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☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
05/25/2009	00	New document to present the results of a study of Y-12 Plant worker and claimant data to determine the feasibility of using claimant data in place of complete coworker data for reconstruction of doses at sites that do not have complete coworker data. Includes Mound and SRS datasets. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Thomas R. LaBone.

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ACRONYMS AND ABBREVIATIONS

CER	Center for Epidemiologic Research
CSV	comma-separated values (file type)
d	day
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
GM	geometric mean
GSD	geometric standard deviation
HPRED	Health Protection Radiation Exposure Database
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Engineering
SRDB Ref ID	Site Research Database Reference Identification (number)
SRS	Savannah River Site
TIB	technical information bulletin
U.S.C.	United States Code
§	section or sections

1.0 INTRODUCTION

Technical information bulletins (TIBs) are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide 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 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)].

2.0 PURPOSE

In the dose reconstruction process, coworker models are used to assign doses to workers who were not monitored at certain times during their employment (ORAUT 2005a). Coworker models are typically developed from essentially complete datasets of worker monitoring data. For example, the collection of all uranium urine bioassay data from 1950 to 1988 for the workers at the Oak Ridge Y-12 Plant (Y-12) was used to develop a coworker model for unmonitored workers at Y-12 (ORAUT 2005b). There are sites where complete worker monitoring datasets are not available to develop coworker models. Complete datasets are not available at these sites because not all of the necessary monitoring results have been transcribed from hard-copy records to an electronic format suitable for analysis. Because of the considerable cost and effort that would be involved with creating complete datasets, there is interest in developing coworker models from a sample of the complete dataset.

An ideal sample would consist of randomly selected workers from the entire monitored worker population. However, random sampling is resource intensive in this situation. One readily obtainable sample of the complete dataset for a site is the bioassay data of the workers (energy employees) who are named in a claim under EEOICPA. These workers are referred to in this paper as the claimants for a site. Strictly speaking, claimant datasets are samples of convenience rather than random samples. Nevertheless, claimant datasets are random enough for this purpose in the same sense that pseudo-random computer-generated numbers are adequate for most applications that require random numbers. Therefore, the purpose of this document is to present the results of a study to determine if claimant datasets can be treated as random samples from the complete datasets from which they were drawn for the purpose of developing coworker models. The study consisted of taking sites where well-defined complete datasets are available and comparing these datasets with the claimant datasets. Such complete datasets are available for the following sites, data types, and periods:

Y-12 Plant	Uranium urine bioassay	1950–1988
Mound Laboratory	Plutonium urine bioassay	1960–1990
Savannah River Site (SRS)	Tritium dose	1991–2001

The first step in the study was a direct, descriptive comparison of annual 50th and 84th percentiles that were obtained from slopes and intercepts of lognormal probability models for the complete and the claimant datasets[1]. Then a bootstrap analysis was used to determine whether the claimant dataset behaves like a random sample from the complete dataset in relation to the values of the slope and intercept of the fits to the data. If there is no significant difference between the claimant and random datasets, it is assumed that the same coworker model would be obtained, on average, from the claimant dataset as from an actual random sample.

Sections 3 to 5 explain this logic in detail using the Y-12 data and present the Y-12 results. Sections 6 and 7 briefly discuss the data and present results for the Mound Laboratory and SRS, respectively.

1 The statistical software R (RDCT 2008) was used for all calculations. The R codes are available as SRDB Ref ID 63507.

3.0 DESCRIPTION OF THE Y-12 DATA

Two Y-12 datasets are discussed in this section. The first is the complete dataset, which is all of the uranium urine bioassay data for all monitored Y-12 workers from 1950 to 1988. This dataset[2] was developed by the Oak Ridge Institute for Science and Engineering (ORISE) Center for Epidemiologic Research (CER) for use in epidemiology studies (Watkins et al. 1993) and has undergone detailed verification of its integrity. A member of the complete dataset is referred to as a worker. There are 7537 workers[3] in the complete dataset who submitted a total of 467757 uranium urine samples. The year-by-year breakdowns of the total number of submitted samples and total number of monitored workers are shown in Figures 3-1 and 3-2, respectively.

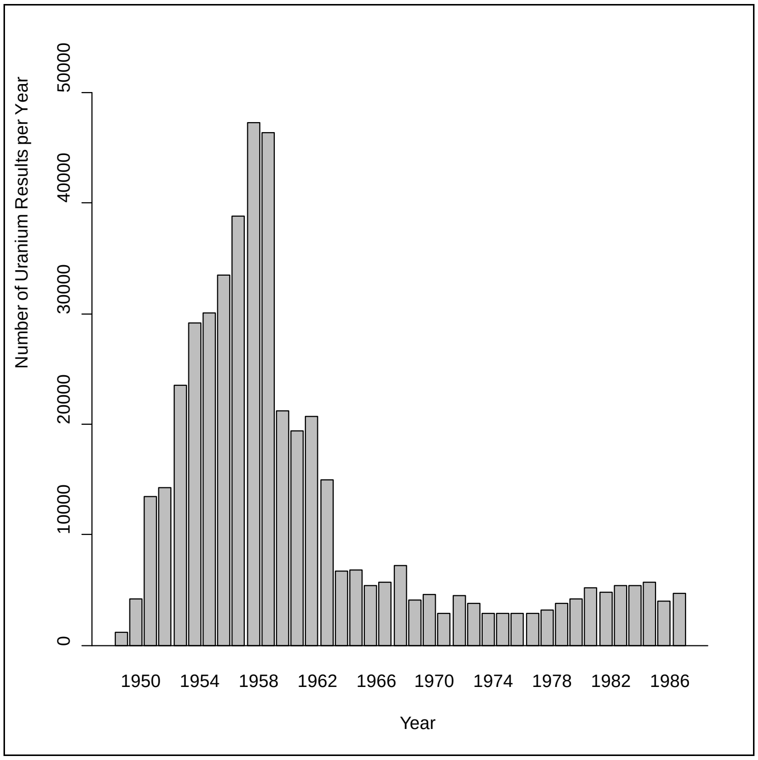

Figure 3-1. Number of samples submitted per year by all Y-12 workers.

The total number of submitted samples per worker ranged from a minimum of 1 to a maximum of 875 in the 39-year monitoring period; the median was 18 samples. An empirical probability density plot[4] of the samples per worker is shown in Figure 3-3. The curve in the plot is a probability density function, which means that the area under the curve is equal to 1 and the area under the curve between two points *a* and *b* on the curve is the fraction of workers who submitted between *a* and *b* samples. As can be clearly seen in Figure 3-3, the distribution of samples per worker is skewed to the high end. This means a randomly selected worker from this dataset could have as few as 1 sample or as many

2 The complete dataset was extracted from the ORISE CER database and supplied in 10 separate comma-separated values (CSV) files.

3 Five workers with extremely high urine results were excluded from the complete dataset because their data inflated the variance of the complete dataset to the extent that the claimant dataset would always agree with the complete dataset.

4 See Section 5.6 of *Modern Applied Statistics with S* (Venables and Ripley 2004) for a discussion of empirical (nonparametric) probability density plots. These plots are smoothed representations of the underlying data and therefore show a small probability of negative samples.

as 875, but it is more likely the worker would have submitted somewhere around 18 samples than 800 samples.

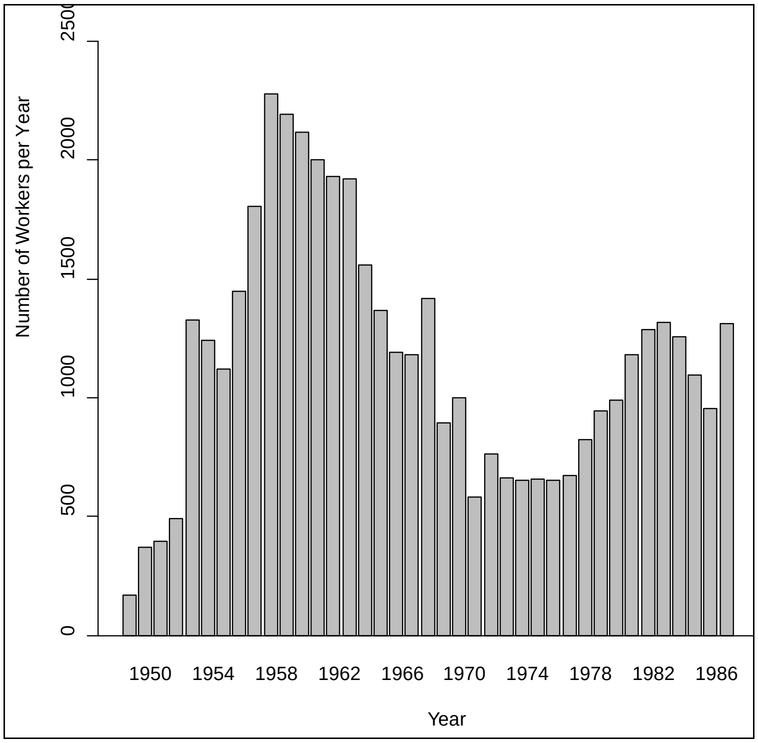

Figure 3-2. Number of Y-12 workers monitored in each year.

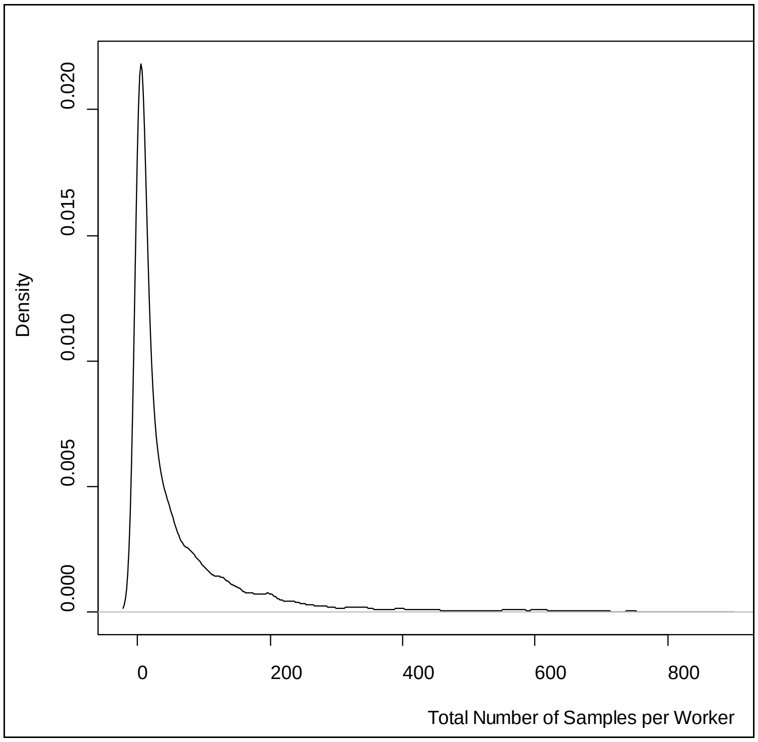

Figure 3-3. Empirical probability density plot of samples per Y-12 worker.

The second dataset[5] consists of all the uranium urine bioassay data for Y-12 workers who were monitored at any time during the period from 1950 to 1988 and who are named as an energy employee in a claim under EEOICPA. For brevity, this dataset is referred to as the claimant dataset, and a member of the claimant dataset is referred to as a claimant. Note that this is not the same meaning for claimant as used in EEOICPA[6].

The claimant dataset is a subset of the complete dataset; that is, all of the claimants are workers. A total of 731 claimants[7] submitted 67923 uranium urine samples. The total number of submitted samples per claimant ranged from a minimum of 1 to a maximum of 769 in the 39-year monitoring period; the median was 46 samples. The year-by-year breakdowns of the number of submitted samples and number of monitored claimants are shown in Figure 3-4 and Figure 3-5, respectively. The empirical probability density plot of samples per claimant is shown in Figure 3-6.

5 The claimant data were extracted from the ORISE CER database and supplied as one CSV file that was separate and distinct from those for the complete dataset.

6 Under EEOICPA, a claimant is the individual who filed a claim and is seeking compensation. The claimant can be the energy employee or a survivor of an energy employee.

7 Out of 1,971 total claimants for Y-12, 731 have uranium urine bioassay results in the complete dataset and 1,240 do not (presumably because they were not monitored).

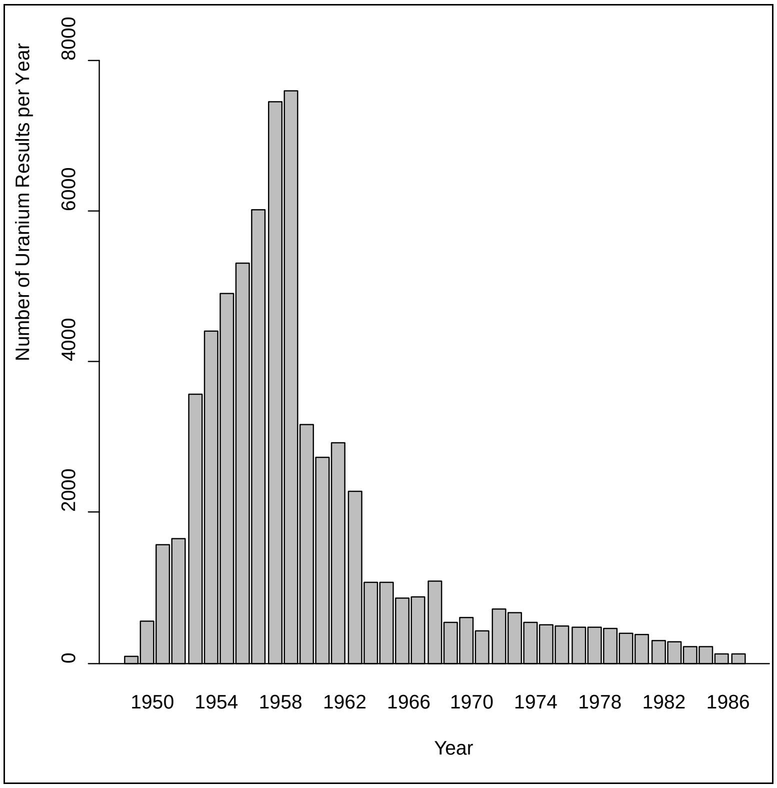

Figure 3-4. Number of samples submitted per year by Y-12 claimants.

A summary of the numbers of samples and workers in the claimant and complete datasets is given in Table 3-1. It is worth noting that the ratio of claimants to all workers for a given year (the fourth column in Table 3-1) is approximately the same as the ratio of number of claimant-submitted samples to the total number of samples in that year (the last column in Table 3-1). This indicates that the claimants submitted samples at the same rate as the rest of the workers, which suggests that they were not monitored differently than other workers.

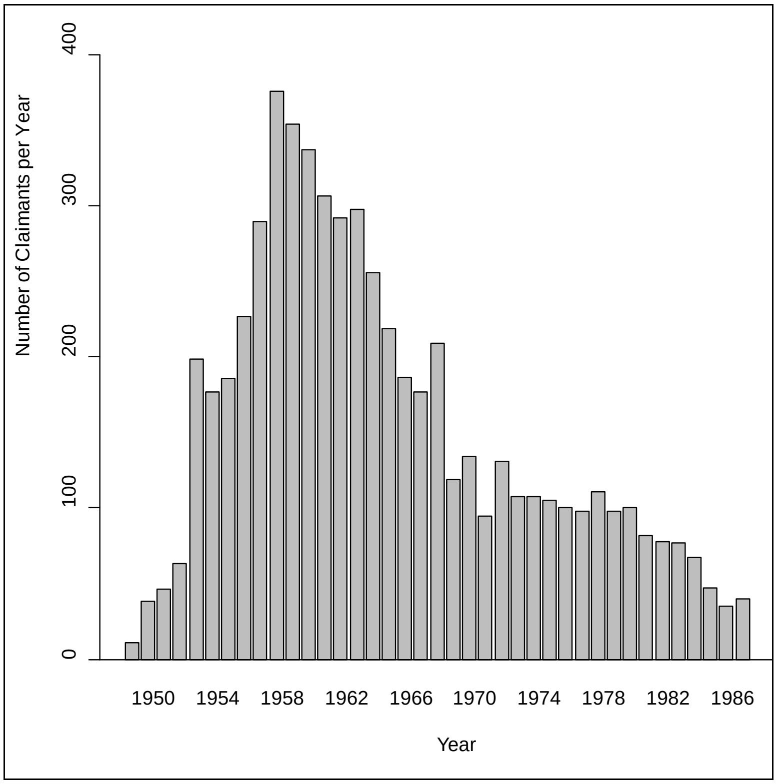

Figure 3-5. Number of Y-12 claimants monitored in each year.

