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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/31/2009	00	New technical information bulletin to provide coworker data for the Fernald Environmental Management Project workers. Incorporates formal internal, NIOSH, and Advisory Board review comments. Training required: As determined by the Objective Manager. Initiated by Robert L. Morris.

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1.0 PURPOSE

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 historic 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)].

Some employees at DOE sites were not monitored for internal ionizing radiation exposure, or the monitoring records 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 OTIB is to provide monitored coworker information for calculating and assigning occupational internal doses to employees at the Fernald Environmental Management Project (FEMP) for whom no, or insufficient, bioassay monitoring records exist. FEMP was previously known as the Feed Materials Production Center.

2.0 DATA AND METHOD OVERVIEW

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

2.1 BIOASSAY DATA SELECTION

The bioassay results for this analysis were obtained by extracting data from HIS-20_ORAU, a database of FEMP bioassay results (ORAUT 2007a). One of the database tables, HIS20_V_BIOASSAY, contains results for urinalyses, fecal analyses, and *in vivo* analyses starting in 1952. The radionuclides in the table include ^{228}Ac, ^{36}Cl, ^{137}Cs, ^{3}H, ^{210,211}Pb, ^{210}Po, ^{239}Pu, ^{226,228}Ra, ^{90}Sr, ^{228,230,232}Th, ^{234,235,238}U, and total uranium. The vast majority of data in the table concerns the uranium radionuclides. Data were extracted from the HIS20_V_BIOASSAY table using the field criterion in Table 2-1.

Table 2-1. Criteria applied to extract for uranium bioassay data.

Field name	Field value
TYPE_BIOASSAY	URINALYSIS
NUC_NAME	U-TOTAL or ^{238}U
SAMPLE_TYPE	Not equal to 10, 50, 5C, 70, VF, VR, VC
ACT_UNITS_SU	µg/L

Samples with code 10 and 70 were collected before employment or reemployment to establish the background for the individual and as such are not appropriate for use in a study to establish intake potential. Samples with code 50 and 5C were collected as a part of a special study. The V series (VF, VR, and VE) are visitor samples and likely not representative of the typical worker. All results in this series were less than the minimum detectable activity.

Fifteen of the 429,338 uranium urinalysis results in ACT_UNITS-SU had units other than micrograms per liter; all fifteen results were discarded. Ten of these had a value for the ACTIVITY field, but no volume or time frame, so it was not clear if those results represented 1-liter samples or 24-hour samples. The other five results were isotopic samples and were excluded from the coworker study for expediency. The impact of discarding data from these 15 samples is judged to be negligible.

2.2 METHOD DESCRIPTION

The uranium in urine bioassay data from HIS-20_ORAU were chronologically grouped into analysis intervals that typically represent all of the data in a calendar quarter. During some intervals, when fewer results were available, the grouping represented a calendar year or a portion of a year. The data in each interval were fit to a lognormal distribution as described in Section 3.0. For 1991 through 1993, fewer than 10 results per year were above the minimum detectable activity, which resulted in an insufficient quantity of data to generate statistics. The result of the fits resulted in excretion rates at the 50th and 84th-percentile values at the midpoint date of the analysis interval as shown in Table 3.1.

The excretion rates for each sample were normalized to represent 24-hour samples assuming 1,400 ml/d urine excretion, which is the daily volume that is excreted by Reference Man in International Commission on Radiological Protection Publication 23 (ICRP 1975). Then the intakes that would result in the observed excretion rates were inferred using the Integrated Modules for Bioassay Analysis (IMBA) computer program as described in Section 4.0.

3.0 ANALYSIS

Bioassay data statistics were generated for each analysis interval. A lognormal distribution was assumed [1]. After log-transforming the data, the 50th- and 84th-percentile values were determined for each period using the method in ORAUT (2006). The results were validated as reported by Arno (2007). Table 3-1 shows the statistical analysis results for uranium urinary excretion parameters.

Table 3-1. Summary of uranium urinary excretion rate analyses, 1952 to 2006.

Analysis interval	Midpoint date of analysis interval	50th percentile (µg/d)	84th percentile (µg/d)
Year	6/30/1952	15.84	62.55
Year	6/30/1953	21.76	69.74
Quarter	2/15/1954	28.92	122.41
Quarter	5/15/1954	26.17	70.14
Quarter	8/15/1954	24.72	68.50
Quarter	11/15/1954	28.59	77.98
Quarter	2/15/1955	35.49	94.21
Quarter	5/15/1955	47.62	157.91
Quarter	8/15/1955	40.05	108.75
Quarter	11/15/1955	43.01	109.90
Quarter	2/15/1956	45.00	105.58
Quarter	5/15/1956	31.80	84.17
Quarter	8/15/1956	27.28	80.02
Quarter	11/15/1956	29.54	79.45
Quarter	2/15/1957	26.08	73.71
Quarter	5/15/1957	23.94	74.78
Quarter	8/15/1957	19.92	57.86
Quarter	11/15/1957	17.15	49.31
Quarter	2/15/1958	22.27	61.46
Quarter	5/15/1958	12.13	29.02
Quarter	8/15/1958	14.08	38.78
Quarter	11/15/1958	11.32	31.55

Analysis interval	Midpoint date of analysis interval	50th percentile (µg/d)	84th percentile (µg/d)
Quarter	2/15/1959	14.18	42.60
Quarter	5/15/1959	13.61	35.63
Quarter	8/15/1959	14.10	38.81
Quarter	11/15/1959	15.99	35.62
Quarter	2/15/1960	17.30	39.86
Quarter	5/15/1960	17.58	38.86
Quarter	8/15/1960	22.77	49.63
Quarter	11/15/1960	25.80	56.26
Quarter	2/15/1961	20.48	41.71
Quarter	5/15/1961	20.65	41.35
Quarter	8/15/1961	20.78	40.45
Quarter	11/15/1961	16.52	33.44
Quarter	2/15/1962	15.43	34.23
Quarter	5/15/1962	16.87	36.65
Quarter	8/15/1962	9.16	22.58
Quarter	11/15/1962	13.06	29.91
Quarter	2/15/1963	14.79	34.22
Quarter	5/15/1963	15.27	33.10
Quarter	8/15/1963	11.78	27.13
Quarter	11/15/1963	14.69	34.01
Quarter	2/15/1964	13.72	36.39
Quarter	5/15/1964	14.89	37.73
Quarter	8/15/1964	12.69	33.20
Quarter	11/15/1964	10.11	23.34
Quarter	2/15/1965	10.20	25.25
Quarter	5/15/1965	9.81	23.24
Quarter	8/15/1965	8.97	27.39
Quarter	11/15/1965	6.32	28.63
Quarter	2/15/1966	10.33	50.00
Quarter	5/15/1966	6.06	22.92
Quarter	8/15/1966	5.45	20.26
Quarter	11/15/1966	5.85	18.77
Quarter	2/15/1967	7.50	19.06
Quarter	5/15/1967	7.07	19.05
Quarter	8/15/1967	7.27	19.42
Quarter	11/15/1967	8.06	20.94
Quarter	2/15/1968	7.72	21.16
Quarter	5/15/1968	6.84	16.68
Quarter	8/15/1968	5.27	14.00
Quarter	11/15/1968	6.30	16.63
Quarter	2/15/1969	6.67	17.32
Quarter	5/15/1969	6.41	15.82
Quarter	8/15/1969	5.43	14.00
Quarter	11/15/1969	5.03	12.75
Quarter	2/15/1970	5.72	13.38
Quarter	5/15/1970	5.39	13.44
Quarter	8/15/1970	3.96	9.63
Quarter	11/15/1970	4.21	9.82
Quarter	2/15/1971	6.16	14.97
Quarter	5/15/1971	6.19	15.95
Quarter	8/15/1971	7.70	19.50
Quarter	11/15/1971	5.09	12.45
Quarter	2/15/1972	7.66	25.21

Analysis interval	Midpoint date of analysis interval	50th percentile (µg/d)	84th percentile (µg/d)
Quarter	5/15/1972	4.60	13.41
Quarter	8/15/1972	5.52	13.60
Quarter	11/15/1972	6.47	15.72
Quarter	2/15/1973	6.89	17.59
Quarter	5/15/1973	6.31	15.61
Quarter	8/15/1973	7.40	21.34
Quarter	11/15/1973	7.84	23.15
Quarter	2/15/1974	7.08	17.46
Quarter	5/15/1974	6.10	14.54
Quarter	8/15/1974	6.16	15.43
Quarter	11/15/1974	7.59	20.43
Quarter	2/15/1975	7.50	17.88
Quarter	5/15/1975	7.24	18.57
Quarter	8/15/1975	5.88	15.12
Quarter	11/15/1975	7.90	18.52
Quarter	2/15/1976	7.90	19.18
Quarter	5/15/1976	6.29	15.11
Quarter	8/15/1976	6.47	14.35
Quarter	11/15/1976	5.99	15.32
Quarter	2/15/1977	6.88	18.35
Quarter	5/15/1977	6.35	13.03
Quarter	8/15/1977	5.14	11.95
Quarter	11/15/1977	5.13	11.43
Quarter	2/15/1978	5.53	12.61
Quarter	5/15/1978	6.02	13.26
Quarter	8/15/1978	5.92	12.70
Quarter	11/15/1978	6.15	13.56
Quarter	2/15/1979	7.20	14.82
Quarter	5/15/1979	6.34	14.01
Quarter	8/15/1979	5.42	13.63
Quarter	11/15/1979	5.13	13.71
Quarter	2/15/1980	6.20	15.59
Quarter	5/15/1980	5.04	12.45
Quarter	8/15/1980	6.32	14.44
Quarter	11/15/1980	6.16	13.91
Quarter	2/15/1981	3.92	10.12
Quarter	5/15/1981	3.24	8.05
Quarter	8/15/1981	4.02	10.38
Quarter	11/15/1981	4.00	10.40
Quarter	2/15/1982	4.85	11.40
Quarter	5/15/1982	4.70	12.42
Quarter	8/15/1982	5.01	11.29
Quarter	11/15/1982	5.01	12.00
Quarter	2/15/1983	5.37	12.96
Quarter	5/15/1983	4.98	13.32
Quarter	8/15/1983	4.27	11.14
Quarter	11/15/1983	4.82	12.68
Quarter	2/15/1984	4.72	11.94
Quarter	5/15/1984	5.14	13.12
Quarter	8/15/1984	5.47	13.26
Quarter	11/15/1984	5.43	13.31
Quarter	2/15/1985	6.89	12.32
Quarter	5/15/1985	5.49	11.49

