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1.0 PURPOSE

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 facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384I(5) and (12)].

There are instances of energy employees who, for a variety of reasons, were not monitored for internal exposure during the course of their employment at a U.S. Department of Energy (DOE) facility, or whose records of such monitoring are incomplete or unavailable. In such cases, data from coworkers may be used to approximate an individual's possible exposure. The purpose of this document is to provide the details of the calculation and assignment of intakes based on coworker data from Oak Ridge National Laboratory (ORNL) for the purpose of estimating unmonitored exposures or where records of monitoring are incomplete or unavailable, whether for discrete periods or for the entire period of employment.

2.0 OVERVIEW

Analysis of Coworker Bioassay Data for Internal Dose Assignment (ORAU 2004a) describes the general process used for analyzing bioassay data for assigning doses to individuals based on coworker results.

Bioassay results for ORNL were obtained from the Oak Ridge Institute for Science and Education (ORISE) Center for Epidemiologic Research (CER) Dosimetry Database, which contains urinalysis records from the ORNL site for the period 1951 to 1988. ORISE obtained this database from ORNL for the purpose of conducting an epidemiology study of site workers. The database results are in units of disintegrations per minute (dpm)/24 hours. Because of the varied operations at the different ORNL facilities over time with the potential for exposure from numerous different radionuclides, the database contains urinalysis data for numerous radionuclides. These data are stored using Electronic Data Processing (EDP) codes, as documented in Section 5.1.5.2 of the X-10 Technical Basis Document (TBD) (ORAU 2004b). In summary, data were stored under 64 different EDP codes and included measurements for five radioisotopes of uranium, four radioisotopes of plutonium, seven other transuranic radionuclides, numerous fission and activation products, and gross alpha and gross beta measurements. The majority of the EDP codes contained fewer than 100 data entries. In reviewing these data, it was determined that only a few of the EDP codes contained enough entries to allow statistical evaluation for purposes of dose reconstruction. These EDP codes were: SR and SR0 for ^{90}Sr (12,893 entries from 1951 to 1988), UR0 and UR for total uranium (11,434 entries from 1951 to 1988), PU0, PU9, PU, GA0, and GU0 for plutonium alpha-emitters (15,476 entries from 1951 to 1988), and TP0 and TP for transplutonium radionuclides, primarily ^{241}Am (5,670 entries from 1968 to 1987). Further review of these data indicated that, except for follow-up for accidental exposures, they were collected on an annual sampling basis; therefore, the analysis that follows considers chronic exposures to estimate annual intakes. A statistical analysis of these data was performed in accordance with ORAU (2004a). The resultant values were input to the Integrated Modules for Bioassay Analysis (IMBA) Expert OCAS-Edition computer program, and a fit to the data for each of the four radionuclides was performed to obtain intake rates for assigning dose distributions.

3.0 DATA

3.1 Selected Bioassay Data

Data for each of the EDP codes considered were extracted from a series of Microsoft® Access files that contain a version of the ORISE/CER Dosimetry Database. These files were titled "tblORNL_Urinalysis_rawData," for the periods 1951-1978, 1979-1985, and 1986-1988.

3.2 Analysis

A lognormal distribution for the annual data for each of the four radionuclides was assumed, and the 50th and 84th percentiles were calculated, using the method described in ORAU (2004a). Tables A-1 through A-4 in Attachment A show the statistical analysis results for strontium, uranium, plutonium, and transplutonium.

4.0 INTAKE MODELING

4.1 Assumptions

All results were assumed to be representative of a full day (24 hr) of urinary excretion. Each result used in the intake calculation was assumed to be normally distributed, and a uniform absolute error of 1 was applied to all results, thus weighting all results equally. A chronic exposure pattern was assumed; while this is unlikely for workers at ORNL, it will approximate a series of acute intakes with unknown intake dates. Intakes were assumed to be via inhalation using a default breathing rate of 1.2 m^3/hr and a 5-µm activity median aerodynamic diameter (AMAD) particle size distribution.

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 for each radionuclide were fit as a series of chronic intakes.

Because the Type S strontium, uranium, and plutonium isotopes and Type M plutonium and americium isotopes present at ORNL have very long 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 early 1950s could contribute to urinary excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked at ORNL for relatively short periods, each intake was fit independently, using only the bioassay results from the single intake period. This will result in an overestimate of intakes, particularly for assumed Type S exposures extending through multiple assumed intake periods.

4.3 Radionuclides And Material Types

For each radionuclide considered, the bioassay results were entered into IMBA with assumed material types as discussed in more detail in the following sections. The assumed 50th-percentile intakes that result are displayed in the figures in Attachment A. In these figures, annual bioassay data used in the fits are shown as the dark dots (●), and data that are not used in the fits are shown as lighter dots (●). For certain radionuclides and material types, it is necessary to show figures for both the composite intake over the entire data period and the individual plots of subsets of selected groups of years during the data period that were used to develop the composite figure. The composite plot shows the merged fit for all of the intake periods to the bioassay data.

The IMBA output figures in Attachment A show the fit to the bioassay data for each annual intake period in terms of days after the date of initial data reporting. For example, for ^{90}Sr, day 1 equals June 1, 1951, and day 13,515 equals June 1, 1988.

4.3.1 Strontium-90

Strontium results were assumed to be Sr-90. Because of the presence of ^{90}Sr both as an effluent from reactor operations and in a highly insoluble titanite form, bioassay results for ^{90}Sr were fit using Type F and S material. Figure A-1 in Attachment A shows the individual fits to the 50th-percentile intake values for Type F ^{90}Sr. Table A-5 summarizes the intake periods and corresponding intake rates for the 50th- and 84th-percentile values, and the geometric standard deviations (GSDs) for Type F ^{90}Sr . The GSDs were determined by dividing the 84th-percentile intake rates by the 50th-percentile intake rates. Figures A-2 through A-6 show the fits corresponding to each of the subsets of years across the intake period used to develop the composite figure for Type S ^{90}Sr. Figure A-7 shows the composite of the subsets of selected groups of years used to fit the 50th-percentile intake values for Type S ^{90}Sr. Table A-6 summarizes the intake periods and corresponding intake rates for the 50th- and 84th-percentile values, and the calculated GSDs for Type S ^{90}Sr. The same intake periods were applied to the 84th-percentile values for both ^{90}Sr Type F and S material because the values followed a similar pattern; results of the individual fits are not shown here since they were largely in agreement. It is noted that the urinalysis data for 1964 were insufficient to support a complete analysis and was therefore was omitted from the sample set.

4.3.2 Uranium-234

Because a variety of uranium enrichments and exposure conditions are possible at the ORNL site, ^{234}U was assumed for the IMBA intake modeling even though the source data are for gross uranium in varying amounts, depending on the enrichment. This does not affect the fitting of the data for intake determination (i.e., the same total intakes would be obtained for any enrichment that was assumed) because all uranium isotopes behave the same biokinetically and the isotopes considered in this analysis have long half-lives relative to the assumed intake period. The ICRP 68 (1995) 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. Because of the isotopic compositions of the source terms, the ^{234}U dose conversion factor will overestimate doses for any combination of the uranium radioisotopes, but the assumption of intake of 100% ^{234}U is made to ensure claimant-favorability of the doses.

Because uranium is found in many forms at ORNL, the bioassay data were fit using Type F, M, and S material. Figures A-8 and A-9 show the individual fits for the 50th-percentile values for Type F and M ^{234}U, respectively. Table A-7 summarizes the intake periods for the 50th- and 84th-percentile values, and the calculated GSDs for Type F ^{234}U, while Table A-8 shows similar information for Type M ^{234}U. Again, the GSDs were determined by dividing the 84th-percentile intake rates by the 50th-percentile intake rates. For Type S ^{234}U, Figures A-10 through A-16 show the fits corresponding to each of the subsets of years across the intake period used to develop the composite figure. Figure A-17 provides the composite of the subsets of selected groups of years used to fit the 50th-percentile intake values. Table A-9 summarizes the intake periods and corresponding intake rates for the 50th- and 84th-percentile values, and the

calculated GSDs for Type S ^{234}U. Plots of the results of the individual fits to the 84th-percentile values for all three solubility types are not shown here since they were largely in agreement.

4.3.3 Plutonium-239

For this analysis, the analyzed material types for ^{239}Pu are assumed to be types M and S. Although the bioassay results are for all alpha-emitting isotopes of plutonium, the results were assumed to represent the concentration of ^{239}Pu alone,. Figures A-18 through A-21 show the fits for Type M material corresponding to each of the subsets of years across the intake period used to develop the composite figure. Figure A-22 shows the composite of the subsets of selected years used to fit the 50th-percentile intake values for type M ^{239}Pu. Table A-10 summarizes the intake periods and corresponding intake rates for the 50th- and 84th-percentile values, and the GSDs for type M ^{239}Pu. The GSDs were determined by dividing the 84th-percentile intake rates by the 50th-percentile intake rates. Again, the same intake periods were applied to the 84th-percentile values for Type M ^{239}Pu because the values followed a similar pattern; results of the individual fits are not shown here since they were largely in agreement.

Figure A-23 shows the fit for Type S material based on a chronic intake for the entire set of years fitted to the bioassay data for the last three years (1986 through 1988). Table A-11 summarizes the intake period and corresponding intake rate for the 50th- and 84th-percentile values, and the GSDs for type S ^{239}Pu. Again, the GSDs were determined by dividing the 84th-percentile intake rates by the 50th-percentile intake rates. The same intake periods were applied to the 84th-percentile values for Type S ^{239}Pu because the values followed a similar pattern; results of the fit are not shown here since they were largely in agreement.

4.3.4 Americium-241

ICRP 68 (1995) assigns all forms of americium to Type M. Figures A-24 and A-25 show the fits corresponding to each of the subsets of years across the intake period used to develop the composite figure. Figure A-26 shows the composite of the subsets of selected years used to fit the 50th-percentile intake values for Type M ^{241}Am. Table A-12 summarizes the intake periods and corresponding intake rates for the 50th- and 84th-percentile values, and the GSDs for Type M ^{241}Am. Again, the GSDs were determined by dividing the 84th-percentile intake rates by the 50th-percentile intake rates. The same intake periods were applied to the 84th-percentile values for Type M ^{241}Am because the values followed a similar pattern; results of the individual fits are not shown here since they were largely in agreement.