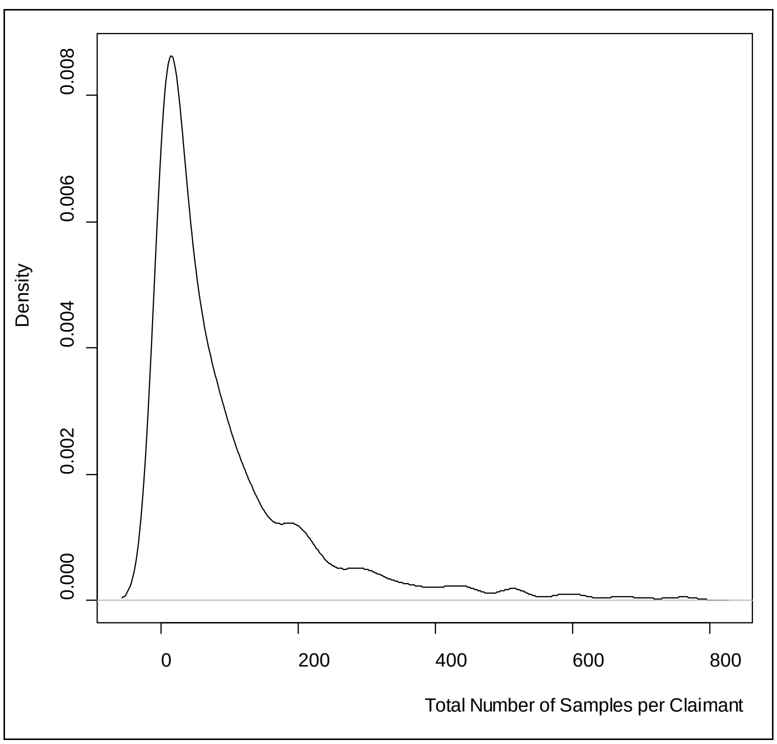

Figure 3-6. Empirical probability density plot of samples per Y-12 claimant.

Table 3-1. Summary of samples and workers in claimant and complete Y-12 datasets by year.

	Workers			Samples		
Year	Complete dataset	Claimant dataset	Ratio	Complete dataset	Claimant dataset	Ratio
1950	169	11	0.07	1127	94	0.08
1951	370	38	0.10	4175	564	0.14
1952	396	46	0.12	13414	1575	0.12
1953	493	63	0.13	14312	1655	0.12
1954	1327	199	0.15	23564	3573	0.15
1955	1244	177	0.14	29160	4417	0.15
1956	1123	186	0.17	30083	4913	0.16
1957	1448	227	0.16	33551	5307	0.16
1958	1805	290	0.16	38848	6028	0.16
1959	2277	376	0.17	47340	7455	0.16
1960	2193	354	0.16	46387	7594	0.16
1961	2120	337	0.16	21216	3168	0.15
1962	2004	307	0.15	19371	2741	0.14
1963	1933	292	0.15	20709	2925	0.14
1964	1924	298	0.15	15013	2279	0.15
1965	1559	256	0.16	6734	1066	0.16
1966	1366	219	0.16	6849	1073	0.16
1967	1191	187	0.16	5369	858	0.16
1968	1181	177	0.15	5676	883	0.16
1969	1417	209	0.15	7161	1085	0.15
1970	892	119	0.13	4107	543	0.13
1971	998	134	0.13	4631	607	0.13
1972	583	95	0.16	2896	436	0.15
1973	763	131	0.17	4520	717	0.16
1974	663	108	0.16	3827	666	0.17
1975	654	108	0.17	2896	535	0.18
1976	658	105	0.16	2896	512	0.18
1977	653	100	0.15	2878	498	0.17
1978	674	98	0.15	2893	474	0.16
1979	823	111	0.13	3141	472	0.15
1980	945	98	0.10	3799	464	0.12
1981	992	100	0.10	4215	401	0.10
1982	1184	82	0.07	5175	377	0.07
1983	1285	78	0.06	4786	292	0.06
1984	1320	77	0.06	5404	284	0.05
1985	1255	67	0.05	5356	218	0.04
1986	1096	47	0.04	5672	212	0.04
1987	957	35	0.04	3958	119	0.03
1988	1312	40	0.03	4648	129	0.03

4.0 MODELING OF DATA

Using the methodology in ORAUT-OTIB-0019, *Analysis of Coworker Bioassay Data for Internal Dose Assignment* (ORAUT 2005a), the complete dataset for 1953 is presented in Figure 4-1 in the form of a lognormal probability plot. The year 1953 was chosen as an example because it is one of the years that has relatively good agreement between the complete and claimant datasets. The data are fit with a straight line and the slope *m*, intercept *b*, and linear correlation coefficient R^2 that were calculated from the fit are given on the plot. The geometric mean (GM) and geometric standard deviation (GSD) of the data are:

$$GM = e^b = e^{2.614} = 13.66 \text{ dpm/d} \quad (4\text{-}1)$$

$$GSD = e^m = e^{1.343} = 3.83 \quad (4\text{-}2)$$

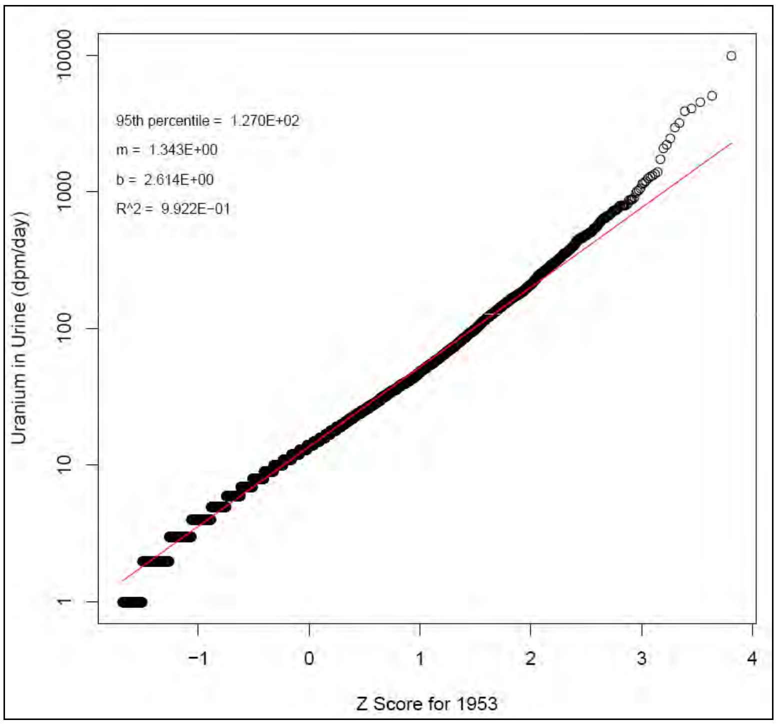

Figure 4-1. Lognormal probability plot of the complete Y-12 dataset for 1953.

The statistics of interest for the coworker model are the 50th and 84th percentiles. The 50th percentile of the data is equal to the GM, and the 84th percentile is equal to the product of the GM and the GSD:

- 50th percentile = 13.66 dpm/d
- 84th percentile = 52.29 dpm/d

These are parametric percentiles, which means that they derive from the parameters of the lognormal model that is fit to the data rather than the data themselves. The validity of the parametric percentiles depends in part on how well a lognormal probability model fits the data. Ultimately, the 50th and 84th percentiles are modeled by an internal dosimetrist and uranium intake rates are calculated for each set of data. The intake rate that is typically calculated from the 50th percentile data is assigned for the period of interest, and the ratio of the 84th-percentile intake rate to the 50th-percentile intake rate gives the GSD of the intake.

There are over 14000 urine bioassay results that are represented in Figure 4-1, which is an unusually large number of results to model. The model in ORAUT-OTIB-0029, *Internal Dosimetry Coworker Data for Y-12* (ORAUT 2005b), took advantage of the large dataset by breaking the data down into months rather than years, which is useful when applying the intakes to an individual. However, for this report the annual data was evaluated.

The lognormal probability plot for the 1953 claimant dataset is given in Figure 4-2. The relevant statistics from this plot are:

$$GM = e^{2.623} = 13.77 \text{ dpm/d} \tag{4-3}$$

$$GSD = e^{1.328} = 3.77 \tag{4-4}$$

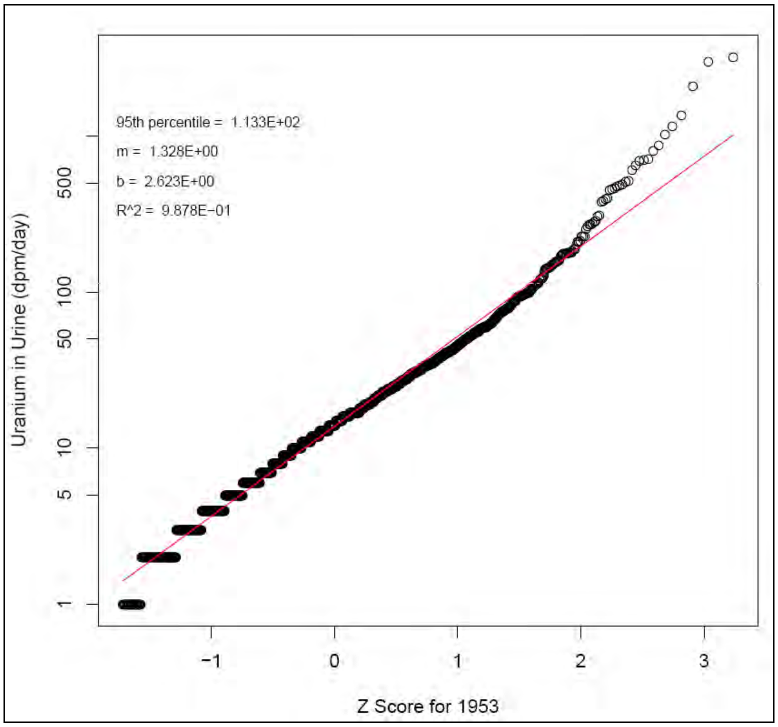

Figure 4-2. Lognormal probability plot of the claimant Y-12 dataset for 1953.

The 50th and 84th percentiles are then:

- 50th percentile = 13.77 dpm/d
- 84th percentile = 51.98 dpm/d

The annual lognormal probability plots for complete and claimant datasets for 1950 to 1988 are given in Attachments A and B, respectively, and the results of the fits are given in Table 4-1. Graphical comparisons of the annual 50th and 84th percentiles for the complete and claimant datasets from Table 4-1 are shown in Figures 4-3 and 4-4. In general, there is excellent agreement between the percentiles that derive from the complete dataset and those from the claimant dataset.

Table 4-1. Summary of the slopes and intercepts of a fit to a lognormal probability model and the corresponding 50th and 84th percentiles for Y-12 . The corresponding plots are in Attachments A and B.

Year	Complete slope	Complete intercept	Claimant slope	Claimant intercept	Complete 50th percentile	Complete 84th percentile	Claimant 50th percentile	Claimant 84th percentile
1950	1.6215	1.9090	1.2029	0.6286	6.75	34.14	1.88	6.24
1951	1.5994	1.7217	1.5734	1.3214	5.59	27.69	3.75	18.08
1952	1.0897	2.8263	1.0757	2.7016	16.88	50.20	14.90	43.70
1953	1.3426	2.6142	1.3281	2.6228	13.66	52.29	13.77	51.98
1954	1.5665	2.4603	1.5690	2.4342	11.71	56.08	11.41	54.77
1955	1.5465	1.7700	1.5643	1.8130	5.87	27.56	6.13	29.29
1956	1.4653	1.9330	1.4397	1.9308	6.91	29.91	6.89	29.09
1957	1.5518	1.9214	1.5245	1.9083	6.83	32.24	6.74	30.96
1958	1.4826	2.2972	1.4747	2.2587	9.95	43.81	9.57	41.82
1959	1.5065	2.2805	1.4821	2.3356	9.78	44.13	10.34	45.50
1960	1.5350	1.8949	1.5459	1.9289	6.65	30.87	6.88	32.29
1961	1.5615	1.6741	1.4966	1.6546	5.33	25.42	5.23	23.36
1962	1.4304	2.3453	1.4191	2.2999	10.44	43.63	9.97	41.22
1963	1.3881	1.9952	1.4020	1.9503	7.35	29.47	7.03	28.57
1964	1.4890	1.3073	1.5135	1.2786	3.70	16.38	3.59	16.31
1965	1.6947	1.3007	1.6693	1.3539	3.67	19.99	3.87	20.56
1966	1.6758	1.6940	1.7764	1.5620	5.44	29.07	4.77	28.17
1967	1.4888	1.7652	1.4861	1.7095	5.84	25.89	5.53	24.42
1968	1.3763	1.9625	1.3093	1.9703	7.12	28.19	7.17	26.56
1969	1.5109	1.5885	1.6410	1.3632	4.90	22.18	3.91	20.17
1970	1.2354	2.2760	1.2283	2.1886	9.74	33.49	8.92	30.47
1971	1.2082	2.2166	1.2266	2.1807	9.18	30.72	8.85	30.18
1972	1.0933	2.5560	1.1360	2.4023	12.88	38.45	11.05	34.41
1973	1.1803	2.6400	1.1592	2.6621	14.01	45.62	14.33	45.67
1974	1.1264	2.3589	1.0790	2.4090	10.58	32.63	11.12	32.72
1975	1.1407	2.3286	1.1124	2.3718	10.26	32.11	10.72	32.60
1976	1.2762	2.1444	1.3575	2.0913	8.54	30.59	8.10	31.46
1977	1.1862	2.3546	1.2050	2.4402	10.53	34.50	11.48	38.29
1978	1.4275	1.8822	1.4318	1.9348	6.57	27.38	6.92	28.98
1979	1.4511	1.7151	1.3193	1.7743	5.56	23.72	5.90	22.05
1980	1.5264	1.7382	1.5066	1.6421	5.69	26.17	5.17	23.31
1981	1.5451	1.6040	1.5781	1.4832	4.97	23.32	4.41	21.35
1982	1.4890	1.5554	1.6356	1.4665	4.74	21.00	4.33	22.25
1983	1.5642	1.3947	1.5739	1.1822	4.03	19.28	3.26	15.74
1984	1.7090	1.2271	2.0629	1.1379	3.41	18.84	3.12	24.55
1985	1.8115	0.6876	1.8104	0.7032	1.99	12.17	2.02	12.35
1986	1.9661	0.5077	1.8868	0.3159	1.66	11.87	1.37	9.05
1987	1.7238	0.9503	1.5815	0.7263	2.59	14.50	2.07	10.05
1988	1.7764	0.8923	1.8287	0.3489	2.44	14.42	1.42	8.83

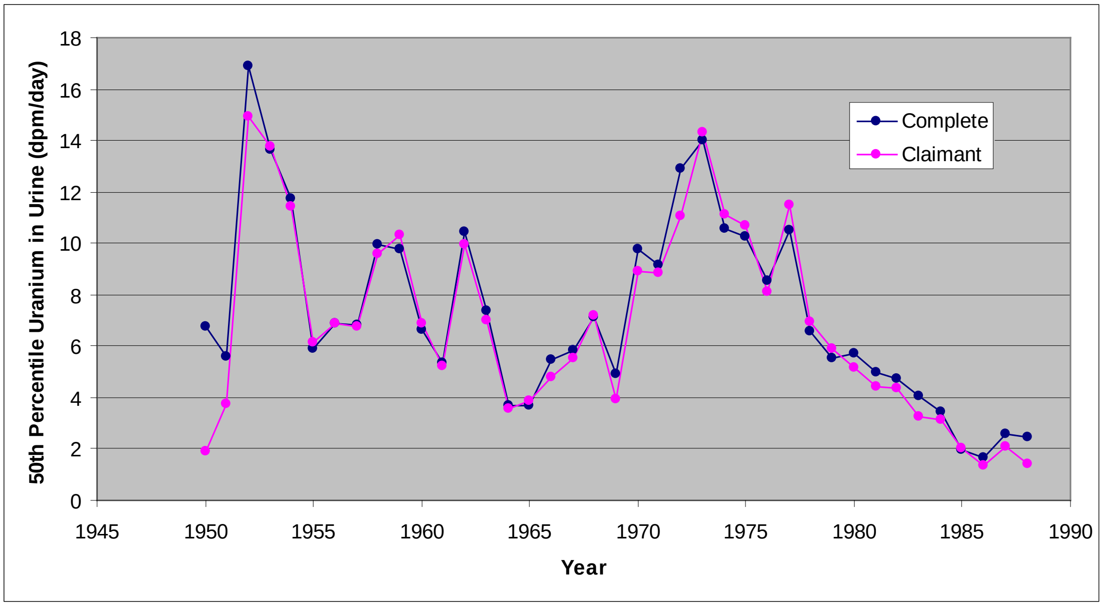

Figure 4-3. Comparison of 50th percentiles for the complete and claimant Y-12 datasets.