Analysis interval	Midpoint date of analysis interval	50th percentile (µg/d)	84th percentile (µg/d)
Quarter	8/15/1985	3.53	8.48
Quarter	11/15/1985	4.06	10.00
Quarter	2/15/1986	5.13	9.58
Quarter	5/15/1986	3.60	7.76
Quarter	8/15/1986	2.54	6.26
Quarter	11/15/1986	1.71	4.59
Quarter	2/15/1987	1.53	4.29
Quarter	5/15/1987	2.18	5.30
Quarter	8/15/1987	2.02	5.89
Quarter	11/15/1987	1.84	5.00
Quarter	2/15/1988	2.55	5.72
Quarter	5/15/1988	2.03	5.04
Quarter	8/15/1988	1.43	3.55
Quarter	11/15/1988	1.73	3.21
Quarter	2/15/1989	0.13	0.79
Quarter	5/15/1989	0.24	1.03
Quarter	8/15/1989	0.27	0.88
Quarter	11/15/1989	1.16	2.81
Quarter	2/15/1990	1.78	3.66
Quarter	5/15/1990	0.48	1.66
Quarter	8/15/1990	0.00	0.05
Year	7/1/1994	0.01	0.06
Year	7/1/1995	0.01	0.07
Year	7/1/1996	0.00	0.04
Jan–May	3/16/1997	0.00	0.02
Quarter	8/1/1997	0.02	0.09
Quarter	11/15/1997	0.02	0.09
Quarter	2/15/1998	0.03	0.09
Quarter	5/15/1998	0.02	0.08
Quarter	8/15/1998	0.01	0.07
Quarter	11/15/1998	0.01	0.07
Quarter	2/15/1999	0.01	0.06
Quarter	5/15/1999	0.02	0.06
Quarter	8/15/1999	0.02	0.08
Quarter	11/15/1999	0.03	0.10
Quarter	2/15/2000	0.02	0.09
Quarter	5/15/2000	0.02	0.10
Quarter	8/15/2000	0.02	0.11
Quarter	11/15/2000	0.03	0.11
Quarter	2/15/2001	0.03	0.11
Quarter	5/15/2001	0.05	0.19
Quarter	8/15/2001	0.06	0.20
Quarter	11/15/2001	0.05	0.17
Quarter	2/15/2002	0.04	0.13
Quarter	5/15/2002	0.05	0.15
Quarter	8/15/2002	0.05	0.17
Quarter	11/15/2002	0.06	0.12
Quarter	2/15/2003	0.03	0.11
Quarter	5/15/2003	0.05	0.17
Quarter	8/15/2003	0.04	0.14
Quarter	11/15/2003	0.06	0.14
Quarter	2/15/2004	0.04	0.11
Quarter	5/15/2004	0.05	0.15

Analysis interval	Midpoint date of analysis interval	50th percentile (µg/d)	84th percentile (µg/d)
Quarter	8/15/2004	0.06	0.15
Quarter	11/15/2004	0.06	0.12
Quarter	2/15/2005	0.09	0.21
Quarter	5/15/2005	0.08	0.20
Quarter	8/15/2005	0.07	0.17
Quarter	11/15/2005	0.06	0.14
Quarter	2/15/2006	0.06	0.16
Quarter	5/15/2006	0.06	0.15
Quarter	9/1/2006	0.08	0.19

4.0 INTAKE MODELING

This section discusses intake modeling assumptions and intake fitting for three different material types of uranium compounds.

4.1 ASSUMPTIONS

Each result in the intake calculations was assumed to have normal distribution [2]. A uniform absolute error of 1 was applied to all results to assign the same weight to each result. Because of the nature of work at FEMP, 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 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 (ICRP 1995).

4.2 BIOASSAY FITTING

The IMBA computer program was used to fit the bioassay results to a series of inhalation intakes. Data from 1952 through 2006 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 and sustained change in the bioassay results. By this method, 1952 through 2006 was divided into multiple chronic intake periods.

Because the uranium isotopes at FEMP have 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 FEMP 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 results in a potential overestimate of intakes for exposures that extend through multiple assumed intake periods. Uranium urinalysis results were analyzed with IMBA to derive intake rates for 1952 to 2006. Attachment A contains the plots that compare predicted uranium bioassay results based on IMBA-derived uranium intake rates with the measured urine results.

5.0 ASSIGNING INTAKES AND DOSES

This section describes the derived intake rates and provides guidance for assigning doses. For each intake period below, the geometric standard deviations (GSDs) were determined by dividing the 84th-percentile intake rates by the 50th-percentile rates. For the calculation of doses to individuals from bioassay data, a GSD of 3 is used to account for biological variation and uncertainty in the

models (ORAUT 2007b). The same models are used for fitting the coworker data so the same uncertainty applies. Therefore, a minimum GSD of 3 was assigned for each of the intake periods.

5.1 INTAKE RATE SUMMARY

Multiple intake periods were fit to the derived 50th- and 84th-percentile uranium excretion data. Table 5-1 summarizes the 50th-percentile uranium intake rates that correspond to an intake of type F materials inferred from the excretion rates. Table 5-2 presents the same information for type M materials, and Table 5-3 presents the information for type S materials. For periods after 2006 in which intakes are feasible, dose reconstructors (DRs) should assume the 2006 intake rates.

Table 5-1. Derived FEMP uranium intake rates, 1952 to 2006 for type F materials.

From	To	50th percentile (µg/d)	50th percentile (pCi/d)[b]	GSD
1/1/1952	12/31/1952	51.2	35.0	5.02
1/1/1953	12/31/1953	86.2	58.9	3.00
1/1/1954	12/31/1954	114.2	78.0	3.00
1/1/1955	12/31/1955	156.2	106.7	3.00
1/1/1956	12/31/1956	114.2	78.0	3.00
1/1/1957	12/31/1957	86.2	58.9	3.00
1/1/1958	12/31/1959	51.2	35.0	3.00
1/1/1960	12/31/1961	79.2	54.1	3.00
1/1/1962	12/31/1964 [c]	51.2	82.7	3.00
1/1/1965	12/31/1984	21.4	34.6	6.44
1/1/1985	12/31/1985	21.4	34.6	3.00
1/1/1986	12/31/1990	5.40	8.7	3.10
1/1/1991	12/31/1993	5.40[a]	8.7	3.10[a]
1/1/1994	12/31/1996	0.0211	0.034	9.26
1/1/1997	12/31/2000	0.0717	0.12	4.10
1/1/2001	12/31/2006	0.205	0.33	3.00

a. For 1991 through 1993, fewer than 10 results per year were above the minimum detectable activity, which resulted in an insufficient quantity of data to generate a meaningful intake model. Intake rates from the previous interval were assumed.
b. The specific activities used to compute this column are 0.683 pCi/µg (natural uranium) for 1952 through 1964 and 1.616 pCi/µg (2% enrichment) for 1965 to the present.
c. This period spans the transition date when the 2% enrichment assumption began in 1964 (ORAUT 2004b). To ensure favorability to claimants, the specific activity for 2% enrichment is assumed for the full duration of the period.

5.2 DOSE ASSIGNMENT

For most cases, individual doses should be calculated from the 50th-percentile intake rates. Dose reconstructors should select the material type that is the most favorable to claimants and also apply any other recycled uranium component calculations that are required by other OTIBs and procedures.

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

Table 5-2. Derived FEMP uranium intake rates, 1952 to 2006 for type M materials.

From	To	50th percentile (µg/d)	50th percentile (pCi/d)[b]	GSD
1/1/1952	12/31/1952	210	143	5.02
1/1/1953	12/31/1953	322	220	3.27
1/1/1954	12/31/1954	462	316	3.00
1/1/1955	12/31/1955	672	459	3.00
1/1/1956	12/31/1956	462	316	3.00
1/1/1957	12/31/1957	322	220	3.27
1/1/1958	12/31/1959	210	143	3.00
1/1/1960	12/31/1961	322	220	3.00
1/1/1962	12/31/1964 [c]	210	339	3.00
1/1/1965	12/31/1985	84.0	136	3.00
1/1/1986	12/31/1990	18.2	29	3.35
1/1/1991	12/31/1993	18.2[a]	29	3.35[a]
1/1/1994	12/31/1996	0.0710	0.11	10.7
1/1/1997	12/31/2000	0.303	0.49	4.11
1/1/2001	12/31/2006	0.859	1.4	3.00

a. For 1991 through 1993, fewer than 10 results per year were above the minimum detectable activity, which resulted in an insufficient quantity of data to generate a meaningful intake model. Intake rates from the previous interval were assumed.
b. The specific activities used to compute this column are 0.683 pCi/µg (natural uranium) for 1952 through 1964 and 1.616 pCi/µg (2% enrichment) for 1965 to the present.
c. This period spans the transition date when the 2% enrichment assumption began in 1964 (ORAUT 2004b). To ensure favorability to claimants, the specific activity for 2% enrichment is assumed for the full duration of the period.

