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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/03/2006	00	New technical information bulletin for assigning Rocky Flats Environmental Technology Site internal doses based on coworker bioassay data. First approved issue. There is no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Robert M. Cherry, Matthew Arno, and Joseph C. Lochamy.

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ACRONYMS AND ABBREVIATIONS

CEDR	Comprehensive Epidemiologic Data Resource
d	day
DOE	Department of Energy
dpm	disintegrations per minute
GSD	geometric standard deviation
hr	hour
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
IREP	NIOSH Interactive RadioEpidemiological Program
mL	milliliter
µg	microgram
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
OCAS	Office of Compensation and Analysis
pCi	picocurie
PoC	Probability of Causation
ppm	parts per million
RFETS	Rocky Flats Environmental Technology Site
TIB	Technical Information Bulletin (also OTIB)

1.0 INTRODUCTION

Technical Information Bulletins (TIBs) are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained. TIBs may be used to assist the National Institute for Occupational Safety and Health 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[1] [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384l(5) and (12)].

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

Bioassay results were obtained through the Comprehensive Epidemiologic Data Resource (CEDR), formerly a DOE public-use repository of data from occupational and environmental health studies of workers at DOE facilities and nearby communities. In 1990, the Department of Health and Human Services assumed responsibility for many aspects of the epidemiology programs and now provides CEDR data. The CEDR database used here contains approximately 300,000 bioassay records from Rocky Flats Environmental Technology Site (RFETS) and includes measurements for uranium, plutonium, and americium for the years 1952 through 1988. Based on a spot check, this data set coincides well with original RFETS paper records. It is appropriate for use only at RFETS. Furthermore, the database is representative of worker bioassay results at RFETS during a substantial part of the operating cycle at this site. However, its use is only appropriate for the specific time periods and radionuclides discussed later in this document.

The database results were labeled with units that varied among the radionuclides, analysis techniques, and measurement period. These units usually were disintegrations per minute per 24 hr but, for example, depleted uranium bioassay results were reported in units of micrograms per 24 hr from 1952 until April 1964. The specific units for each radionuclide are provided in the appropriate sections of this document.

A statistical analysis of the data was performed according to ORAUT (2004a) and its implementing procedure, ORAUT (2005). The results were entered in the Integrated Modules for Bioassay Analysis (IMBA) Expert^{TM} Office of Compensation and Analysis (OCAS)-Edition computer software to obtain intake rates for assigning dose distributions.

2.0 PURPOSE

Some employees at DOE sites were not monitored for internal ionizing radiation exposure or the records of such monitoring are incomplete or unavailable. In such cases, data from monitored coworkers can be used to estimate an individual's possible exposure. The purpose of this TIB is to

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[1] References to DOE in this document include DOE and its predecessor agencies: the Manhattan Engineer District (1942 to 1946), the U.S. Atomic Energy Commission (1947 to 1975), the Energy Research and Development Administration (1975 to 1977), and DOE (1977 to the present).

provide monitored coworker information for calculating and assigning occupational internal doses to employees at RFETS for whom no or insufficient bioassay monitoring records exist.

3.0 DATA OVERVIEW

This section provides information on the general selection characteristics of the data and the methods of analysis. More detailed radionuclide-specific information is provided in section 4.

3.1 BIOASSAY DATA SELECTION

Urinalysis data for uranium and plutonium from 1952 to 1988 were extracted from a Microsoft® Access table named "RFFACW02_BIOASSAY." There were just over 300,000 records in the urinalysis database. Four cases had a date prior to 1952: one each in 1950 and 1951 and two that appeared to be date errors (years incorrectly entered as 1911 and 1923).

In most cases, both the uranium and plutonium results were recorded as dpm/24 hr. However, the depleted uranium units are date-dependent: through April 1964 the units were µg/24 hr; from May 1964 to 1988, the units were dpm/24 hr. Micrograms of uranium were converted to dpm by a 0.89 multiplier determined from the isotopic abundances specified for depleted uranium in IMBA. Once converted to dpm, the uranium data were assumed to be entirely U-234. See section 4.1 for additional discussion on using U-234 for the analyses.

All of the uranium and plutonium urinalysis results were recorded either as positive numbers or zeros. In general, a zero entry meant the result was less than some reporting level; however, after April 6, 1970, actual results were reported according to *Technical Basis Document for the Rocky Flats Plant – Occupational Internal Dose* (ORAUT 2004c). Zeros were reported in 176,900 records, a little over half of the results for all measurements. The technical basis document (TBD; ORAUT 2004c) states that uranium and plutonium urinalysis data with a "1" flag in the "nocalc" column of the database (about 2,500 records out of roughly 300,000) should be (and were) excluded from analysis because the data did not meet quality objectives.

***In vivo* ^{241}Am lung data** from 1965 to 1988 were extracted from a Microsoft® Access table named "RFFACW02_RFWB." There were just fewer than 80,000 ^{241}Am records in the lung database. From 1965 through 1971, all results (about 4,000) were reported as zero, with no explanation of what those values might have meant. Therefore, no analyses were performed on those data. Furthermore, the TBD (ORAUT 2004c) mentions that the ^{241}Am activities were quantified only if a known plutonium incident occurred. However, the TBD also says that results were sometimes recorded (in counts per minute) when no known incident had occurred. Some results were also recorded in micrograms or nanocuries. Thus, careful interpretation of the data units was imperative. After 1971, positive values began to appear but there still were no exclusion instructions for when 0 values were reported. (See the "nocalc" discussion above.) Therefore, 0 results were treated as zeros because no better information was available. Calculations of the lung plutonium values recorded with the ^{241}Am lung data were determined by using the ^{241}Am data and an assumed concentration of 100 ppm (by weight) of ^{241}Am in the plutonium.

In both the urinalysis and lung counting data sets, badge numbers (column "ID") are associated with most records. However, in the urinalysis data, 55,200 records had a "0" in the badge-number column. It was not determined what a "0" badge ID meant other than, perhaps, to identify unbadged personnel. For the urinalysis data, about 34,000 of the "0" badges were plutonium records; 15,000 were gross alpha, "A;" and 6,000 were "U". It was decided to treat "0" badge numbers as one individual when counting the number of unique individuals in any period. The “sdate” column provided the date of each analysis in YYMMDD order.

3.2 ANALYSIS

Bioassay data were analyzed by quarter or year, depending on the amount of data available during the periods. A lognormal distribution was assumed. As mentioned in the previous section, a large fraction of the uranium and plutonium urinalysis data were entered as zeros. In many cases, this fact made analysis of the data difficult, since so few positive values were reported. Thus, where a reporting level was specified in the site Technical Basis Document (ORAUT 2004c) and where zeros were inserted for the actual values (below the reporting level) in the original data, a linear distribution between zero and the reporting level was substituted for the zeros. The linear distribution had the form, c/n, 2c/n, 3c/n,…, nc/n, where n is the number of zero values less than the reporting level, c. Using R^2 as the goodness-of-fit criterion, this linear distribution (alone) fits a lognormal transformation by better than 80% and typically significantly improves the goodness of fit for the entire data set. Furthermore, the linear distribution has an average equal to half of the reporting value, consistent with the general dose reconstruction practice of assigning half of the lower limit of detection for missed dose calculations. Consequently, substituting a linear distribution for these zero entries appears reasonable.

Whenever a linear distribution was substituted for values below a reporting level, the reporting levels given in the version of ORAUT (2004c) used to develop this document were used. For enriched uranium, these reporting levels were 8.8 dpm/24 hr through 1963, and 20-28 dpm/24 hr after 1963. For depleted uranium, the reporting levels were 5.8 dpm/24 hr through April 1964, 20-28 dpm for May 1964-79, and actual measured values thereafter. For plutonium, these reporting levels were 0.88 dmp/24 hr through 1961, 0.2 dpm/24 hr for 1962-April 1970, and actual measured values after April 1970. The reporting level fro gross alpha through 1963 was 8.8 dpm/24 hr (assigned as enriched uranium) and 0.9 dpm/24 hr thereafter (assigned as plutonium). No reporting level was given for americium-in-lung measurements.

After log transforming the data, the 50th and 84th percentiles were determined for each period using the method described in ORAUT (2004a). Tables A-1, A-2, and A-3 in Attachment A show the statistical analysis results for uranium, plutonium, and ^{241}Am, respectively.

4.0 INTAKE MODELING

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

4.1 ASSUMPTIONS

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

Because of the nature of work at RFETS, it is possible that intakes could have been either chronic or acute. However, a series of acute intakes can be approximated as a chronic intake. Therefore, intakes were assumed to be chronic and were assumed to occur through inhalation, using 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 behave the same biokinetically 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 those for ^{235}U, ^{236}U, and ^{238}U (ICRP 1995). Therefore, the assumption that the intake is 100% ^{234}U provides a claimant-favorable result.

For plutonium, ^{239}Pu was assumed for the intake modeling. Prior to the mid-1970s, plutonium urinalysis was performed by chemical separation followed by the counting of all alpha-emitting isotopes of plutonium (i.e., ^{238}Pu, ^{239}Pu, and ^{240}Pu). In the mid-1970s, alpha spectroscopy was used to differentiate between the various alpha-emitting plutonium isotopes. For this modeling, the gross-plutonium alpha results are assumed to represent only alphas from ^{239}Pu, which results in approximately a 2% overestimate of the modeled intakes. This assumption is made to enable consistent modeling of data from both types of urinalysis.

Starting in 1972, lung counts were performed to determine the lung burden of ^{241}Am. These lung counts can be used to determine the intake of plutonium. For each plutonium material type, the more limiting value of the intakes as determined by the americium lung counts or plutonium urinalysis was used. Use of the higher value (from the less sensitive bioassay method for a given material type) would be inconsistent with the available bioassay records since a higher intake would result in higher-than-observed bioassay results from the more sensitive bioassay method.

4.2 BIOASSAY FITTING

The IMBA Expert OCAS-Edition computer program was used to fit the bioassay results to a series of inhalation intakes. Data from 1952 through 1988 were fit as a series of chronic intakes.

The intake assumptions were based on patterns observed in the bioassay data. Periods with constant chronic intake rates were chosen by selecting periods where 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, 1952 through 1988 was divided into multiple chronic intake periods.

4.3 MATERIAL TYPES

ORAUT (2004c) discusses Rocky Flats internal dosimetry data for the dose reconstructor, including guidance for the appropriate use of that information. Workers at Rocky Flats had the potential to receive intakes of plutonium, americium, enriched uranium, and depleted uranium. Site-specific internal dosimetry information for other radionuclides is rare or not available (ORAU 2004c).

4.3.1 Uranium

Because the uranium isotopes present at RFETS have very long radiological half-lives, and 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 RFETS for relatively short periods, each chronic intake was fit independently, using only the bioassay results from the single intake period for Type S solubility. For Type M and F solubility, this approach was used where it was determined that earlier intake rates significantly biased later intake rates. This method will result in an overestimate of intakes for exposures extending through multiple assumed intake periods. Only the results within the intake period were selected for use in fitting each period. Excluded results are shown in light gray in the figures in Attachment B.

Uranium urinalysis results were analyzed with IMBA to derive intake rates for 1953 to 1988. Excretion data are shown in Table A-1. The solid lines in Figures B-1 and B-2 show the individual fits to the 50th-percentile excretion rates for type F material. Figure B-3 is the combined fit for all the intake periods. Figure B-4 shows the overall fit to the 84th-percentile excretion rates for type F material. The same intake periods were applied for both percentiles because the values followed a similar pattern. Similarly, Figures B-5 and B-6 show the individual fits to the 50th-percentile excretion rates for type M material. Figure B-7 is the combined fit for all the intake periods. Figure B-8 shows the overall fit to the 84th-percentile excretion rates for type M material. Figures B-9 to B-13 and B-14 to B-18 show the individual fits to the 50th-and 84th- percentile excretion rates for type S material, respectively. Figures B-19 and B-20 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type S intakes. Table B-1 tabulates the derived intake rates for Types F, M, and S materials at both the 50th and 84th percentiles levels along with the associated GSDs.