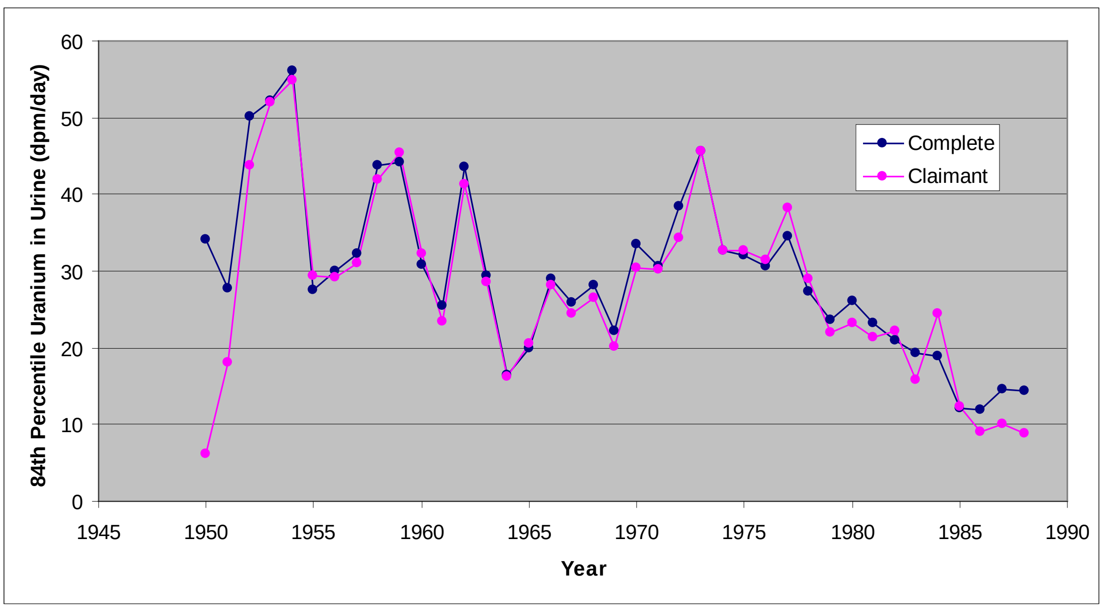

Figure 4-4. Comparison of 84th percentiles for the complete and claimant Y-12 datasets.

In this specific case (i.e., for Y-12 uranium urine bioassay from 1950 to 1988) the sample consisting of the claimant dataset gives estimates of slope and intercept that appear to agree quite well with the slope and intercepts of the complete dataset. This raises the question of whether the claimant dataset can be expected to give good estimates of the slope and intercept for all sites, radionuclides, and years.

To answer this question, consider the situation in which neither the complete dataset nor the claimant dataset are available in a database. The urine bioassay data for all 7537 workers could be entered into a database and then used to calculate the slopes and intercepts for the complete dataset for each year. This approach requires the most effort, but it would give the best available answer.

Another approach that requires less effort is to pick a number of the workers as a sample and calculate the slopes and intercepts from the sample. The ideal result would be that the slopes and intercepts of the sample would be the same as the slopes and intercepts of the complete dataset. However, because each sample contains only part of the complete dataset, the slopes and intercepts from a sample will almost certainly vary from those from the complete dataset and from another sample. This variation is referred to as the sampling error.

Given that the slopes and intercepts of the sample are unlikely to be exactly equal to the slopes and intercepts of the complete dataset, it is desirable that:

- On average, the slopes and intercepts of the sample are equal to the slopes and intercepts from the complete dataset.

- The sampling error is acceptably small.

Another way of saying the first bullet is that the slopes and intercepts of the sample should be an unbiased estimate of the slopes and intercepts of the complete dataset. Unbiased estimates of the slopes and intercepts can be obtained from properly collected random samples, and the likely size of the sampling error decreases as the size of this random sample increases. Therefore, to generalize the conclusion that the claimant dataset is useful for estimating the slopes and intercepts of the complete dataset, it must be shown that the claimant dataset can be treated as if it were a random sample.

5.0 RANDOM SAMPLES

The claimant datasets are best described as samples of convenience; that is, they were not constructed through a designed random sampling of the complete dataset. Nevertheless, this section shows that, in general, claimant datasets can be used as if they were true random samples from the complete dataset. Verifying that the claimant datasets behave like true random samples is important because coworker models that are based on random samples will, on average, provide the same coworker models that would have been derived from the complete dataset. Random sampling provides a statistical basis for stating that the sample is representative of the complete dataset and eliminates selection bias. Therefore, if the claimant dataset is large enough and has properties very much like those of a truly random sample from the complete dataset then, in relation to the estimates of the lognormal parameters, meaningful statements can be made about the sampling errors that are associated with the percentiles without having access to the complete dataset.

5.1 THEORY AND METHODS

There are n = 7537 monitored workers in the complete dataset, each of which has a mostly unique set of bioassay data. The slopes and intercepts of the complete dataset are the true slopes and intercepts, and they are the parameters to be estimated from a sample of the complete dataset (the claimant dataset is such a sample). For example, the slope and intercept of the complete dataset for 1953 is (1.343, 2.614). The claimant dataset of k = 731 workers (some of whom do not have results in 1953) has a slope and intercept of (1.328, 2.623) for 1953. If the complete dataset was not available, the slope and intercept of the claimant dataset for 1953 would be the logical choice to be the estimate of the complete dataset slope and intercept for 1953. The natural question at this point is how good an estimate is the slope and intercept of the claimant data; that is, how close is it to the slope and intercept of the complete dataset?

One way to answer this question begins with an examination of the distribution of annual slopes and intercepts that can be calculated from all possible samples of k = 731 claimants of the n = 7537 monitored workers. There are:[8]

$$C = \frac{7537!}{731!(7537-731)!} = 2.8189 \cdot 10^{1040} \tag{5-1}$$

equally probable ways of selecting 731 different workers from a population of 7537 workers. Each of the C combinations of the 731 workers can potentially have a different collection of bioassay results[9] with its own slope and intercept for each year. Note that only one of these C ways (the claimant dataset) was actually observed (realized). In theory, the slope and intercept for each of the C datasets for each year could be calculated, and the ranges where most (95% for example) of the slopes and intercepts occurred could be established. For a given year, the estimated slope and intercept would be considered to be statistically the same as the true slope and intercept if the estimated slope and intercept fall in the range where 95% of the results would be observed.

While theoretically possible, the calculations above are not feasible because of the immense number of samples of size k = 731 that can be drawn from the complete dataset. However, the 95% range

8 The number of combinations, n choose k or nCk, was calculated with Maxima 5.15.0 (SourceForge 2008). Note that the order of the workers does not count and a particular worker only appears once in each sample of 731 workers.
9 Selecting workers rather than bioassay results is an example of clustered sampling.

can be estimated using the following simulation, which is a type of bootstrap analysis (Efron and Tibshirani 1998; Davison and Hinkley 1997):

1. Assume that there are *n* workers in the complete dataset and *k* claimants in the claimant dataset, where $n > k$ and the claimant dataset is a subset of the complete dataset.

2. Calculate the slope and intercept of the lognormal fit to the bioassay results for the claimant dataset for each year. Do the same for the complete dataset and plot these two points.

3. Randomly draw $k = 731$ workers without replacement[10] from the complete dataset. Fit a lognormal model to the bioassay results for the *k* workers for each year.

4. Repeat step 3 *m* times (e.g., $m = 1000$ times). Note that each time the experiment is run a new set of *k* bootstrap workers are drawn and new slopes and intercepts are calculated for each year.

5. Plot the *m* points for each year at their slope *x* and intercept *y* coordinates.

6. Calculate a 95% joint confidence ellipse of all *m* slopes and intercepts for the bootstrap workers in each year.

For example, the results of the bootstrap analysis for $k = 731$ and $m = 1000$ for 1953 are shown in Figure 5-1, where:

- The solid red point is the slope and intercept (1.343, 2.614) of the complete dataset.

- The solid blue point is the slope and intercept (1.328, 2.623) of the claimant dataset.

- The open pink points are the slopes and intercepts of the fits to the *m* random sets of 731 workers taken from the complete dataset.

- The ellipse is the 95% joint normal confidence ellipse.

- The numbers in the corners are the full scale of the respective axes in terms of positive and negative percentages of the slope or intercept of the complete dataset.

The desired result is that the slope and intercept of the claimant data are close to the slope and intercept of the complete data. One way to gauge how close the two points are is to see if the slope and intercept of the claimant data falls in the 95% confidence ellipse of the bootstrap samples. When they do, it is concluded that the slope and intercept of the claimant data is statistically no different than the slope and intercept of a true random sample of 731 workers from the complete dataset. As can be seen in Figure 5-1, there was excellent agreement for 1953. If there is a strong tendency for the slopes and intercepts of the claimant data to fall in the 95% confidence ellipse each year, this would be evidence to support the assumption that the claimant dataset behaves as if it were a random sample from the complete dataset. In addition, it is important to note that two sets of slopes and intercepts can be statistically different but practically the same. For example, Table 5-1 lists a summary of the percentiles for the claimant and complete datasets for 1953.

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[10] "Without replacement" means that no workers appear more than once in any given sample of k workers.

Table 5-1. Summary of the percentiles for the claimant and complete Y-12 datasets for 1953.

Dataset	50th percentile	84th percentile
Claimant	13.77	51.98
Complete	13.66	52.29

Whether or not the percentiles of the claimant dataset for 1953 are different statistically , in consideration of how these percentiles are to be used by an internal dosimetrist, there is clearly no difference of practical significance.

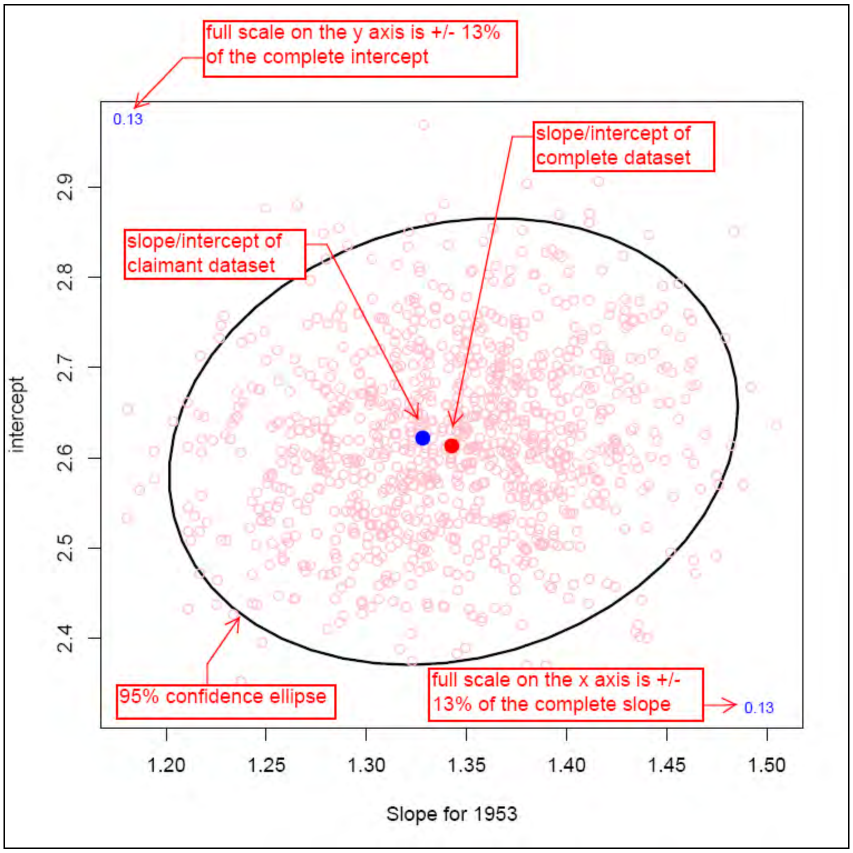

Figure 5-1. Bootstrap analysis of slope and intercept for 1953 complete Y-12 dataset with a sample of 731 workers.

5.2 Y-12 RESULTS

Based on the discussion in the previous section, the general strategy was to draw 731 unique workers at random[11] from the 7537 workers in the complete dataset and determine the slope and intercept of the fit. The results of the *m* = 1000 iterations are presented in scatter plots like the one shown in Figure 5-1 for 1953. The results of the fits for 1950 to 1988 are summarized in Table 4-1, and the plots are given in Attachment C. The slopes and intercepts of the claimant datasets fall in the 95% confidence ellipse for 34 of the 39 years. The slopes and intercepts for 1950, 1951, 1984, 1987, and 1988 fall outside of the 95% confidence ellipse.

[11] Sample without replacement.

6.0 MOUND PLUTONIUM URINE BIOASSAY DATA AND RESULTS

For the Mound Laboratory a single plutonium urine bioassay dataset, PURECON, was provided for 1960 to 1990 along with a list that identified claimants in the dataset. This list was used to extract claimants from the complete dataset to construct the claimant dataset.

The PURECON database was established in 1991 by work performed by the University of Lowell Research Foundation. This work was undertaken to meet the requirements of DOE Order 5480.11, *Radiation Protection for Occupational Workers* (DOE 1988), which became effective on January 1, 1989. Mound staff recognized the need to develop more reliable internal dosimetry recordkeeping for plutonium; this resulted in the construction of a computer database from the original raw data. Subsequent quality assurance and repair work on the PURECON database has been performed (and documented) by the MJW Corporation during its work on the Pre-1989 Dose Assessment Project (MJW 2002). PURECON is considered to be a complete dataset.

There are 2070 workers in the complete dataset who submitted a total of 53340 plutonium urine samples. Urine samples that were influenced by chelation therapy were not included in the analysis. The year-by-year breakdowns of the total number of submitted samples and total number of monitored workers are shown in Figures 6-1 and 6-2, respectively. The total number of submitted samples per worker ranged from a minimum of 1 to a maximum of 235 in the 31-year monitoring period; the median was 12 samples. An empirical probability density plot of the samples per worker is shown in Figure 6-3.

The claimant dataset is a subset of the complete dataset; that is, all of the claimants are workers. A total of 225 claimants submitted 8849 plutonium urine samples. The total number of submitted samples per claimant ranged from a minimum of 1 to a maximum of 200 in the 31-year monitoring period; the median was 24 samples. The year-by-year breakdowns of the number of submitted samples and number of monitored claimants are shown in Figures 6-4 and 6-5, respectively. The empirical probability density plot of samples per claimant is shown in Figure 6-6.

A summary of the number of samples and workers in the claimant and complete datasets is given in Table 6-1. A summary of the slopes and intercepts of the fits to the complete and claimant data is given in Table 6-2. The lognormal probability plots for the complete and claimant datasets are given in Attachments D and E, respectively.

Following the general procedure established for the Y-12 data, k = 225 unique workers were drawn at random without replacement from the n = 2070 workers in the complete dataset and the slope and intercept of the fit determined. The results of the m = 1000 iterations of this process are presented in scatter plots for 1960 to 1990 in Attachment F. The slopes and intercepts of the claimant datasets fall inside the 95% confidence ellipse for 29 out of 31 years. The slopes and intercepts for 1983 and 1984 fall outside of the 95% confidence ellipses.

Table 6-1. Summary of samples and workers in claimant and complete Mound datasets by year.

Year	Workers			Samples		
	Complete Dataset	Claimant Dataset	Ratio	Complete Dataset	Claimant Dataset	Ratio
1960	88	12	0.14	336	51	0.15
1961	178	30	0.17	802	135	0.17
1962	292	44	0.15	1385	247	0.18
1963	487	76	0.16	2009	345	0.17
1964	662	91	0.14	2625	418	0.16
1965	715	100	0.14	3203	536	0.17
1966	822	121	0.15	3520	602	0.17
1967	781	112	0.14	3611	567	0.16
1968	652	102	0.16	2815	485	0.17
1969	466	75	0.16	2425	422	0.17
1970	605	97	0.16	2716	418	0.15
1971	531	92	0.17	2264	378	0.17
1972	495	85	0.17	2568	470	0.18
1973	505	88	0.17	2177	392	0.18
1974	442	78	0.18	1940	353	0.18
1975	391	72	0.18	1533	297	0.19
1976	363	70	0.19	1134	207	0.18
1977	405	70	0.17	1270	227	0.18
1978	409	76	0.19	1321	227	0.17
1979	447	85	0.19	1188	239	0.20
1980	445	82	0.18	1181	232	0.20
1981	461	83	0.18	1235	246	0.20
1982	440	72	0.16	1198	211	0.18
1983	444	67	0.15	1247	202	0.16
1984	446	66	0.15	1262	174	0.14
1985	461	62	0.13	1325	163	0.12
1986	435	57	0.13	1151	134	0.12
1987	415	55	0.13	818	96	0.12
1988	391	52	0.13	793	103	0.13
1989	430	55	0.13	899	116	0.13
1990	603	69	0.11	1389	156	0.11

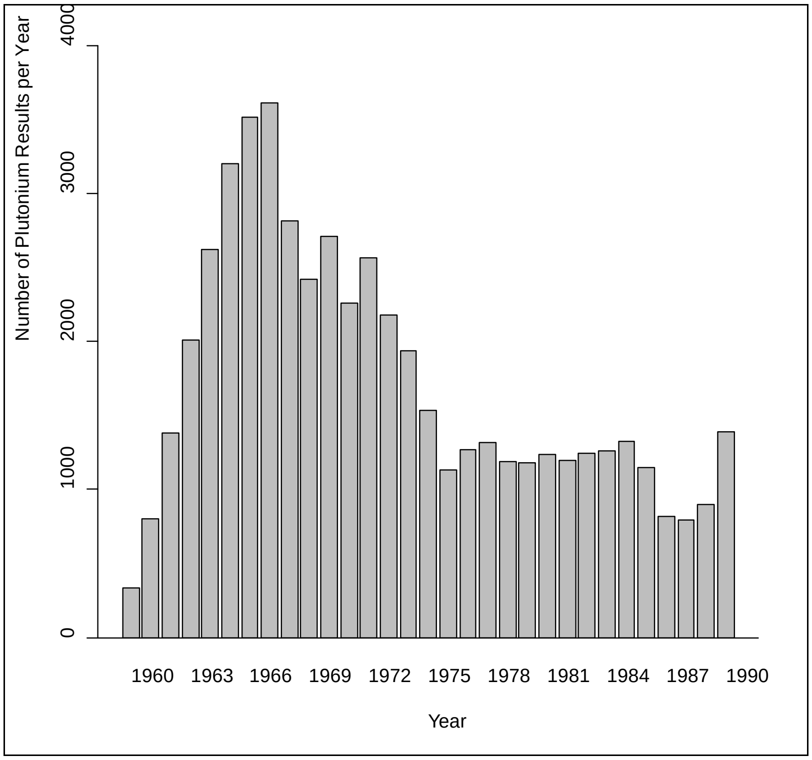

Figure 6-1. Number of samples submitted per year by all Mound workers.