Table 5-3. Derived FEMP uranium intake rates, 1952 to 2006 for type S materials.

From	To	50th percentile (µg/d)	50th percentile (pCi/d)[b]	GSD
1/1/1952	12/31/1953	8,197	5599	3.44
1/1/1954	12/31/1956	15,042	10274	3.00
1/1/1957	12/31/1957	7,140	4877	3.95
1/1/1958	12/31/1958	7,140	4877	3.00
1/1/1959	12/31/1960	7,772	5308	3.00
1/1/1961	12/31/1965 [c]	3,628	5863	3.00
1/1/1966	12/31/1980	3,628	5863	3.00
1/1/1981	12/31/1986	1,252	2023	3.00
1/1/1987	12/31/1990	361	583	3.16
1/1/1991	12/31/1993	361[a]	583	3.16[a]
1/1/1994	6/30/1997	1.34	2.2	18.6
7/1/1997	12/31/1999	7.29	12	3.41
1/1/2000	12/31/2006	14.0	23	3.00

a. For 1991 through 1993, fewer than 10 results per year were above the minimum detectable activity, which resulted in an insufficient quantity of data to generate a meaningful intake model. Intake rates from the previous interval were assumed..
b. The specific activities used to compute this column are 0.683 pCi/µg (natural uranium) for 1952 through 1965 and 1.616 pCi/µg (2% enrichment) for 1966 to the present.
c. This period spans the transition date when the 2% enrichment assumption began in 1964 (ORAUT 2004b). To ensure favorability to claimants, the specific activity for 2% enrichment is assumed for the full duration of the period.

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.

[1] Arno, Matthew. Oak Ridge Associated Universities Team (ORAU). Dose Reconstructor. June 18, 2007.
Lognormal distributions typically provide the best fit to the available data and are a distribution suitable for input into IREP.

[2] Arno, Matthew. ORAU Team. Dose Reconstructor. June 18, 2007.
The error in individual bioassay results has a normal distribution because the dominant source of uncertainty is the counting statistics. Although the underlying group statistics have normal distribution, each result was treated as if it had a normal distribution to match what was done for analysis of an individual's bioassay data and because the lognormal distribution of the data is addressed by analyzing both the 50th and 84th percentiles of the data.

REFERENCES

Arno, M., 2007, *Summary Statistics Validation Report Fernald Uranium Bioassay 1952 – 2006*. [SRDB Ref ID: 35324]

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This attachment shows comparisons of measured uranium urine bioassay results with predicted results that were calculated using IMBA-derived uranium intake rates. Blue dots represent the measured values that were retained for the fit. Red dots in the type S plots represent results that were excluded because they were outside the Type S intake period being fit. The green lines represent the predicted values. The figures provide the fits as follows:

- Figures A-1 and A-2 show the individual fits to the 50th-percentile excretion rates for type F material.
- Figures A-3 and A-4 show the individual fits to the 84th-percentile excretion rates for type F material.
- Figures A-5 and A-6 show the individual fits to the 50th-percentile excretion rates for type M material.
- Figures A-7 and A-8 show the individual fits to the 84th-percentile excretion rates for type M material.
- Figures A-9 through A-19 show the individual fits to the 50th-percentile excretion rates for type S material. Figure A-20 summarizes the results for the period 1952 through 1990.
- Figures A-21 through A-28 show the individual fits to the 84th-percentile excretion rates for type S material. Figure A-29 summarizes the type S results for the period 1952 through 1990.

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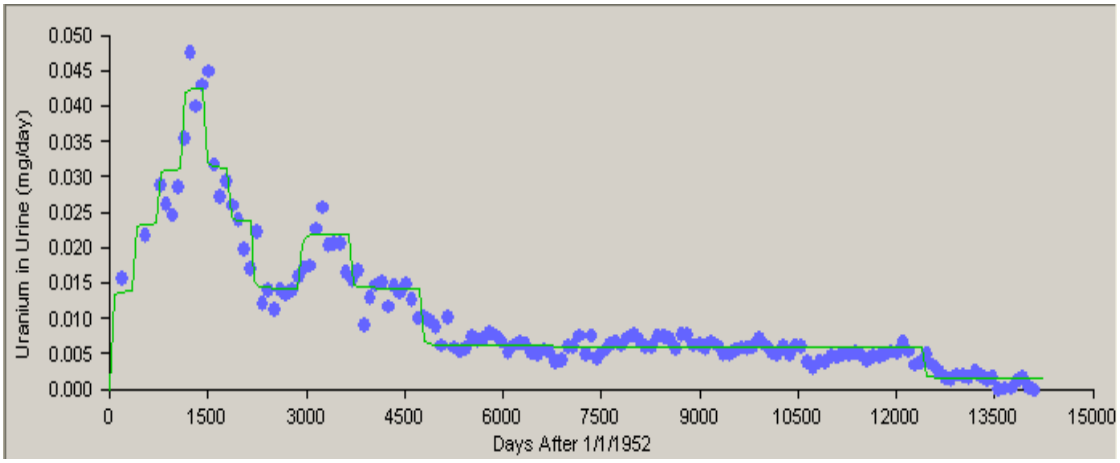

Figure A-1. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1990, 50th percentile, type F.

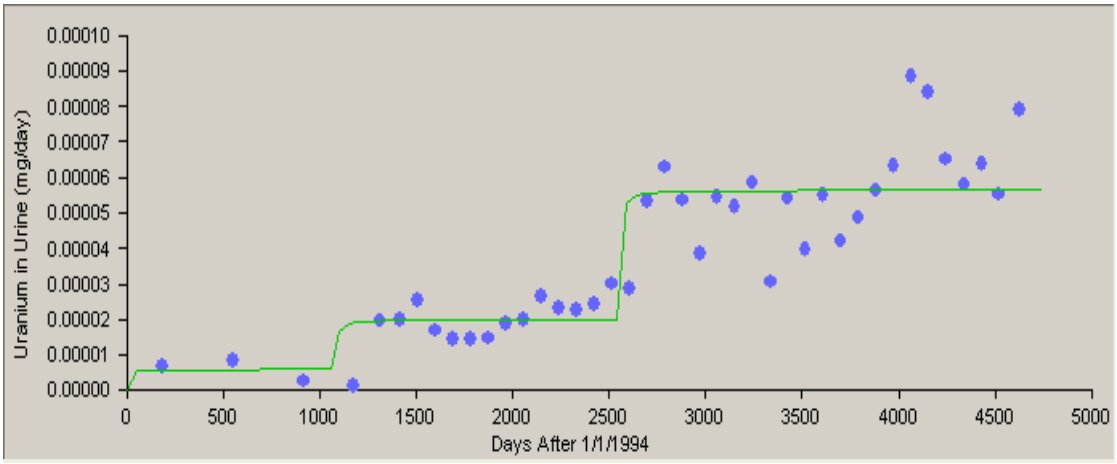

Figure A-2. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 12/31/2006, 50th percentile, type F.

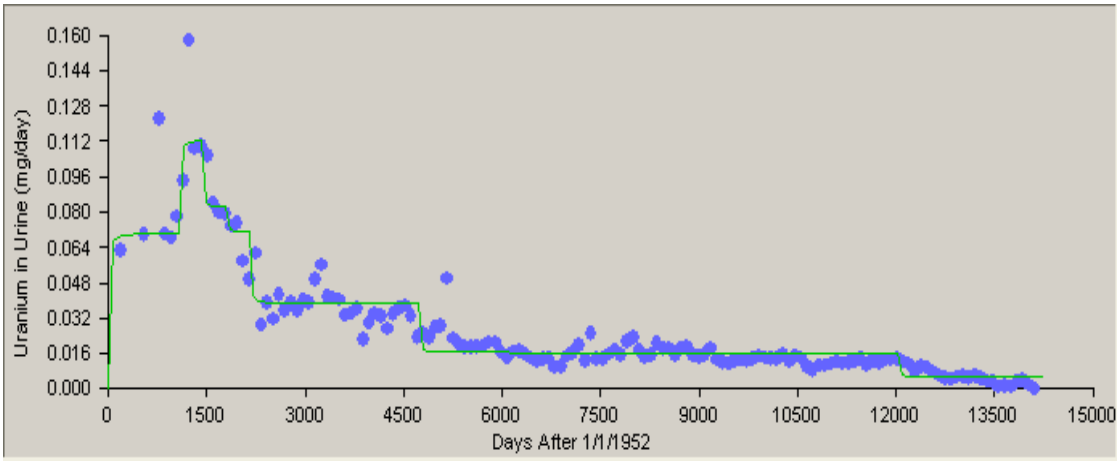

Figure A-3. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1990, 84th percentile, type F.