4.3.2 <u>Plutonium</u>

Plutonium urinalysis results were analyzed with IMBA using type M and S materials to derive intake rates for 1952 to 1988. Type M intakes should be applied to all systemic organs. Type S must be considered for non-systemic (i.e., lung and GI tract) cancers.

Plutonium Type M—The solid lines in Figures B-21 to B-24 and B-25 to B-28 show the individual fits to the 50th- and 84th-percentile excretion rates for type M materials, respectively. The same intake periods were applied for both percentiles because the values followed a similar pattern. Figures B-29 and B-30 show the 50th- and 84th-percentile predicted excretion rates, respectively, from all type M intakes. In addition, intake rates for Type M plutonium based on lung counting measurements of the associated americium-241 were also derived. The plutonium urinalysis results were determined to be more limiting and thus were used for the final values. Table B-2 lists the 50th percentile and 84th percentile intake rates along with the associated GSD determined from plutonium urinalysis. For comparison, the intake rate determined from the americium lung counts at the 50th percentile level are also given.

Plutonium Type S—Because type S plutonium clears slowly from the lungs, the plutonium exposure was fit as a single chronic intake based on the bioassay measurements from 1983 through 1988. This period was used because the measurements were relatively consistent; in addition, as the most recent measurements, they had the lowest minimum detectable activity and, therefore, are presumably the most accurate. During this time, the plutonium urinalysis results were more limiting for type S intakes and were, therefore, used to determine these intakes. Figures B-31 and B-32 show the 50th- and 84th-percentile predicted plutonium 50th- and 84th-percentile excretion rates, respectively. Figures B-33 and B-34 show the corresponding predicted ^{241}Am lung burdens, respectively, for comparison to the lung count data. Table B-3 lists the 50th percentile and 84th percentile intake rates along with the associated GSD determined from the plutonium urinalysis. For comparison, the intake rate determined from the americium lung count results at the 50th percentile level are also given.

The type S intake rate can only be used as an *underestimate*. If an *overestimate* or best estimate is needed for type S material, an individualized fit to the bioassay data for the specific work period of the energy employee being evaluated must be performed. Tables A-2 and A-3 provide the bioassay data to be used to perform the individualized fit.

5.0 ASSIGNING INTAKES AND DOSES

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

5.1 INTAKE RATE SUMMARY

Five intake periods were fit to the derived 50th- and 84th-percentile uranium excretion data. Table 5-1 summarizes the derived uranium intake rates that produced the fits. Where the geometric standard deviation was less than 3, the value was set to a minimum of 3 to account for biological variation when determining dose. Subsequently, because many of the GSDs were relatively similar, they were further combined and the largest value within a given timeframe was assigned for simplicity. Actual GSDs are provided in Tables B-1 through B-3 located in Appendix B after Figures B-20, B-30, and B-34 respectively.

Table 5-1. Derived uranium intake rates, 1953 to 1988.

	Type F material		Type M material		Type S material	
Period	**50th percentile (dpm/d)**	**Geometric standard deviation**	**50th percentile (dpm/d)**	**Geometric standard deviation**	**50th percentile (dpm/d)**	**Geometric standard deviation**
1953-1958	13.37	3.48	54.8	3.38	937	3.36
1959	19.7	3.48	103	3.38	2,770	3.36
1960	27.23	3.48	103	3.38	2,770	3.36
1961	21.62	3.48	71.9	3.38	1,680	3.36
1962	16.27	4.05	71.9	3.38	1,680	3.36
1963	16.27	3.48	71.9	3.38	1,680	3.36
1964	27.26	3.48	113	3.38	1,630	3.36
1965-1976	27.26	3.48	113	3.38	1,630	3.36
1977-1988	0.597	5.03	2.44	3.38	28.6	5.4

Four intake periods were fit to the data for type M material and one was fit for type S material to the derived 50th- and 84th-percentile plutonium excretion and americium lung burden data. Table 5-2 summarizes the derived plutonium intake rates that produced the fits. Where the geometric standard deviation was less than 3, the value was set to 3. Because of the interdependence between the bioassay results, it is not possible to fit type S plutonium to the data in a manner that would be representative of all individuals for all time periods. Therefore, only a minimizing intake has been calculated for type S plutonium. Type M plutonium should be applied for all systemic organs.

Table 5-2. Derived plutonium intake rates, 1952 to 1988.

	Type M material	
Period	**50th percentile (dpm/d)**	**Geometric standard deviation**
1952-1961	121	3
1962-1969	43.5	3
1970-1979	7.05	4.23
1980-1988	1.62	5.49
	Type S material (underestimate)	
Period	**50th percentile (dpm/d)**	**Geometric standard deviation**
1952-1988	8.142	5.39

For ***non-systemic*** **(respiratory and GI tracts) organs**, the following shall be done:

1. Run the type M intakes. If this action does not result in a PoC >50% (which is determined by the Department of Labor),

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

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

   Standard fitting techniques should be used to fit the plutonium urinalysis and americium lung count data from the employee's work period contained in Tables A-2 and A-3. Acute or chronic intakes can be assigned, depending on the patterns in the data. Both the 50th- and 84th-percentile data must be fit using the same intake dates or periods; the 50th-percentile intakes are used to assign the intake and the 84th-percentile is used to determine the GSD for each intake. For input into IREP, the dose from each intake must be determined separately.

4. The more claimant-favorable doses from the type M and S fits should be assigned.

5.2 DOSE ASSIGNMENT

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

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

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ATTACHMENT A. COWORKER DATA TABLES

Table A-1. Summary of uranium urinary excretion rate analyses, 1953 to 1988.

Effective sample date	50th percentile (dpm/24 hr)	84th percentile (dpm/24 hr)
7/1/1953	**3.727**	**10.008**
2/15/1954	3.866	10.362
5/15/1954	4.161	11.472
8/15/1954	3.732	10.074
11/15/1954	3.409	9.389
2/15/1955	3.225	9.019
5/15/1955	3.333	9.487
8/15/1955	3.434	9.406
11/15/1955	3.442	9.875
2/15/1956	3.310	9.039
5/15/1956	3.497	9.843
8/15/1956	3.635	10.213
11/15/1956	3.302	9.121
2/15/1957	3.460	9.894
5/15/1957	3.492	10.173
8/15/1957	3.655	10.781
11/15/1957	3.700	10.996
2/15/1958	4.089	12.575
5/15/1958	3.739	10.593
8/15/1958	3.907	11.266
11/15/1958	4.705	14.316
2/15/1959	4.381	13.159
5/15/1959	5.518	17.908
8/15/1959	5.544	16.566
11/15/1959	5.887	19.134
2/15/1960	8.806	33.071
5/15/1960	6.856	22.227
8/15/1960	7.476	24.214
11/15/1960	6.602	23.668
2/15/1961	5.944	20.258
5/15/1961	5.722	18.628
8/15/1961	5.574	18.290
11/15/1961	6.598	22.669
2/15/1962	5.862	20.451
5/15/1962	4.692	15.380
8/15/1962	5.654	16.742
11/15/1962	4.397	13.827
2/15/1963	4.166	13.230
5/15/1963	4.175	13.154
8/15/1963	3.841	12.283
11/15/1963	3.601	11.507
2/15/1964	6.354	18.506
5/15/1964	8.368	23.389
8/15/1964	8.161	22.172
11/15/1964	8.297	23.535
7/1/1965	**7.823**	**20.789**
7/1/1966	**7.432**	**18.360**
7/1/1967	**7.445**	**18.440**
7/1/1968	**7.430**	**18.459**
7/1/1969	**7.509**	**18.518**
7/1/1970	**7.440**	**18.275**
7/1/1971	**7.421**	**18.131**
7/1/1972	**7.316**	**18.176**
7/1/1973	**7.403**	**18.059**
7/1/1974	**7.388**	**18.084**
7/1/1975	**7.378**	**18.104**
7/1/1976	**7.418**	**18.037**
7/1/1977	**0.172**	**0.538**
7/1/1978	**0.893**	**2.355**
7/1/1979	**0.444**	**2.037**
7/1/1980	**0.241**	**1.049**
7/1/1981	**0.178**	**1.109**
2/15/1982	0.237	1.152
5/15/1982	0.062	0.677
8/15/1982	0.016	0.211
11/15/1982	0.112	0.741
2/15/1983	0.221	1.062
5/15/1983	0.432	1.330
8/15/1983	0.327	1.576
11/15/1983	0.072	0.646
2/15/1984	0.273	1.400
5/15/1984	0.221	1.330
8/15/1984	0.133	0.997
11/15/1984	0.065	0.464
2/15/1985	0.034	0.410
5/15/1985	0.030	0.281
8/15/1985	0.040	0.511
11/15/1985	0.037	0.415
2/15/1986	0.029	0.357
5/15/1986	0.033	0.339
8/15/1986	0.018	0.207
11/15/1986	0.022	0.316
7/1/1987	**0.057**	**0.467**
7/1/1988	**0.059**	**0.412**

All results shown in **bold** are annual averages rather than quarterly averages.

Table A-2. Summary of plutonium urinary excretion rate analyses, 1952 to 1988.