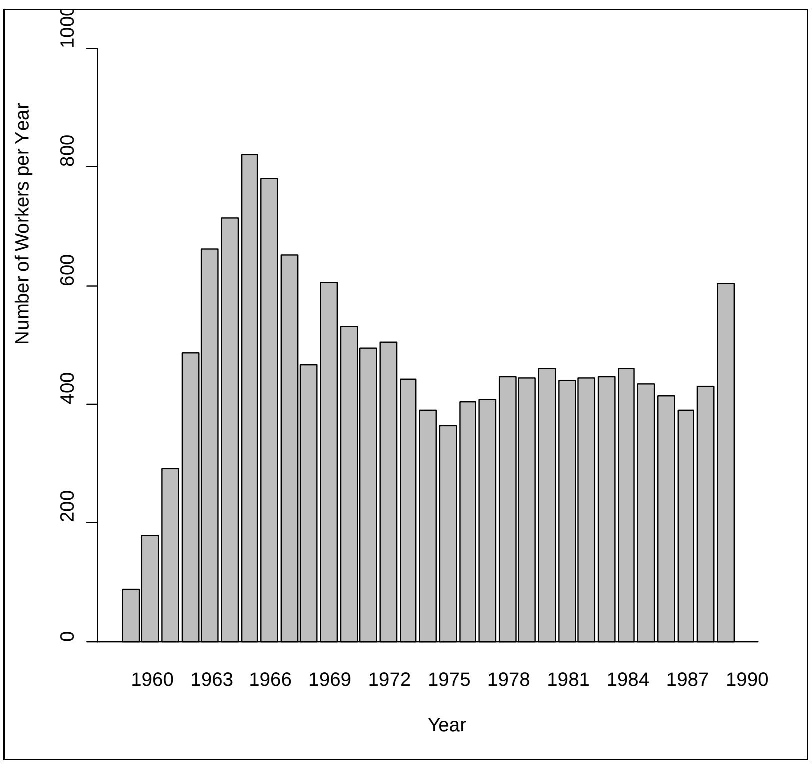

Figure 6-2. Number of Mound workers monitored in each year.

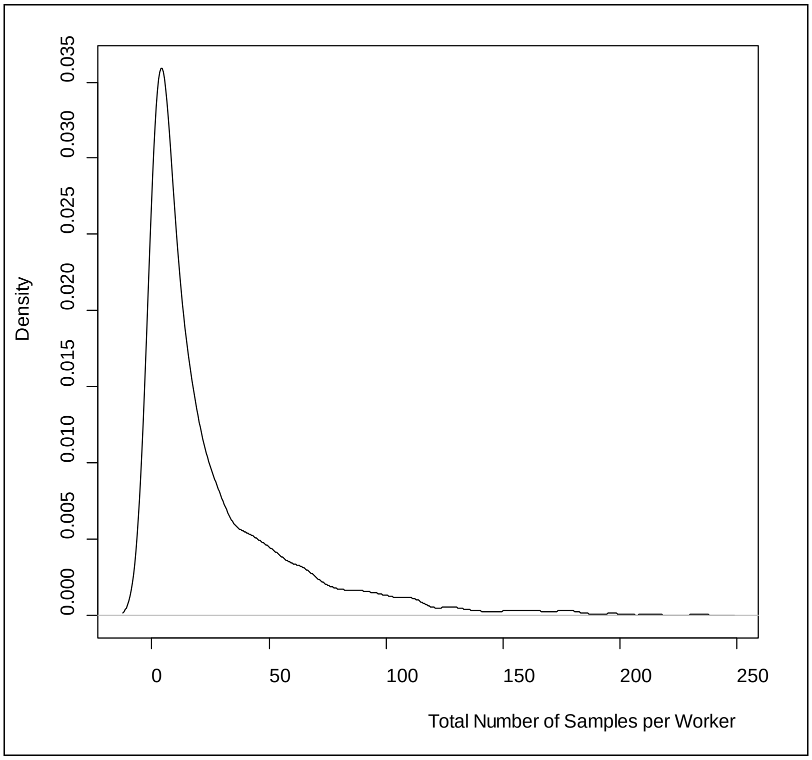

Figure 6-3. Empirical probability density plot of samples per Mound worker.

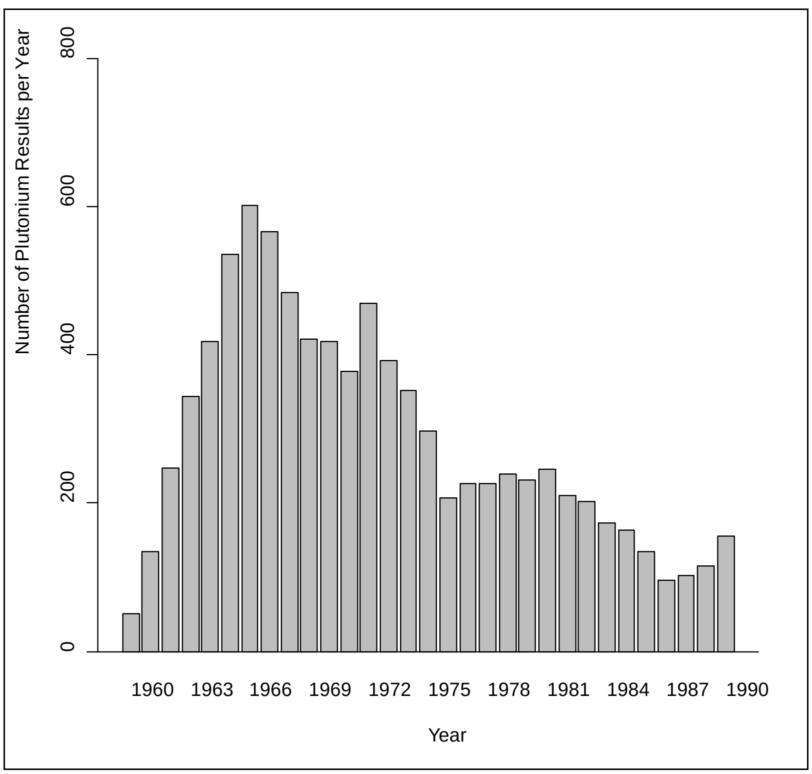

Figure 6-4. Number of samples submitted per year by all Mound claimants.

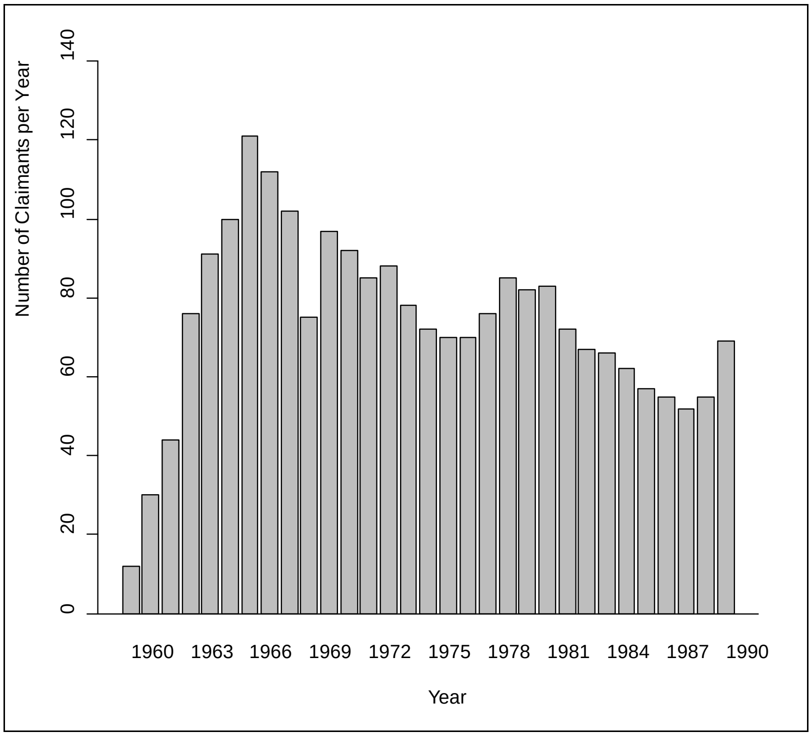

Figure 6-5. Number of Mound claimants monitored in each year.

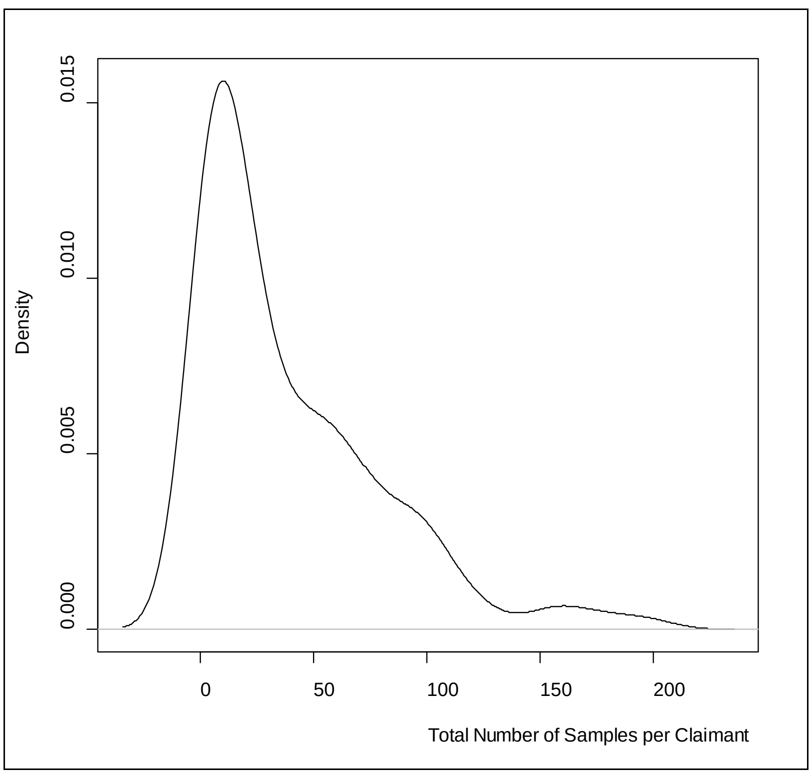

Figure 6-6. Empirical probability density plot of samples per Mound claimant.

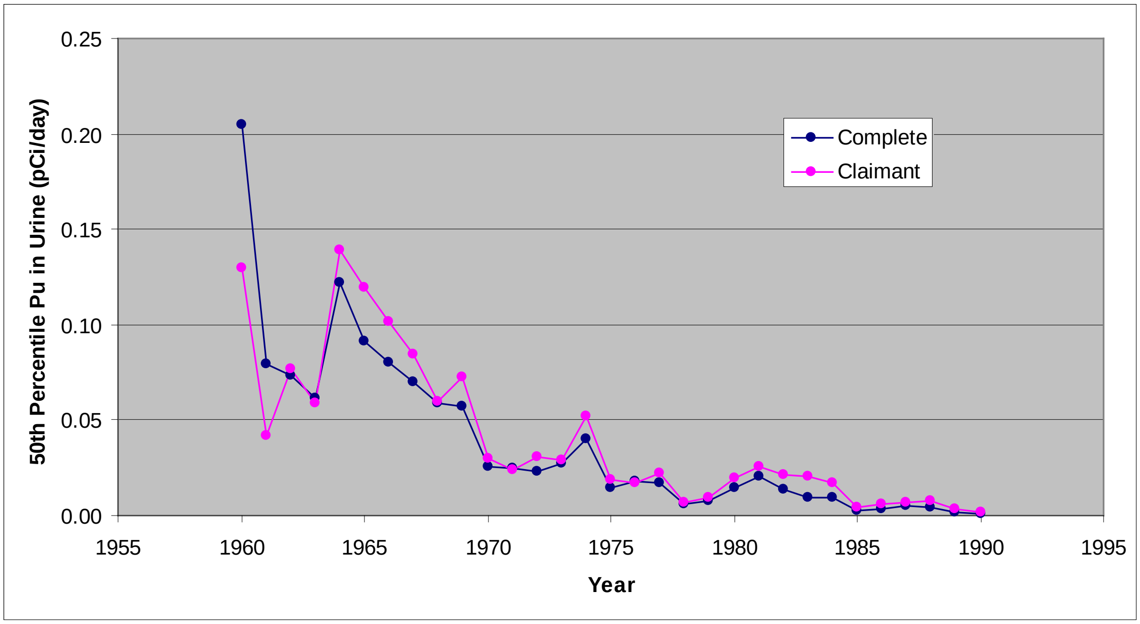

Figure 6-7. Comparison of 50th percentiles for the complete and claimant Mound datasets.

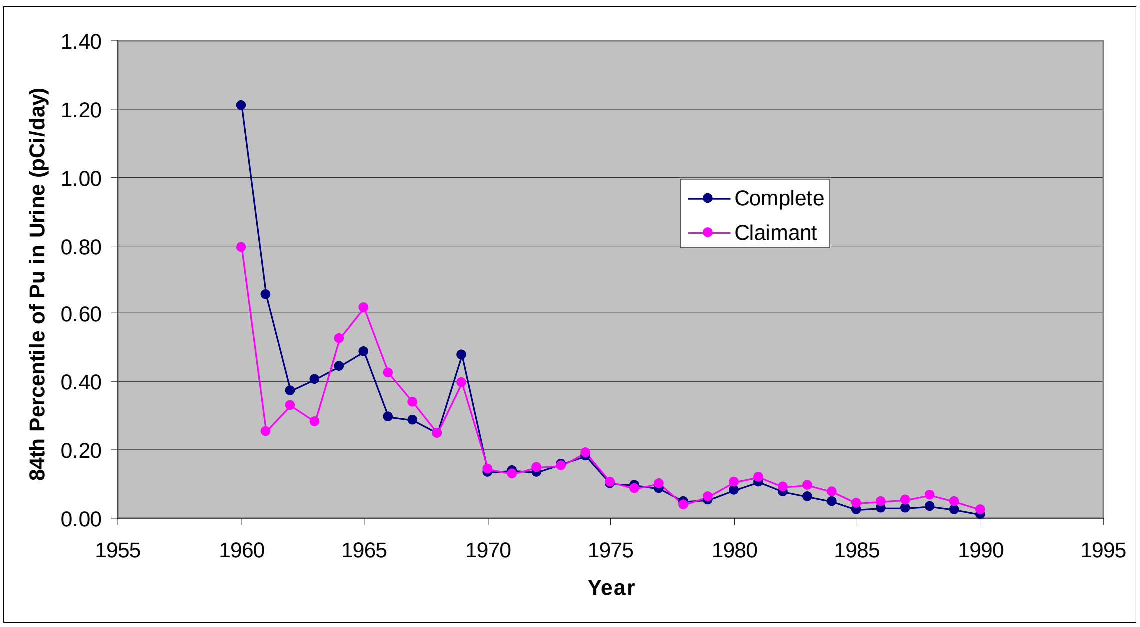

Figure 6-8. Comparison of 84th percentiles for the complete and claimant Mound datasets.

Table 6-2. Summary of the slopes and intercepts of a fit to a lognormal probability model and the corresponding 50th and 84th percentiles for Mound. The corresponding plots are in Attachments D and E.