4.3.5 Additional Radionuclides

It is recognized that hundreds of different radionuclides were present at ORNL at some point during its operations. However, bioassay data for additional radionuclides beyond ^{90}Sr, ^{238}U, ^{239}Pu, and ^{241}Am were deemed to be of little use for coworker estimations, largely because there were too few measurements to be statistically reliable for intake estimation. For this analysis, three additional radionuclides, both important to internal dosimetry and present in the reported air monitoring data, were considered. These are ^{106}Ru, ^{137}Cs, and ^{144}Ce.

5.0 ASSIGNMENT OF INTAKES AND DOSES

The resulting calculated intake rate information, useful in dose reconstruction for the radionuclides identified for ORNL, is discussed in this section. For each radionuclide, the 50th- and 84th-percentile intake rates, and the GSDs, are provided in specific tables. The GSD values have been adjusted from the values given in the tables in Appendix A to allow for the addition of doses from different intake periods into a single input line for a given year in the IREP input file, and to ensure that none are less than 3, the value used when assigning intakes to individuals from person-specific bioassay results.

- Strontium-90. For ^{90}Sr, several intake periods were defined as shown in Table 5-1 for Type F material and Table 5-2 for Type S material. Note that there were five intake periods defined for ^{90}Sr Type F intakes and six intake periods defined for ^{90}Sr Type S intakes.

Table 5-1. Combined ^{90}Sr Type F intake periods and rates.

Date range		^{90}Sr Type F intake rate, dpm/d	
From	To	50th percentile	GSD
1/1/1951	12/31/1953	475.2	10.0
1/1/1954	12/31/1954	80.99	10.0
1/1/1955	12/31/1960	47.34	4.17
1/1/1961	12/31/1964	47.34	3.00
1/1/1965	12/31/1988	15.52	3.00

Table 5-2. Combined ^{90}Sr Type S intake periods and rates.

Date range		^{90}Sr Type S intake rate, dpm/d	
From	To	50th percentile	GSD
1/1/1951	12/31/1953	24646	9.53
1/1/1954	12/31/1954	7,232	9.53
1/1/1955	12/31/1960	2,379	5.73
1/1/1961	12/31/1964	2,379	3.00
1/1/1965	12/31/1983	795.0	3.00
1/1/1984	12/31/1988	425.5	4.51

- **Uranium-234.** Table 5-3 contains the calculated annual intake rates for the years 1951 through 1987, for Types F, M, and S material.

- Plutonium-239**.** Tables 5-4 and 5-5 contains the calculated annual intake rates for ^{239}Pu for Types M and S material respectively for the years 1951 through 1988.

- **Americium-241.** Table 5-6 contains the combined ^{241}Am Type M material intake periods and rates for 1968 through 1988. Note that there were two intake periods defined.

5.1 Contribution From Additional Radionuclides

To account for additional intakes, an evaluation of air monitoring data from the ORNL perimeter reporting stations for the period 1975 through 1984 was conducted. The approach was to develop the ratios of the isotopic concentration ratios of other radionuclides to the concentration ratio of ^{90}Sr reported in the air monitoring data. The

results of this evaluation are summarized in Table 5-7, which shows the reported radionuclide concentrations, the ratio of the concentrations of the three selected radionuclides to ^{90}Sr, the peak concentration ratio, range of the concentration ratios, and the average concentration ratio.

5.2 Dose Assignment

In most cases, doses to be assigned to individuals potentially exposed on a routine basis are calculated from the 50th-percentile intake rates; the material type resulting in the largest probability of causation (which is determined by the Department of Labor) is selected. A comparison of the intake rates shows:

- For ^{90}Sr, the calculated intake rates for Type S material are one to two orders of magnitude higher than the intake rates of Type F material for all intake periods. However, because the Type S material remains in the lungs for an extended period while the Type F material is transferred to the systemic organs, it is necessary to compare the annual doses on a case-by-case basis to determine which will deliver the larger dose to the organ of interest.

Table 5-3. Annual ^{234}U Type F, M, and S intake periods and rates.

	^{234}U Type F intake rate, dpm/d		^{234}U Type M intake rate, dpm/d		^{234}U Type S intake rate, dpm/d	
Year	50th percentile	GSD	50th percentile	GSD	50th percentile	GSD
1951	11.19	3.08	47.03	3.33	850.7	3.0
1952	11.19	3.08	47.03	3.33	850.7	3.0
1953	11.19	3.08	47.03	3.33	850.7	3.00
1954	11.19	3.08	47.03	3.33	850.7	3.00
1955	11.19	3.08	47.03	3.33	850.7	3.00
1956	4.213	6.71	11.45	9.70	675.7	3.00
1957	1.942	9.25	7.49	9.70	247.7	7.74
1958	1.942	9.25	7.49	9.70	247.7	7.74
1959	5.171	3.48	21.81	3.33	509	4.17
1960	5.171	3.48	21.81	3.33	509	4.17
1961	5.171	3.48	21.81	3.33	509	4.17
1962	1.881	6.71	6.56	7.24	235.3	6.04
1963	1.881	6.71	6.56	7.24	235.3	6.04
1964	0.413	3.08	1.641	3.33	23.7	3.00
1965	0.413	3.08	1.641	3.33	23.7	3.00
1966	0.413	3.08	1.641	3.33	23.7	3.00
1967	0.413	3.08	1.641	3.33	23.7	3.00
1968	0.413	3.08	1.641	3.33	23.7	3.00
1969	0.413	3.08	1.641	3.33	23.7	3.00
1970	0.413	3.08	1.641	3.33	23.7	3.00
1971	0.413	3.08	1.641	3.33	23.7	3.00
1972	0.413	3.08	1.641	3.33	23.7	3.00
1973	0.413	3.08	1.641	3.33	23.7	3.00
1974	0.413	3.08	1.641	3.33	23.7	3.00
1975	0.413	3.08	1.641	3.33	23.7	3.00
1976	0.413	3.08	1.641	3.33	23.7	3.00
1977	0.413	3.08	1.641	3.33	23.7	3.00
1978	0.413	3.08	1.641	3.33	23.7	3.00
1979	0.413	3.08	1.641	3.33	23.7	3.00
1980	0.413	3.08	1.641	3.33	23.7	3.00
1981	0.413	3.08	1.641	3.33	23.7	3.00
1982	0.413	3.08	1.641	3.33	23.7	3.00
1983	0.413	3.08	1.641	3.33	15.25	4.67

1984	0.413	3.08	1.641	3.33	15.25	3.0
1985	0.0957	3.08	0.294	3.33	15.25	3.0
1986	0.0957	3.08	0.294	3.33	15.25	3.0
1987	0.0957	3.08	0.294	3.33	15.25	3.0

Table 5-4. Annual ^{239}Pu Type M intakes and rates.

Years	^{239}Pu Type M intake rate, dpm/d	
	50th percentile	GSD
1951-1952	40.75	3.0
1953-1959	10.98	7.9
1960-1968	10.98	3.0
1969-1984	7.35	3.0
1985-1988	1.614	4.2

Table 5-5. Annual ^{239}Pu Type S intakes and rates.

Year	^{239}Pu Type S intake rate, dpm/d	
	50th percentile	GSD
1951-1988	4.15	5.50

- For ^{234}U, the calculated intake rates for Type S material are one to two orders of magnitude higher than the intake rates of Type F and M material for all intake periods. Again, because Type S material remains in the lungs while Type F and M material is transferred to the systemic organs, it is necessary to compare the annual doses on a case-by-case basis to determine which will deliver the larger dose to the organ of interest.

- For ^{239}Pu, The calculated intake rates for type M material should be used for all systemic organs and intake periods. For non-systemic (respiratory and GI tracts) organs, the type S intake rate may only be used as an underestimate. If an overestimate or best estimate is needed for non-systemic organs, an individualized fit to the bioassay data, assuming type S material, for the specific work period of the Energy Employee being evaluated must be performed. Table A-3 provides the bioassay data to be used to perform the individualized fit. Both the 50th- and 84th-percentile values must be fit using the same intake dates and/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. The GSD for each intake will be the ratio of the 84th percentile intake rate to the 50th percentile intake rate. For input into IREP, the dose from each intake must be determined separately.

- For ^{241}Am, the calculated intake rates for Type M material should be used for all organs and intake periods as given in Table 5-6.

Table 5-6. Combined ^{241}Am Type M intake periods and rates.

Year	^{241}Am Type M intake rate, dpm/d		
	50th percentile	84th percentile	GSD
1968-1984	6.673	14.61	3.00
1985-1988	2.207	6.659	3.00

- When a ^{90}Sr intake is assigned, the worker should also be assigned intakes of ^{106}Ru, ^{137}Cs, and ^{144}Ce, consistent with the average isotopic ratios developed from the air monitoring data given in Table 5-7, using the ^{90}Sr intake as the basis. For example, if a worker were exposed in 1965 to Type F ^{90}Sr, the intake (from Table 5-1) would be 15.5 dpm/d. Intake of ^{106}Ru would also be assigned at a value of 103.8 dpm/d (i.e., 15.5 dpm/d of ^{90}Sr times 6.7, the average ratio of ^{106}Ru to ^{90}Sr from Table 5-7), along with a 34.1 dpm/d intake of ^{137}Cs and 170.5 dpm/d intake of ^{144}Ce. Although Table 5-7 is based on data from 1975 through 1984, the average ratios calculated should be used for all years.

  The lognormal distribution is selected in the Interactive RadioEpidemiological Program (IREP), with the calculated dose entered as Parameter 1 and the associated GSD as Parameter 2. The GSD is associated with the intake, so it is applied to all annual doses determined from the intake period. The GSD for ^{90}Sr should be assigned when intakes of ^{106}Ru, ^{137}Cs, and/or ^{144}Ce are included.

Table 5-7. Evaluation of the contribution of additional radionuclides.