Effective sample date	50th percentile (dpm/24 hr)	84th percentile (dpm/24 hr)
7/1/1952	**2.514**	**8.198**
7/1/1953	**0.716**	**1.046**
7/1/1954	**0.575**	**1.053**
7/1/1955	**0.469**	**0.919**
7/1/1956	**0.615**	**1.264**
7/1/1957	**2.610**	**12.006**
2/15/1958	2.173	10.041
5/15/1958	1.037	2.872
8/15/1958	1.295	3.801
11/15/1958	0.919	2.581
2/15/1959	0.709	1.542
5/15/1959	0.942	2.276
8/15/1959	0.945	2.482
11/15/1959	0.560	1.211
2/15/1960	0.614	1.353
5/15/1960	0.596	1.221
8/15/1960	0.453	0.955
11/15/1960	0.573	1.528
2/15/1961	0.728	1.625
5/15/1961	0.691	1.377
8/15/1961	0.754	2.035
11/15/1961	0.656	1.645
2/15/1962	0.337	0.809
5/15/1962	0.326	0.735
8/15/1962	0.271	0.589
11/15/1962	0.220	0.431
2/15/1963	0.250	0.467
5/15/1963	0.248	0.496
8/15/1963	0.238	0.432
11/15/1963	0.252	0.562
2/15/1964	0.296	0.810
5/15/1964	0.249	0.483
8/15/1964	0.379	1.668
11/15/1964	0.334	1.066
2/15/1965	0.283	0.757
5/15/1965	0.348	1.085
8/15/1965	0.221	0.417
11/15/1965	0.266	0.646
2/15/1966	0.293	0.821
5/15/1966	0.237	0.554
8/15/1966	0.213	0.430
11/15/1966	0.252	0.625
2/15/1967	0.251	0.622
5/15/1967	0.240	0.565
8/15/1967	0.199	0.413
11/15/1967	0.236	0.535
2/15/1968	0.228	0.526
5/15/1968	0.205	0.461
8/15/1968	0.252	0.585
11/15/1968	0.278	0.724
2/15/1969	0.292	0.692
5/15/1969	0.266	0.606
8/15/1969	0.240	0.519
11/15/1969	0.264	0.558
2/15/1970	0.242	0.515
5/15/1970	0.165	0.623
8/15/1970	0.100	0.423
11/15/1970	0.120	0.470
2/15/1971	0.091	0.366
5/15/1971	0.055	0.209
8/15/1971	0.073	0.293
11/15/1971	0.061	0.249
2/15/1972	0.046	0.398
5/15/1972	0.046	0.442
8/15/1972	0.029	0.199
11/15/1972	0.028	0.168
2/15/1973	0.024	0.145
5/15/1973	0.033	0.180
8/15/1973	0.067	0.305
11/15/1973	0.061	0.268
2/15/1974	0.060	0.224
5/15/1974	0.049	0.189
8/15/1974	0.033	0.144
11/15/1974	0.016	0.109
2/15/1975	0.021	0.104
5/15/1975	0.019	0.095
8/15/1975	0.022	0.200
11/15/1975	0.015	0.097
2/15/1976	0.016	0.144
5/15/1976	0.021	0.102
8/15/1976	0.015	0.104
11/15/1976	0.043	0.184
2/15/1977	0.083	0.262
5/15/1977	0.092	0.245
8/15/1977	0.072	0.190
11/15/1977	0.062	0.188
2/15/1978	0.095	0.307
5/15/1978	0.060	0.199
8/15/1978	0.056	0.201
11/15/1978	0.033	0.134
2/15/1979	0.062	0.237
5/15/1979	0.013	0.100
8/15/1979	0.013	0.087
11/15/1979	0.029	0.139
2/15/1980	0.017	0.106
5/15/1980	0.017	0.064
8/15/1980	0.013	0.061
11/15/1980	0.004	0.035
2/15/1981	0.006	0.037
5/15/1981	2.25E-04	0.006
8/15/1981	0.005	0.036
11/15/1981	0.008	0.056
2/15/1982	1.43E-04	0.007
5/15/1982	3.11E-04	0.011
8/15/1982	1.37E-04	0.004
11/15/1982	2.90E-04	0.006
2/15/1983	0.001	0.017
5/15/1983	3.99E-04	0.008
8/15/1983	0.002	0.016
11/15/1983	0.004	0.029
2/15/1984	0.008	0.050
5/15/1984	0.053	0.222
8/15/1984	0.011	0.071
11/15/1984	0.054	0.196
2/15/1985	0.010	0.080
5/15/1985	0.025	0.100
8/15/1985	0.014	0.081
11/15/1985	0.017	0.100
2/15/1986	0.005	0.033
5/15/1986	0.004	0.038
8/15/1986	0.007	0.038
11/15/1986	0.008	0.042
2/15/1987	0.004	0.030
5/15/1987	0.005	0.036

Table A-2 (Continued). Summary of plutonium urinary excretion rate analyses, 1952 to 1988.

Effective sample date	50th percentile (dpm/24 hr)	84th percentile (dpm/24 hr)
8/15/1987	0.008	0.051
11/15/1987	0.008	0.050
2/15/1988	0.003	0.032
5/15/1988	0.002	0.033
8/15/1988	0.005	0.034
11/15/1988	0.006	0.038

All results shown in **bold** are annual averages rather than quarterly averages. Very large results for: badge 395943 excluded from 1964-1965; badges 164455 and 184168 excluded from quarter 3, 1971; 164455 and 184169 excluded from quarter 4, 1971; badge 184106 excluded from quarter 2, 1976.
Results for quarter 2, 1981, all of 1982, and quarter 2, 1983 were not used in calculations—too few results.

Table A-3. ^{241}Am lung count bioassay data for individualized ^{239}Pu Type S fits.

Effective Sample date	50th percentile (nCi)	84th percentile (nCi)
7/1/1972	**6.73E-05**	**0.003**
2/15/1973	0.005	0.059
5/15/1973	0.010	0.107
8/15/1973	0.025	0.188
11/15/1973	0.009	0.095
2/15/1974	0.005	0.067
5/15/1974	0.007	0.080
8/15/1974	0.007	0.079
11/15/1974	0.007	0.079
2/15/1975	0.017	0.150
5/15/1975	0.027	0.180
8/15/1975	0.039	0.244
11/15/1975	0.048	0.278
2/15/1976	0.043	0.261
5/15/1976	0.044	0.254
8/15/1976	0.017	0.133
11/15/1976	0.012	0.111
2/15/1977	0.010	0.097
5/15/1977	0.008	0.082
8/15/1977	0.007	0.061
11/15/1977	0.004	0.051
2/15/1978	0.008	0.083
5/15/1978	0.007	0.070
8/15/1978	0.007	0.066
11/15/1978	0.004	0.045
7/1/1979	**0.012**	**0.108**
2/15/1980	0.026	0.195
5/15/1980	0.020	0.159
8/15/1980	0.021	0.171
11/15/1980	0.027	0.207
2/15/1981	0.018	0.151
5/15/1981	0.016	0.140
8/15/1981	0.016	0.138
11/15/1981	0.016	0.136
2/15/1982	0.013	0.126
5/15/1982	0.011	0.111
8/15/1982	0.010	0.102
11/15/1982	0.009	0.081
2/15/1983	0.006	0.066
5/15/1983	0.002	0.031
8/15/1983	0.005	0.055
11/15/1983	0.008	0.063
2/15/1984	0.005	0.058
5/15/1984	0.006	0.058
8/15/1984	0.005	0.054
11/15/1984	0.008	0.067
2/15/1985	0.004	0.042
5/15/1985	0.005	0.051
8/15/1985	0.003	0.035
11/15/1985	0.003	0.037
2/15/1986	0.004	0.049
5/15/1986	0.007	0.054
8/15/1986	0.005	0.057
11/15/1986	0.004	0.043
2/15/1987	0.008	0.072
5/15/1987	0.005	0.051
8/15/1987	0.009	0.091
11/15/1987	0.009	0.072
2/15/1988	0.006	0.061
5/15/1988	0.008	0.073
8/15/1988	0.005	0.043
11/15/1988	0.004	0.042

All results shown in **bold** are annual averages rather than quarterly averages.

ATTACHMENT B. COWORKER DATA FIGURES

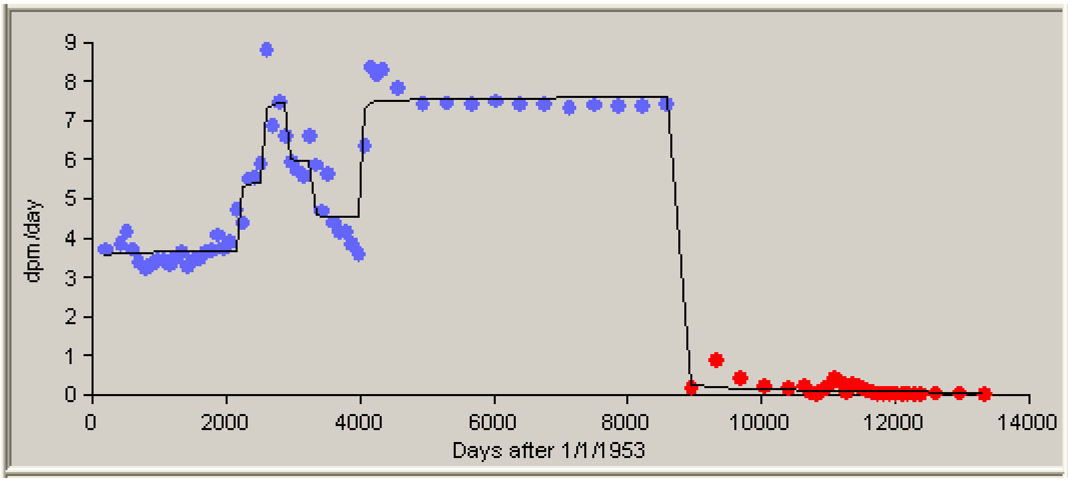

Figure B-1. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1953 to 12/31/1976, 50th-percentile, Type F.

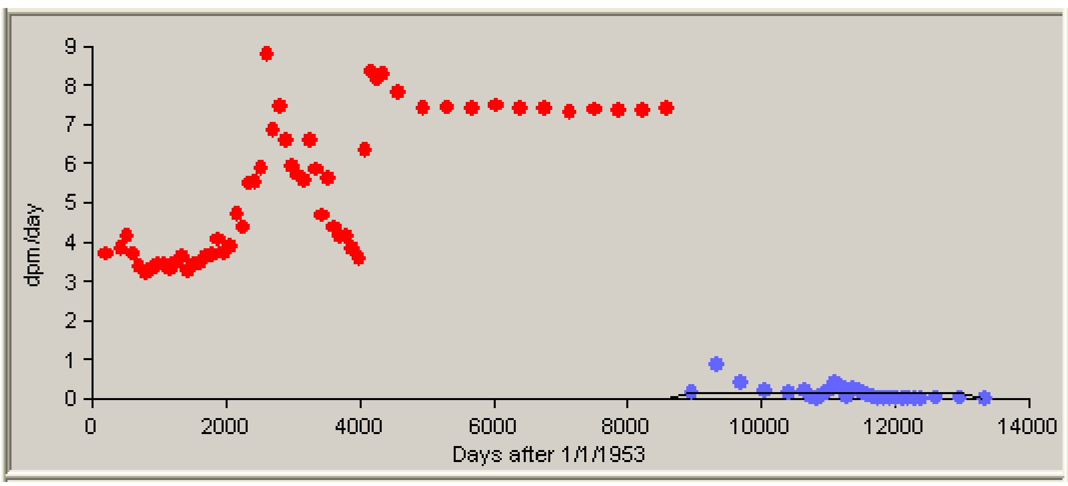

Figure B-2. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1977 to 12/31/1988, 50th-percentile, Type F.

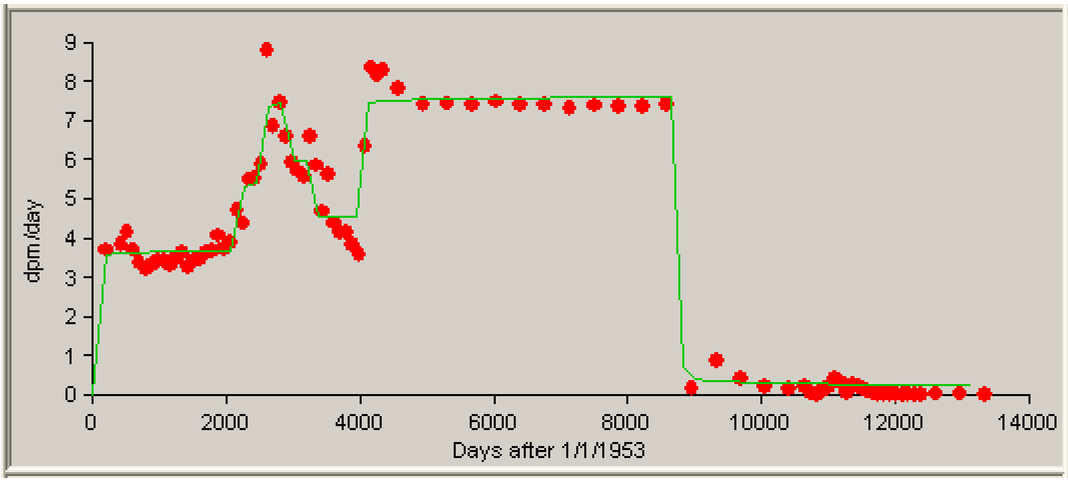

Figure B-3. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots) from all intakes 1/1/1953 to 12/31/1988, 50th-percentile, Type F.