Year	Complete slope	Complete intercept	Claimant slope	Claimant intercept	Complete 50th Percentile	Complete 84th Percentile	Claimant 50th Percentile	Claimant 84th Percentile
1960	1.7763	-1.5862	1.8095	-2.0435	0.204710	1.209380	0.129575	0.791393
1961	2.1146	-2.5365	1.8071	-3.1797	0.079142	0.655775	0.041599	0.253446
1962	1.6158	-2.6065	1.4565	-2.5661	0.073796	0.371351	0.076833	0.329692
1963	1.8854	-2.7882	1.5736	-2.8320	0.061533	0.405427	0.058897	0.284125
1964	1.2949	-2.1031	1.3343	-1.9731	0.122076	0.445635	0.139021	0.527915
1965	1.6706	-2.3940	1.6368	-2.1236	0.091267	0.485102	0.119601	0.614590
1966	1.3078	-2.5246	1.4308	-2.2846	0.080088	0.296159	0.101819	0.425814
1967	1.4166	-2.6593	1.3872	-2.4689	0.070001	0.288612	0.084677	0.339009
1968	1.4494	-2.8382	1.4152	-2.8119	0.058528	0.249357	0.060091	0.247422
1969	2.1301	-2.8659	1.6939	-2.6241	0.056933	0.479156	0.072503	0.394479
1970	1.6636	-3.6645	1.5592	-3.5080	0.025617	0.135208	0.029957	0.142445
1971	1.7206	-3.7142	1.6911	-3.7395	0.024375	0.136210	0.023766	0.128944
1972	1.7577	-3.7794	1.5781	-3.4781	0.022837	0.132439	0.030865	0.149560
1973	1.7519	-3.6106	1.6661	-3.5463	0.027035	0.155879	0.028831	0.152553
1974	1.5019	-3.2137	1.3124	-2.9578	0.040208	0.180547	0.051931	0.192933
1975	1.9122	-4.2239	1.6938	-3.9566	0.014642	0.099094	0.019129	0.104061
1976	1.6938	-4.0184	1.6080	-4.0822	0.017982	0.097821	0.016870	0.084226
1977	1.6241	-4.0770	1.5031	-3.8166	0.016959	0.086048	0.022003	0.098920
1978	2.0539	-5.1288	1.7285	-4.9391	0.005924	0.046193	0.007161	0.040330
1979	1.9136	-4.8783	1.8700	-4.6350	0.007610	0.051579	0.009706	0.062974
1980	1.6979	-4.2114	1.6884	-3.9503	0.014826	0.080988	0.019249	0.104152
1981	1.6252	-3.8792	1.5381	-3.6495	0.020666	0.104976	0.026004	0.121072
1982	1.7509	-4.3251	1.4625	-3.8362	0.013232	0.076214	0.021575	0.093133
1983	1.9152	-4.6603	1.5766	-3.9017	0.009464	0.064241	0.020207	0.097767
1984	1.7055	-4.6980	1.5008	-4.0907	0.009113	0.050160	0.016728	0.075025
1985	2.2658	-6.0526	2.3053	-5.4686	0.002352	0.022669	0.004217	0.042285
1986	2.1396	-5.6411	1.9829	-5.0589	0.003549	0.030153	0.006353	0.046143
1987	1.8579	-5.3456	2.0961	-5.0362	0.004769	0.030570	0.006498	0.052859
1988	2.0619	-5.5173	2.1948	-4.9160	0.004017	0.031575	0.007329	0.065796
1989	2.3594	-6.1590	2.6004	-5.6553	0.002114	0.022378	0.003499	0.047124
1990	2.5491	-7.0146	2.5931	-6.2503	0.000899	0.011499	0.001930	0.025805

7.0 SRS TRITIUM DOSE DATA AND RESULTS

The ideal type of data with which to develop a coworker model is dose data. For example, dose data are used to develop external dose coworker models. In the case of external coworker models the relevant data, if available, are reported in terms of dose. However, the datasets for most internal dose coworker models (such as Y-12 and Mound) consist of urine bioassay data. The required effort to convert all of the uranium and plutonium urine bioassay data to doses for each individual is prohibitive, so the coworker modeling is performed on the bioassay data. One case where it is feasible[12] to convert urine bioassay data to individual doses is for tritium urine bioassay data. Therefore, the SRS analysis used tritium dose data rather than tritium urine bioassay data. These doses were calculated from the tritium urine bioassay dataset that was extracted from the SRS HPRED[13] database, which is considered complete for the period of 1990 onward.

The tritium dose dataset for this analysis is for 1991 to 2001. There are 10711 workers in the complete dose dataset and 451 claimants in the claimant dose dataset. The original urine bioassay dataset from HPRED contained 521,798 individual bioassay results. It is important to note that while an individual might have hundreds of tritium urine samples in a given year, there is only one annual dose.

The year-by-year breakdowns of the total number of monitored workers and claimants are shown in Figures 7-1 and 7-2, respectively. A summary of the data in these plots is given in Table 7-1. A summary of the slopes and intercepts of the fits to the complete and claimant dose data is given in Table 7-2, and plots of these data are given in Figures 7-3 and 7-4. The lognormal probability plots for the complete and claimant datasets are given in Attachments G and H, respectively.

Once again following the general procedure established for the Y-12 data, k = 451 unique workers were drawn at random without replacement from the n = 10711 workers in the complete dataset and the slope and intercept of the fit determined. The results of the m = 1000 iterations of this process are presented in scatter plots for 1991 to 2001 in Attachment I. The slopes and intercepts of all 11 claimant datasets are within[14] the 95% confidence ellipses.

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[12] The methodology of ORAUT-OTIB-0011, *Technical Information Bulletin: Tritium Calculated and Missed Dose Estimates* (ORAUT 2004), can be implemented in a computer program that is capable of quickly calculating dose from tritium urine bioassay datasets without manual intervention.

[13] Health Protection Radiation Exposure Database.

[14] The point is considered to be within the ellipse if it falls on the ellipse.

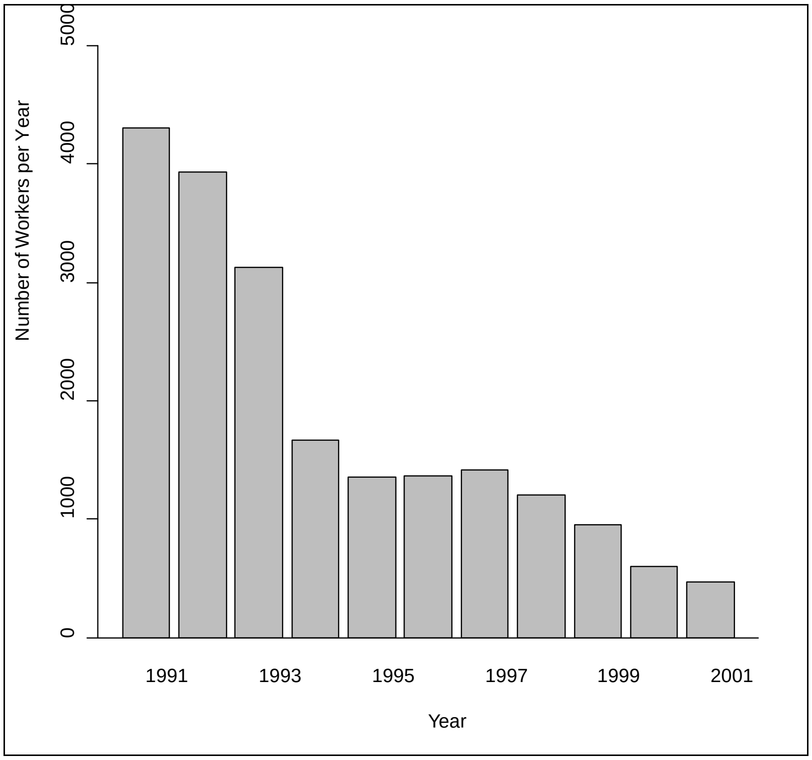

Figure 7-1. Number of SRS workers monitored in each year.

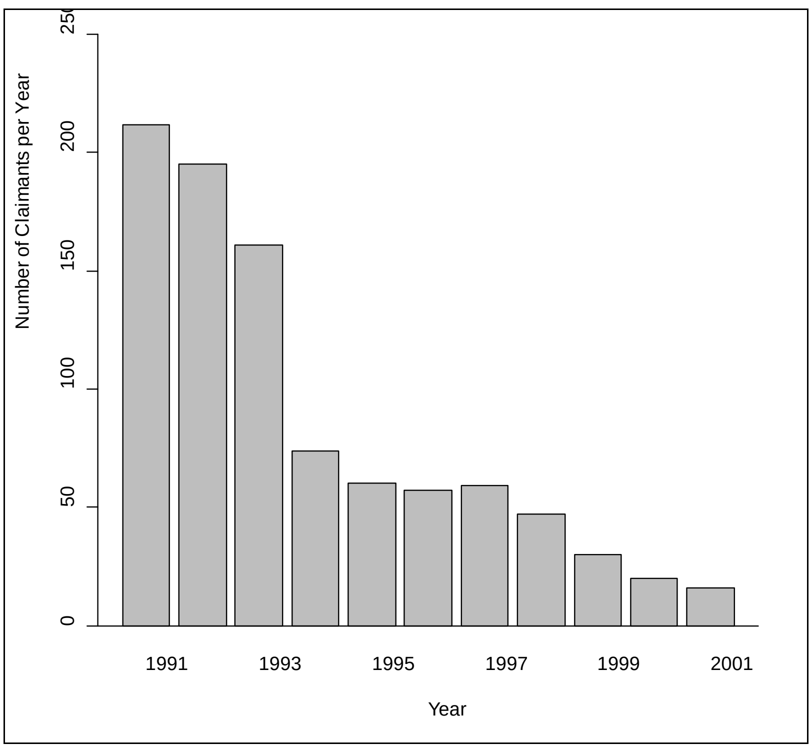

Figure 7-2. Number of SRS claimants monitored in each year.

Table 7-1. Summary of workers in claimant and complete SRS datasets by year.

Year	Workers in complete dataset	Workers in claimant dataset	Ratio
1991	4303	212	0.049
1992	3939	195	0.050
1993	3130	161	0.051
1994	1667	74	0.044
1995	1355	60	0.044
1996	1367	57	0.042
1997	1414	59	0.042
1998	1200	47	0.039
1999	953	30	0.031
2000	599	20	0.033
2001	472	16	0.034

Table 7-2. Summary of the slopes and intercepts of a fit to a lognormal probability model and the corresponding 50th and 84th percentiles for SRS. The corresponding plots are in Attachments G and H.

Year	Complete slope	Complete intercept	Claimant slope	Claimant intercept	Complete 50th Percentile	Complete 84th Percentile	Claimant 50th Percentile	Claimant 84th Percentile
1991	0.8152	1.3796	0.8207	1.4210	3.97	8.98	4.14	9.41
1992	0.6738	1.1651	0.6488	1.2351	3.21	6.29	3.44	6.58
1993	0.6499	1.0756	0.6956	1.0538	2.93	5.62	2.87	5.75
1994	0.6639	1.2011	0.6862	1.1921	3.32	6.46	3.29	6.54
1995	0.5997	1.1877	0.5610	1.1159	3.28	5.97	3.05	5.35
1996	0.5460	1.2287	0.4993	1.2180	3.42	5.90	3.38	5.57
1997	0.5025	1.2346	0.4754	1.1480	3.44	5.68	3.15	5.07
1998	0.4789	1.2311	0.4636	1.0961	3.43	5.53	2.99	4.76
1999	0.5014	1.1111	0.4378	1.0928	3.04	5.02	2.98	4.62
2000	0.4347	1.1685	0.6381	1.1710	3.22	4.97	3.23	6.11
2001	0.4514	1.1059	0.3570	1.0784	3.02	4.75	2.94	4.20

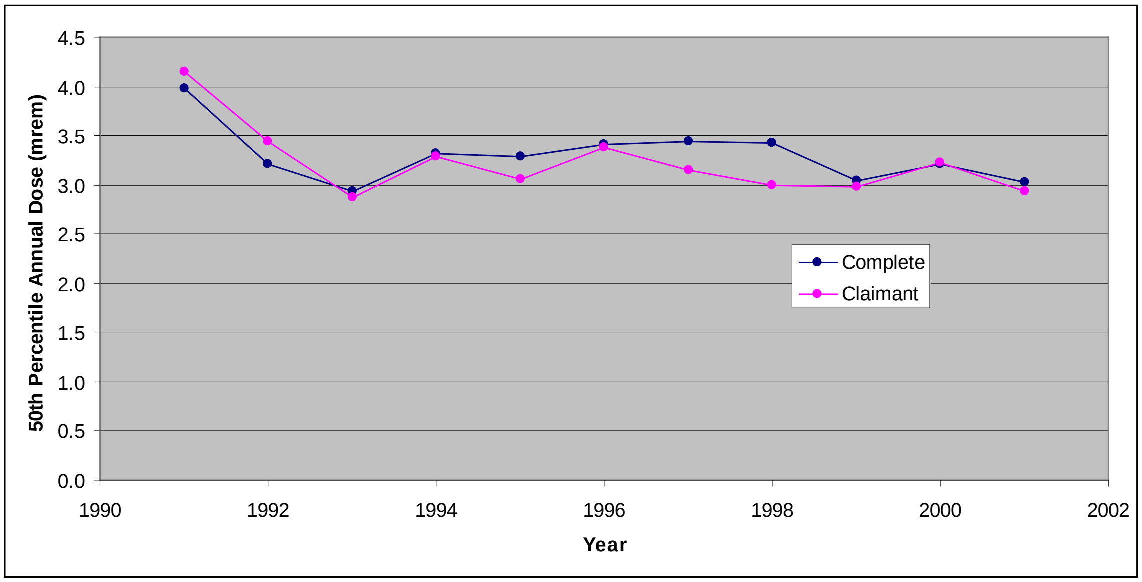

Figure 7-3. Comparison of 50th percentiles for the complete and claimant SRS datasets.

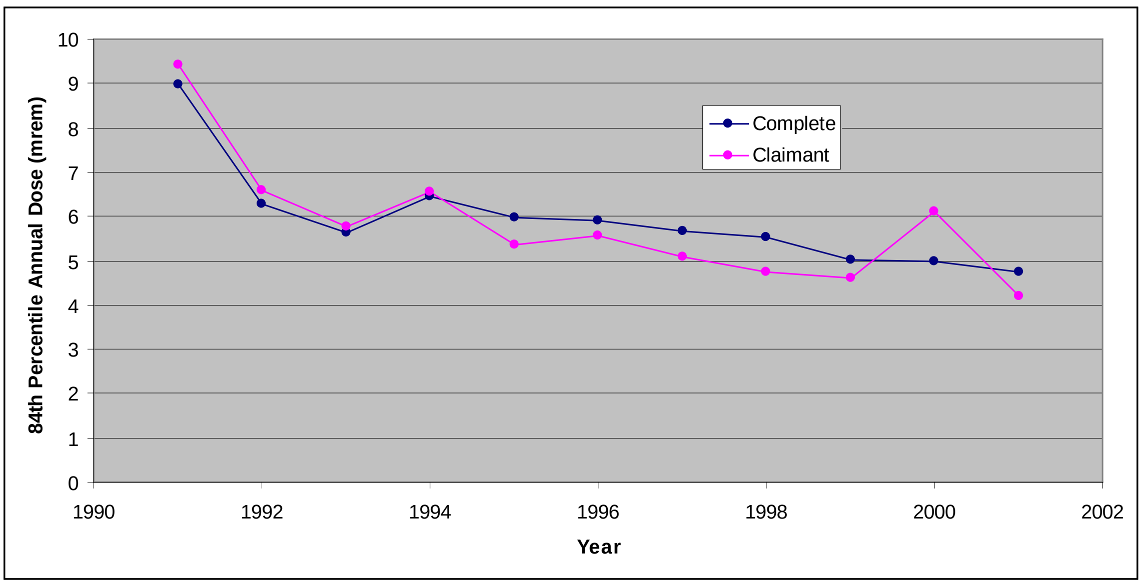

Figure 7-4. Comparison of 84th percentiles for the complete and claimant SRS datasets.

8.0 SUMMARY AND CONCLUSIONS

In the dose reconstruction process, coworker models are used to assign doses to workers who were not monitored at certain times during their employment. Coworker models of the 50th- and 84th-percentile bioassay results for specific periods are typically developed from essentially complete datasets of worker monitoring data. However, there are sites where complete worker monitoring datasets are not available for developing coworker models. Because of the considerable cost and effort necessary to create a complete dataset, there is interest in developing coworker models from a sample of the complete dataset. There is no technical reason this cannot be carried out provided that the sample is selected by a random process and is sufficiently large. Samples that are collected in this way provide unbiased estimates of the percentiles of the complete dataset and permit estimation of the uncertainty in the percentile estimates.

A sample of the complete dataset that is readily obtainable is the bioassay data of the workers who have a claim under EEOICPA that names them as the energy employee (i.e., the claimants for a site who comprise the claimant dataset). However, the claimant datasets were not intentionally selected by an appropriate sampling process, so it is not clear that they would provide unbiased estimates of the percentiles of the complete dataset. It would be ideal to show that the claimant datasets behave essentially like a random sample in relation to the parameters that are entered into coworker models. The approach taken here to show this was:

1. Select sites with well-defined claimant and complete datasets.

2. Examine the distribution of slopes and intercepts from randomly selected datasets the same size as the claimant dataset that are drawn from the complete dataset.

3. Use this distribution to determine how likely it would be to observe slopes and intercepts like those from the claimant dataset.

4. If the slopes and intercepts from the claimant dataset are indistinguishable from those from the random samples, then the claimant dataset can be used as a random sample of the complete dataset and can be used to develop coworker models.

This proof-of-principle technique was used to show that the claimant datasets from Y-12, Mound, and SRS can, in general, be used as if they were random samples for the purpose of estimating the slopes and intercepts of lognormal fits to the data. Further, this exercise can be used as a technical justification for applying this assumption to other sites for which complete datasets are not available.