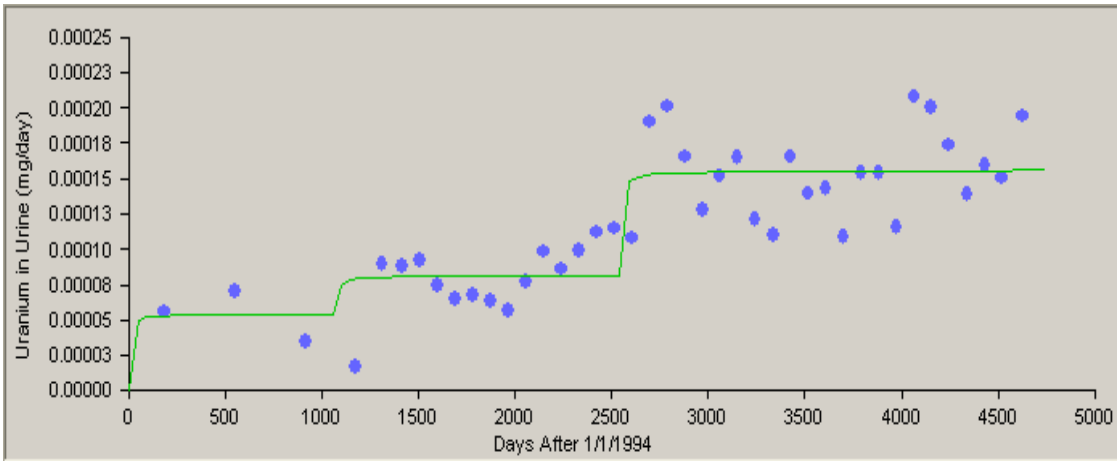

Figure A-4. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 12/31/2006, 84th percentile, type F.

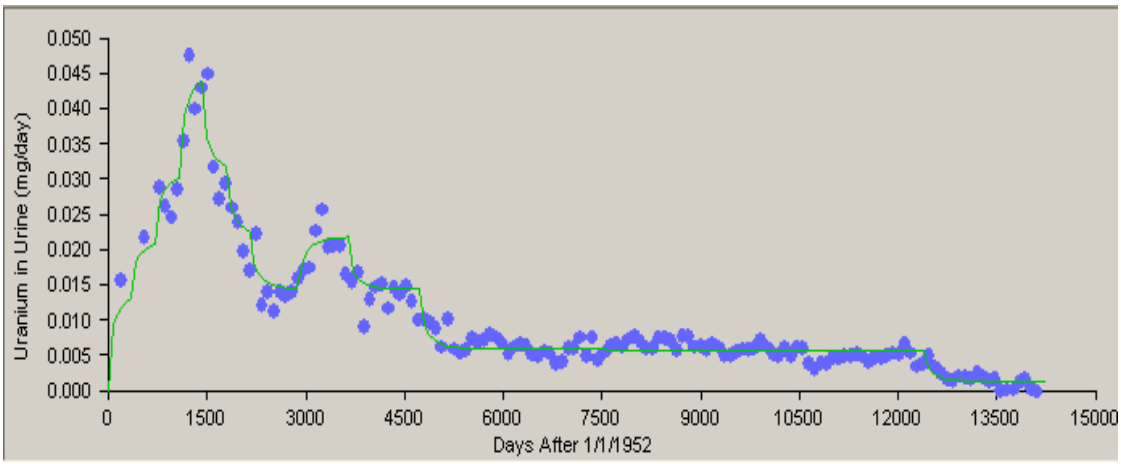

Figure A-5. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1990, 50th percentile, type M.

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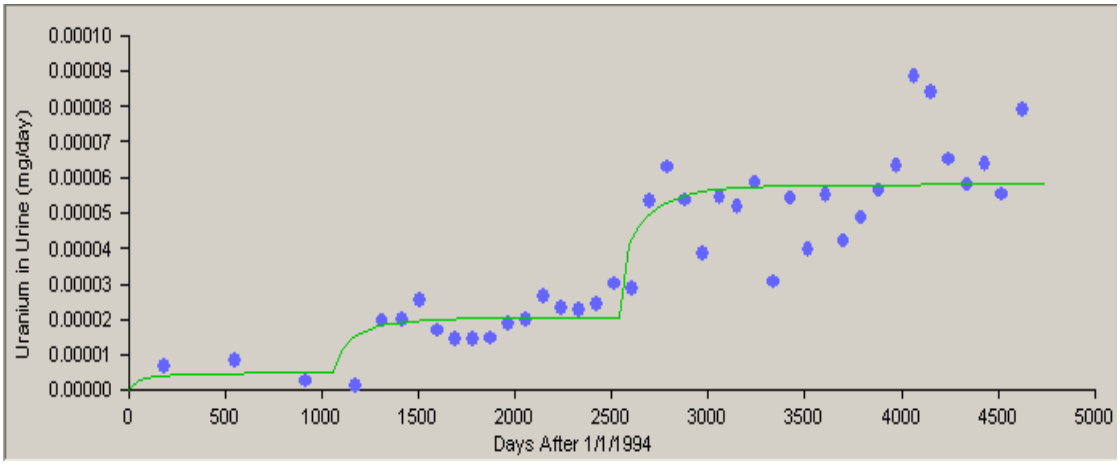

Figure A-6. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 12/31/2006, 50th percentile, type M.

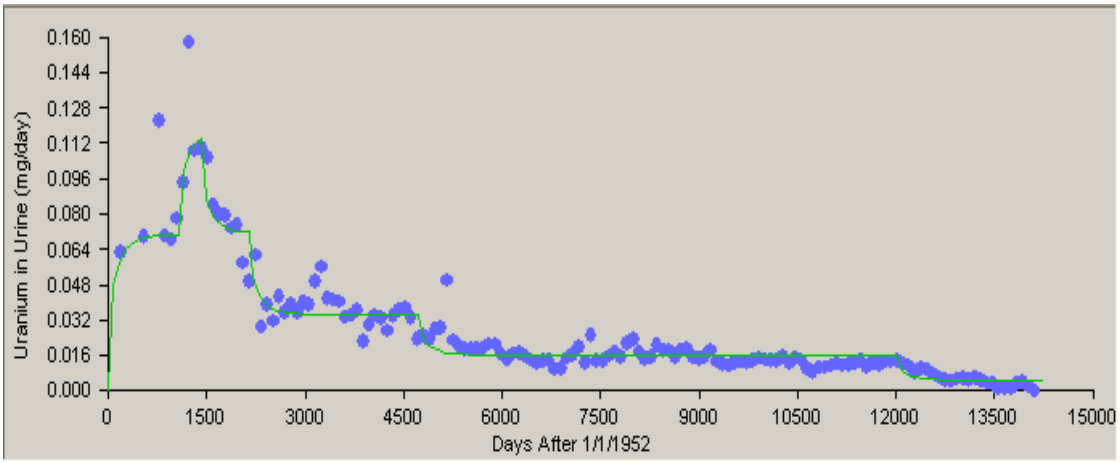

Figure A-7. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1990, 84th percentile, type M.

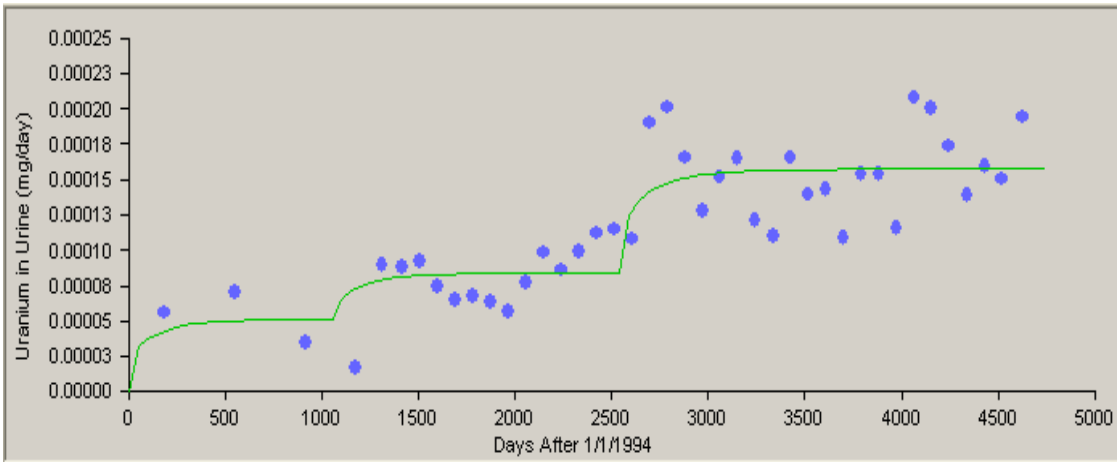

Figure A-8. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 12/31/2006, 84th percentile, type M.

