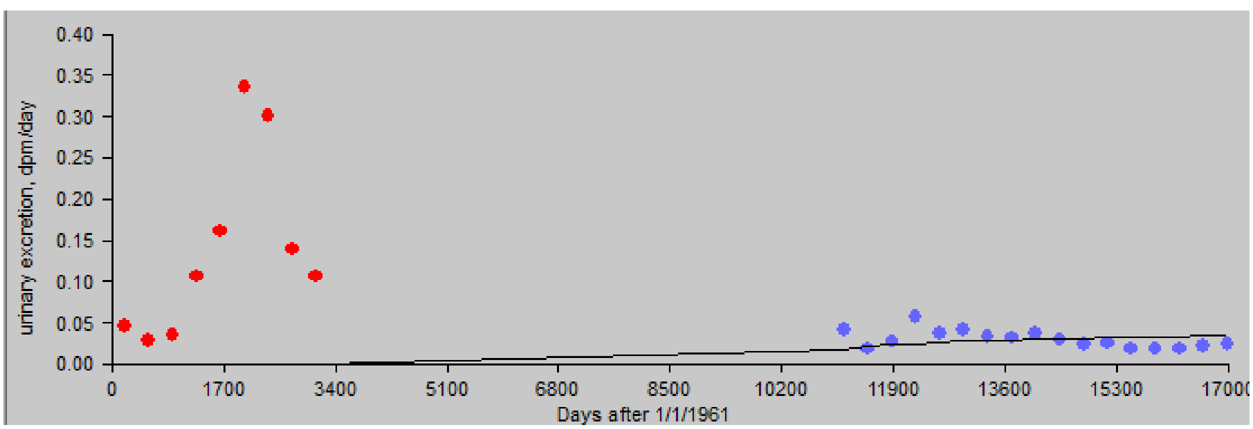

Figure B-79. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1991–2007, type M.

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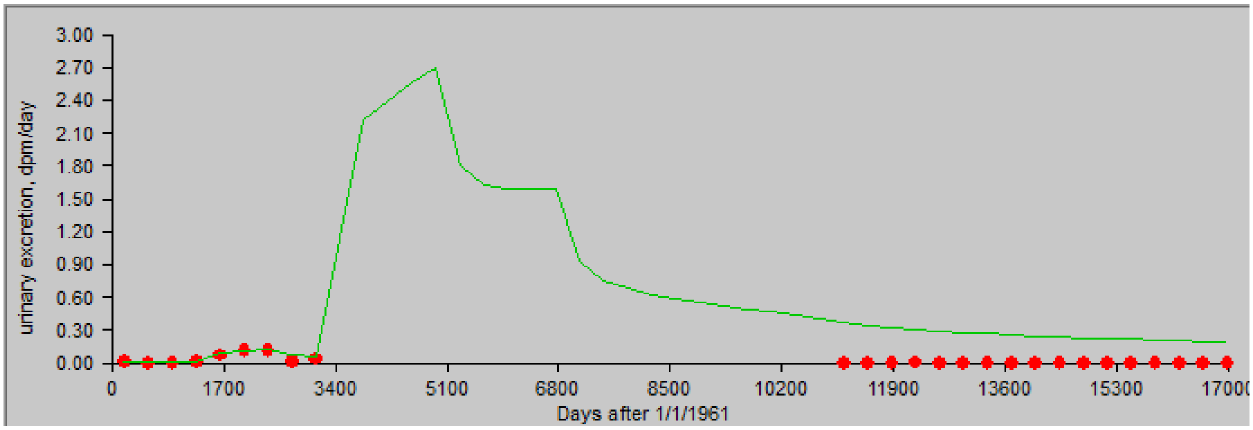

Figure B-80. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1961–2007 cumulative, type M, urinalysis data.

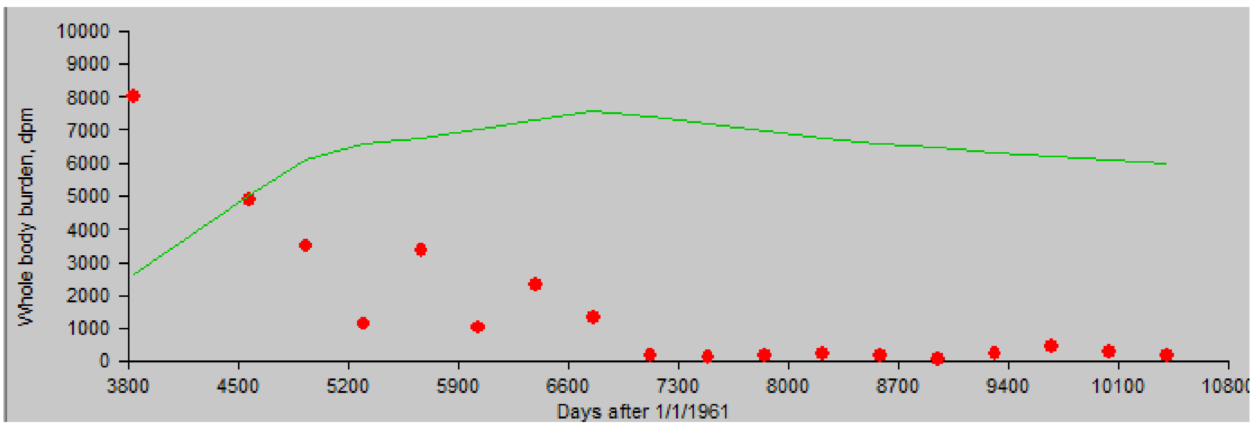

Figure B-81. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 50th percentile, 1961–2007 cumulative, type M, whole-body count data.

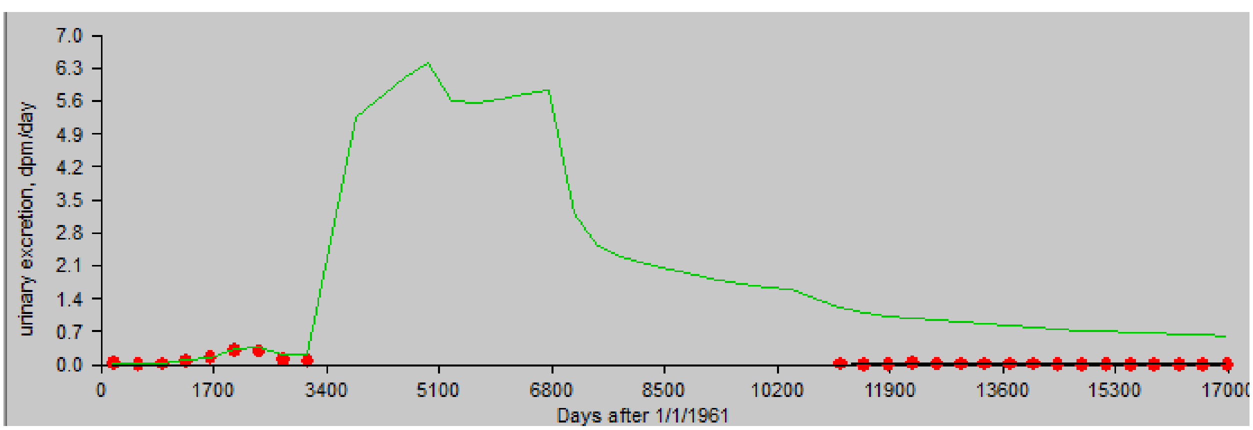

Figure B-82. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results (dots), 84th percentile, 1961–2007 cumulative, type M, urinalysis data.