Year	Reported ^{90}Sr concentration (10^{-15} µCi/mL)	Reported ^{106}Ru concentration (10^{-15} µCi/mL)	Ratio: ^{106}Ru to ^{90}Sr	Reported ^{137}Cs concentration (10^{-15} µCi/mL)	Ratio: ^{137}Cs to ^{90}Sr	Reported ^{144}Ce concentration (10^{-15} µCi/mL)	Ratio: ^{144}Ce to ^{90}Sr
1975[a]	0.78	6.7	8.6	1.4	1.8	11	14
1976[a]	0.77	0.88	1.1	0.55	0.7	2.4	3.1
1977[a]	1.30	11	8.5	1.60	1.2	21	16
1978[a]	0.81	9.7	12	2.14	2.6	16	19
1979[a]	0.15	1.56	10	0.67	4.5	1.8	12
1980[a]	0.08	0.49	6.1	0.37	4.6	0.98	12
1981[a]	0.46	4.40	9.6	1.2	2.6	11	24
1982[a]	0.15	0.40	2.7	0.24	1.6	0.03	0.2
1983[a]	0.08	0.12	1.5	0.10	1.2	N/A	N/A
1984[a]	0.07	N/A	N/A	0.07	1.0	N/A	N/A
Peak ratio	-	-	12	-	5	-	24
Ratio range	-	-	1.1 - 12	-	0.7 – 4.6	-	0.2 - 24
Average ratio	**-**	**-**	**6.7**	**-**	**2.2**	**-**	**11**

a. References: 1975 – (Union Carbide 1975); 1976 – (Union Carbide 1976); 1977 – (Union Carbide 1977); 1978 – (Union Carbide 1978); 1979 – (Union Carbide 1979); 1980 – (Union Carbide 1980); 1981 – (Union Carbide 1981); 1982 – (Union Carbide 1982); 1983 – (Martin Marietta 1983); and 1984 – (Martin Marietta 1984).

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ATTACHMENT A

Table A-1. Statistical summary of annual ORNL strontium 24-hour urinary excretion rates, 1951-1988.

Effective bioassay date	GM (50th) dpm/day	GM*GSD (84th) dpm/day
7/1/1952	109.15	1,008.55
7/1/1954	24.68	241.98
7/1/1955	13.10	63.17
7/1/1956	13.54	82.88
7/1/1957	15.71	68.85
7/1/1958	17.01	75.45
7/1/1959	12.20	59.03
7/1/1960	15.67	65.07
7/1/1961	9.48	28.06
7/1/1962	12.04	29.49
7/1/1963	10.08	26.23
N/A*	N/A*	N/A*
7/1/1965	4.86	15.75
7/1/1966	3.62	17.78
7/1/1967	3.35	12.86
7/1/1968	1.02	7.77
7/1/1969	3.89	8.96
7/1/1970	6.07	13.96
7/1/1971	6.91	15.08
7/1/1972	7.54	22.75
7/1/1973	5.18	13.45
7/1/1974	7.66	24.76
7/1/1975	5.27	10.68
7/1/1976	5.14	11.59
7/1/1977	5.19	11.58
7/1/1978	5.04	9.61
7/1/1979	2.44	6.68
7/1/1980	5.69	23.05
7/1/1981	3.04	7.22
7/1/1982	5.23	12.06
7/1/1983	5.71	14.48
7/1/1984	4.38	14.14
7/1/1985	2.11	5.93
7/1/1986	0.67	2.88
7/1/1987	3.37	15.98
7/1/1988	0.56	1.96

* Insufficient data for analysis.

Table A-2. Statistical summary of annual ORNL uranium 24-hour urinary excretion rates, 1951-1987.

Effective bioassay date	GM (50th) dpm/day	GM*GSD (84th) dpm/day
7/1/1951	3.41	7.81
7/1/1952	2.88	8.01
7/1/1953	3.64	7.54
7/1/1954	2.27	5.46
7/1/1955	3.07	9.34
7/1/1956	1.20	8.16
7/1/1957	0.50	3.65
7/1/1958	0.64	4.74
7/1/1959	1.43	6.93
7/1/1960	1.36	3.97
7/1/1961	1.52	5.73
7/1/1962	0.52	3.57
7/1/1963	0.58	3.24
7/1/1964	0.25	1.29
7/1/1965	0.17	0.62
7/1/1966	0.18	0.52
7/1/1967	0.09	0.21
7/1/1968	0.13	0.34
7/1/1969	0.10	0.33
7/1/1970	0.16	0.65
7/1/1971	0.09	0.26
7/1/1972	0.13	0.39
7/1/1973	0.07	0.30
7/1/1974	0.06	0.22
7/1/1975	0.08	0.32
7/1/1976	0.10	0.46
7/1/1977	0.20	0.48
7/1/1978	0.14	0.31
7/1/1979	0.14	0.52
7/1/1980	0.11	0.39
7/1/1981	0.13	0.22
7/1/1982	0.17	0.31
7/1/1983	0.12	0.28
7/1/1984	0.10	0.19
7/1/1985	0.07	0.17
7/1/1986	0.04	0.08
7/1/1987	0.00	0.03

Table A-3. Statistical summary of annual ORNL plutonium 24-hour urinary excretion rates, 1951-1988.

Effective bioassay date	GM (50th) dpm/day	GM*GSD (84th) dpm/day
7/1/1951	0.13	0.30
7/1/1952	0.11	0.31
7/1/1953	0.04	0.14
7/1/1954	0.07	0.36
7/1/1955	0.07	0.26
7/1/1956	0.04	0.36
7/1/1957	0.14	0.73
7/1/1958	0.15	0.52
7/1/1959	0.12	0.62
7/1/1960	0.13	0.28
7/1/1961	0.07	0.21
7/1/1962	0.01	0.08
7/1/1963	0.01	0.09
7/1/1964	0.08	0.23
7/1/1965	0.13	0.26
7/1/1966	0.12	0.21
7/1/1967	0.10	0.19
7/1/1968	0.12	0.24
7/1/1969	0.04	0.17
7/1/1970	0.08	0.19
7/1/1971	0.06	0.23
7/1/1972	0.06	0.18
7/1/1973	0.03	0.11
7/1/1974	0.06	0.12
7/1/1975	0.04	0.12
7/1/1976	0.05	0.13
7/1/1977	0.07	0.15
7/1/1978	0.06	0.15
7/1/1979	0.08	0.14
7/1/1980	0.05	0.11
7/1/1981	0.09	0.16
7/1/1982	0.10	0.17
7/1/1983	0.07	0.13
7/1/1984	0.07	0.11
7/1/1985	0.01	0.05
7/1/1986	0.01	0.04
7/1/1987	0.01	0.04
7/1/1988	0.00	0.03

Table A-4. Statistical summary of annual ORNL transplutonium 24-hour urinary excretion rates, 1968-1987.

Effective bioassay date	GM (50th) dpm/day	GM*GSD (84th) dpm/day
7/1/1968	0.12	0.31
7/1/1969	0.10	0.42
7/1/1970	0.10	0.33
7/1/1971	0.09	0.24
7/1/1972	0.12	0.27
7/1/1973	0.09	0.16
7/1/1974	0.08	0.15
7/1/1975	0.12	0.30
7/1/1976	0.15	0.52
7/1/1977	0.11	0.18
7/1/1978	0.10	0.18
7/1/1979	0.10	0.17
7/1/1980	0.10	0.14
7/1/1981	0.07	0.17
1/1/1983	0.10	0.17
7/1/1984	0.10	0.15
7/1/1985	0.05	0.09
7/1/1986	0.01	0.05
7/1/1987	0.01	0.04

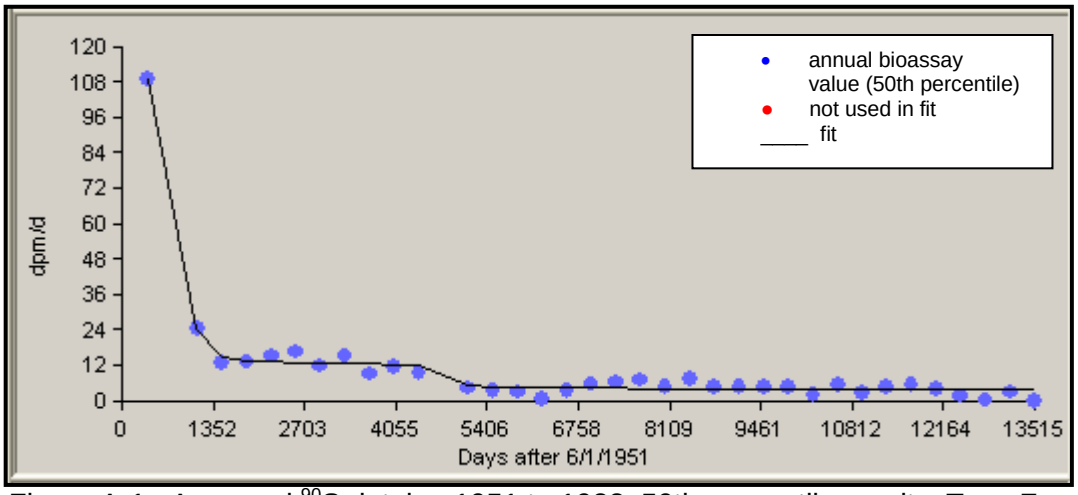

Figure A-1. Assumed ^{90}Sr intake, 1951 to 1988, 50th-percentile results, Type F.

Table A-5. Type F ^{90}Sr intake periods and rates.

Start date	End date	^{90}Sr intake rate (dpm/day)		GSD
		50th percentile	84th percentile	
1/1/1951	12/31/1953	475.2	4389	9.24
1/1/1954	12/31/1954	80.99	810.4	10.04
1/1/1955	12/31/1960	47.34	197.3	4.17
1/1/1961	12/31/1964	47.34	62.43	1.32
1/1/1965	12/31/1988	15.52	36.88	2.38

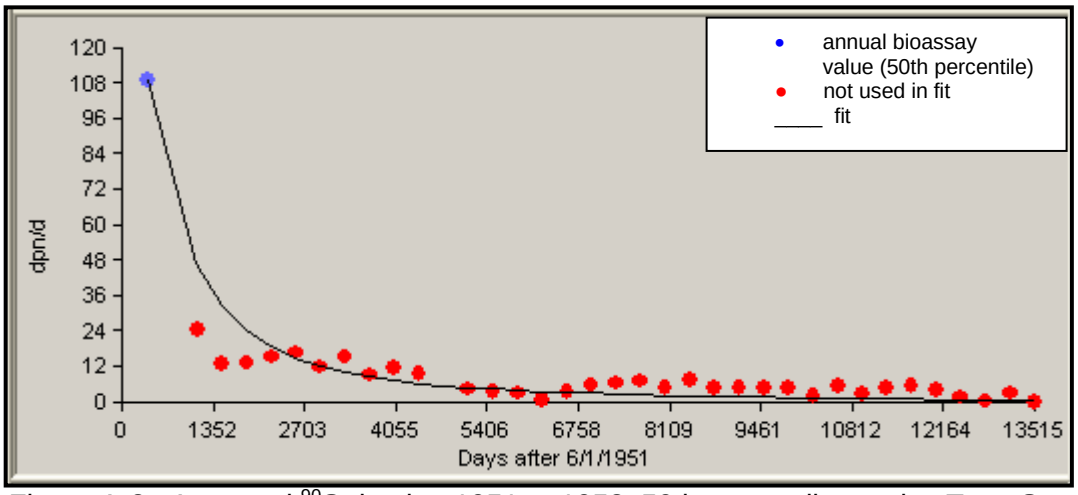

Figure A-2. Assumed ^{90}Sr intake, 1951 to 1953, 50th-percentile results, Type S.