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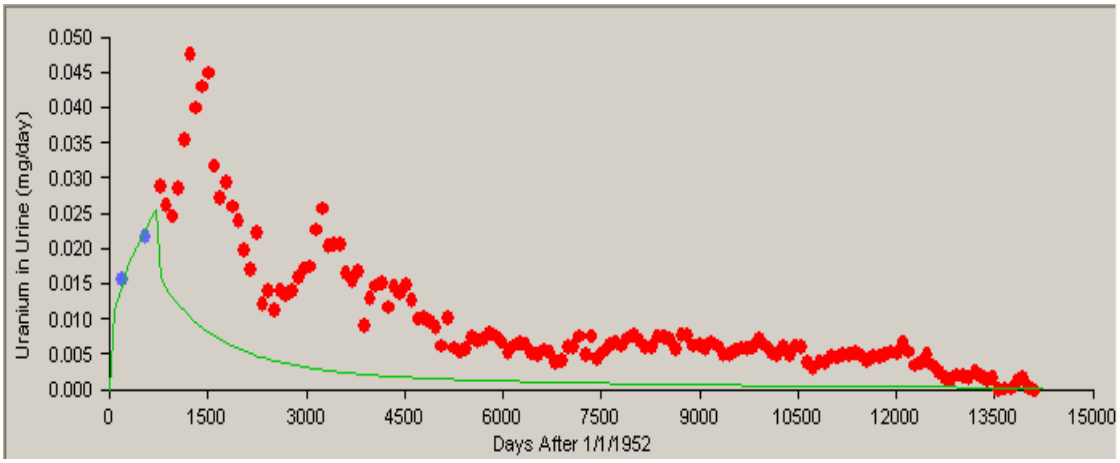

Figure A-9. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1953, 50th percentile, type S. Red dots represent excluded results.

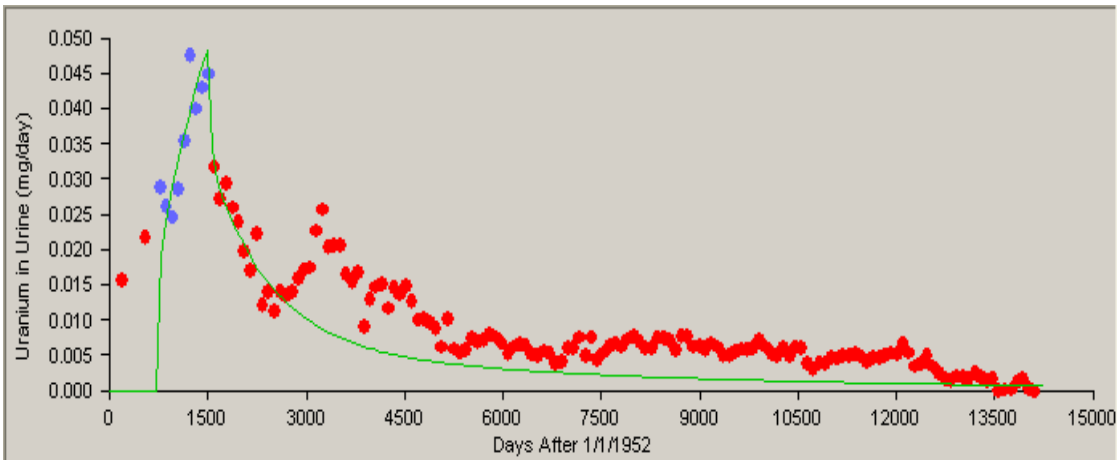

Figure A-10. Predicted values (line) versus measured results (blue dots), 1/1/1954 to 03/31/1956, 50th percentile, type S. Red dots represent excluded results.

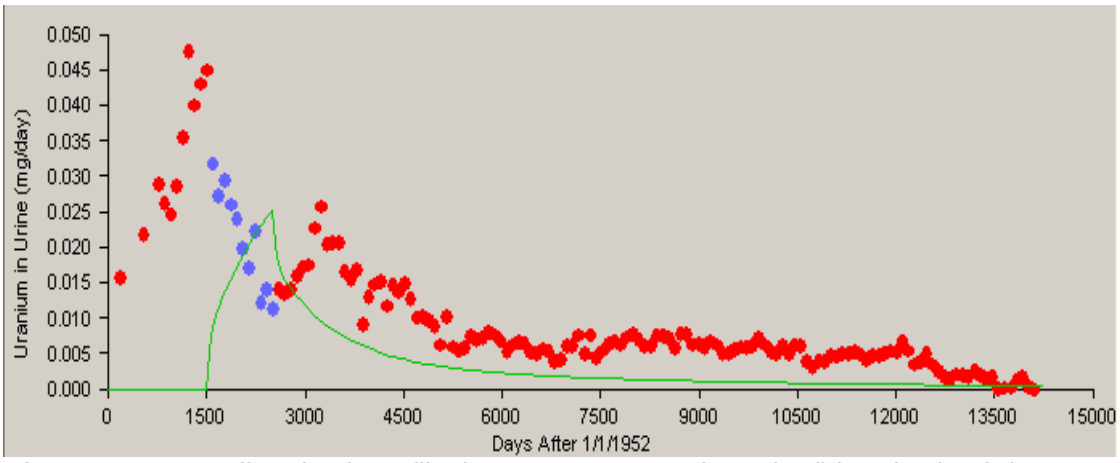

Figure A-11. Predicted values (line) versus measured results (blue dots), 4/1/1956 to 12/31/1958, 50th percentile, type S. Red dots represent excluded results.

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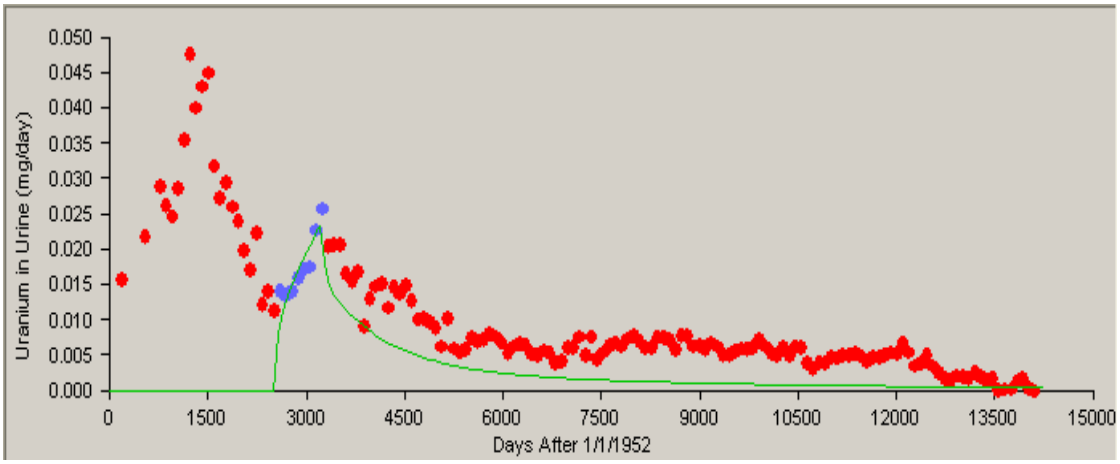

Figure A-12. Predicted values (line) versus measured results (blue dots), 1/1/1959 to 12/31/1960, 50th percentile, type S. Red dots represent excluded results.

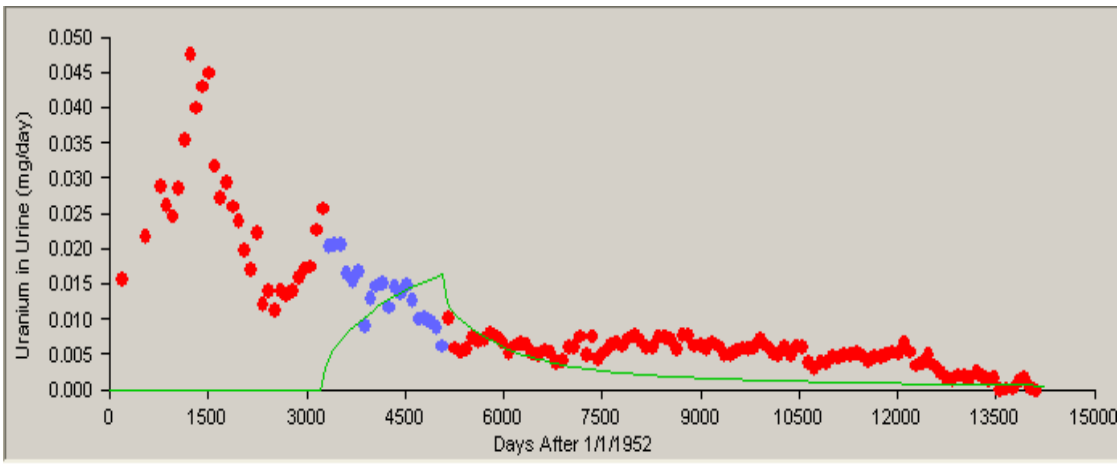

Figure A-13. Predicted values (line) versus measured results (blue dots), 1/1/1961 to 12/31/1965, 50th percentile, type S. Red dots represent excluded results.

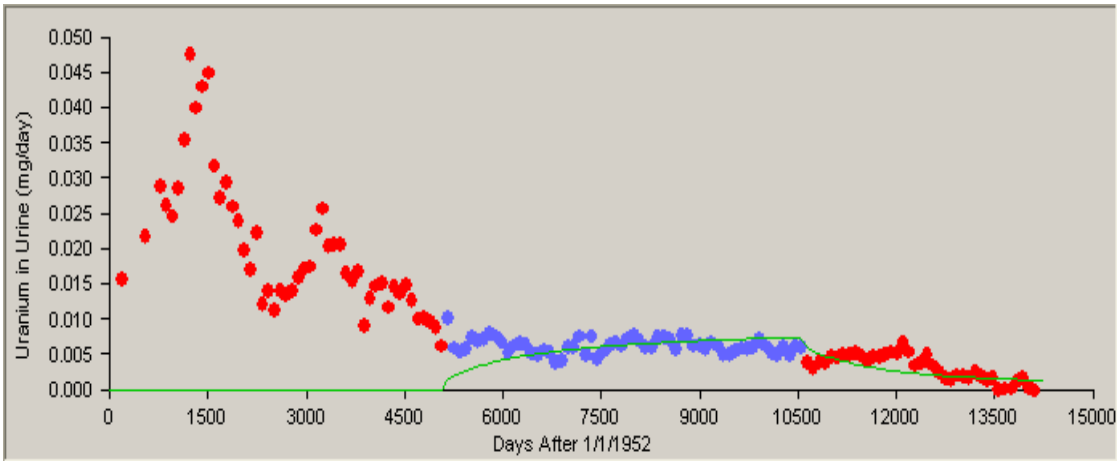

Figure A-14. Predicted values (line) versus measured results (blue dots), 1/1/1966 to 12/31/1980, 50th percentile, type S. Red dots represent excluded results.