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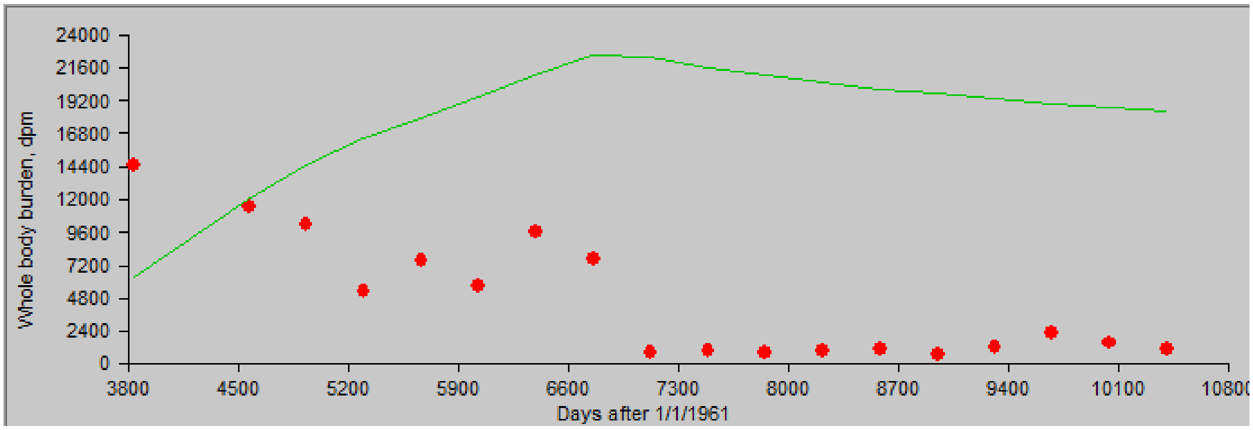

Figure B-83. Predicted neptunium bioassay results calculated using IMBA-derived neptunium intake rates (line) compared with bioassay results, 84th percentile, 1961–2007 cumulative, type M, urinalysis data, WBC data.

Table B-9. Summary of neptunium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1961–1963	0.528	1.59	3.02	3.02	3.24
1964	0.528	6.53	12.37	12.37	33.0
1965	4.84	6.53	1.35	3.00	29.5
1966–1967	4.84	14.9	3.08	3.08	30.9
1968–1969	1.79	5.74	3.21	3.21	12.2
1970–1974	93.5	221	2.37	3.00	570
1975–1979	38.7	164	4.25	4.25	418
1980–1989	2.90	15.8	5.46	5.46	47.2
1991–2007	0.336	0.920	2.74	3.00	2.05

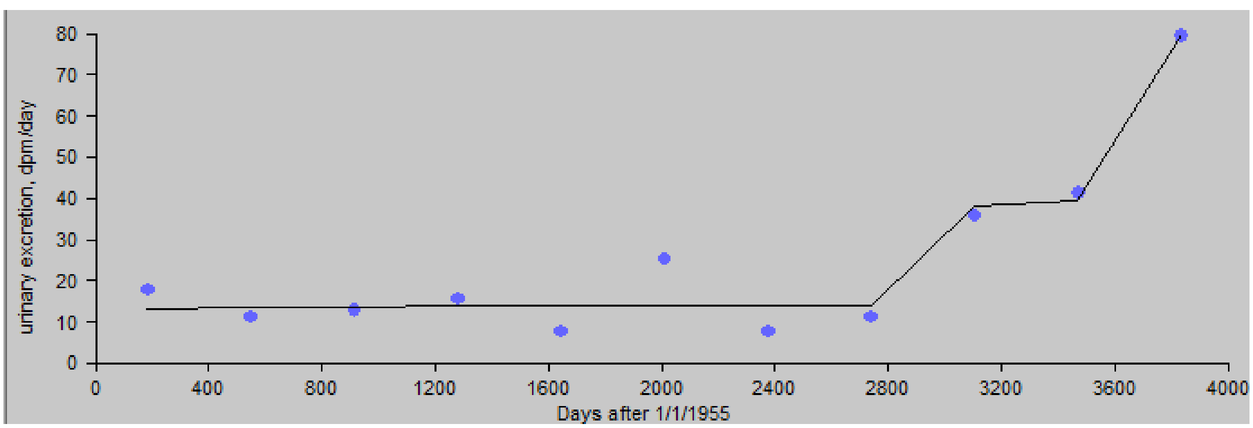

Figure B-84. Predicted strontium bioassay results calculated using IMBA-derived strontium intake rates (line) compared with bioassay results (dots), 50th percentile, 1955–1965, type F.

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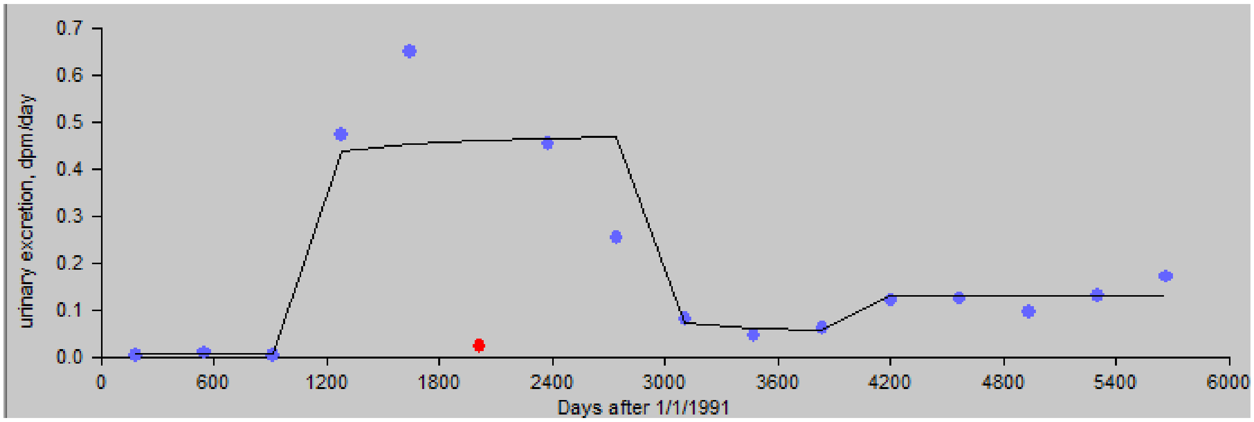

Figure B-85. Predicted strontium bioassay results calculated using IMBA-derived strontium intake rates (line) compared with bioassay results (dots), 50th percentile, 1991–2006, type F.