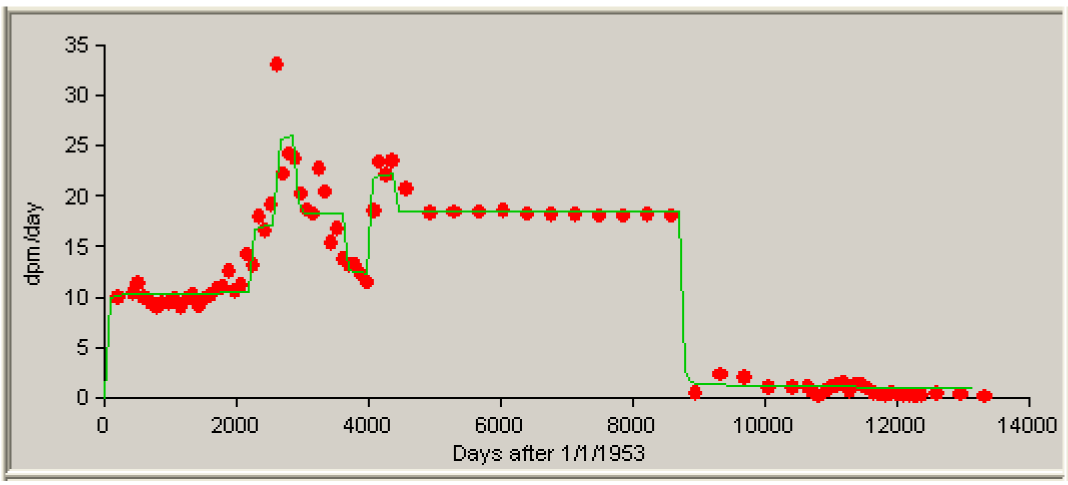

Figure B-4. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1953 to 12/31/1988, 84th-percentile, Type F.

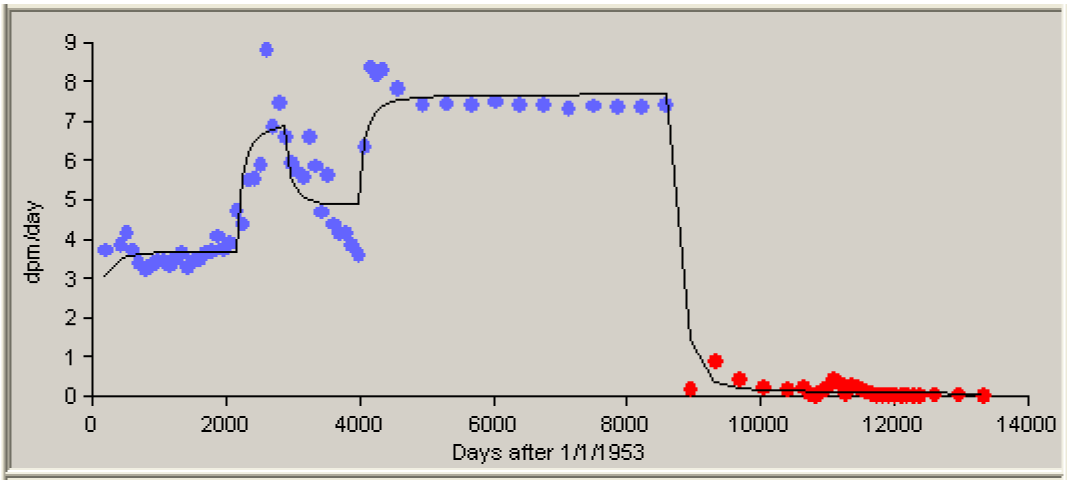

Figure B-5. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1953 to 12/31/1976, 50th-percentile, Type M.

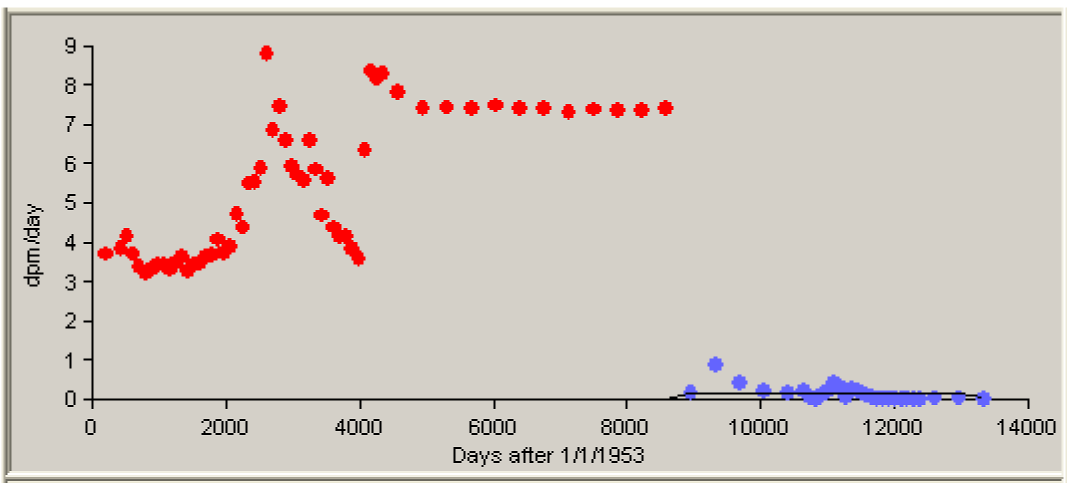

Figure B-6. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1977 to 12/31/1988, 50th-percentile, Type M.

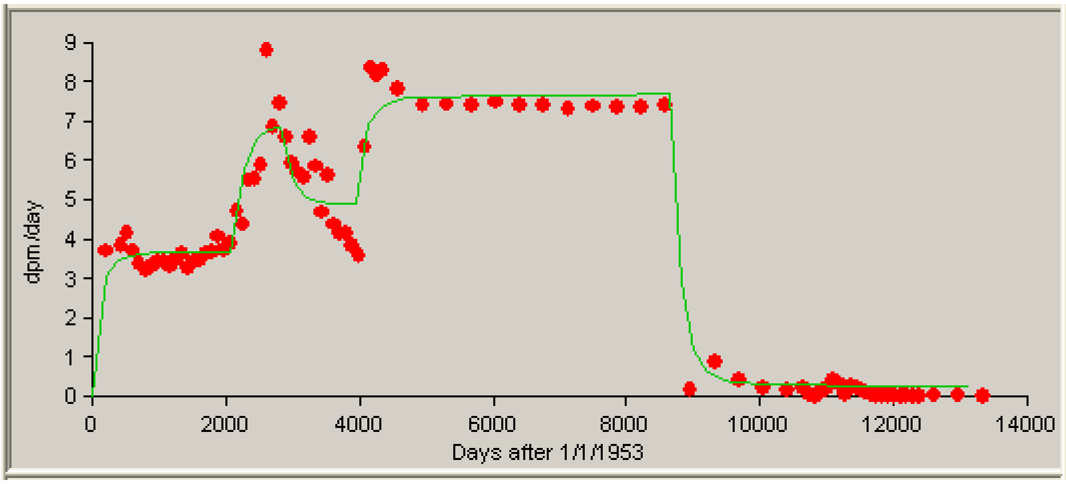

Figure B-7. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots) from all intakes 1/1/1953 to 12/31/1988, 50th-percentile, Type M.

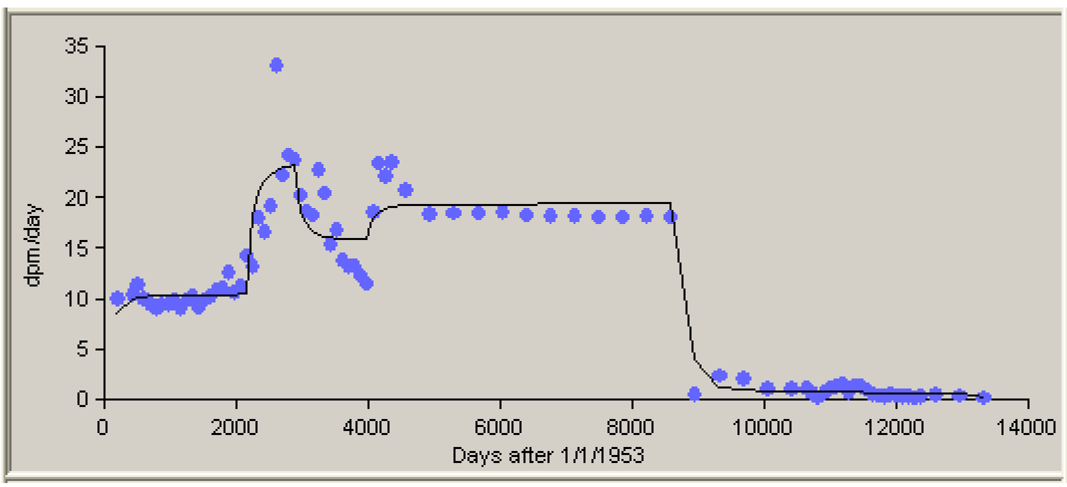

Figure B-8. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1953 to 12/31/1988, 84th-percentile, Type M.

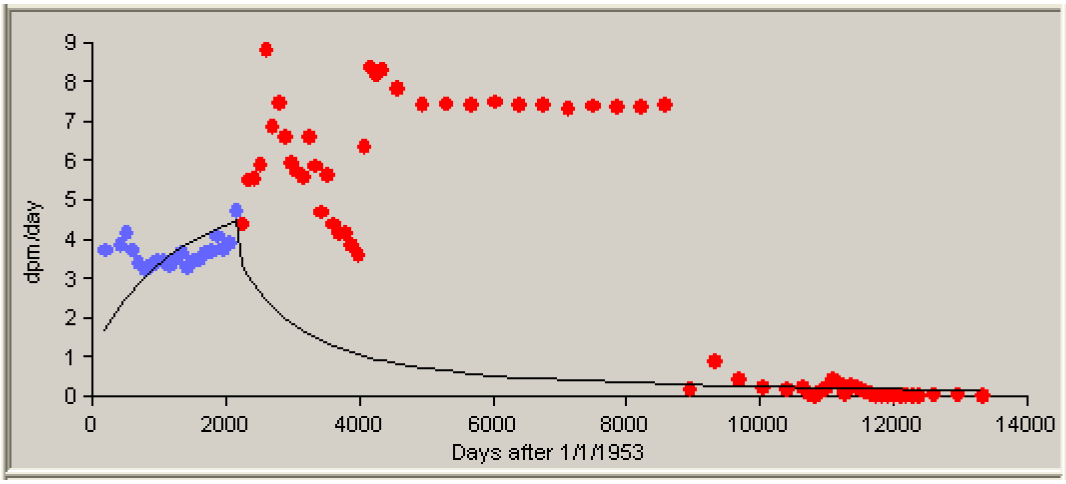

Figure B-9. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1953 to 12/31/1958, 50th-percentile, Type S.

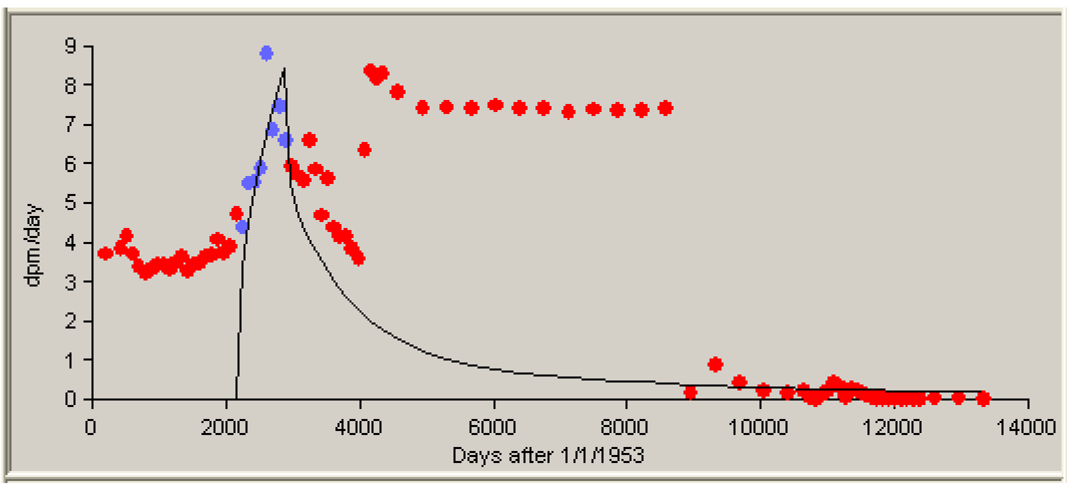

Figure B-10. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1959 to 12/31/1960, 50th-percentile, Type S.