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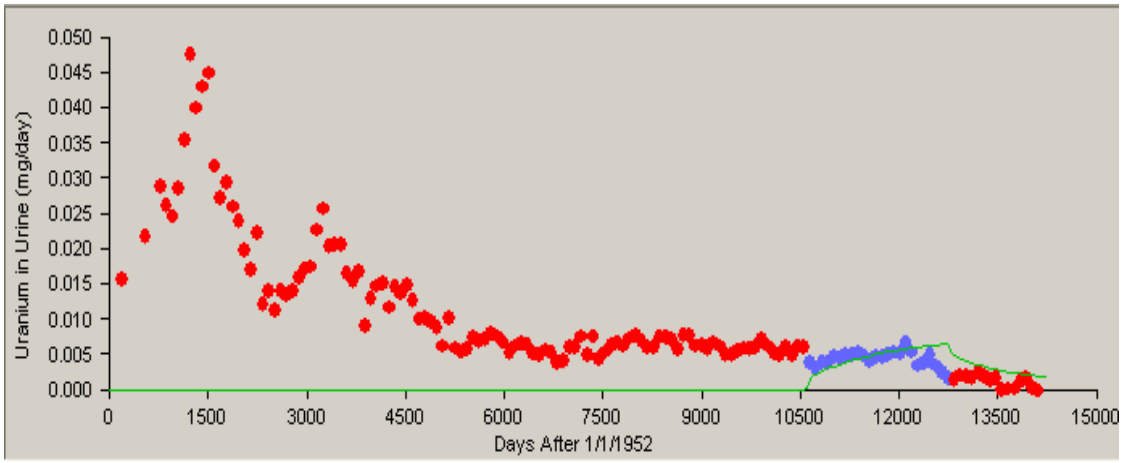

Figure A-15. Predicted values (line) versus measured results (blue dots), 1/1/1981 to 12/31/1986, 50th percentile, type S. Red dots represent excluded results.

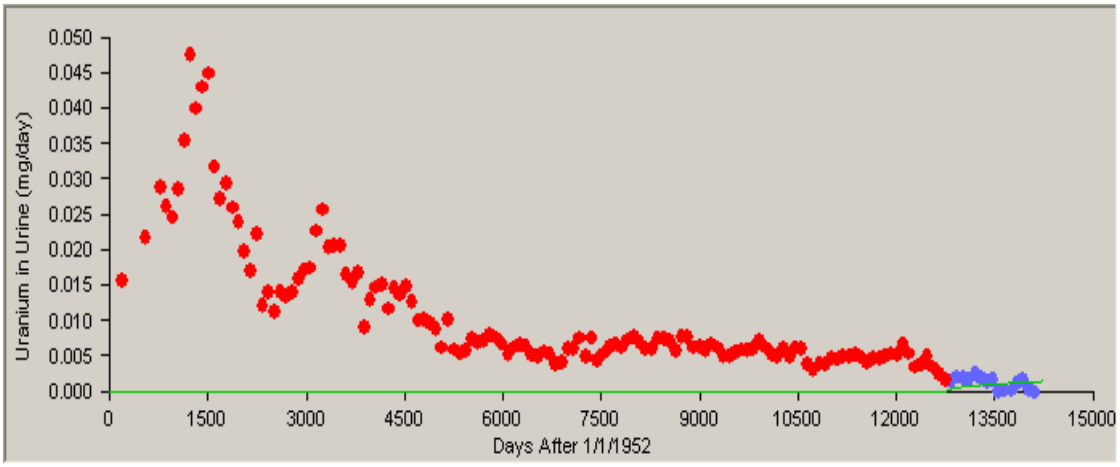

Figure A-16. Predicted values (line) versus measured results (blue dots), 1/1/1987 to 12/31/1990, 50th percentile, type S. Red dots represent excluded results.

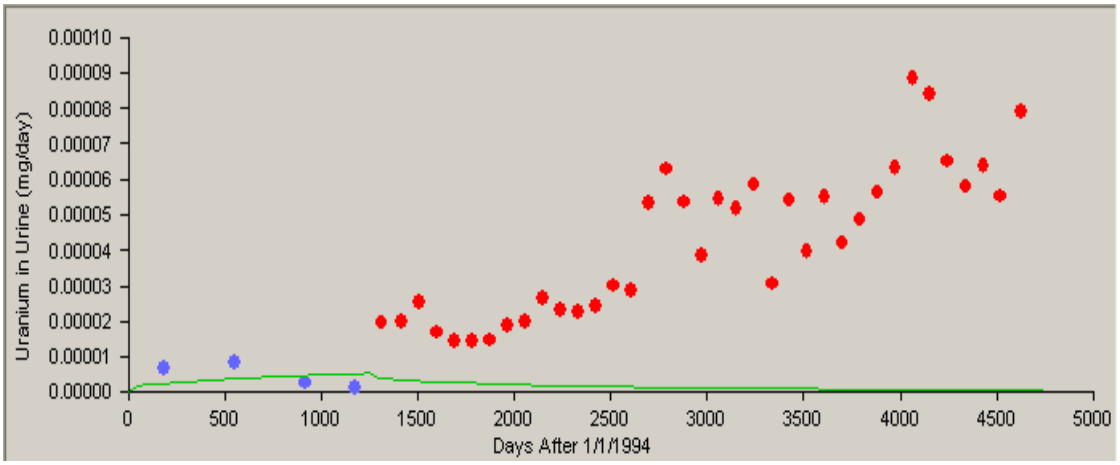

Figure A-17. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 06/30/1997, 50th percentile, type S. Red dots represent excluded results.

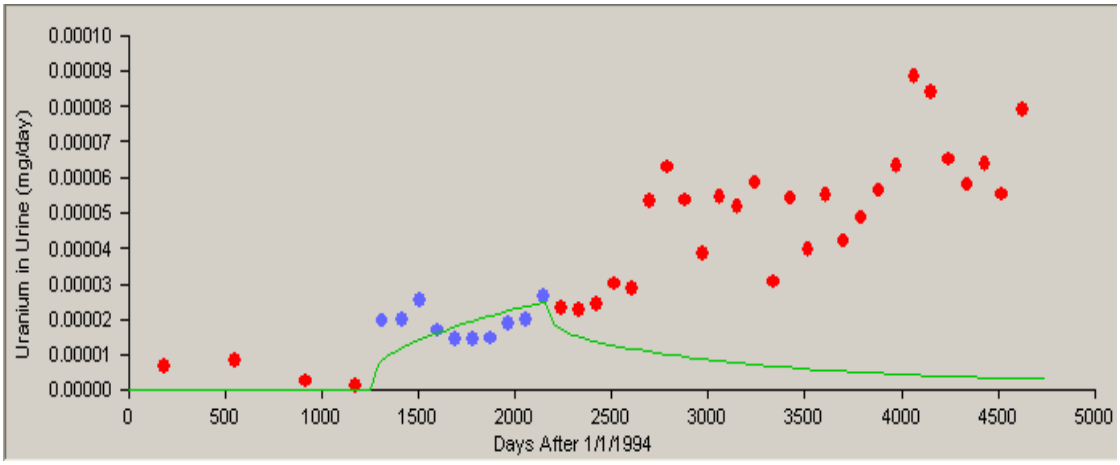

Figure A-18. Predicted values (line) versus measured results (blue dots), 7/1/1997 to 12/31/1999, 50th percentile, type S. Red dots represent excluded results.

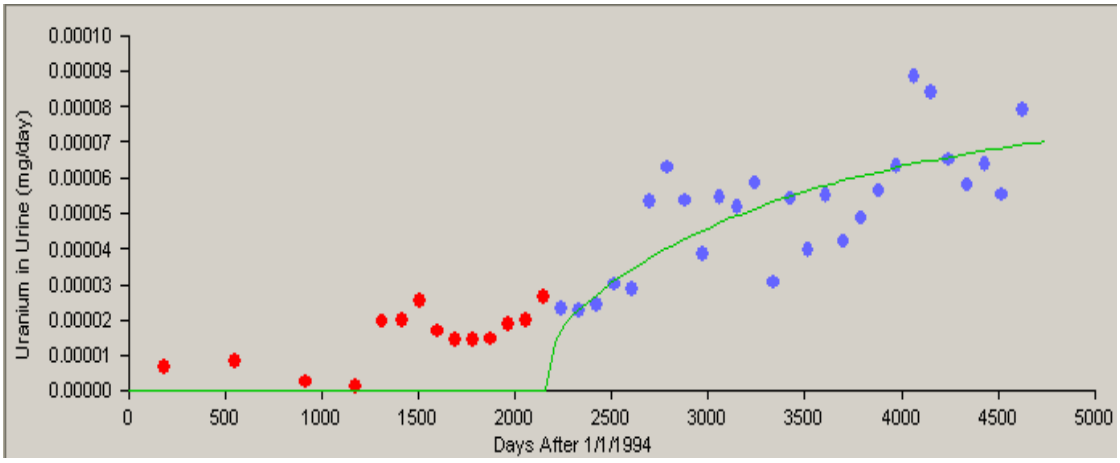

Figure A-19. Predicted values (line) versus measured results (blue dots), 1/1/2000 to 12/31/2006, 50th percentile, type S. Red dots represent excluded results.