9.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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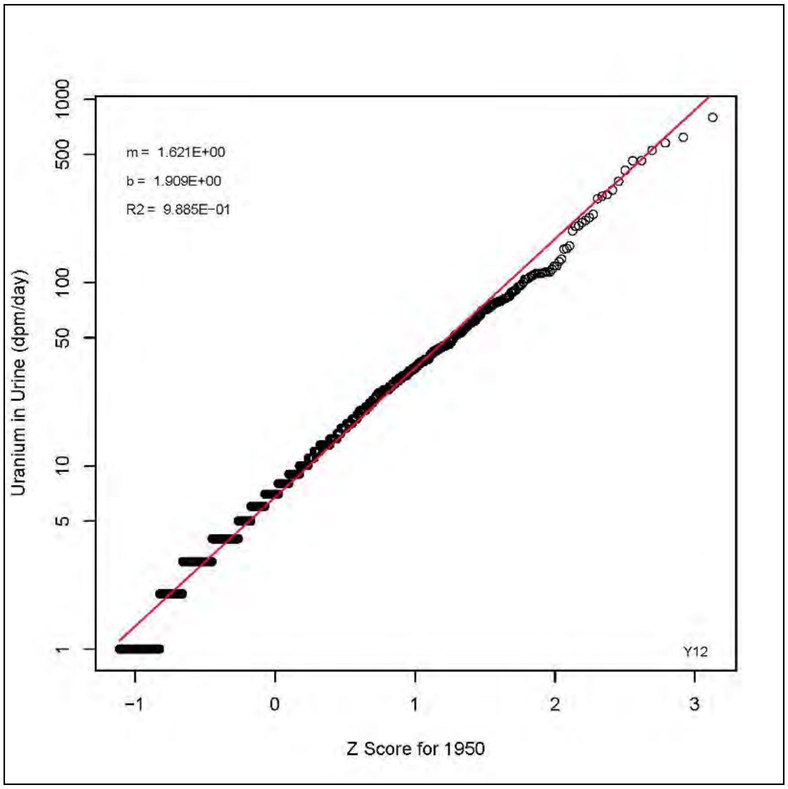
ATTACHMENT A
LOGNORMAL PROBABILITY PLOTS, COMPLETE Y-12 DATASET

This attachment presents lognormal probability plots for the complete Y-12 uranium urine bioassay dataset for 1950 to 1988. The slope and intercept for the line of best fit to the data are given on the plot.



ATTACHMENT A
LOGNORMAL PROBABILITY PLOTS,
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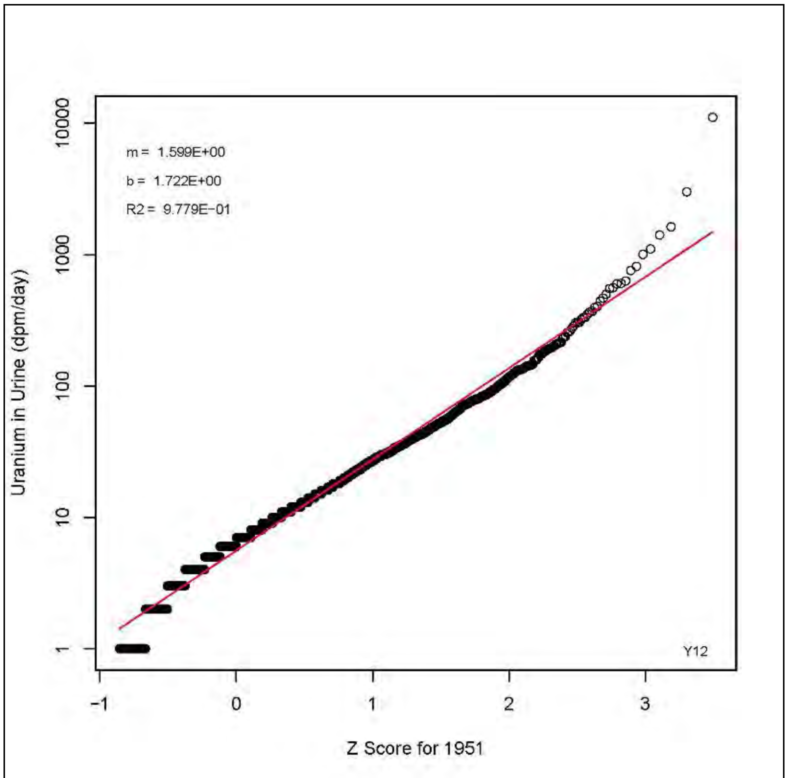

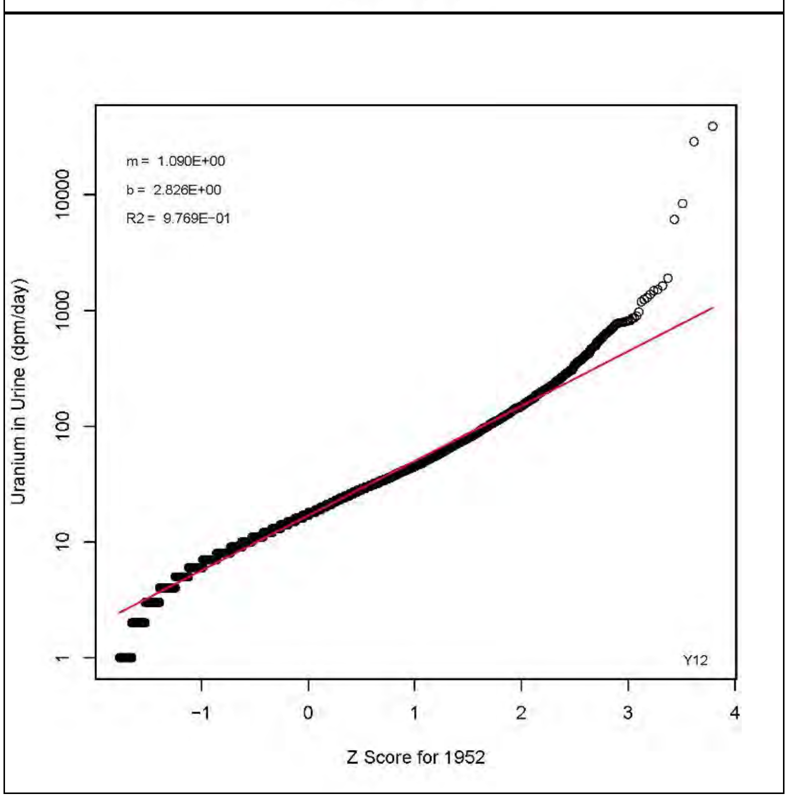

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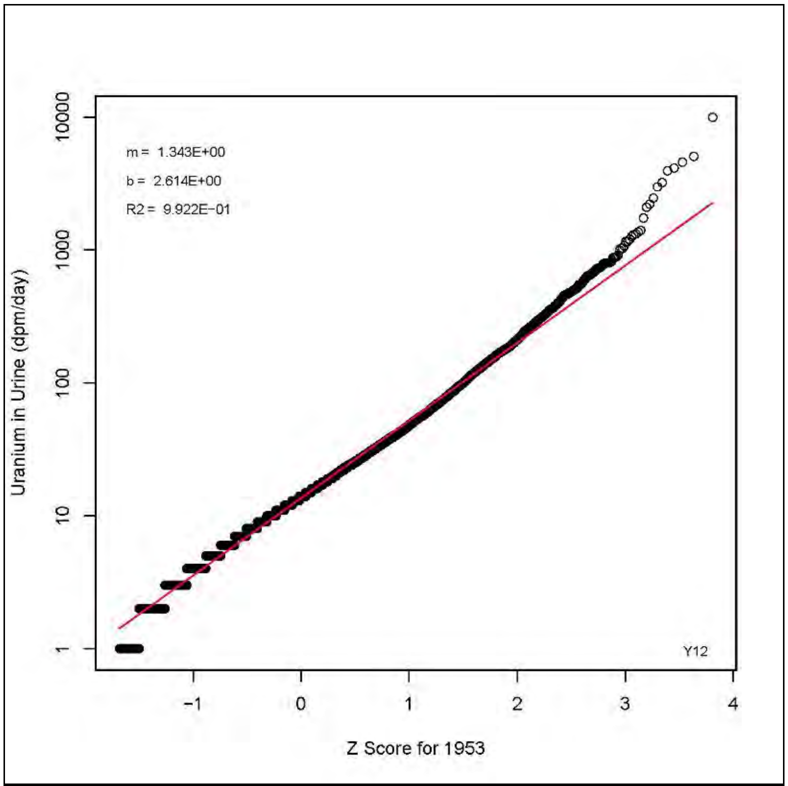

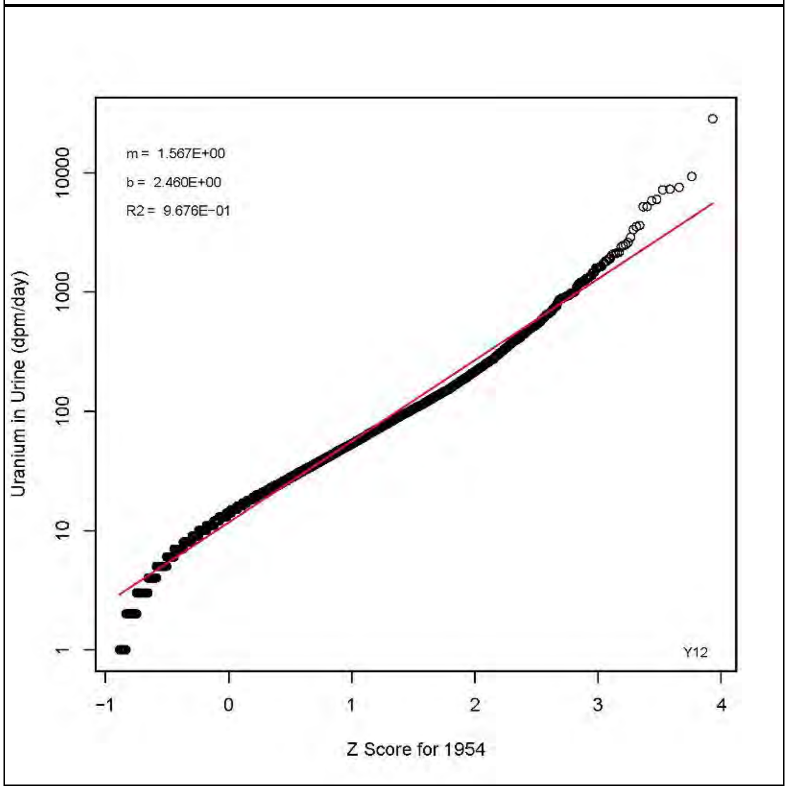

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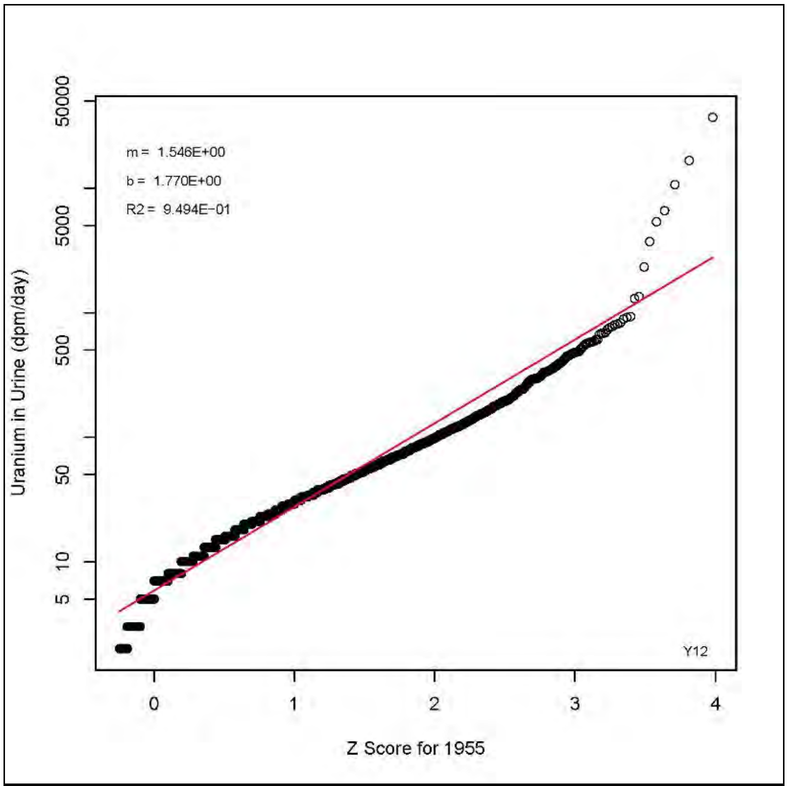

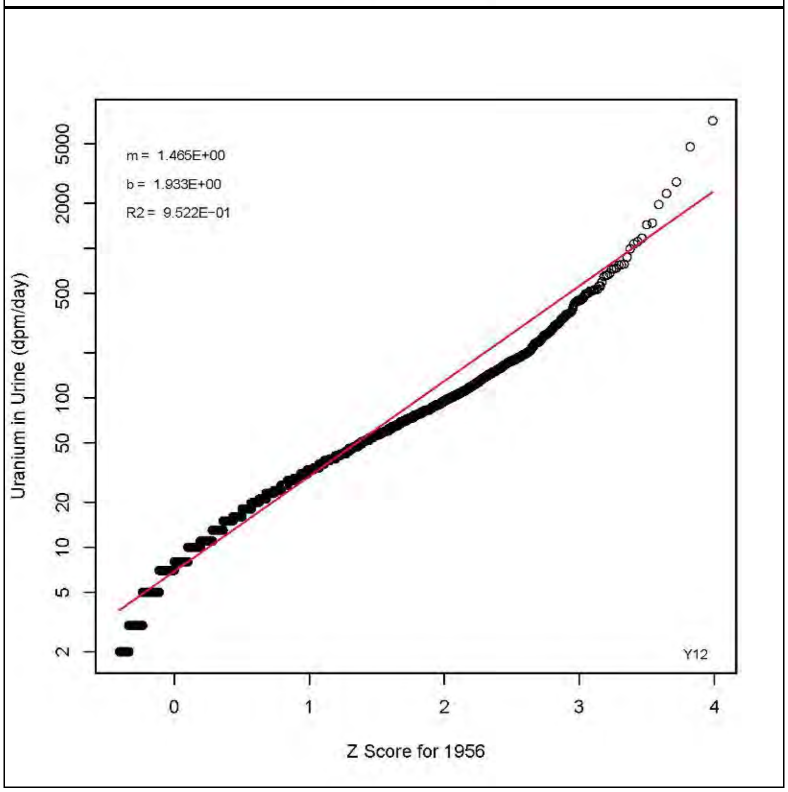

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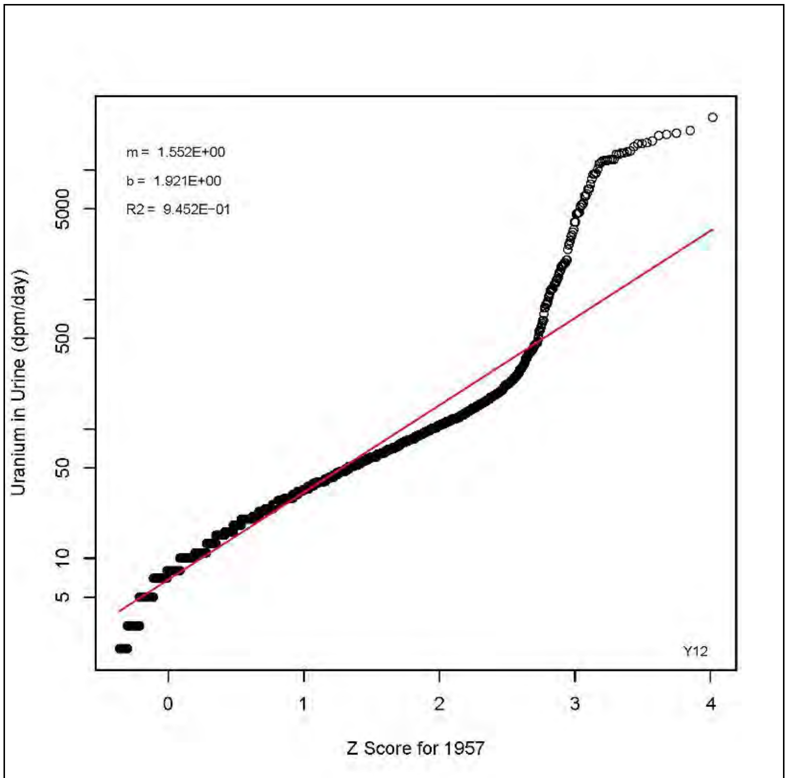