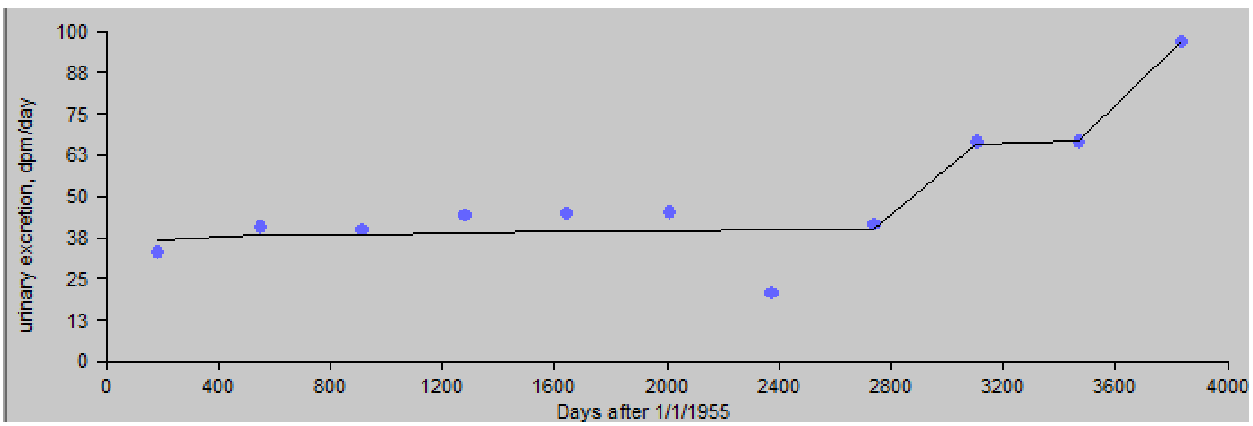

Figure B-86. Predicted strontium bioassay results calculated using IMBA-derived strontium intake rates (line) compared with bioassay results (dots), 84th percentile, 1955–1965, type F.

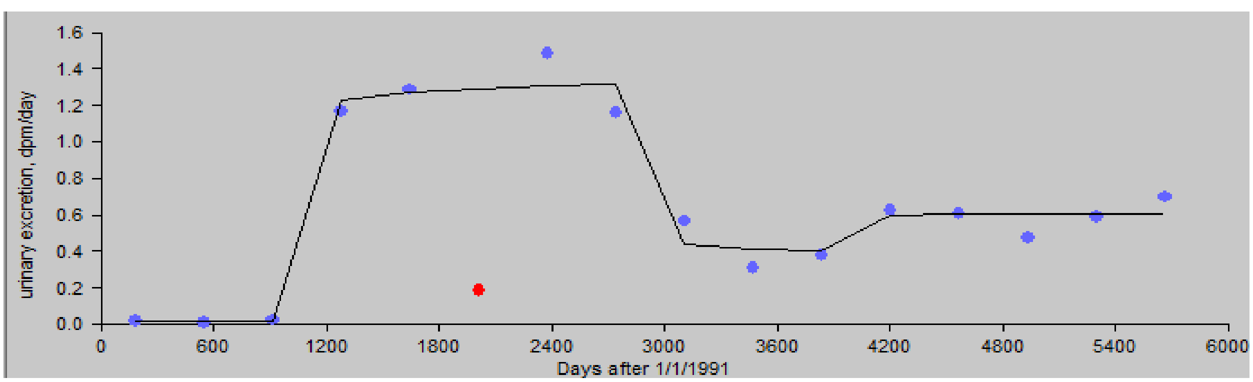

Figure B-87. Predicted strontium bioassay results calculated using IMBA-derived strontium intake rates (line) compared with bioassay results (dots), 84th percentile, 1991–2006, type F.

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Table B-10. Summary of strontium type F intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1955–1962	58.93	166.3	2.82	3.00	359
1963–1964	168	283.1	1.69	3.00	1,024
1965	350	417	1.19	3.00	2,132
1991–1993	0.0393	0.09039	2.30	3.00	0.239
1993–1998	1.98	5.556	2.80	3.00	12.07
1999–2001	0.177	1.552	8.79	8.79	6.31
2002–2006	0.517	2.441	4.72	4.72	6.64

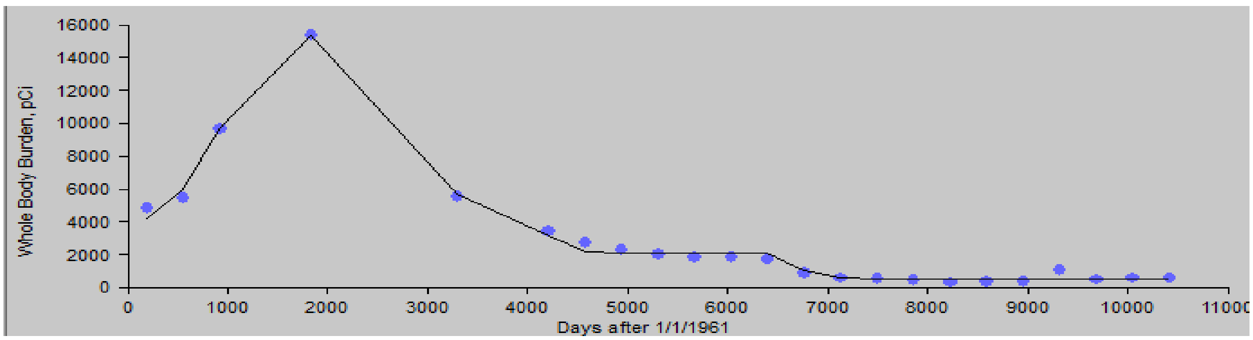

Figure B-88. Predicted cesium bioassay results calculated using IMBA-derived cesium intake rates (line) compared with bioassay results (dots), 50th percentile, type F.