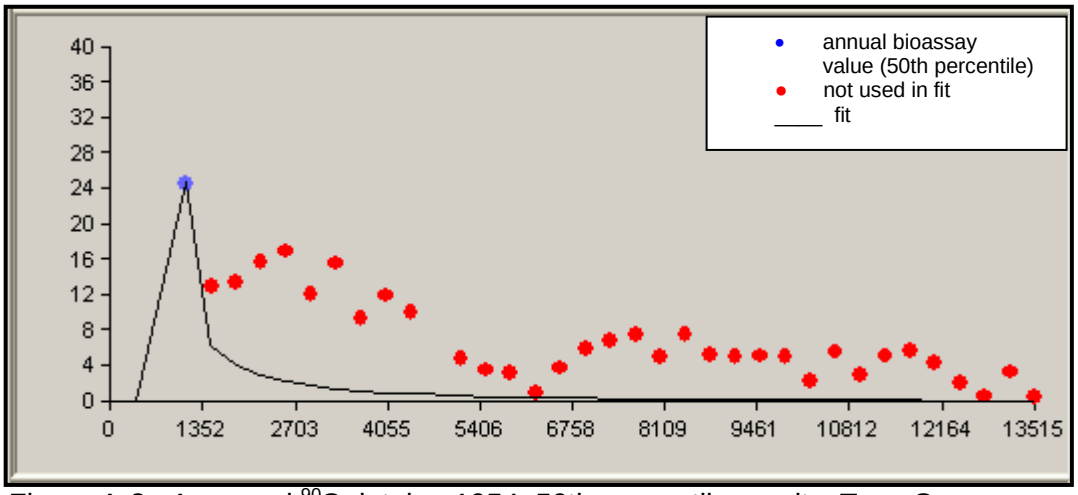

Figure A-3. Assumed ^{90}Sr intake, 1954, 50th-percentile results, Type S.

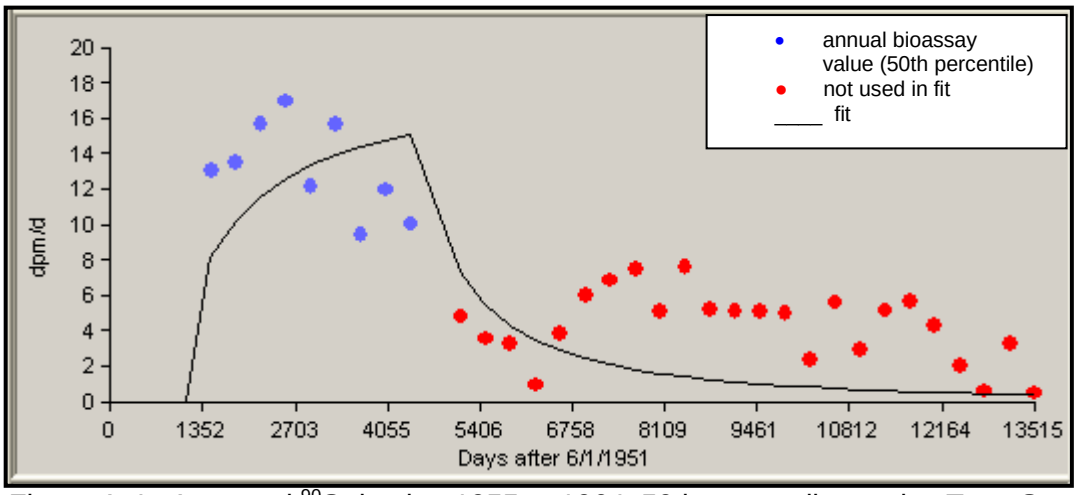

Figure A-4. Assumed ^{90}Sr intake, 1955 to 1964, 50th-percentile results, Type S.

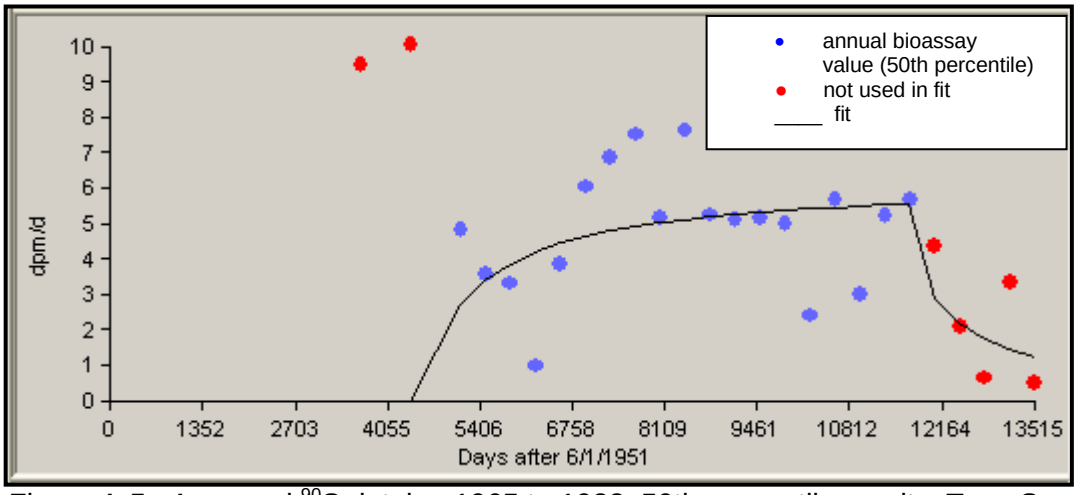

Figure A-5. Assumed ^{90}Sr intake, 1965 to 1983, 50th-percentile results, Type S.

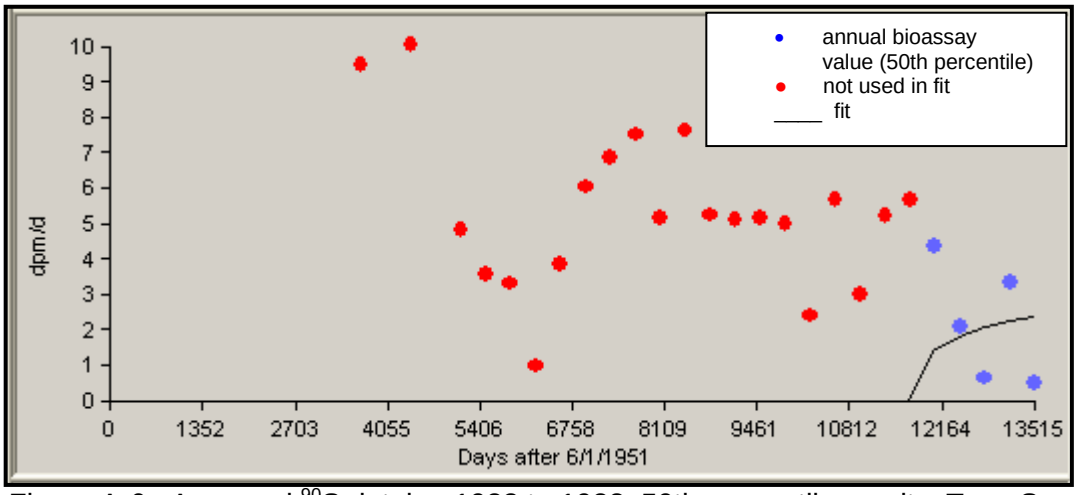

Figure A-6. Assumed ^{90}Sr intake, 1983 to 1988, 50th-percentile results, Type S.

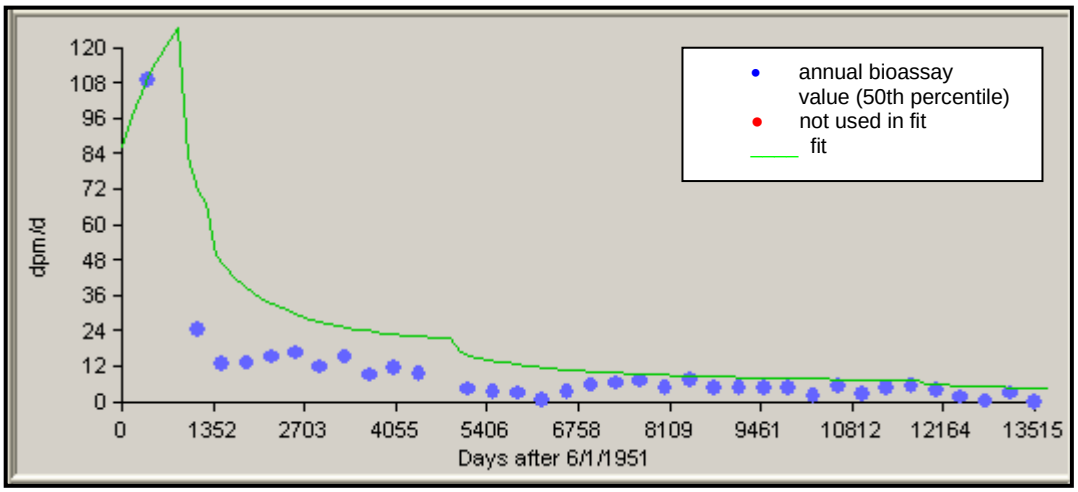

Figure A-7. Predicted strontium excretion rate from independently fit intakes, 1951 to 1988, 50th-percentile, Type S.

Table A-6. Type S ^{90}Sr intake periods and rates.