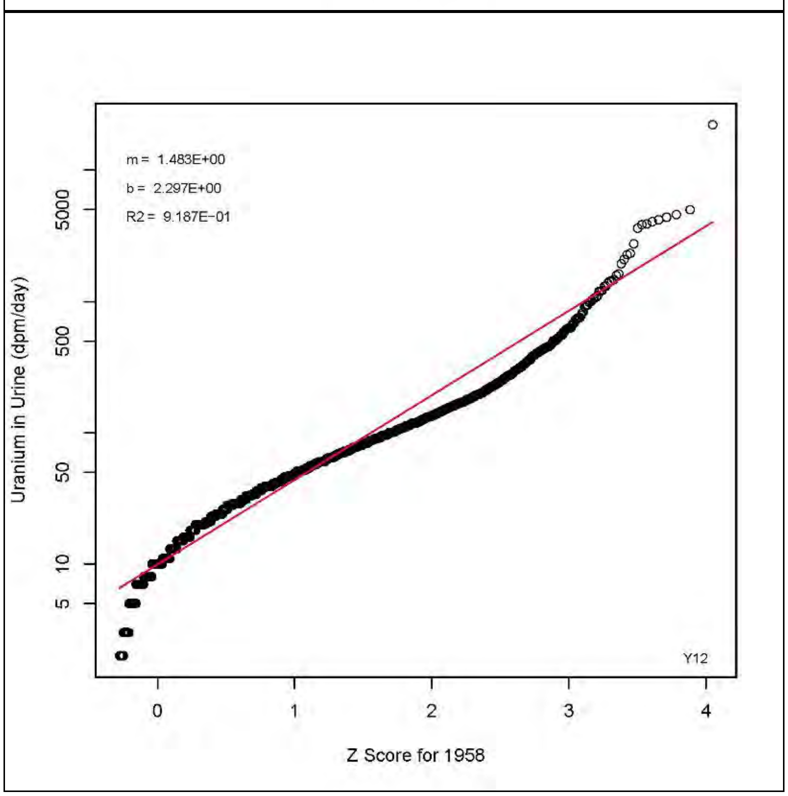

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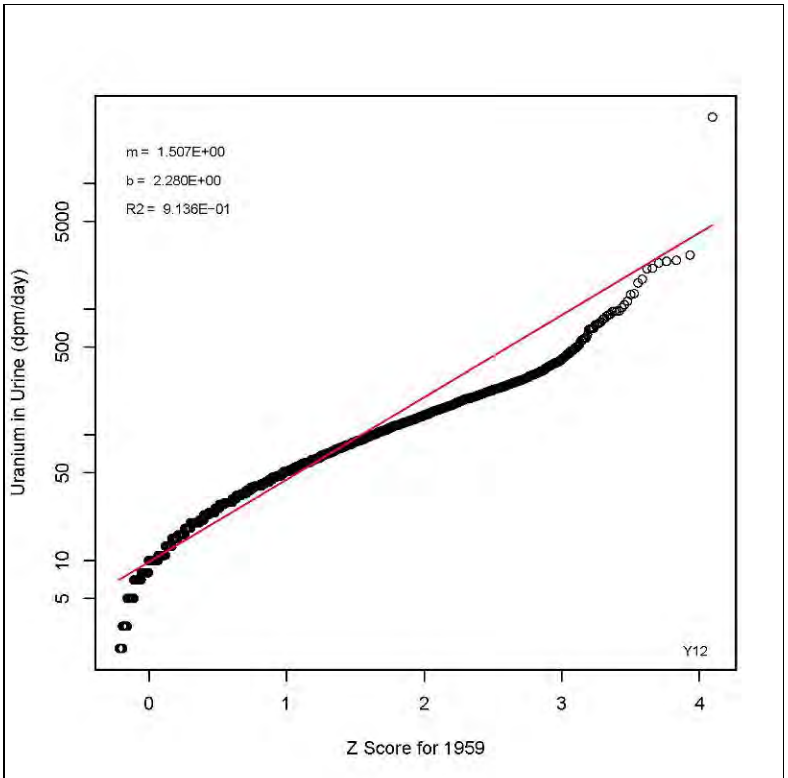

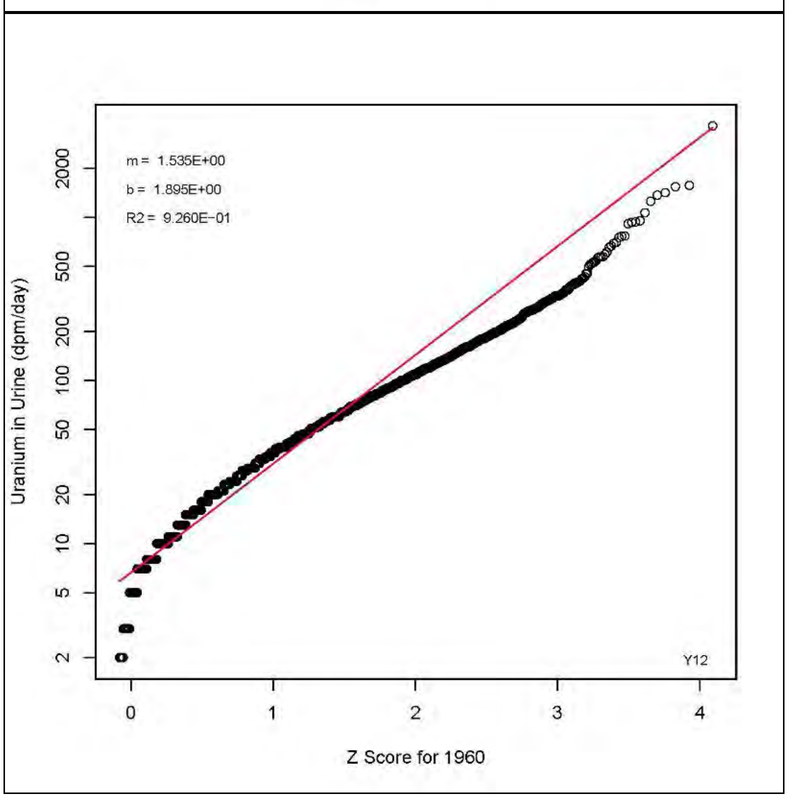

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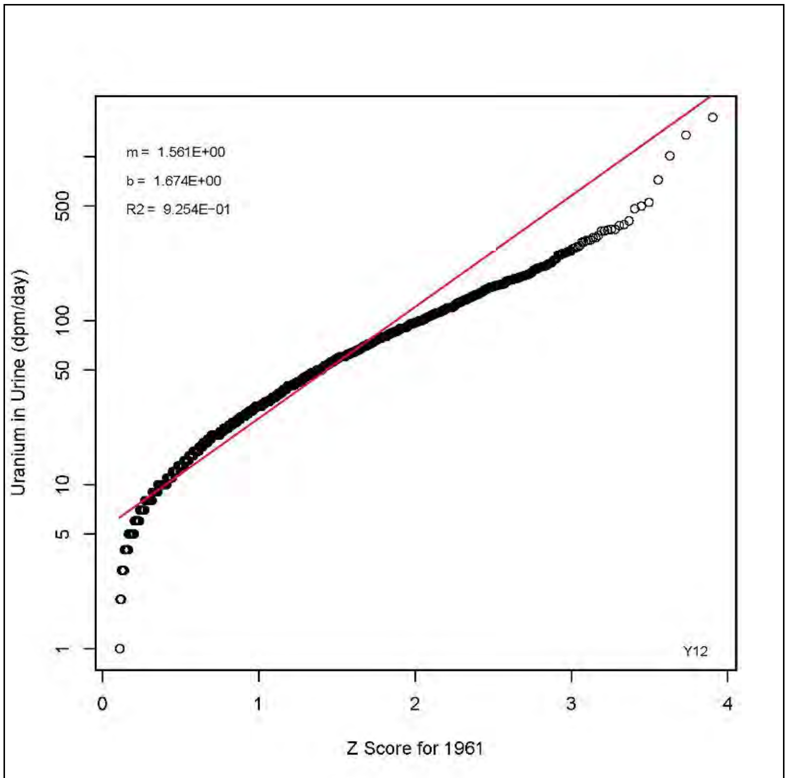

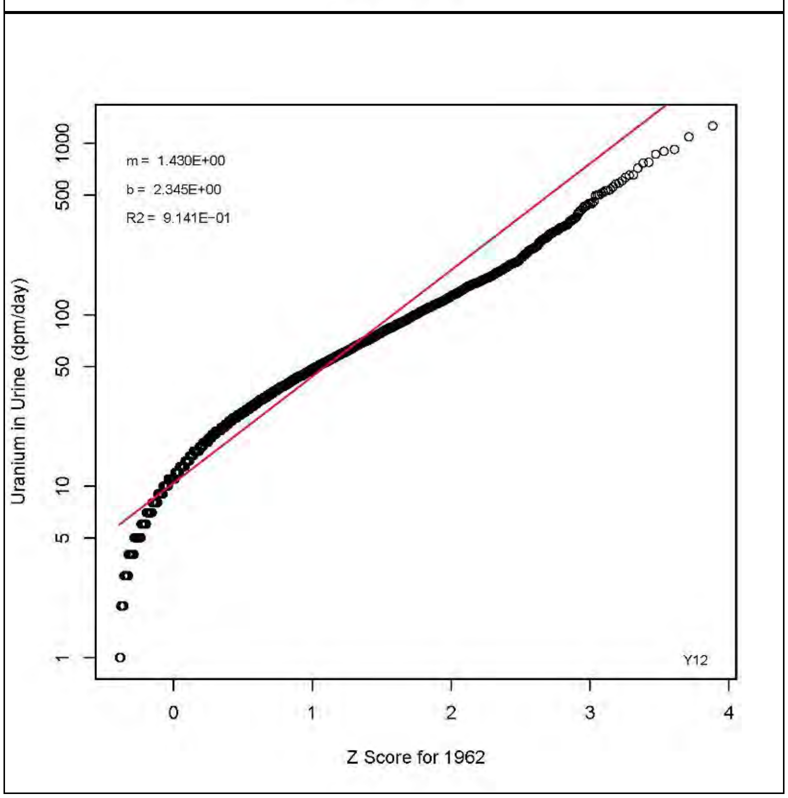

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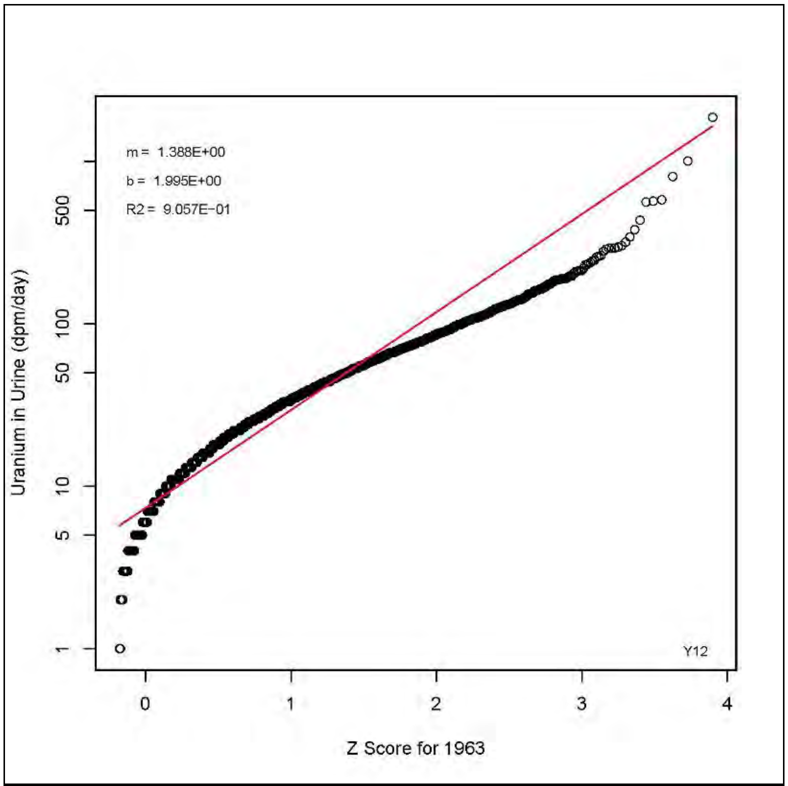

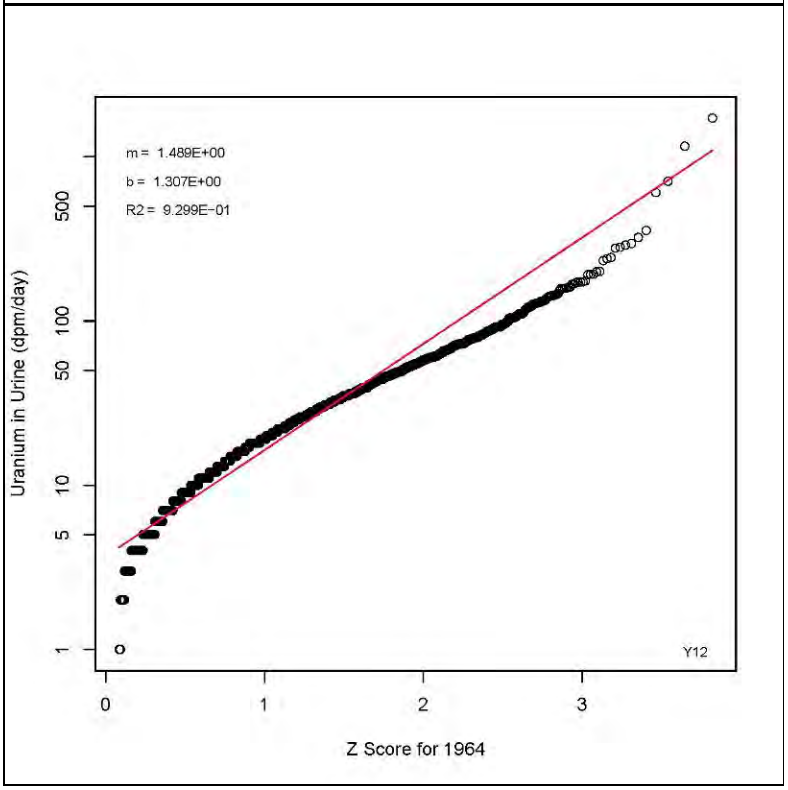

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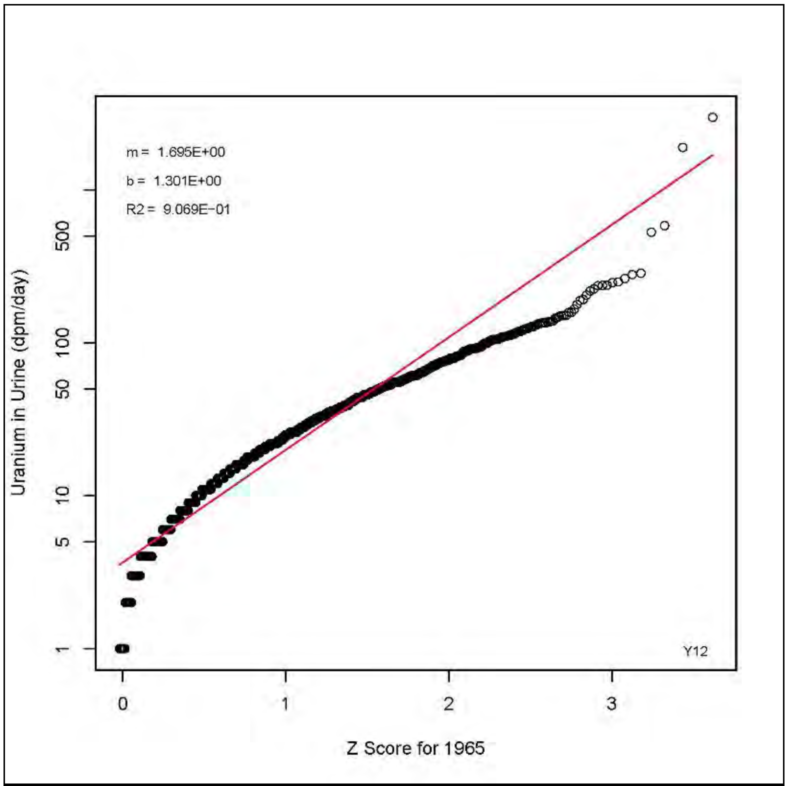