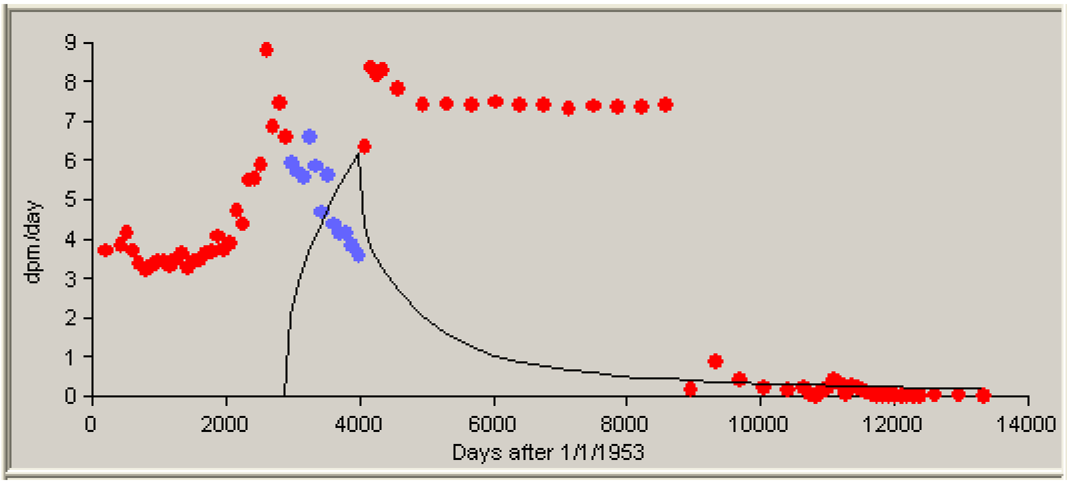

Figure B-11. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1961 to 12/31/1963, 50th-percentile, Type S.

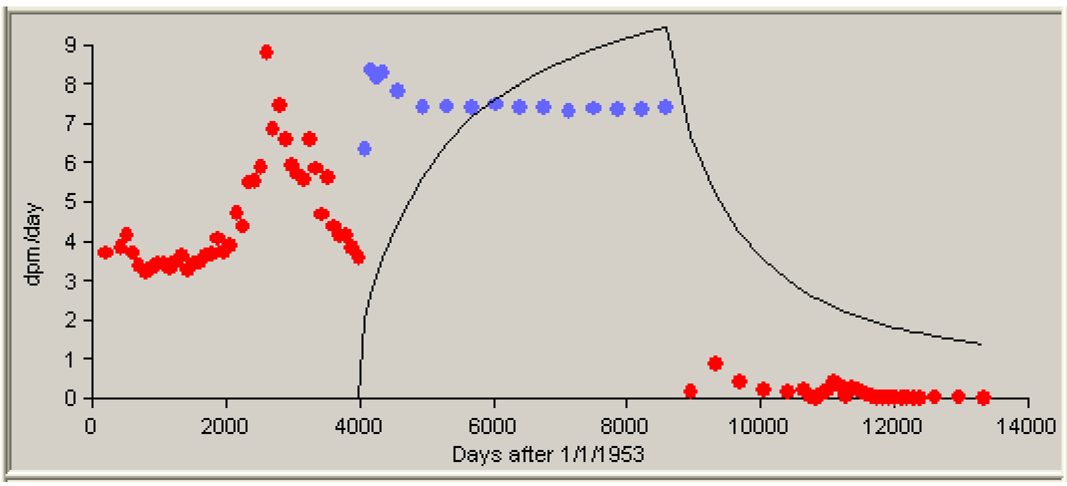

Figure B-12. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1964 to 12/31/1976, 50th-percentile, Type S.

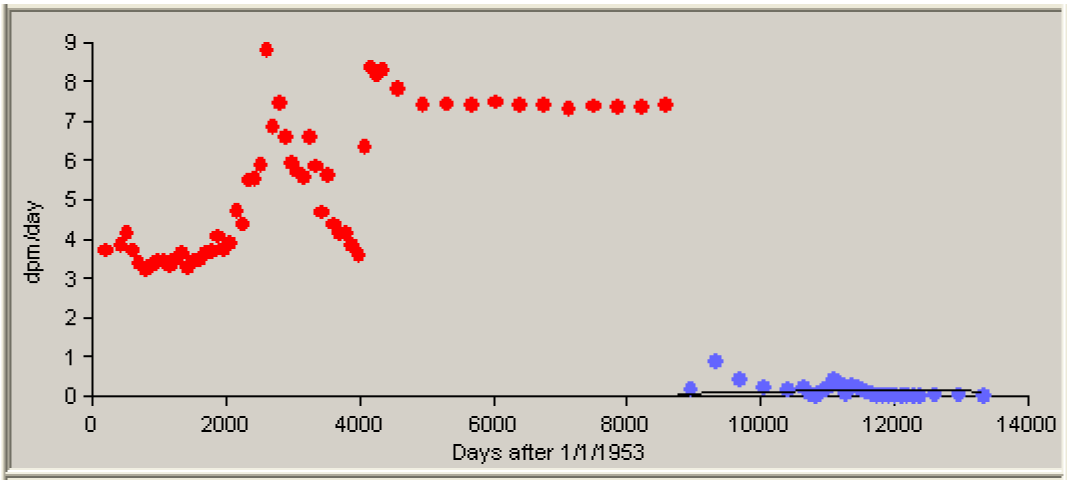

Figure B-13. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1977 to 12/31/1988, 50th-percentile, Type S.

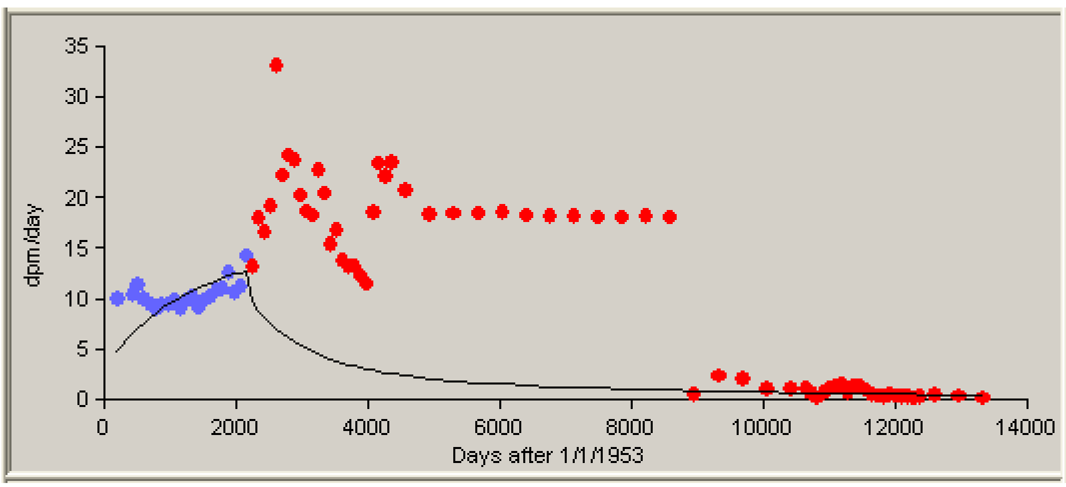

Figure B-14. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1953 to 12/31/1958, 84th-percentile, Type S.

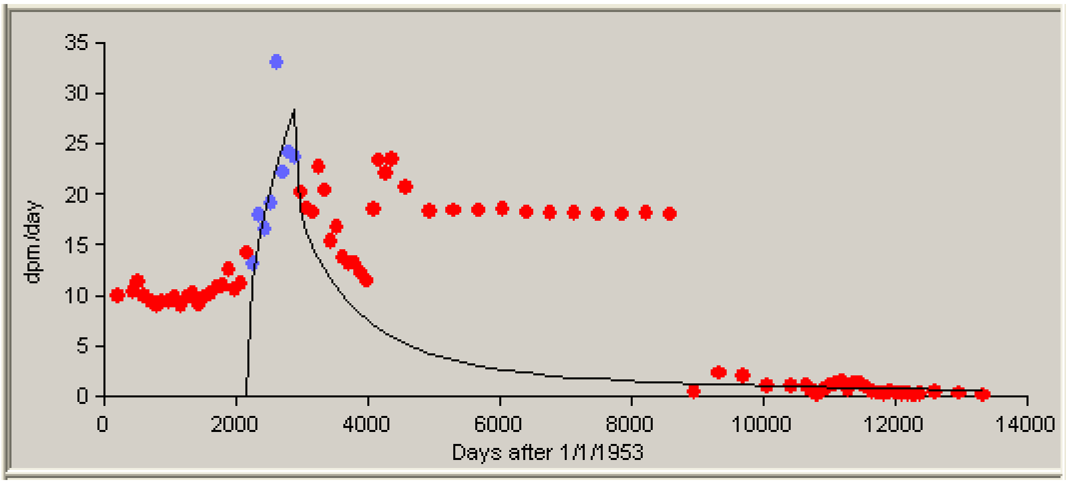

Figure B-15. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1959 to 12/31/1960, 84th-percentile, Type S.

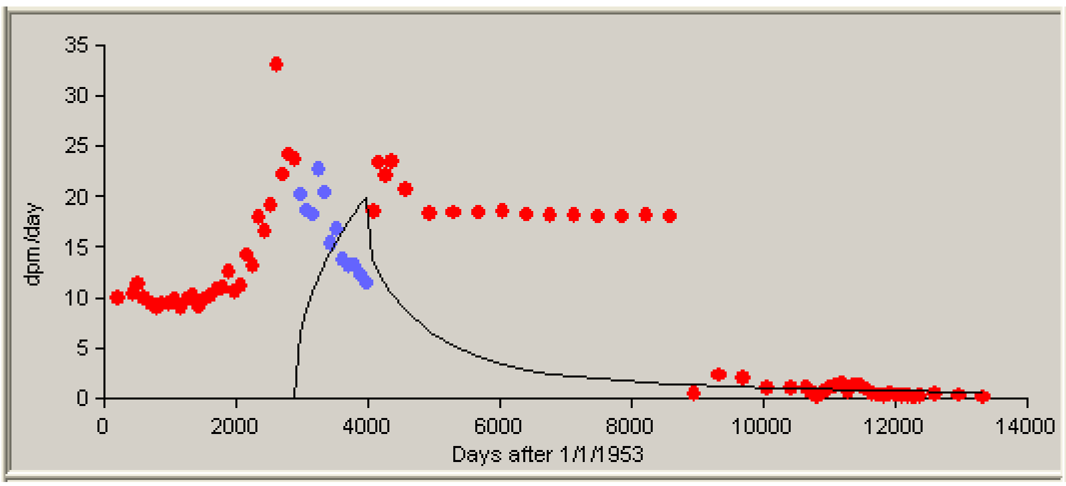

Figure B-16. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1961 to 12/31/1963, 84th-percentile, Type S.