		^{90}Sr intake rate (dpm/day)		
Start date	**End date**	**50th percentile**	**84th percentile**	**GSD**
1/1/1951	12/31/1953	24646	227730	9.24
1/1/1954	12/31/1954	7,232	68924	9.53
1/1/1955	12/31/1960	2379	13628	5.73
1/1/1961	12/31/1964	2,389	6431	2.69
1/1/1965	12/31/1983	795.0	1,917	2.41
1/1/1984	12/31/1988	425.5	1,917	4.51

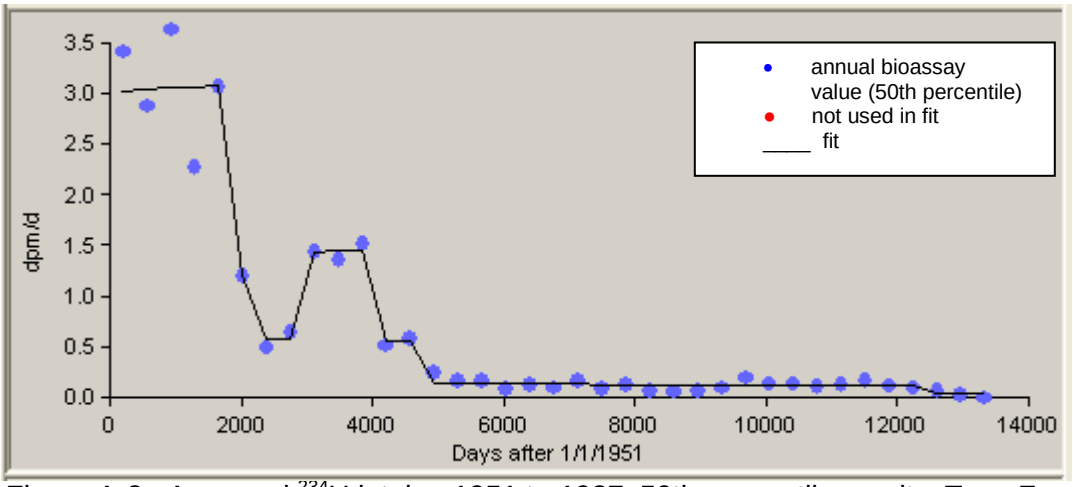

Figure A-8. Assumed ^{234}U intake, 1951 to 1987, 50th-percentile results, Type F.

Table A-7. Type F ^{234}U intake periods and rates.

Year	Type F ^{234}U intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1951	11.19	28.28	2.53
1952	11.19	28.28	2.53
1953	11.19	28.28	2.53
1954	11.19	28.28	2.53
1955	11.19	28.28	2.53
1956	4.213	28.28	6.71
1957	1.942	17.97	9.25
1958	1.942	17.97	9.25
1959	5.171	17.97	3.48
1960	5.171	17.97	3.48
1961	5.171	17.97	3.48
1962	1.881	12.05	6.41
1963	1.881	12.05	6.41
1964	0.413	1.272	3.08
1965	0.413	1.272	3.08
1966	0.413	1.272	3.08
1967	0.413	1.272	3.08
1968	0.413	1.272	3.08
1969	0.413	1.272	3.08

Year	Type F ^{234}U intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1970	0.413	1.272	3.08
1971	0.413	1.272	3.08
1972	0.413	1.272	3.08
1973	0.413	1.272	3.08
1974	0.413	1.272	3.08
1975	0.413	1.272	3.08
1976	0.413	1.272	3.08
1977	0.413	1.272	3.08
1978	0.413	1.272	3.08
1979	0.413	1.272	3.08
1980	0.413	1.272	3.08
1981	0.413	1.272	3.08
1982	0.413	1.272	3.08
1983	0.413	1.272	3.08
1984	0.413	1.272	3.08
1985	0.0957	0.227	2.37
1986	0.0957	0.227	2.37
1987	0.0957	0.227	2.37

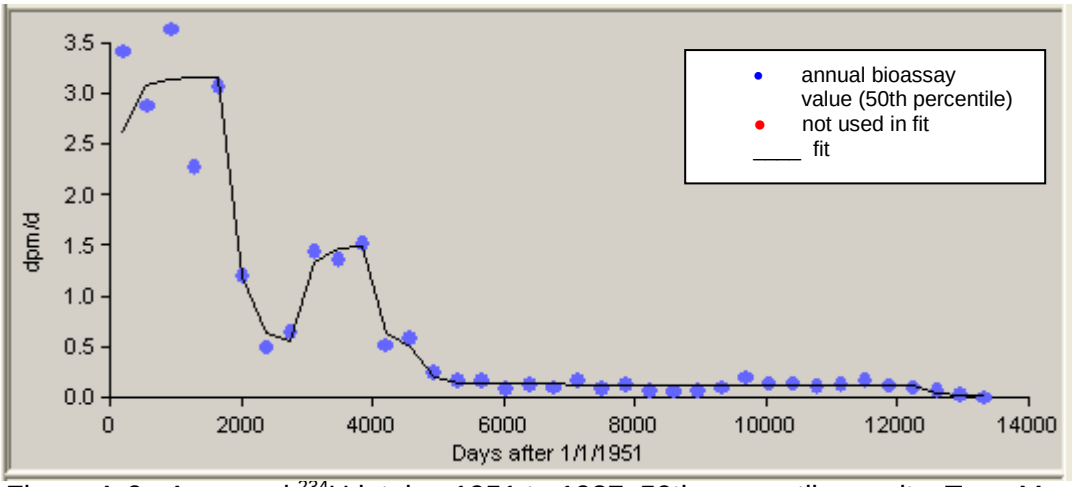

Figure A-9. Assumed ^{234}U intake, 1951 to 1987, 50th-percentile results, Type M.

Table A-8. Type M ^{234}U intake periods and rates.

Year	Type M ^{234}U intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1951	47.03	117.8	2.50
1952	47.03	117.8	2.50
1953	47.03	117.8	2.50
1954	47.03	117.8	2.50
1955	47.03	117.8	2.50
1956	11.45	117.8	10.29
1957	7.49	72.66	9.70
1958	7.49	72.66	9.70
1959	21.81	72.66	3.33
1960	21.81	72.66	3.33
1961	21.81	72.66	3.33
1962	6.56	47.49	7.24
1963	6.56	47.49	7.24
1964	1.641	4.809	2.93
1965	1.641	4.809	2.93
1966	1.641	4.809	2.93
1967	1.641	4.809	2.93
1968	1.641	4.809	2.93
1969	1.641	4.809	2.93

Year	Type M ^{234}U intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1970	1.641	4.809	2.93
1971	1.641	4.809	2.93
1972	1.641	4.809	2.93
1973	1.641	4.809	2.93
1974	1.641	4.809	2.93
1975	1.641	4.809	2.93
1976	1.641	4.809	2.93
1977	1.641	4.809	2.93
1978	1.641	4.809	2.93
1979	1.641	4.809	2.93
1980	1.641	4.809	2.93
1981	1.641	4.809	2.93
1982	1.641	4.809	2.93
1983	1.641	4.809	2.93
1984	1.641	4.809	2.93
1985	0.294	0.659	2.24
1986	0.294	0.659	2.24
1987	0.294	0.659	2.24

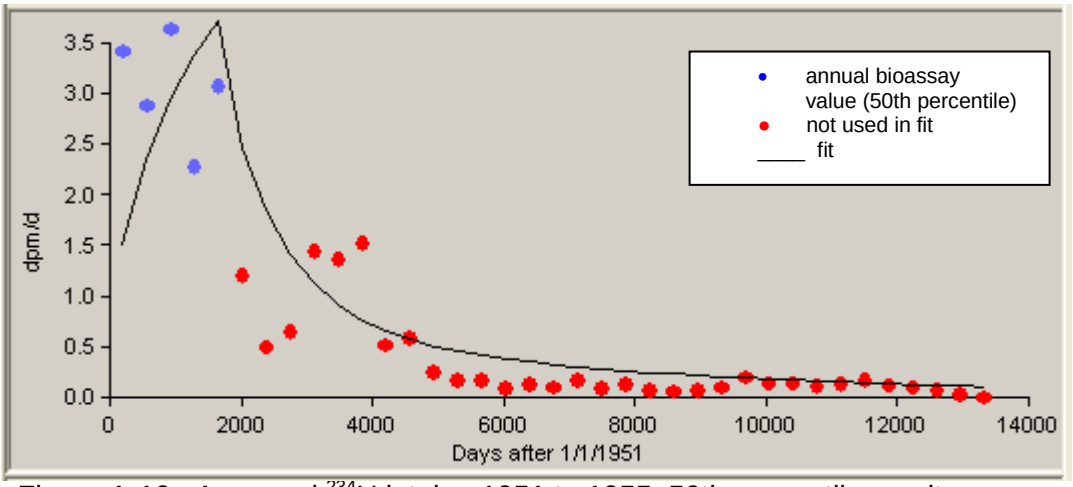

Figure A-10. Assumed ^{234}U intake, 1951 to 1955, 50th-percentile results, Type S.

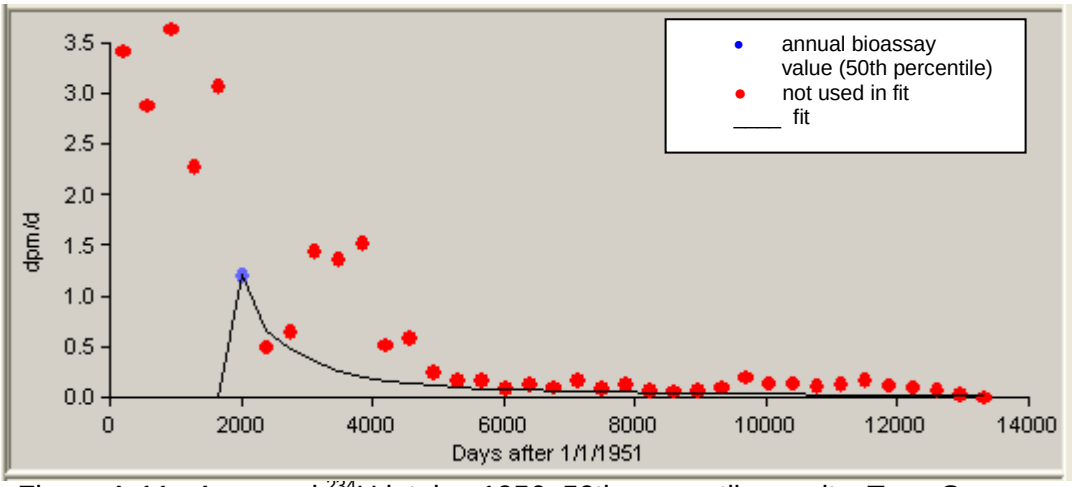

Figure A-11. Assumed ^{234}U intake, 1956, 50th-percentile results, Type S.