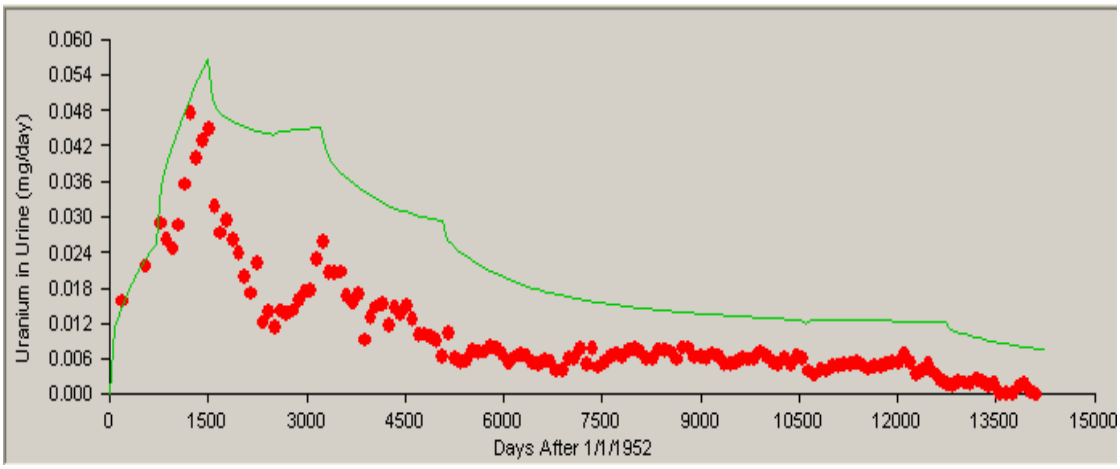

Figure A-20. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1990, 50th percentile, type S. Red dots represent excluded results.

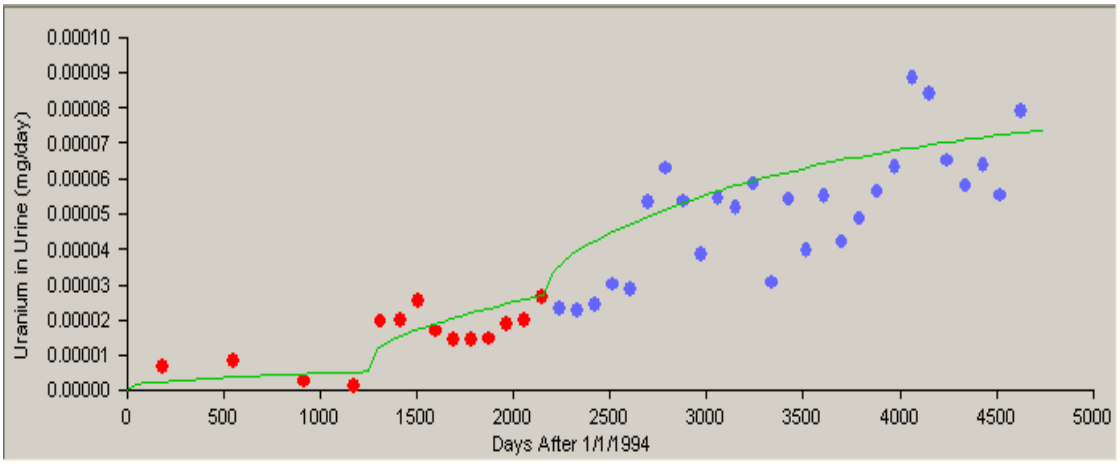

Figure A-21. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 12/31/2006, 50th percentile, type S. Red dots represent excluded results.

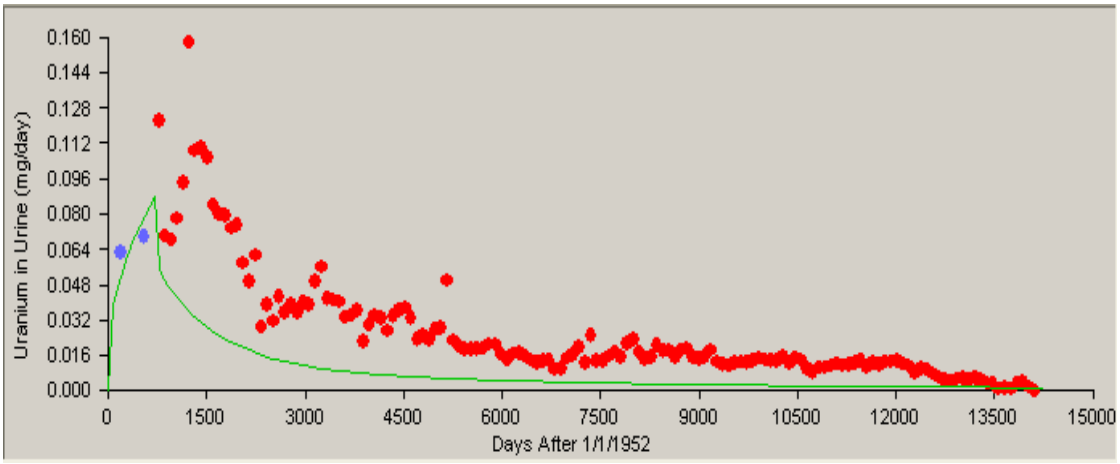

Figure A-22. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1953, 84th percentile, type S. Red dots represent excluded results.

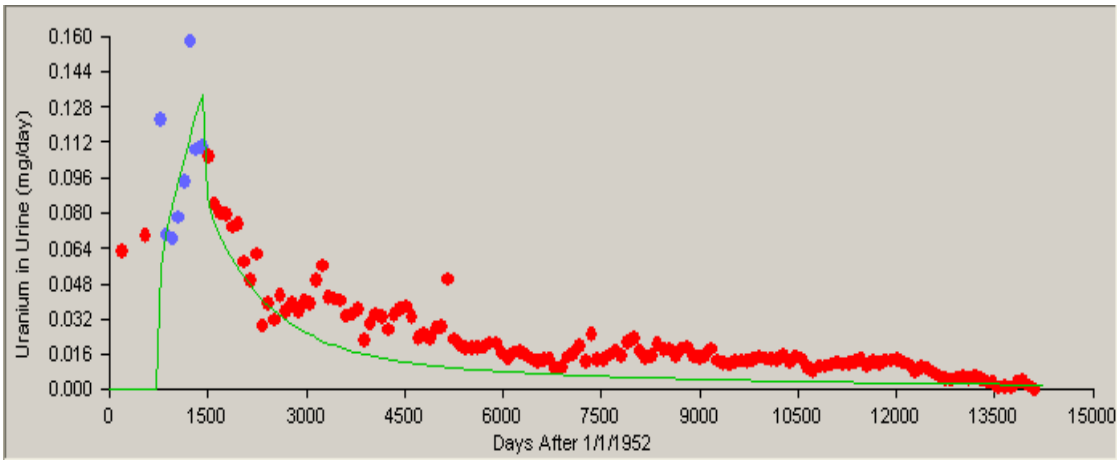

Figure A-23. Predicted values (line) versus measured results (blue dots), 1/1/1954 to 12/31/1955, 84th percentile, type S. Red dots represent excluded results.

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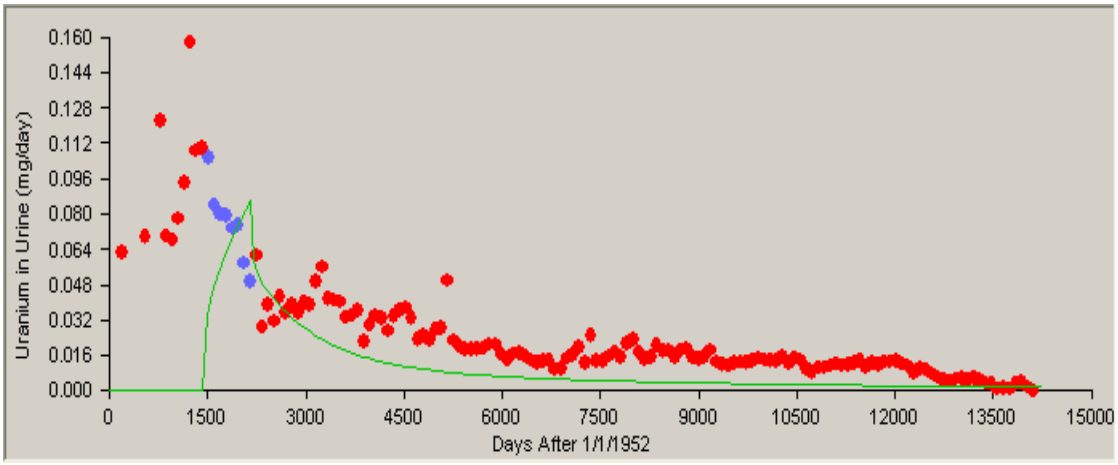

Figure A-24. Predicted values (line) versus measured results (blue dots), 1/1/1956 to 12/31/1957, 84th percentile, type S. Red dots represent excluded results.