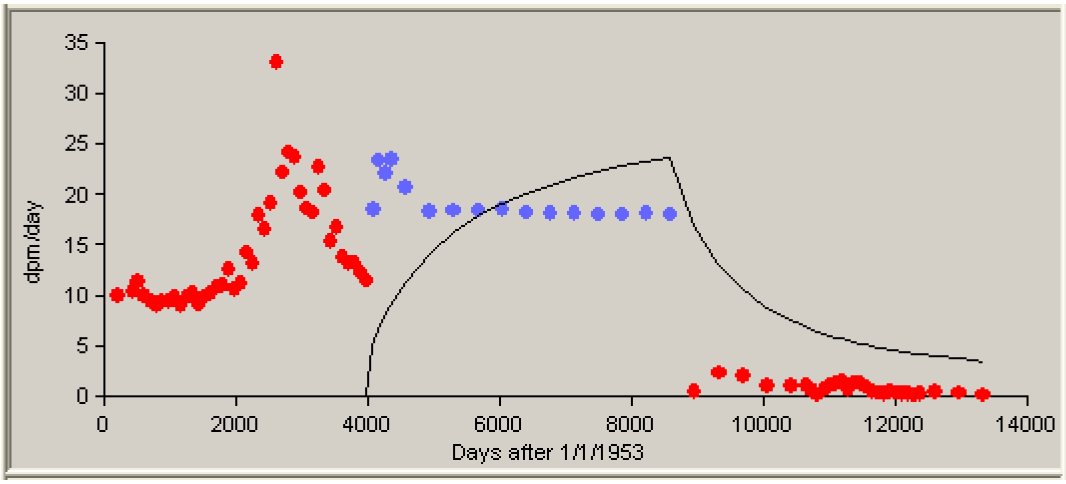

Figure B-17. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1964 to 12/31/1976, 84th-percentile, Type S.

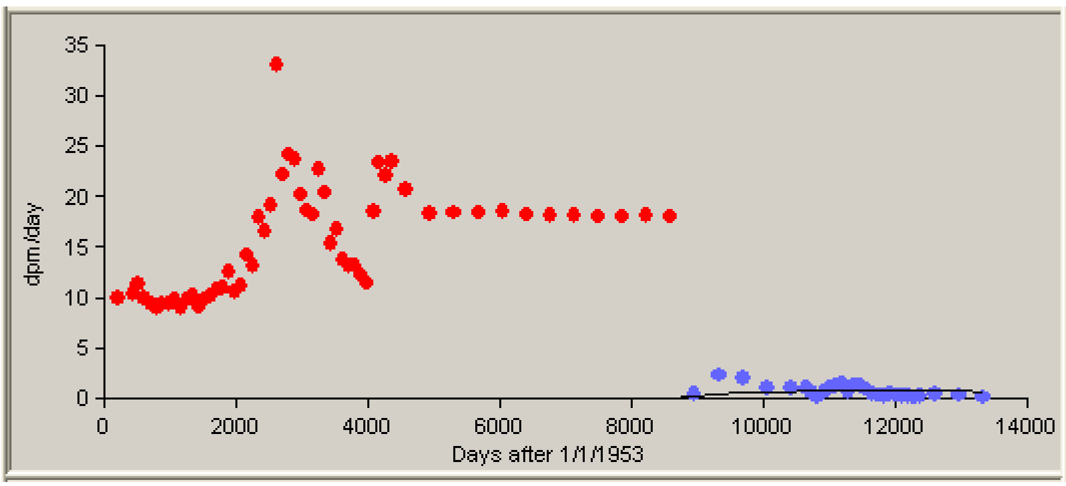

Figure B-18. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots), 1/1/1977 to 12/31/1988, 84th-percentile, Type S.

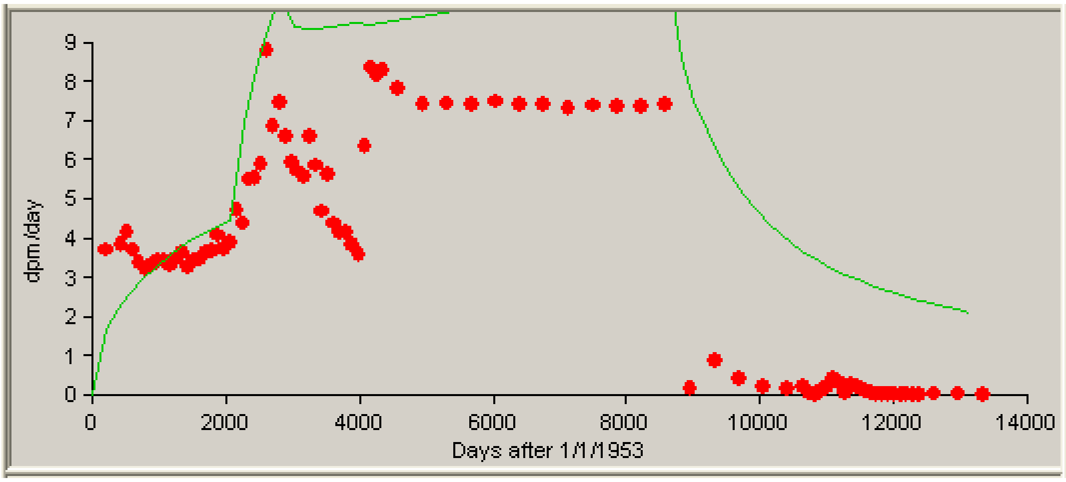

Figure B-19. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots) from all intakes 1/1/1953 to 12/31/1988, 50th-percentile, Type S.

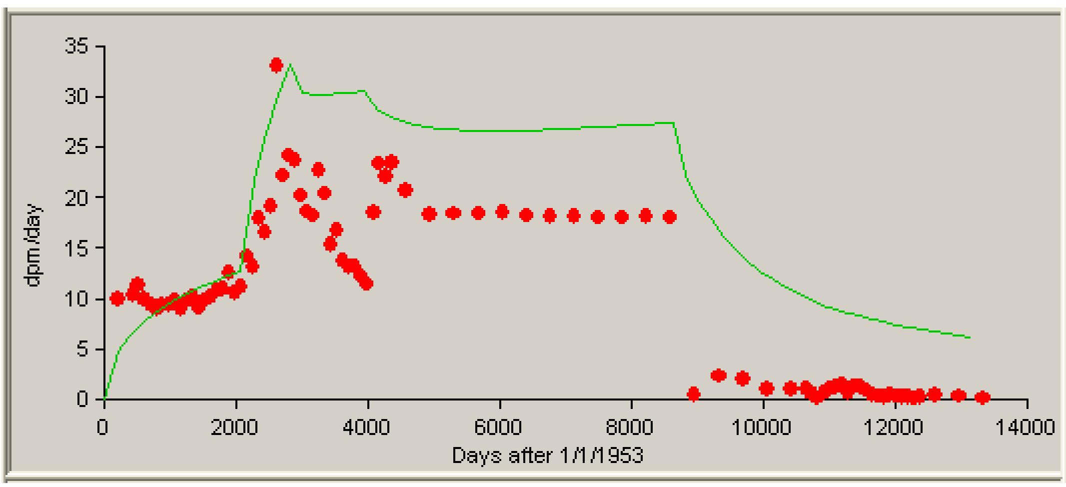

Figure B-20. Predicted uranium bioassay results (line) calculated using IMBA-derived U intake rates compared with measured uranium-in-urine results (dots) from all intakes 1/1/1953 to 12/31/1988, 84th-percentile, Type S.

Table B-1. IMBA-derived uranium intake rates, dpm/day.

Years	Type F			Type M			Type S		
	50%	84%	GSD	50%	84%	GSD	50%	84%	GSD
1953-1958	13.37	37.91	2.84	54.75	154.8	2.83	936.9	2,676	2.86
1959	19.7	61.99	3.15	102.7	347.5	3.38	2,768	9,300	3.36
1960	27.23	94.74	3.48	102.7	347.5	3.38	2,768	9,300	3.36
1961	21.62	65.97	3.05	71.85	234.2	3.26	1,680	5,438	3.24
1962	16.27	65.97	4.05	71.85	234.2	3.26	1,680	5,438	3.24
1963	16.27	44.36	2.73	71.85	234.2	3.26	1,680	5,438	3.24
1964	27.26	80.39	2.95	112.8	284.2	2.52	1,630	4,086	2.51
1965-1976	27.26	66.26	2.43	112.8	284.2	2.52	1,630	4,086	2.51
1977-1988	0.597	3.004	5.03	2.443	6.263	2.56	28.6	154.3	5.40

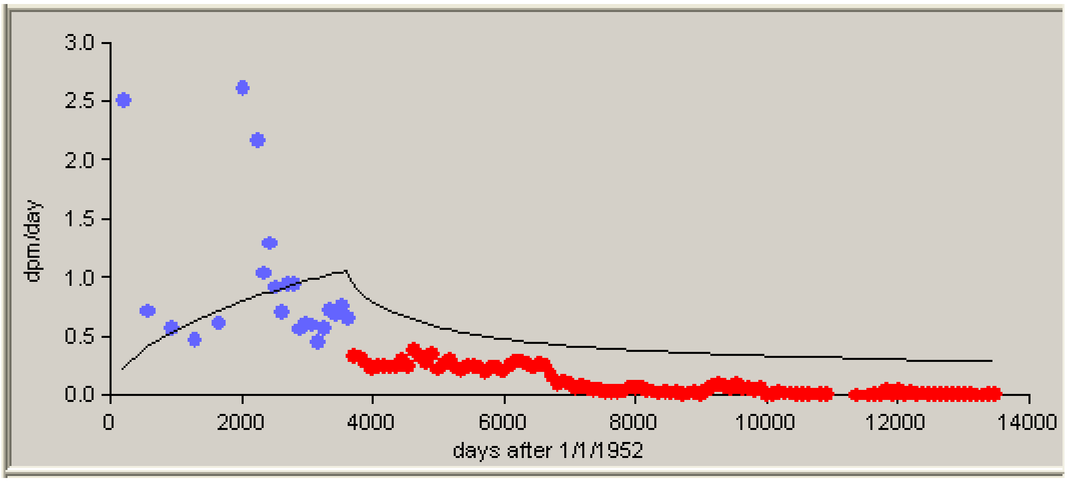

Figure B-21. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1952 to 12/31/1961, 50th-percentile, Type M.

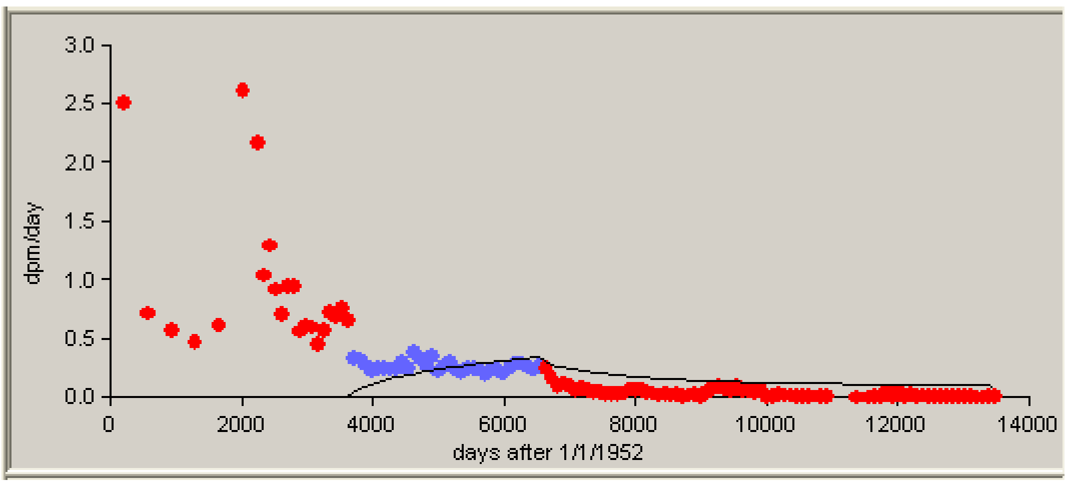

Figure B-22. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1962 to 12/31/1969, 50th-percentile, Type M.