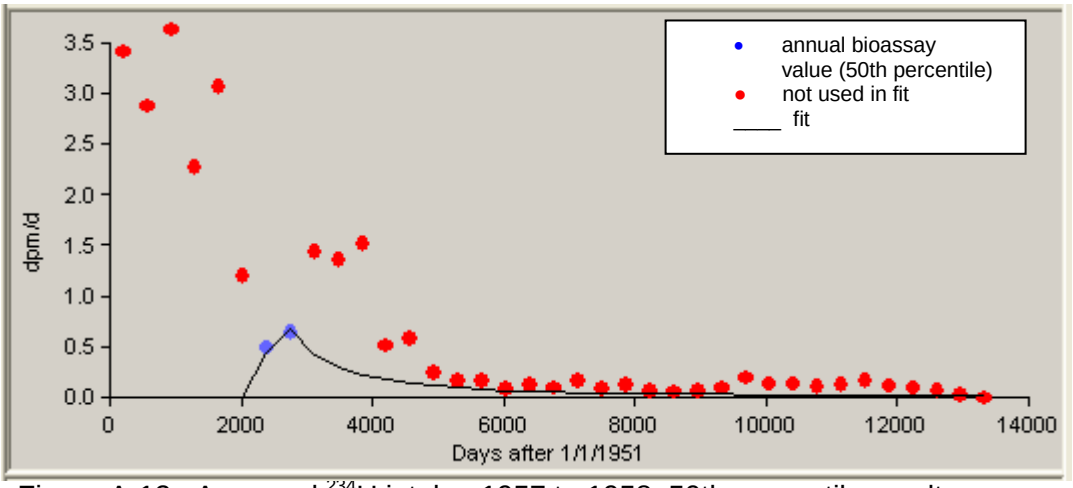

Figure A-12. Assumed ^{234}U intake, 1957 to 1958, 50th-percentile results, Type S.

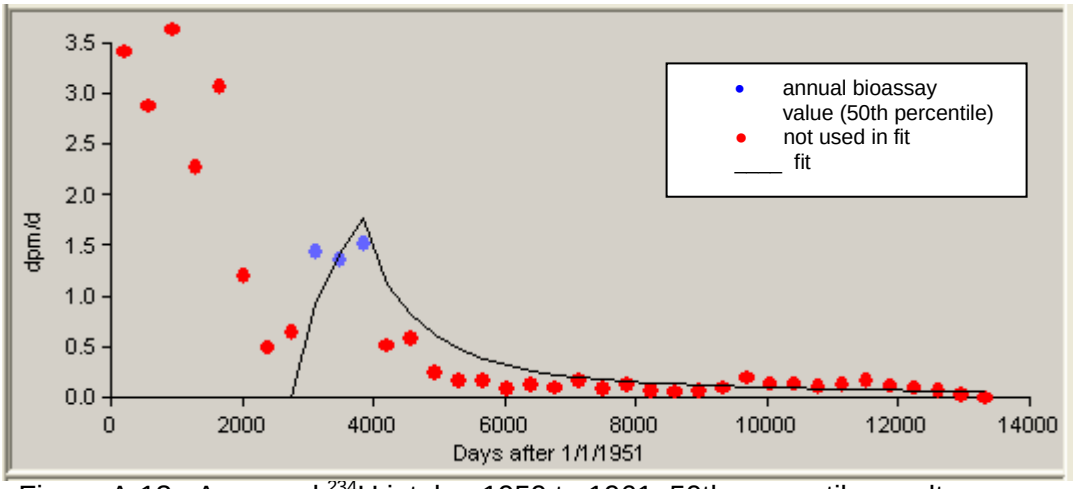

Figure A-13. Assumed ^{234}U intake, 1959 to 1961, 50th-percentile results, Type S.

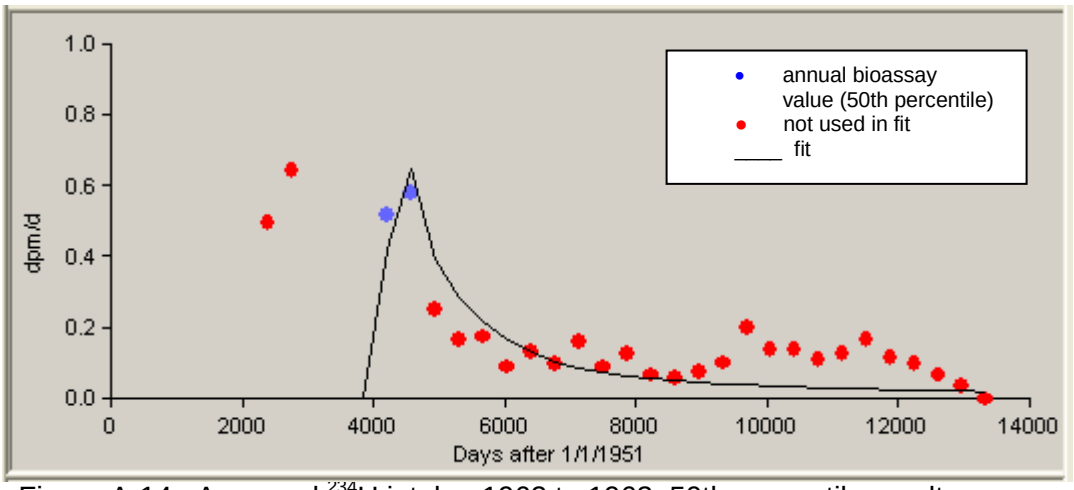

Figure A-14. Assumed ^{234}U intake, 1962 to 1963, 50th-percentile results, Type S.

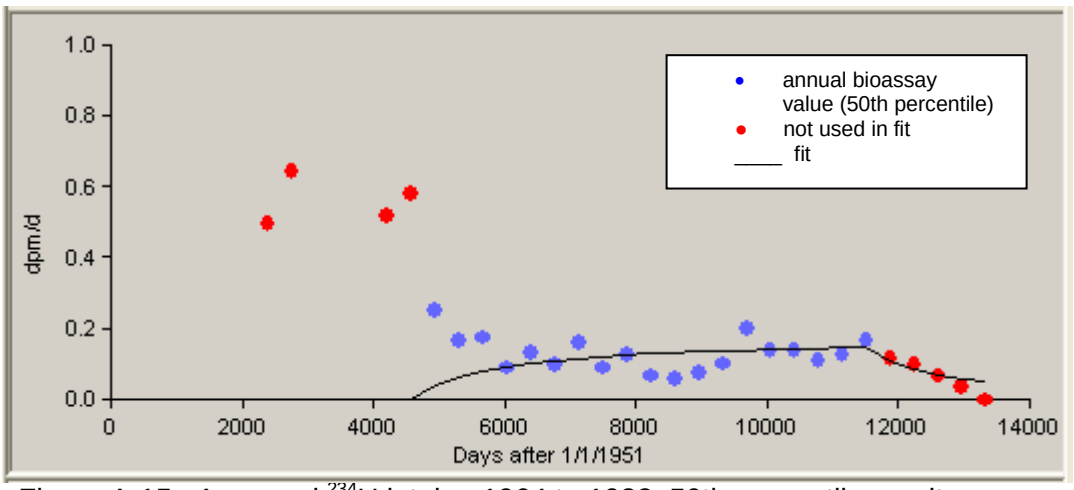

Figure A-15. Assumed ^{234}U intake, 1964 to 1982, 50th-percentile results, Type S.

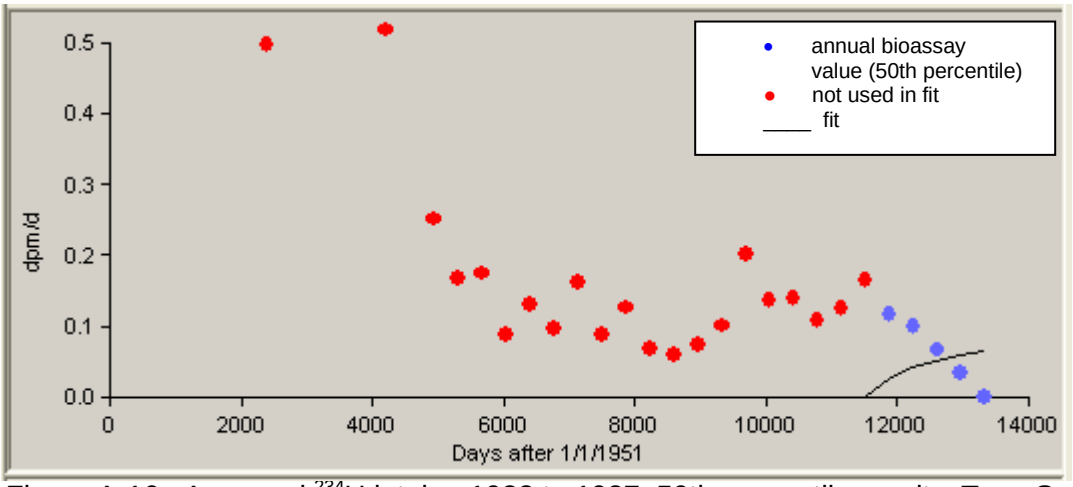

Figure A-16. Assumed ^{234}U intake, 1983 to 1987, 50th-percentile results, Type S.