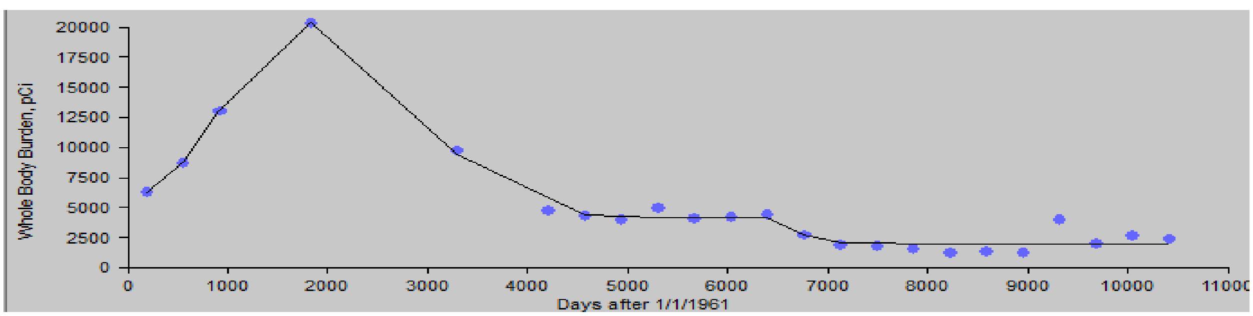

Figure B-89. Predicted cesium bioassay results calculated using IMBA-derived cesium intake rates (line) compared with bioassay results (dots), 84th percentile, type F.

Table B-11. Summary of cesium type F intake rates (pCi/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1961–1962	89.27	131.5	1.47	3.00	544
1963	164.8	216.7	1.31	3.00	1,004
1964–1967	224.1	296.4	1.32	3.00	1,366
1968–1971	80.89	135.8	1.68	3.00	493
1972–1978	30.76	61.25	1.99	3.00	187
1979–1989	7.979	29.37	3.68	3.68	68.1

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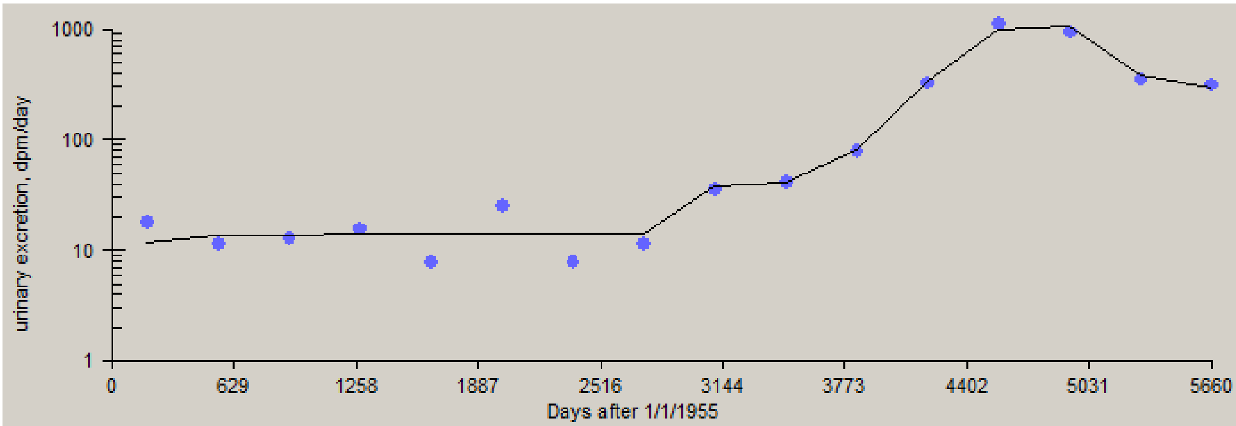

Figure B-90. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with bioassay results (dots), 50th percentile, type M.

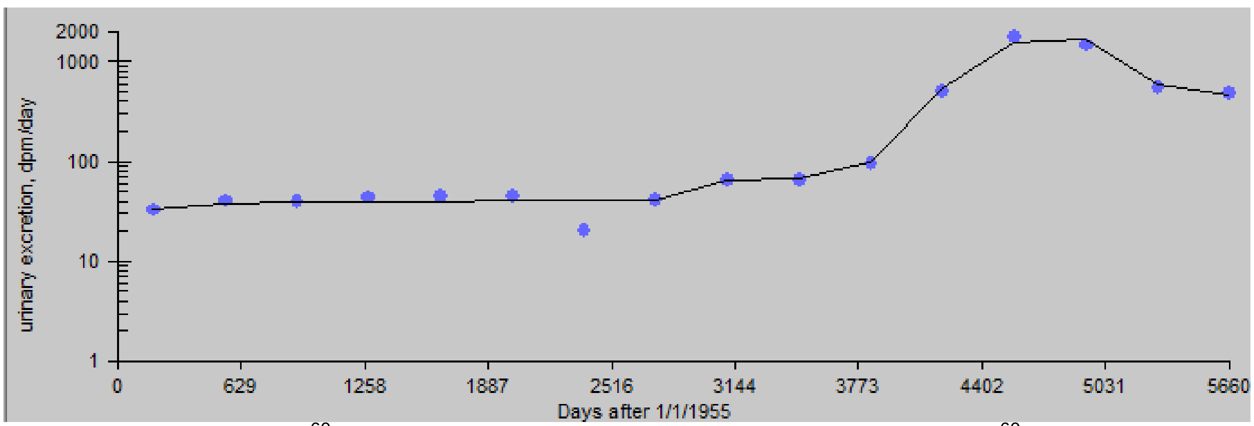

Figure B-91. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with bioassay results (dots), 84th percentile, type M.