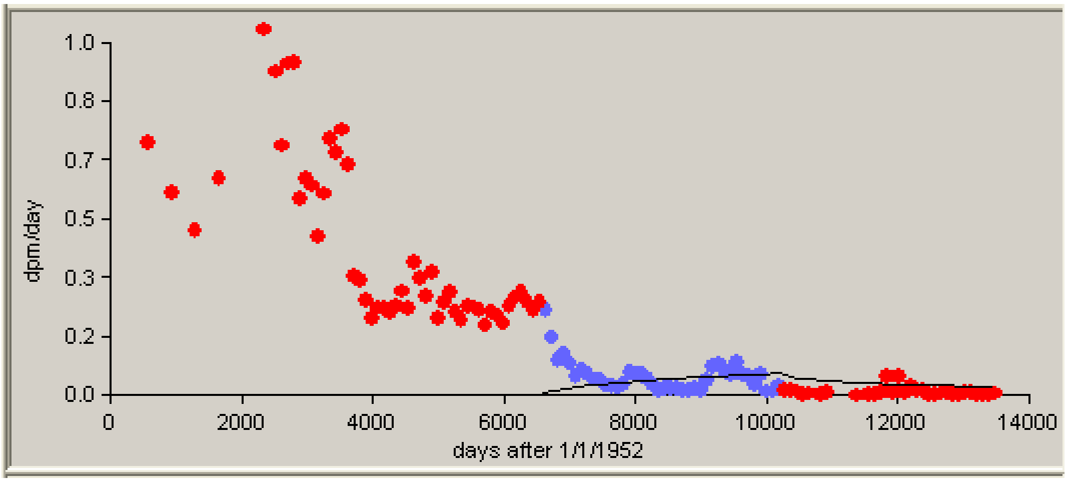

Figure B-23. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1970 to 12/31/1979, 50th-percentile, Type M.

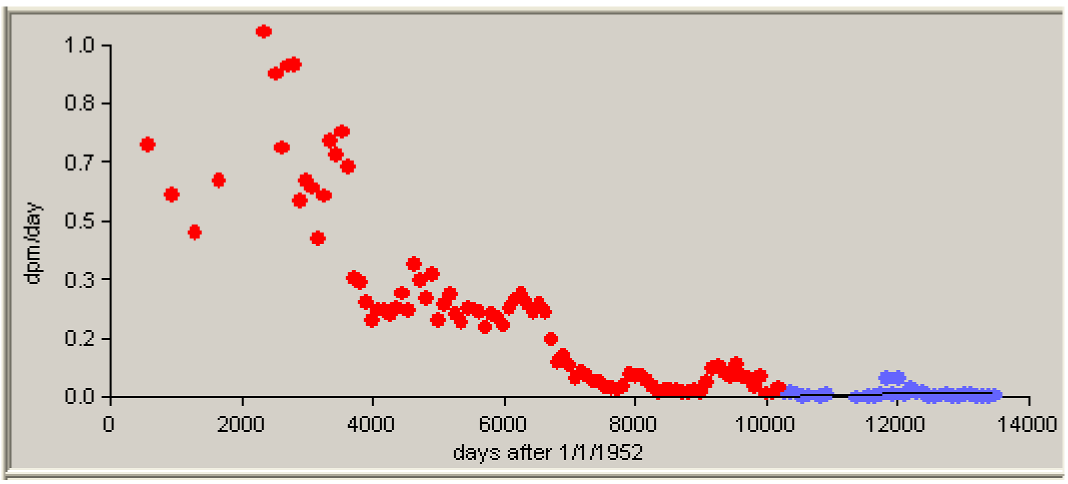

Figure B-24. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1980 to 12/31/1988, 50th-percentile, Type M.

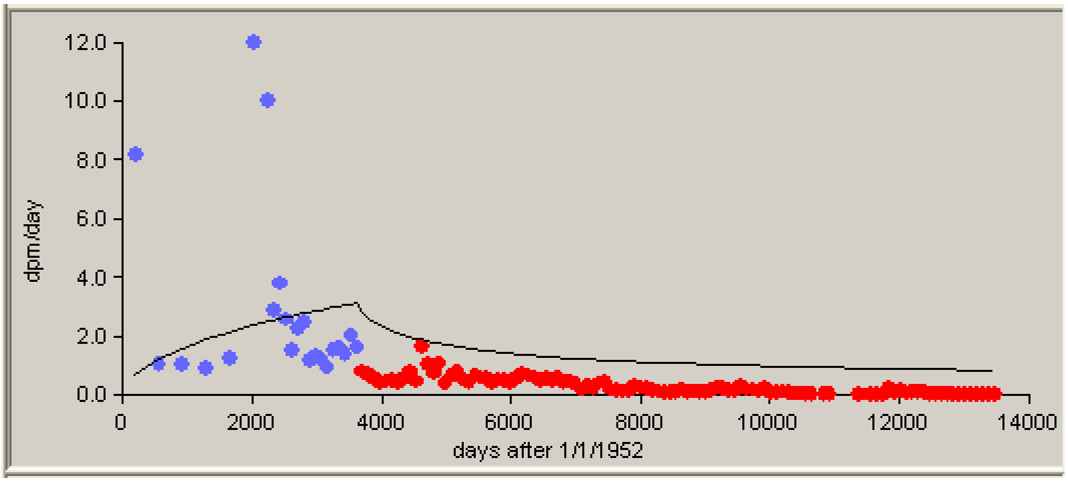

Figure B-25. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1952 to 12/31/1961, 84th-percentile, Type M.

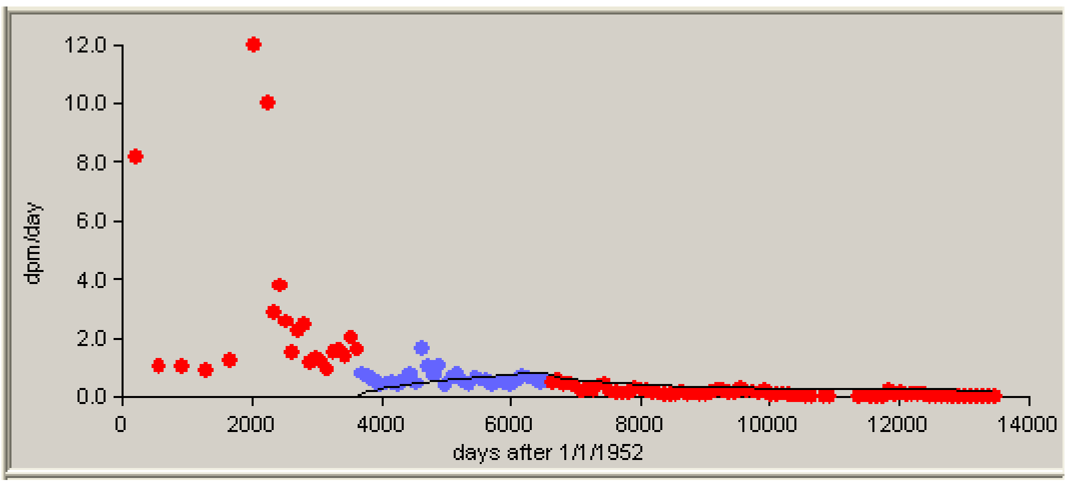

Figure B-26. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1962 to 12/31/1969, 84th-percentile, Type M.

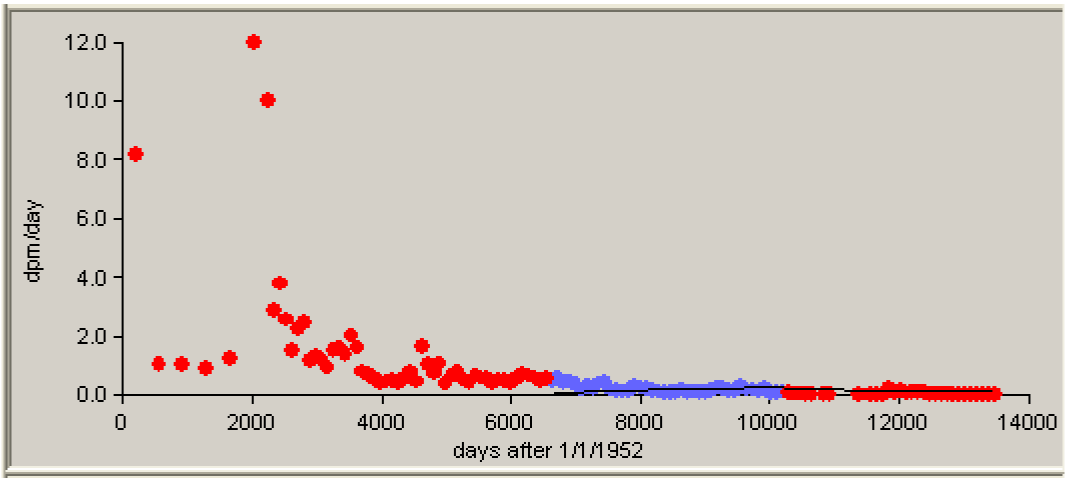

Figure B-27. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1970 to 12/31/1979, 84th-percentile, Type M.

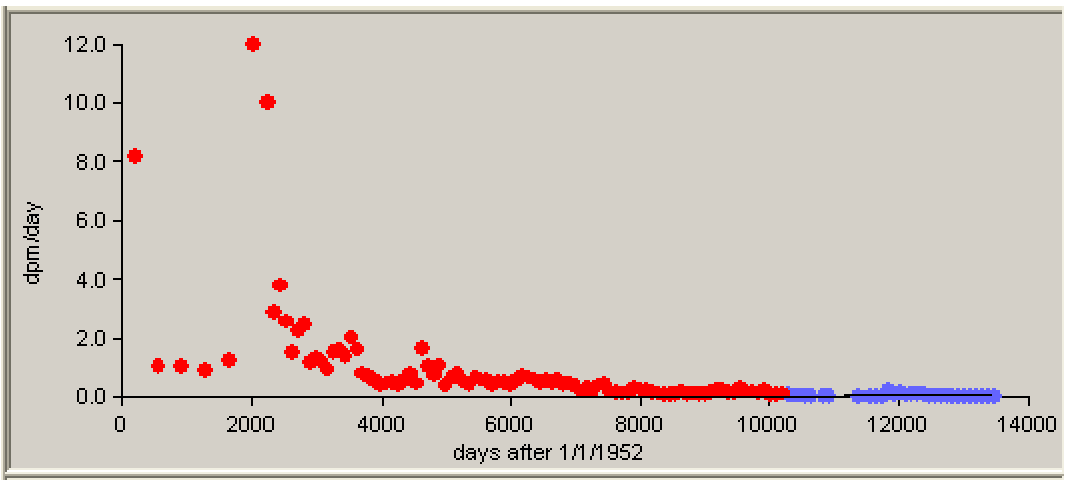

Figure B-28. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1980 to 12/31/1988, 84th-percentile, Type M.