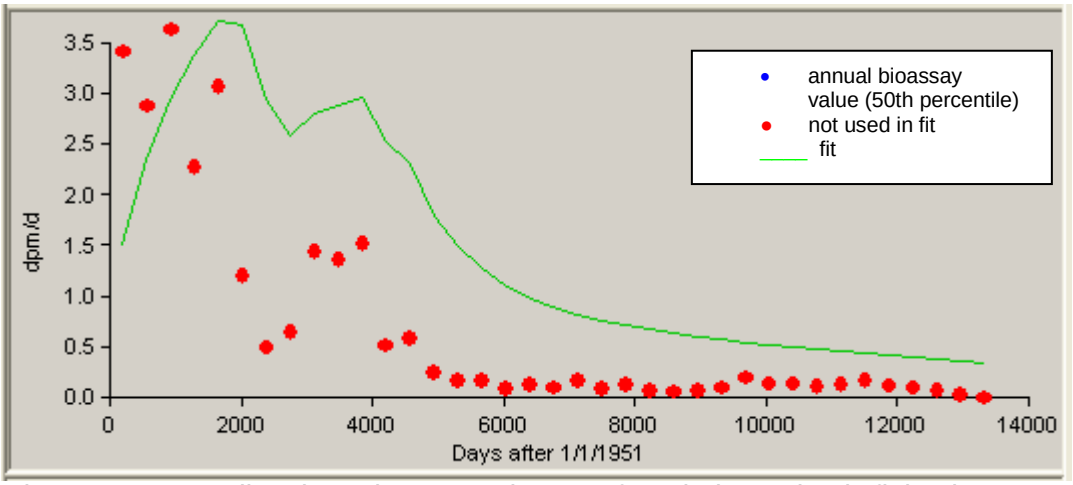

Figure A-17. Predicted uranium excretion rate from independently fit intakes, 1951 to 1987, 50th-percentile, Type S.

Table A-9. Type S ^{234}U intake periods and rates.

Year	Type S ^{234}U intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1951	850.7	2048	2.41
1952	850.7	2048	2.41
1953	850.7	2048	2.41
1954	850.7	2048	2.41
1955	850.7	2048	2.41
1956	675.7	2048	3.03
1957	247.7	1,917	7.74
1958	247.7	1,917	7.74
1959	509	1,917	3.77
1960	509	2,125	4.17
1961	509	2,125	4.17
1962	235.3	1,422	6.04
1963	235.3	1,422	6.04
1964	23.7	71.203	3.00
1965	23.7	71.203	3.00
1966	23.7	71.203	3.00
1967	23.7	71.203	3.00
1968	23.7	71.203	3.00
1969	23.7	71.203	3.00

Year	Type S ^{234}U intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1970	23.7	71.203	3.00
1971	23.7	71.203	3.00
1972	23.7	71.203	3.00
1973	23.7	71.203	3.00
1974	23.7	71.203	3.00
1975	23.7	71.203	3.00
1976	23.7	71.203	3.00
1977	23.7	71.203	3.00
1978	23.7	71.203	3.00
1979	23.7	71.203	3.00
1980	23.7	71.203	3.00
1981	23.7	71.203	3.00
1982	23.7	71.203	3.00
1983	15.25	71.203	4.67
1984	15.25	31.58	2.07
1985	15.25	31.58	2.07
1986	15.25	31.58	2.07
1987	15.25	31.58	2.07

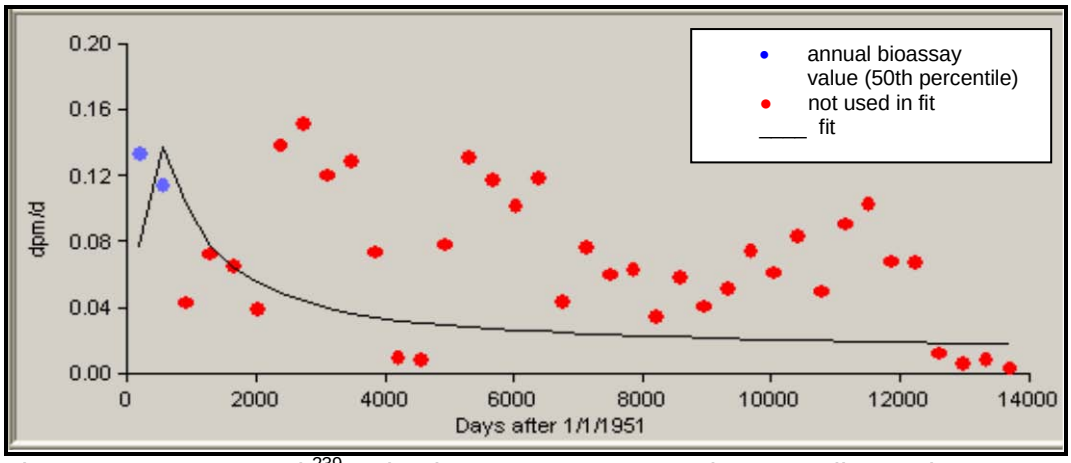

Figure A-18. Assumed ^{239}Pu intake, 1951 to 1952, 50th-percentile results, Type M.

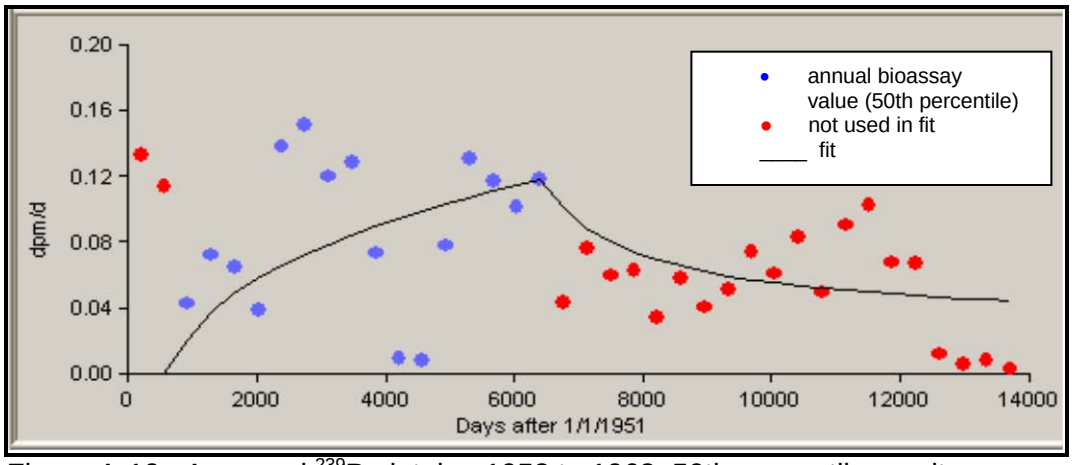

Figure A-19. Assumed ^{239}Pu intake, 1953 to 1968, 50th-percentile results, Type M.

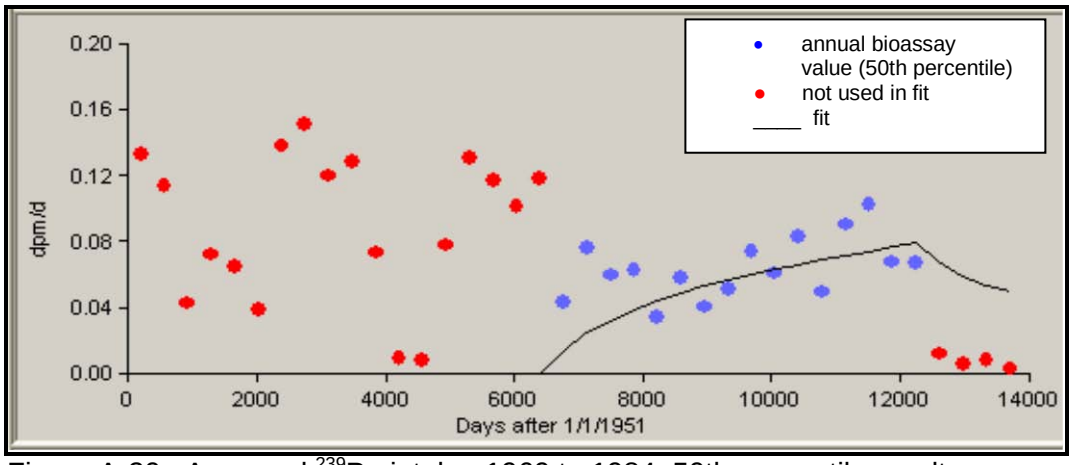

Figure A-20. Assumed ^{239}Pu intake, 1969 to 1984, 50th-percentile results, Type M.

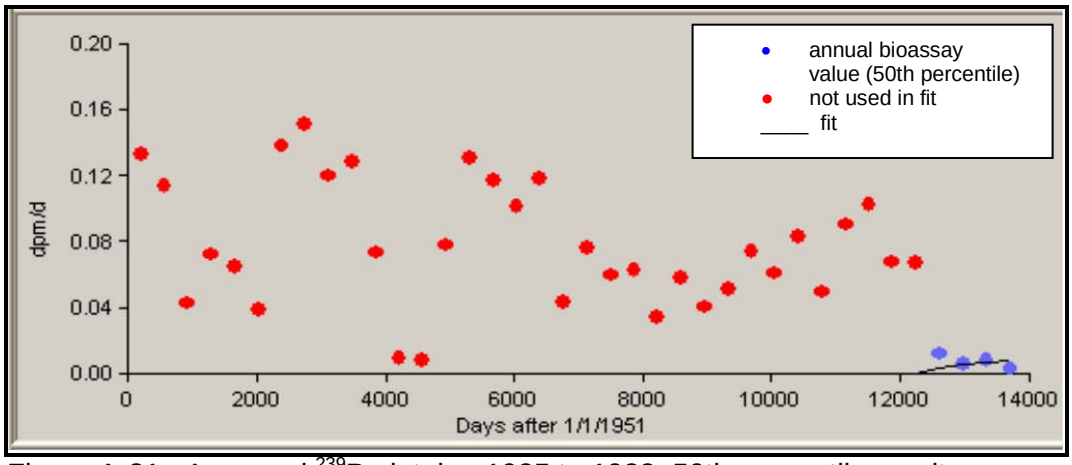

Figure A-21. Assumed ^{239}Pu intake, 1985 to 1988, 50th-percentile results, Type M.