Table B-12. Summary of ^{60}Co type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1955–1962	169.4	480.3	2.84	3.00	1,032
1963–1964	499.7	833	1.67	3.00	3,045
1965	1,050	1,236	1.18	3.00	6,398
1966	4,743	7,391	1.56	3.00	28,901
1967–1968	13,290	20,600	1.55	3.00	80,982
1969–1970	3,189	4,946	1.55	3.00	19,432

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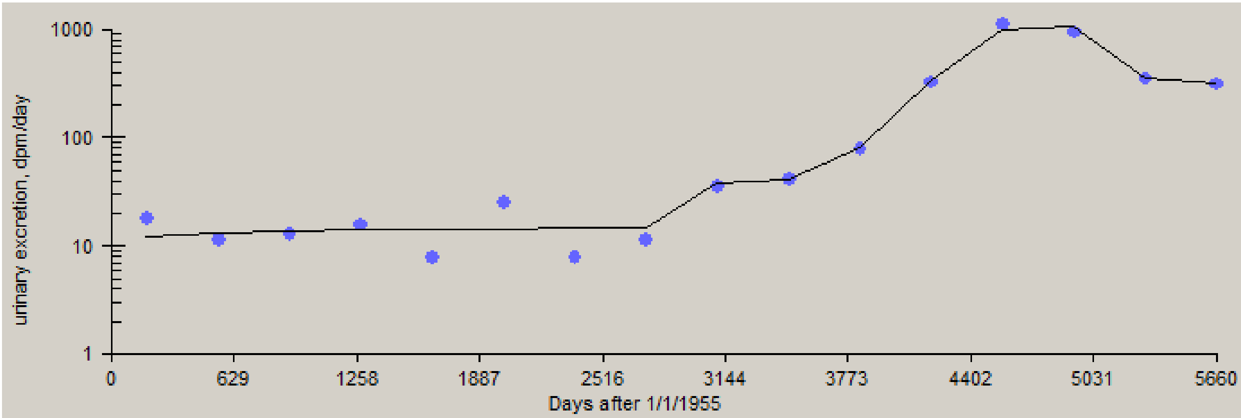

Figure B-92. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with bioassay results (dots), 50th percentile, type S.

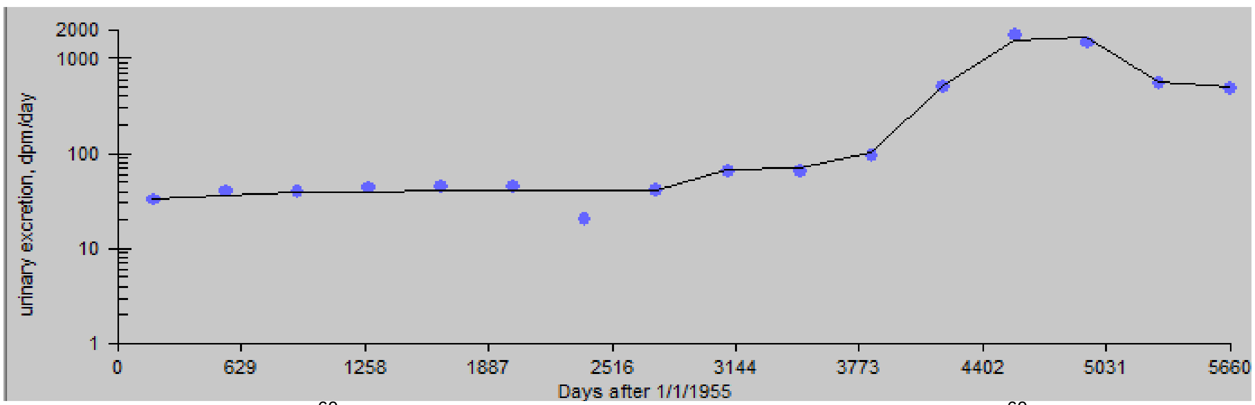

Figure B-93. Predicted ^{60}Co bioassay results calculated using IMBA-derived ^{60}Co intake rates (line) compared with bioassay results (dots), 84th percentile, type S.

Table B-13. Summary of ^{60}Co type S intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1955–1962	667	1,882	2.82	3.00	4,064
1963–1964	2,004	3,294	1.64	3.00	12,211
1965	4,221	4,963	1.18	3.00	25,721
1966	18,150	28,180	1.55	3.00	110,596
1967–1968	53,580	83,080	1.55	3.00	326,488
1969–1970	11,680	18,110	1.55	3.00	71,172

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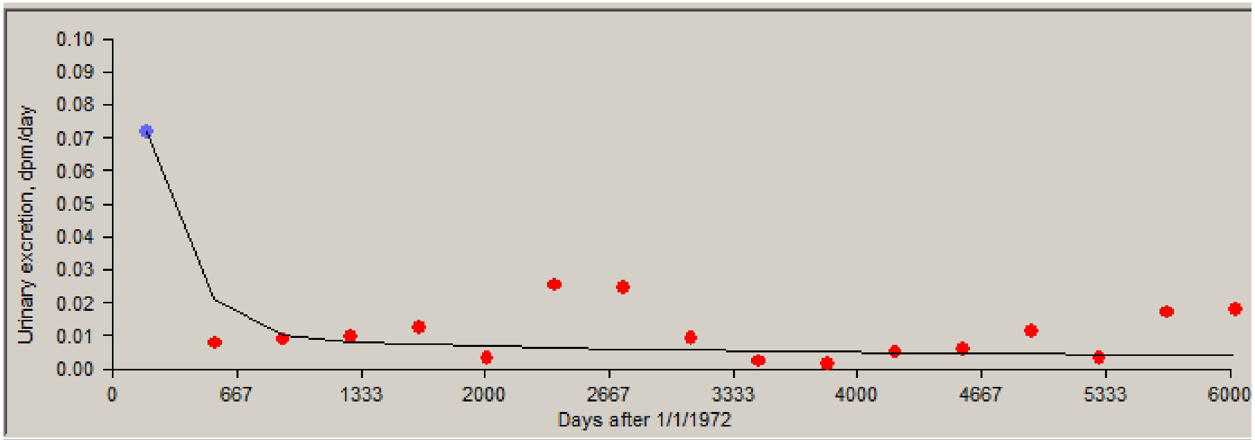

Figure B-94. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 50th percentile, 1972, type M.

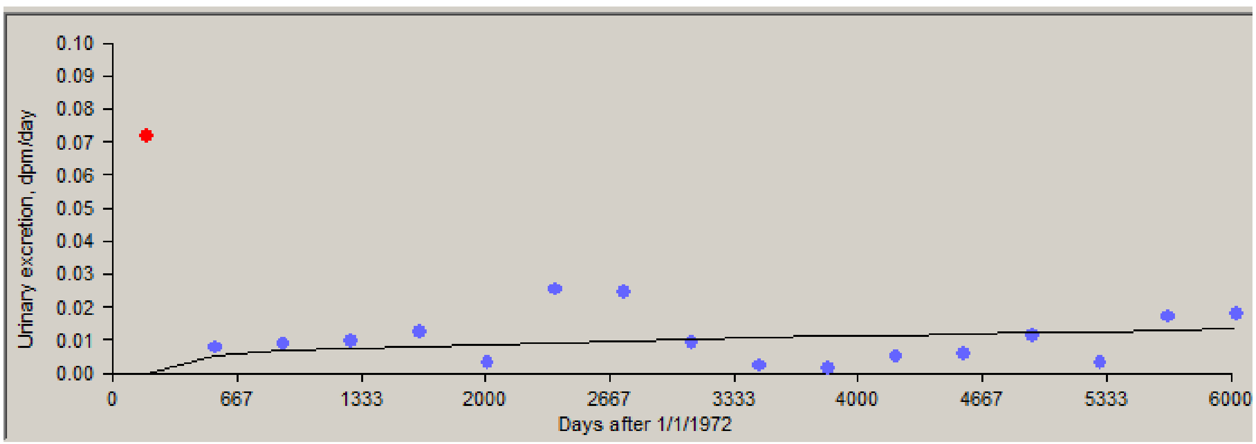

Figure B-95. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 50th percentile, 1973 through 1989, type M.