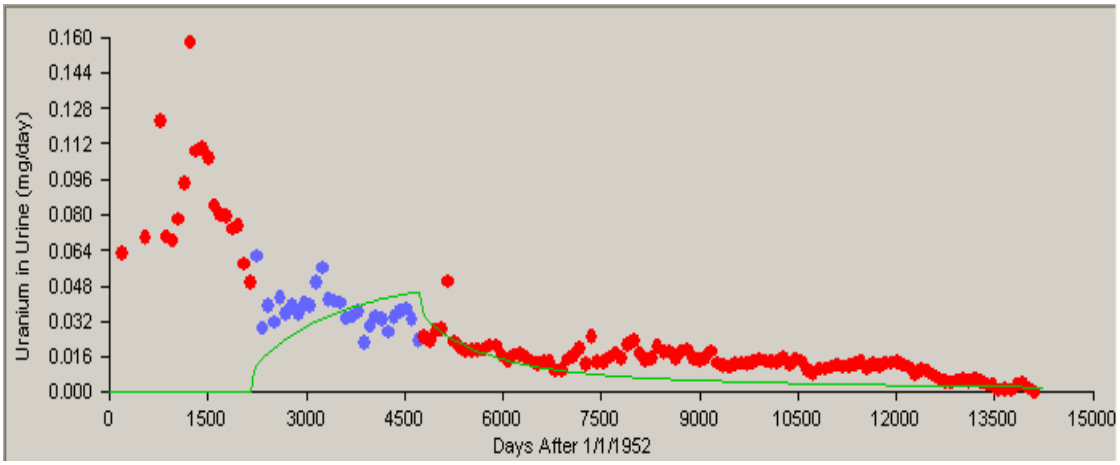

Figure A-25. Predicted values (line) versus measured results (blue dots), 1/1/1958 to 12/31/1964, 84th percentile, type S. Red dots represent excluded results.

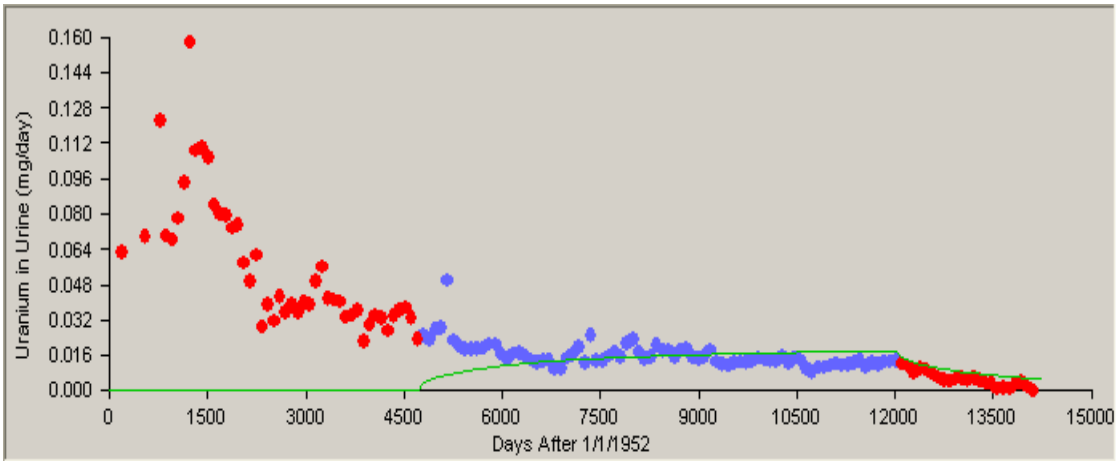

Figure A-26. Predicted values (line) versus measured results (blue dots), 1/1/1965 to 12/31/1984, 84th percentile, type S. Red dots represent excluded results.

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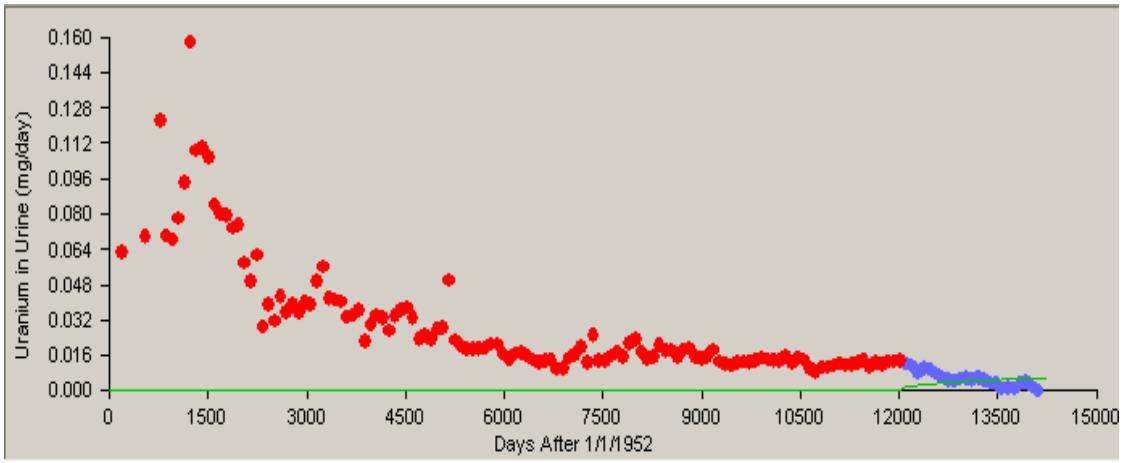

Figure A-27. Predicted values (line) versus measured results (blue dots), 1/1/1985 to 12/31/1990, 84th percentile, type S. Red dots represent excluded results.

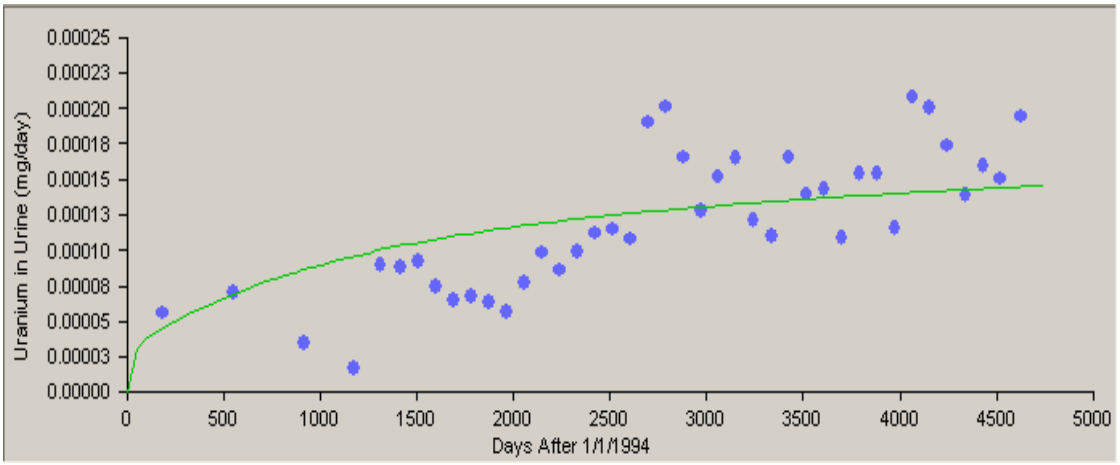

Figure A-28. Predicted values (line) versus measured results (blue dots), 1/1/1994 to 12/31/2006, 84th percentile, type S.

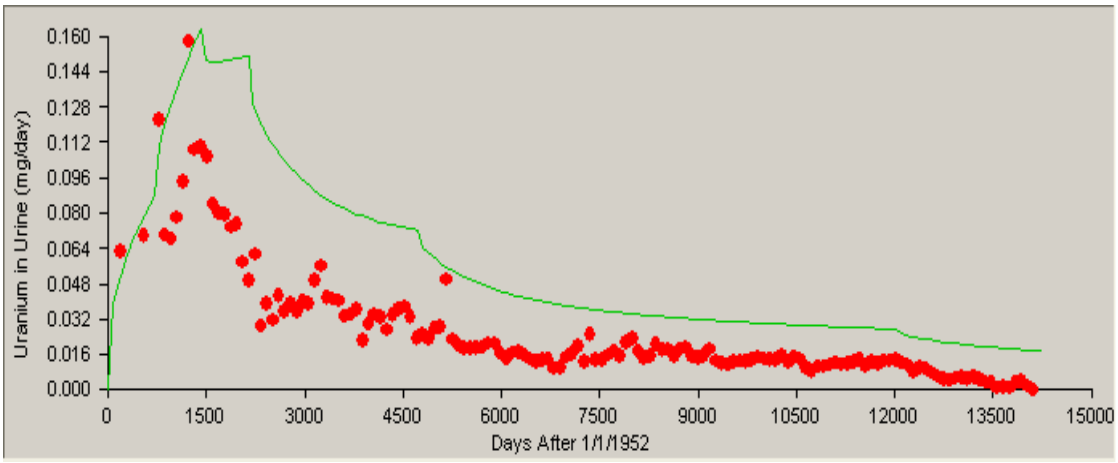

Figure A-29. Predicted values (line) versus measured results (blue dots), 1/1/1952 to 12/31/1990, 84th percentile, type S. Red dots represent excluded results.