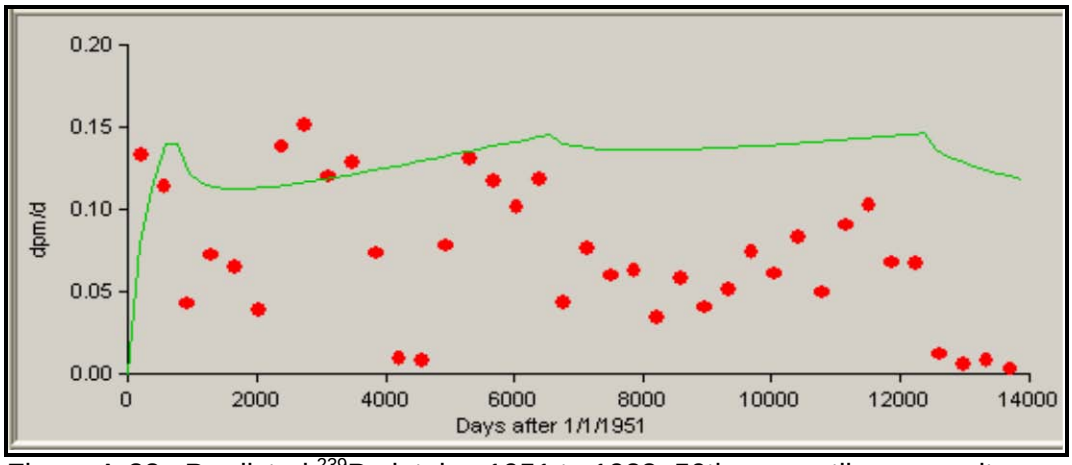

Figure A-22. Predicted ^{239}Pu intake, 1951 to 1988, 50th-percentile composite results, Type M.

Table A-10. Type M ^{239}Pu intake periods and rates.

Year	^{239}Pu intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1951	40.75	109.8	2.69
1952	40.75	109.8	2.69
1953	10.98	86.42	7.87
1954	10.98	86.42	7.87
1955	10.98	86.42	7.87
1956	10.98	86.42	7.87
1957	10.98	86.42	7.87
1958	10.98	86.42	7.87
1959	10.98	86.42	7.87
1960	10.98	22.45	2.04
1961	10.98	22.45	2.04
1962	10.98	22.45	2.04
1963	10.98	22.45	2.04
1964	10.98	22.45	2.04
1965	10.98	22.45	2.04
1966	10.98	22.45	2.04
1967	10.98	22.45	2.04
1968	10.98	22.45	2.04
1969	7.35	22.45	3.05
1970	7.35	22.45	3.05

Year	^{239}Pu intake rate (dpm/day)		GSD
	50th percentile	84th percentile	
1971	7.35	22.45	3.05
1972	7.35	22.45	3.05
1973	7.35	18.4	2.50
1974	7.35	18.4	2.50
1975	7.35	18.4	2.50
1976	7.35	18.4	2.50
1977	7.35	18.4	2.50
1978	7.35	18.4	2.50
1979	7.35	18.4	2.50
1980	7.35	18.4	2.50
1981	7.35	18.4	2.50
1982	7.35	18.4	2.50
1983	7.35	18.4	2.50
1984	7.35	18.4	2.50
1985	1.614	6.811	4.22
1986	1.614	6.811	4.22
1987	1.614	6.811	4.22
1988	1.614	6.811	4.22

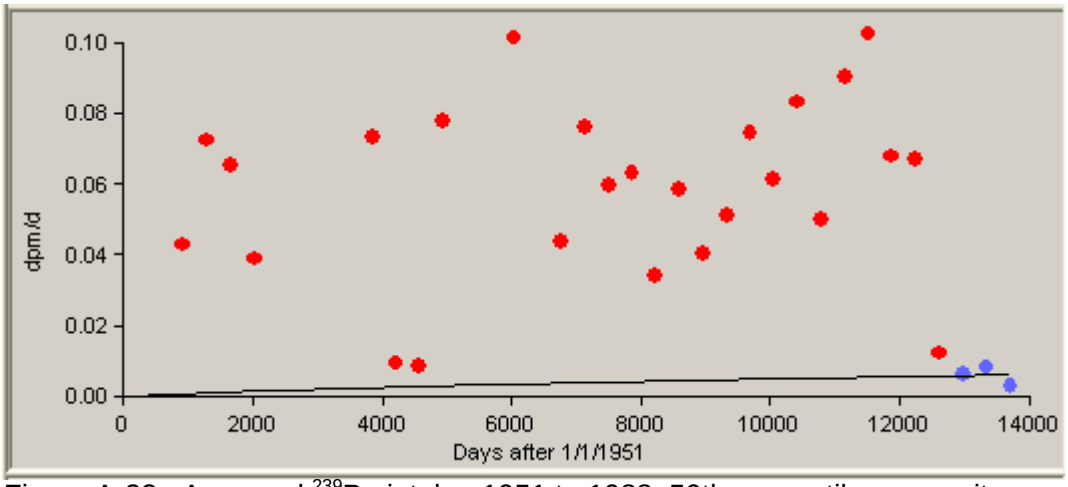

Figure A-23. Assumed ^{239}Pu intake, 1951 to 1988, 50th-percentile composite results, Type S.

Table A-11. Type S ^{239}Pu intake period and rates.

		^{241}Am intake rate (dpm/day)		
Start date	**Stop date**	**50th percentile**	**84th percentile**	**GSD**
1951	1988	4.15	22.86	5.50

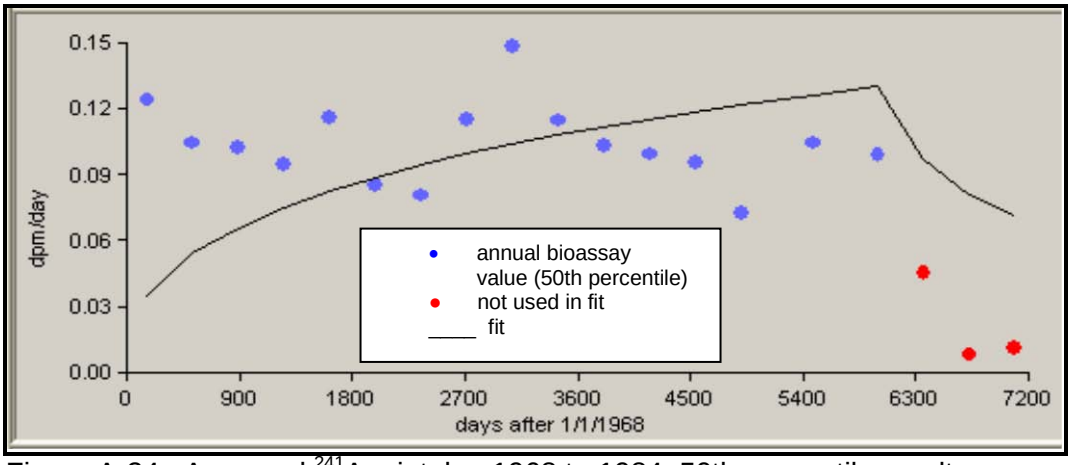

Figure A-24. Assumed ^{241}Am intake, 1968 to 1984, 50th-percentile results, Type M.

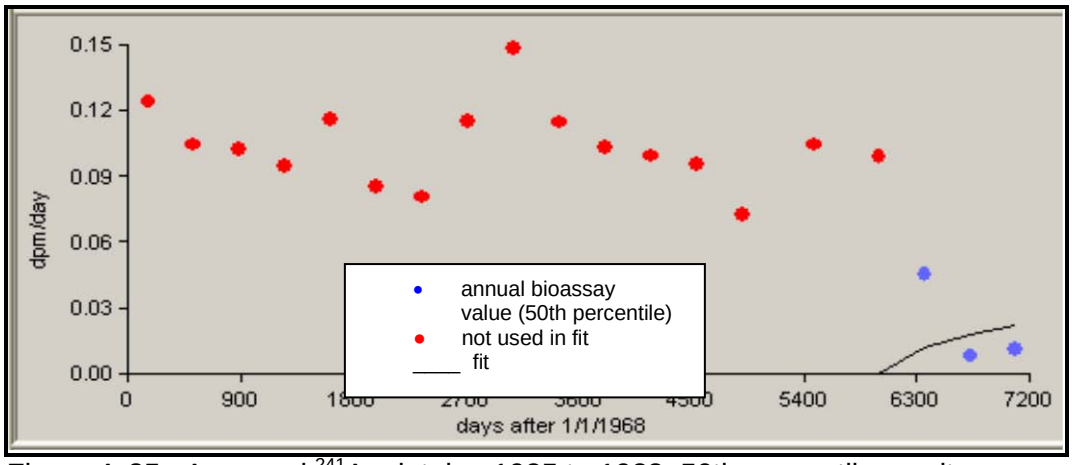

Figure A-25. Assumed ^{241}Am intake, 1985 to 1988, 50th-percentile results, Type M.

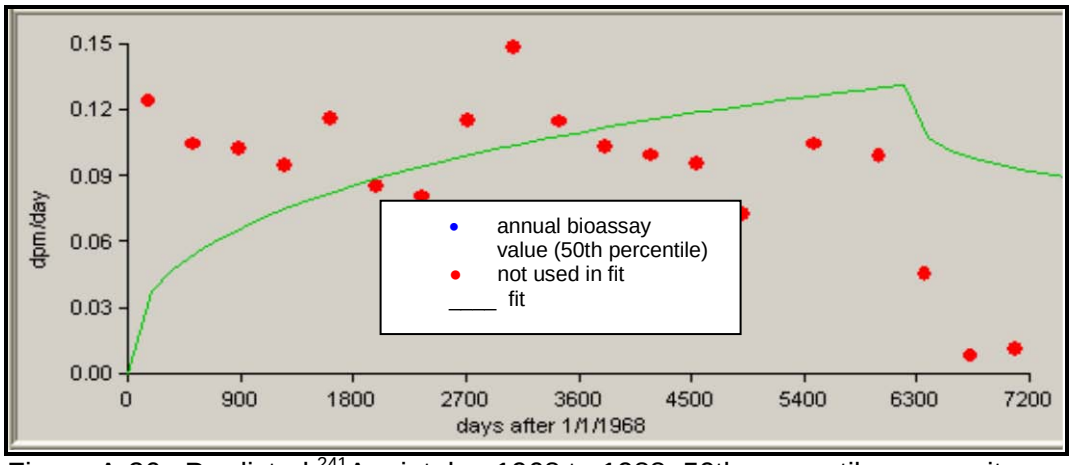

Figure A-26. Predicted ^{241}Am intake, 1968 to 1988, 50th-percentile composite results, Type M.

Table A-12. Type M ^{241}Am intake periods and rates.

		^{241}Am intake rate (dpm/day)		
Start date	**Stop date**	**50th percentile**	**84th percentile**	**GSD**
1968	1984	6.673	14.61	2.19
1985	1988	2.207	6.659	2.99