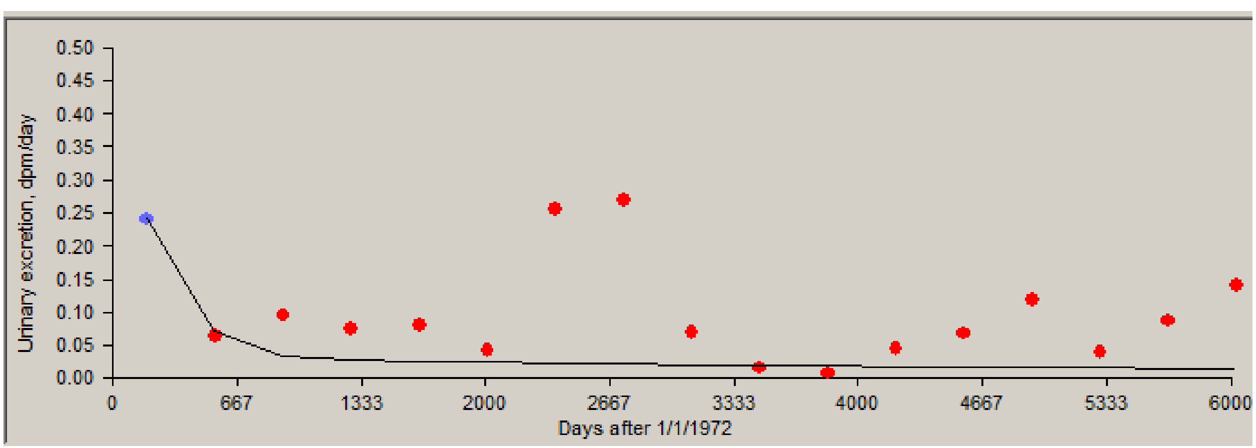

Figure B-96. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 84th percentile, 1972, type M.

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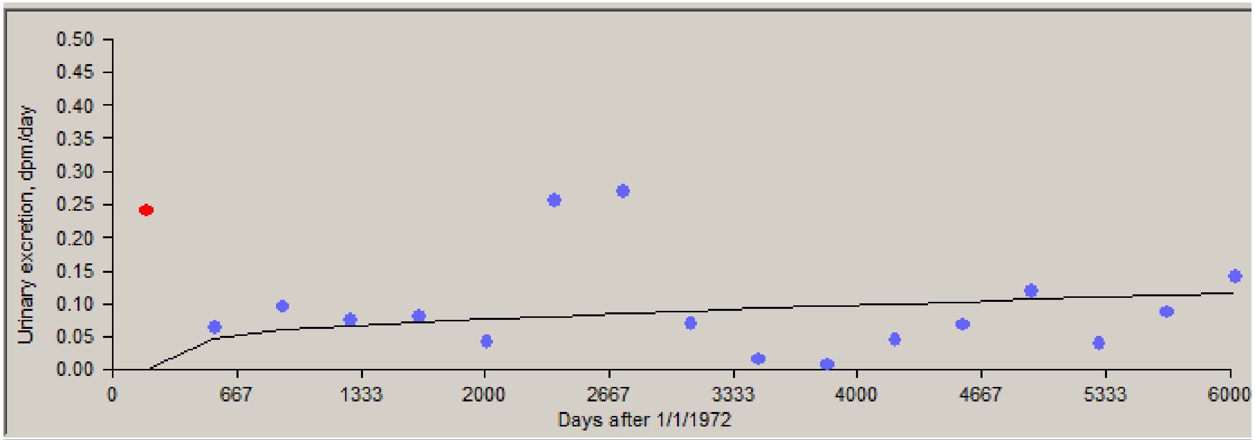

Figure B-97. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 84th percentile, 1973 through 1989, type M.

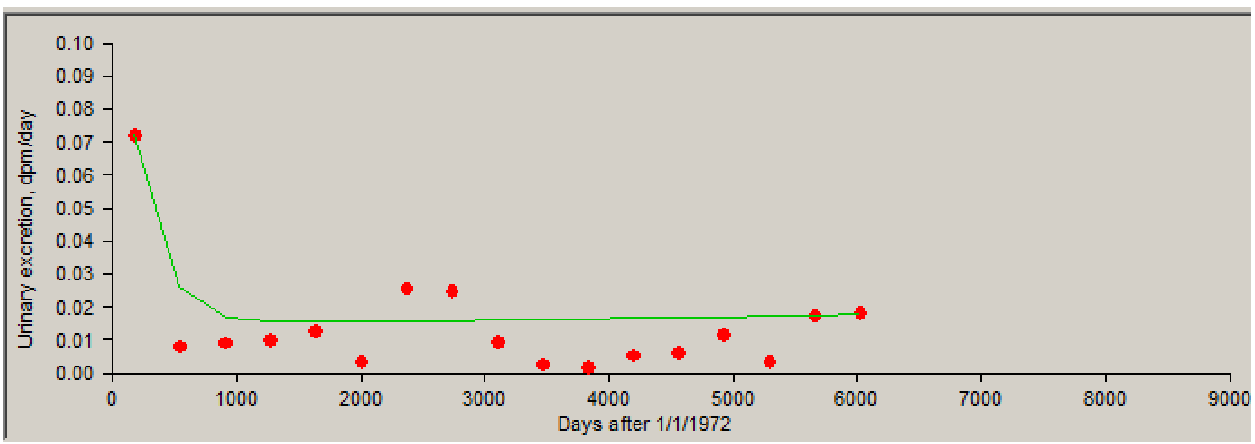

Figure B-98. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 50th percentile, all intakes periods, type M.