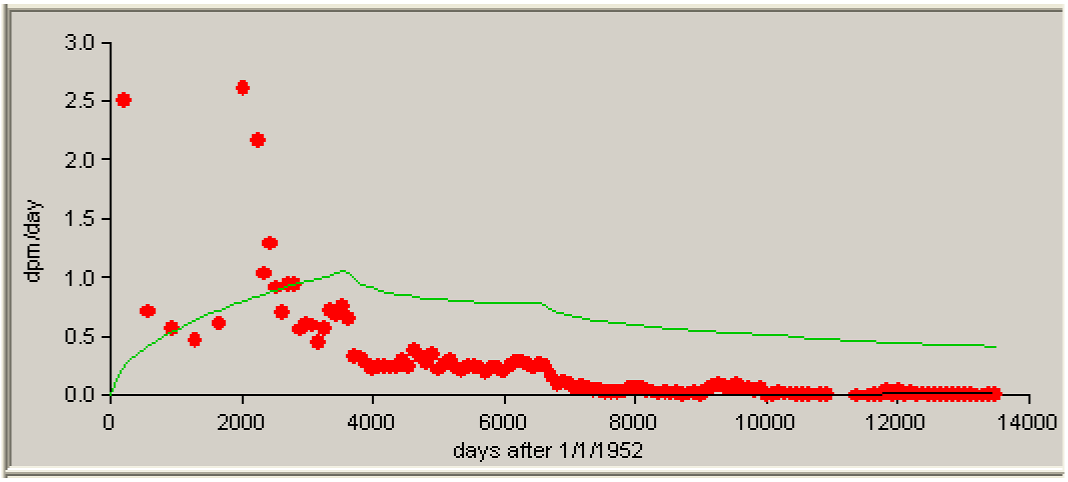

Figure B-29. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), from all intakes 1/1/1952 to 12/31/1988, 50-percentile, Type M.

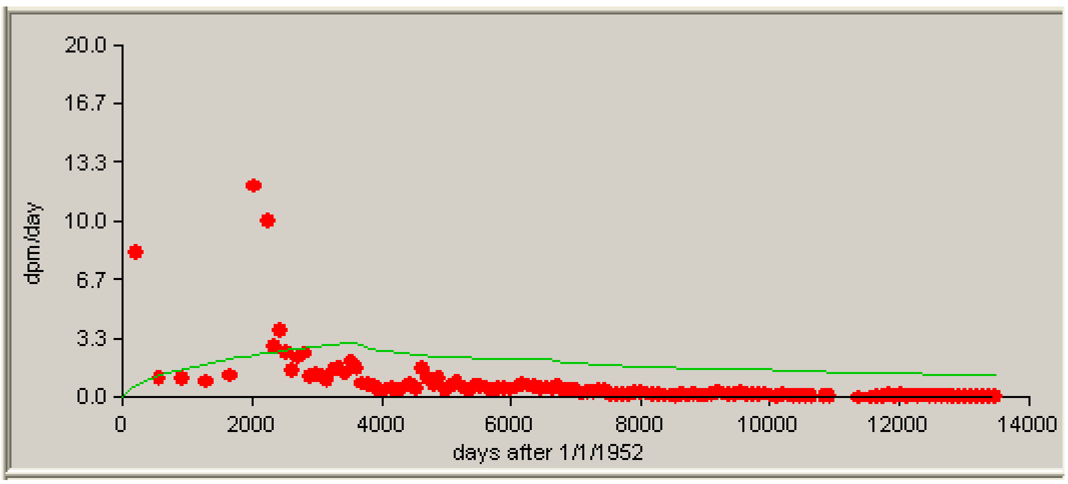

Figure B-30. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), from all intakes 1/1/1952 to 12/31/1988, 84th-percentile, Type M.

Table B-2. IMBA-derived plutonium/americium intake rates, Type M.

Year	Plutonium urinalysis-based results, dpm/day			Americium lung count-based results, 50th percentile	
	Pu 50%	**Pu 84%**	**GSD**	**Am, pCi/day**	**Pu, dpm/day**
1952-1961	121	357.3	2.95		
1962-1969	43.5	106.5	2.45		
1970-1971	7.05	29.82	4.23		
1972-1976	7.05	29.82	4.23	1.845	871.5
1977-1979	7.05	29.82	4.23	1.154	545.1
1980-1982	1.622	8.907	5.49	1.154	545.1
1983-1988	1.622	8.907	5.49	0.513	242.5

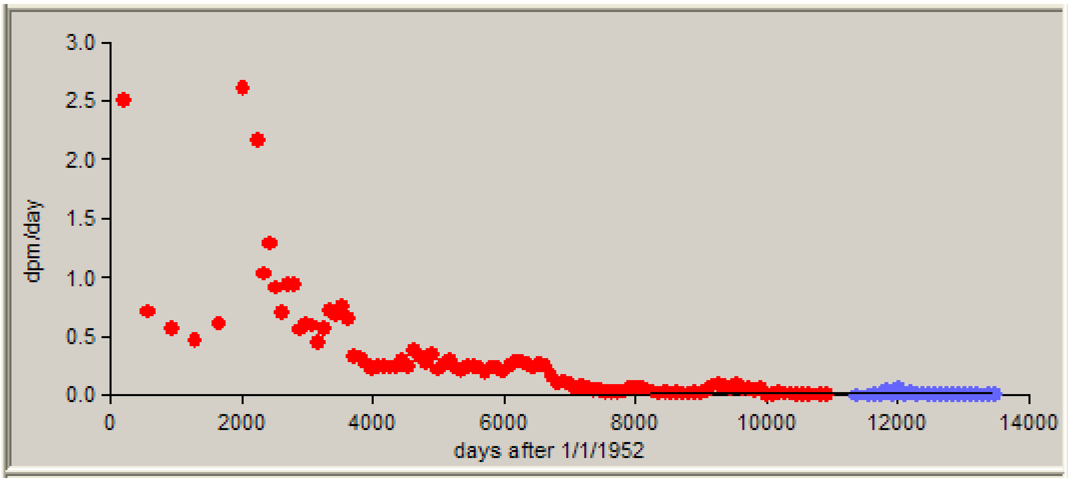

Figure B-31. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1952 to 12/31/1988, 50-percentile, Type S.

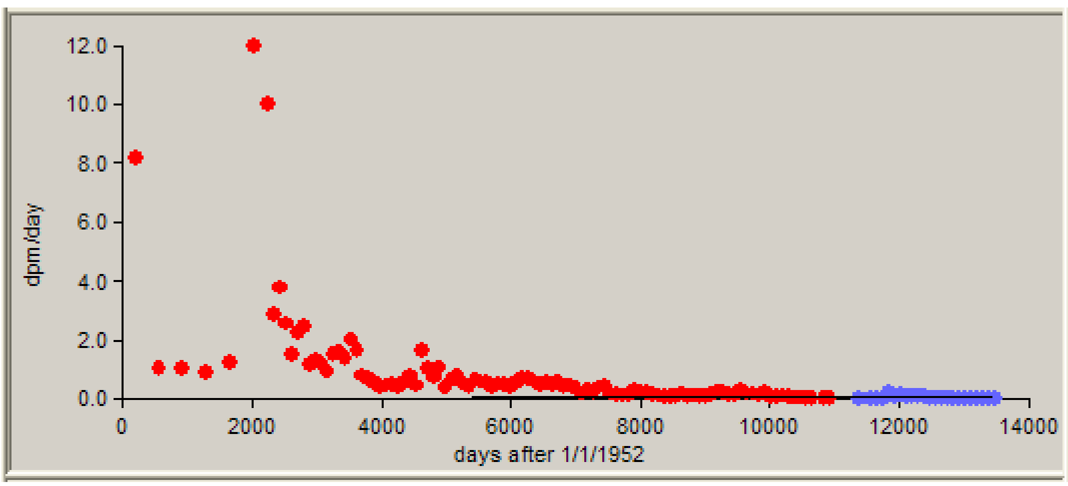

Figure B-32. Predicted plutonium bioassay results (line) calculated using IMBA-derived Pu intake rates compared with measured Pu-in-urine results (dots), 1/1/1952 to 12/31/1988, 84th-percentile, Type S.

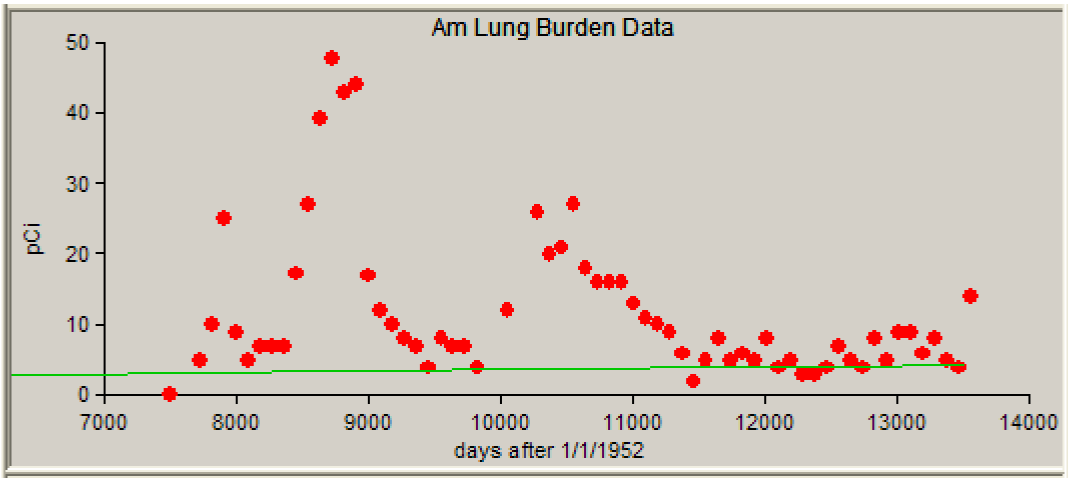

Figure B-33. Predicted Am bioassay results (line) calculated using IMBA-derived Am intake rates compared with measured Am lung burden results (dots), 1/1/1952 to 12/31/1988, 50th-percentile, Type S.

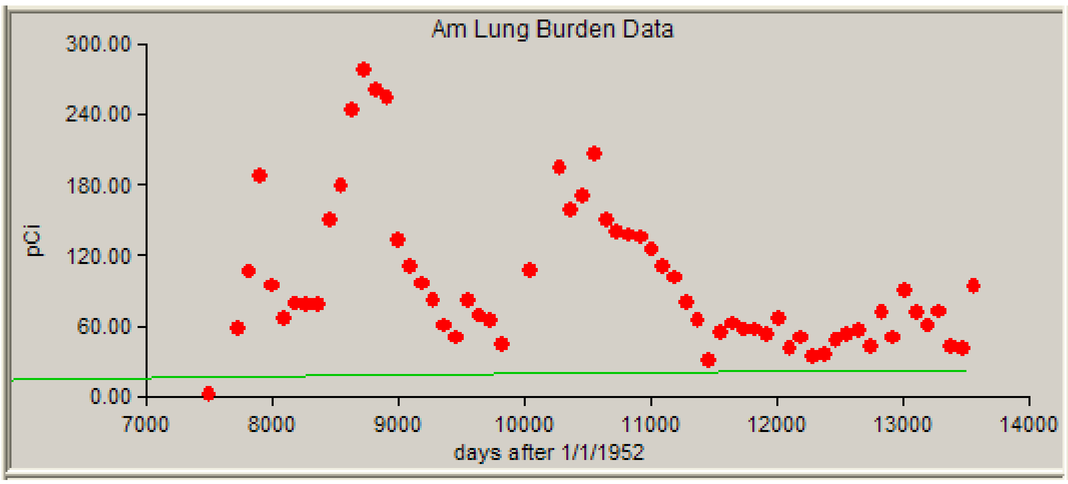

Figure B-34. Predicted Am bioassay results (line) calculated using IMBA-derived Am intake rates compared with measured Am lung burden results (dots), 1/1/1952 to 12/31/1988, 84th-percentile, Type S.

Table B-3. IMBA-derived plutonium/americium intake rates, Type S.

Intake rate modeling type	**50%**	**84%**	**GSD**
Plutonium from Am lung counts, dpm/day	11.83	113.4	9.58
Americium from Am lung counts, pCi/day	0.025	0.240	9.58
Plutonium from Pu urinalysis dpm/day	8.142	43.87	5.39
Americium from Pu urinalysis, pDi/day	0.017	0.093	5.39