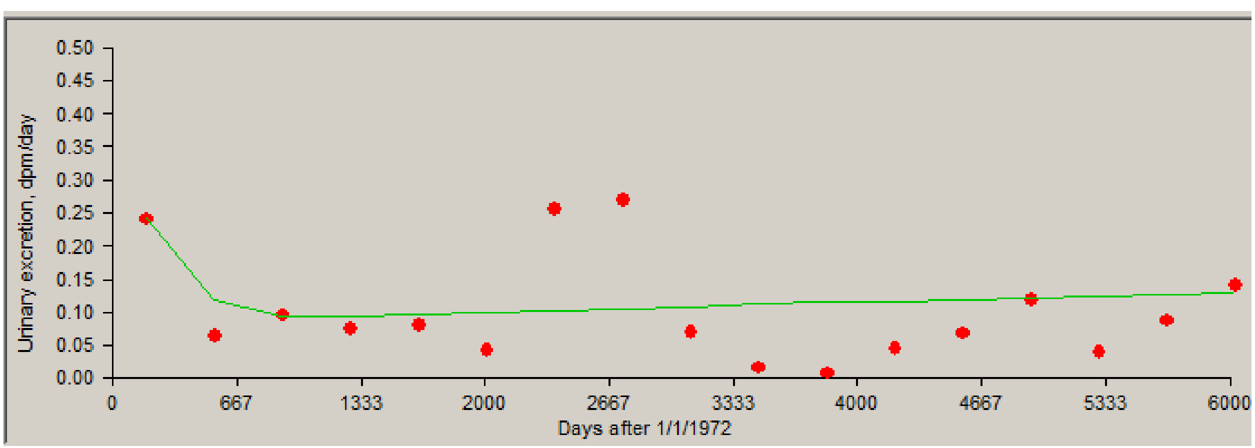

Figure B-99. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 84th percentile, all intakes periods, type M.

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Table B-14. Summary of thorium type M intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1972	15.31	51.16	3.34	3.34	111.4
1973–1989	1.149	9.758	8.49	8.49	38.8

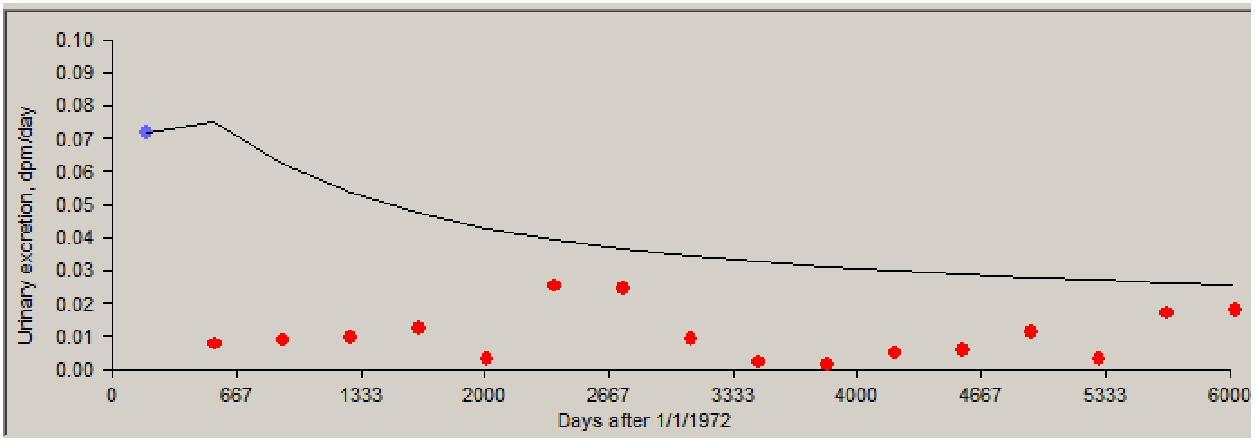

Figure B-100. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 50th percentile, 1972, type S.

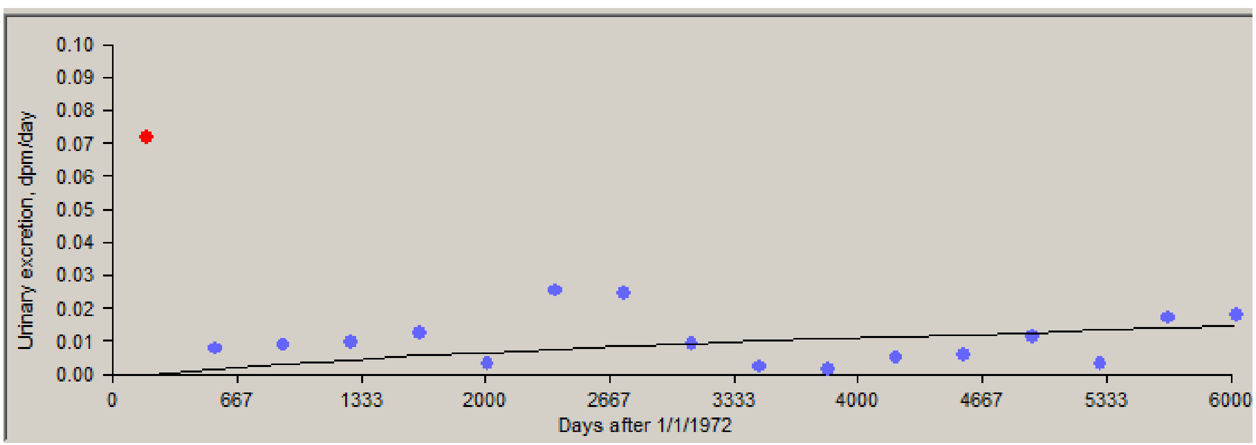

Figure B-101. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 50th percentile, 1973 through 1989, type S.

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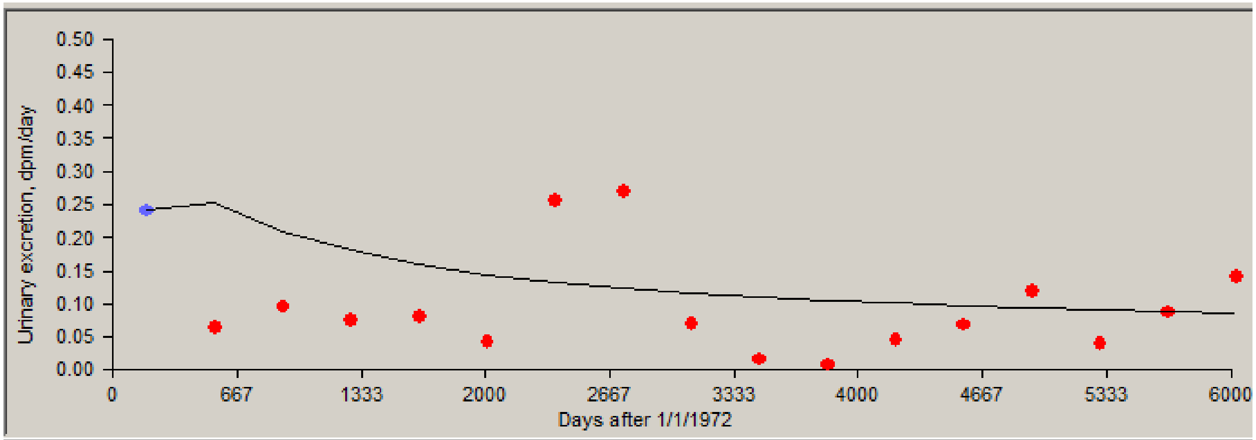

Figure B-102. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 84th percentile, 1972, type S.

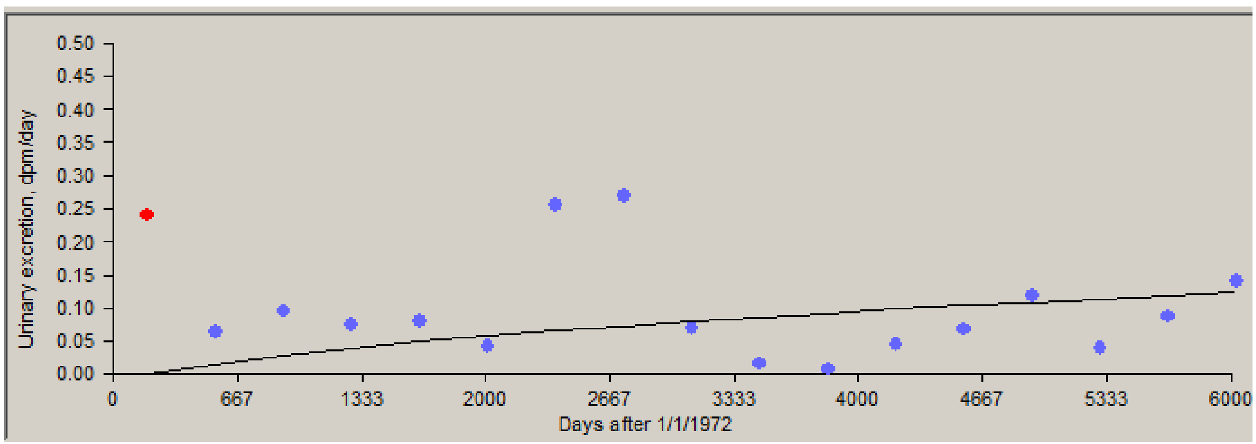

Figure B-103. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 84th percentile, 1973 through 1989, type S.

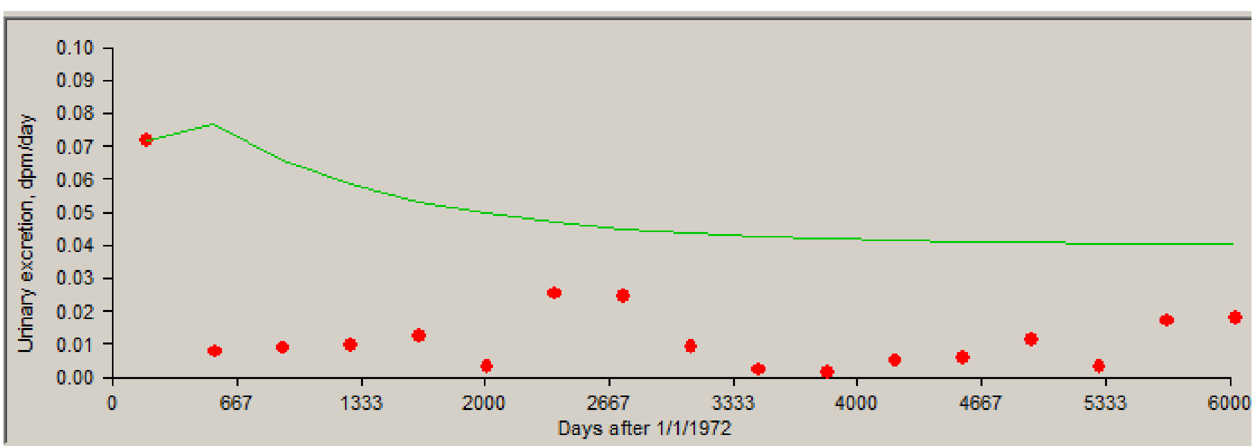

Figure B-104. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 50th percentile, all intakes periods, type S.

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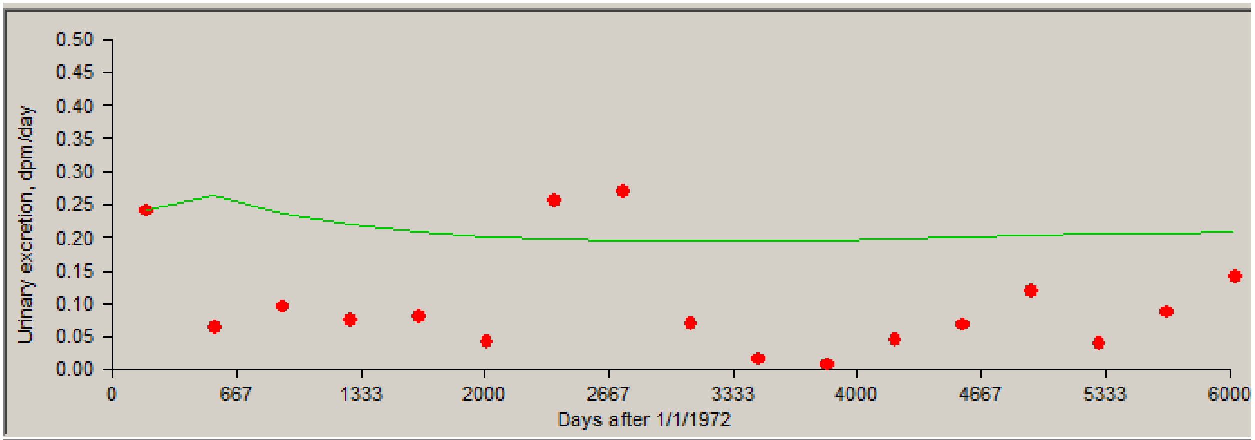

Figure B-105. Predicted thorium bioassay results calculated using IMBA-derived thorium intake rates (line) compared with bioassay results (dots), 84th percentile, all intakes periods, type S.

Table B-15. Summary of thorium type S intake rates (dpm/d) and dates.

Years	50%	84%	GSD	Adj GSD	95%
1972	725.5	2,425	3.34	3.34	5,281.3
1973–1989	15.9	133.7	8.41	8.41	527.9