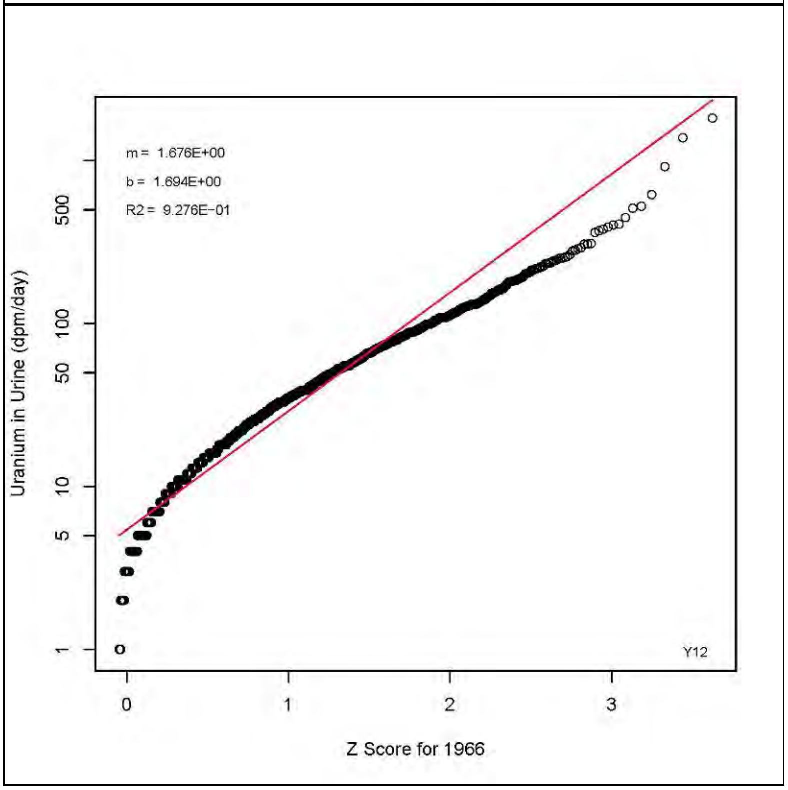

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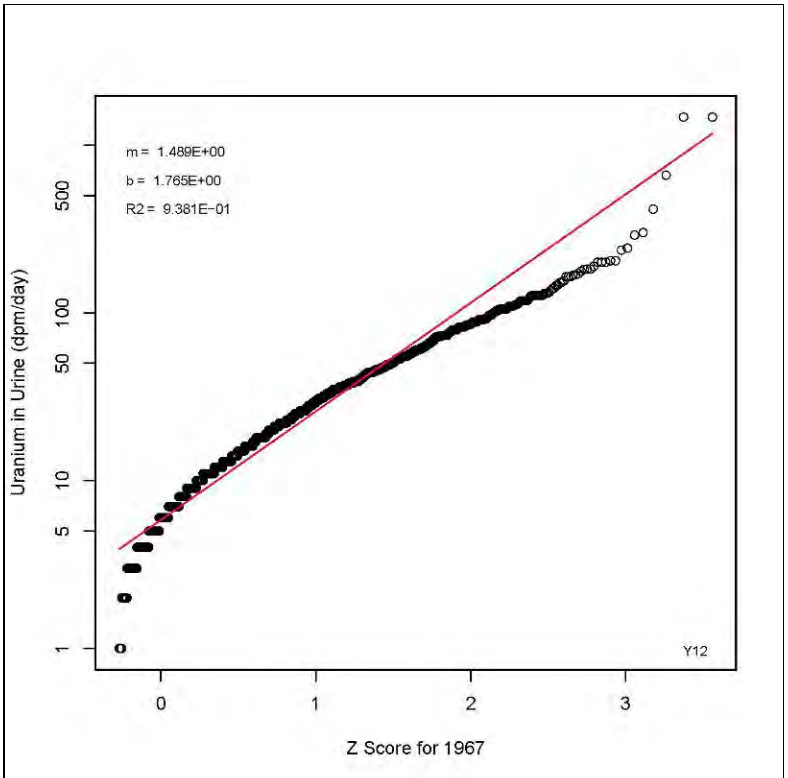

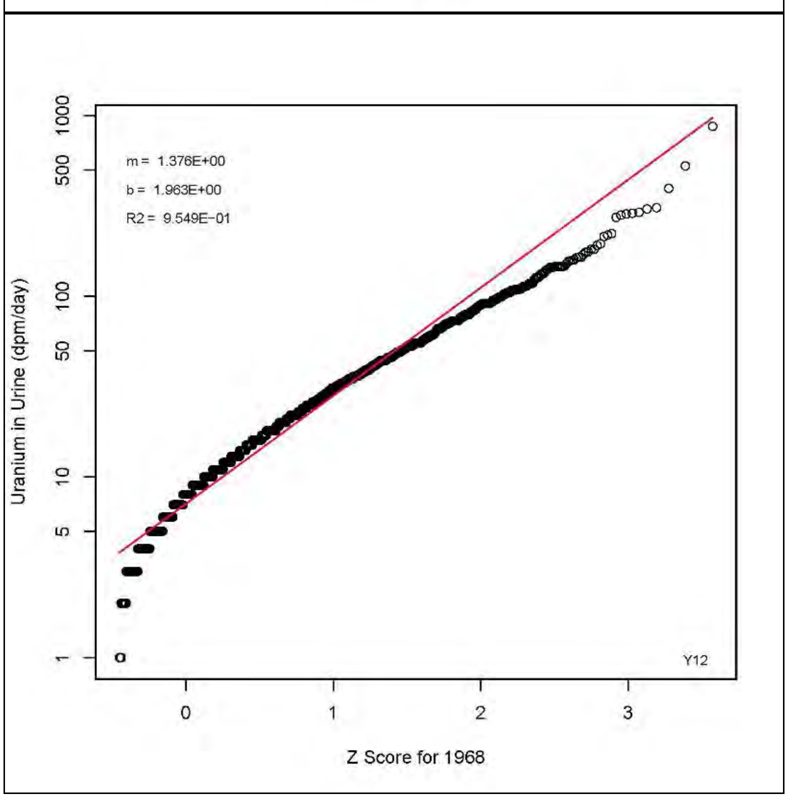

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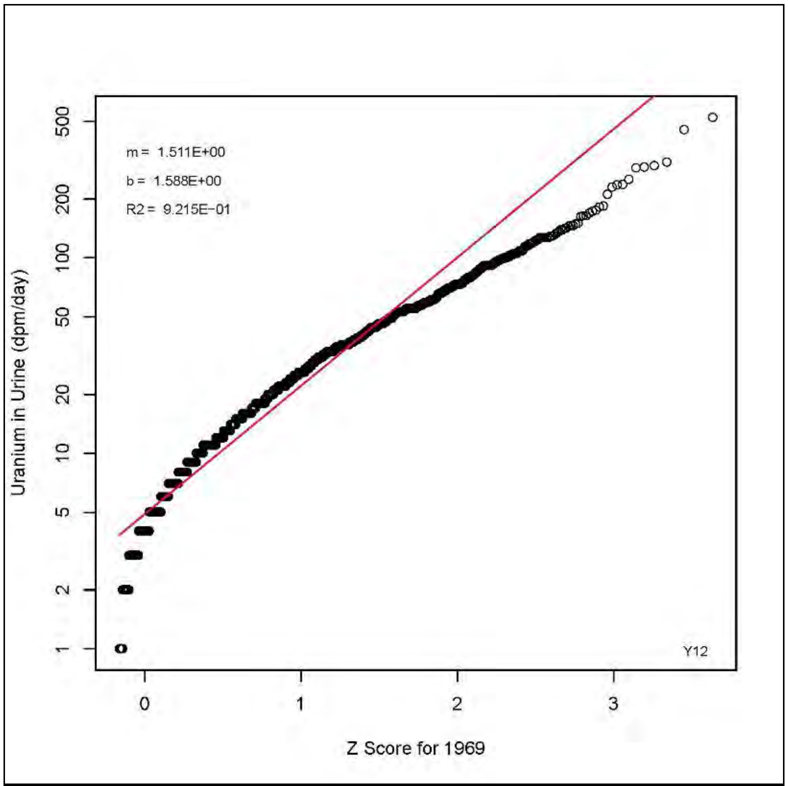

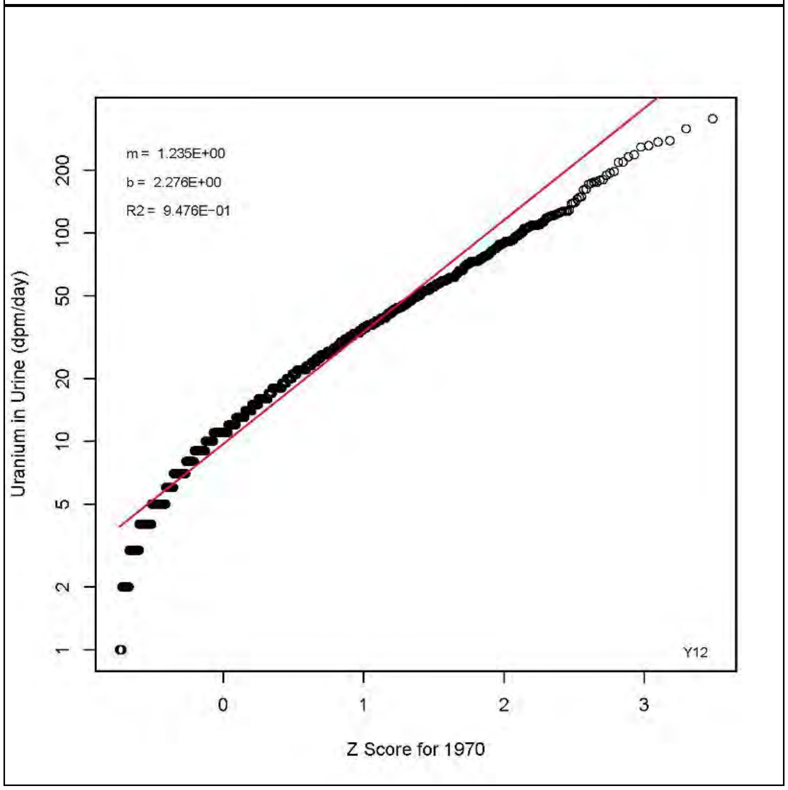

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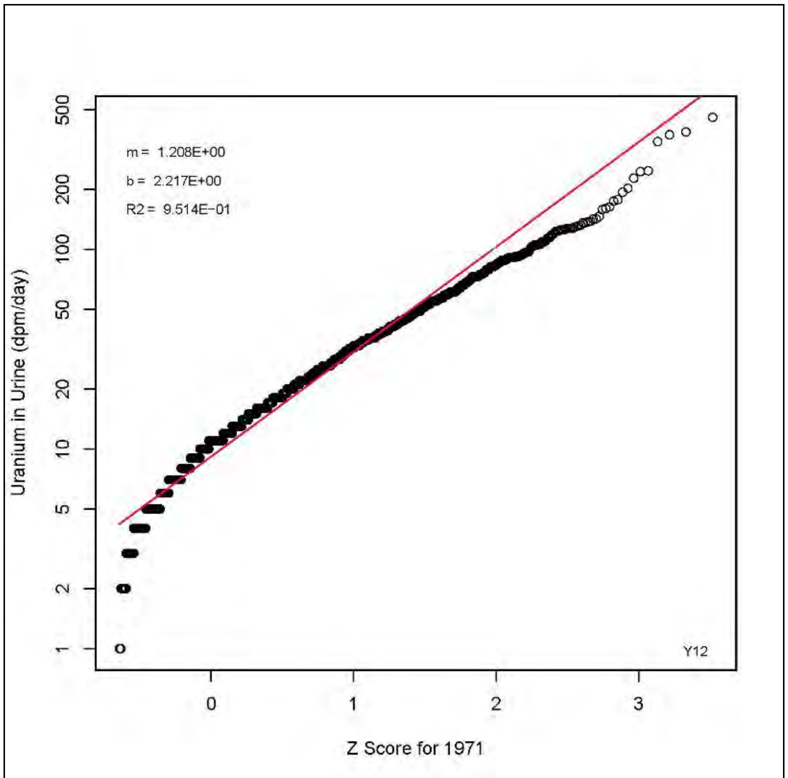

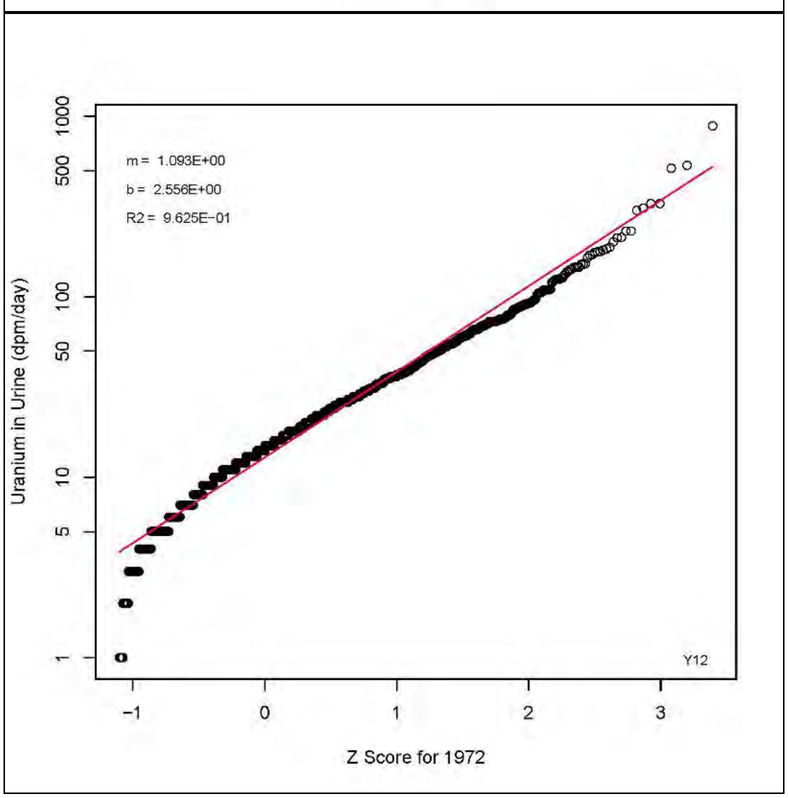

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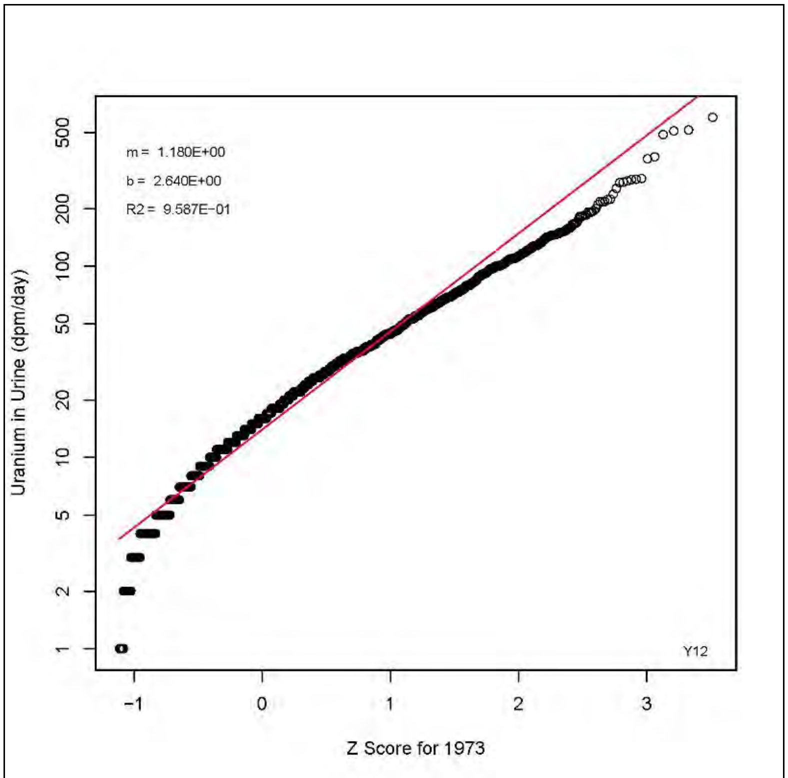

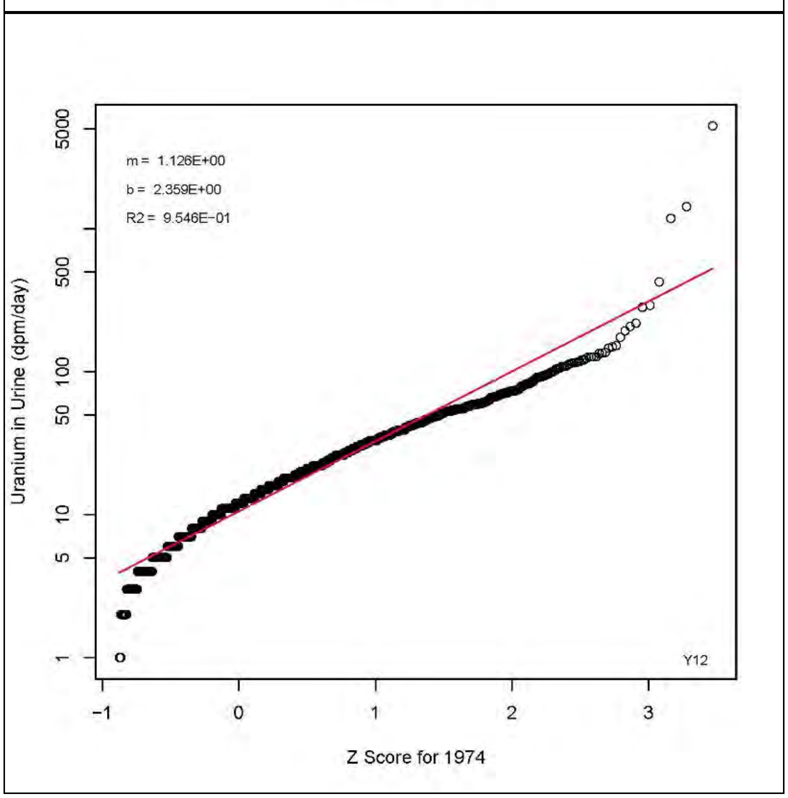

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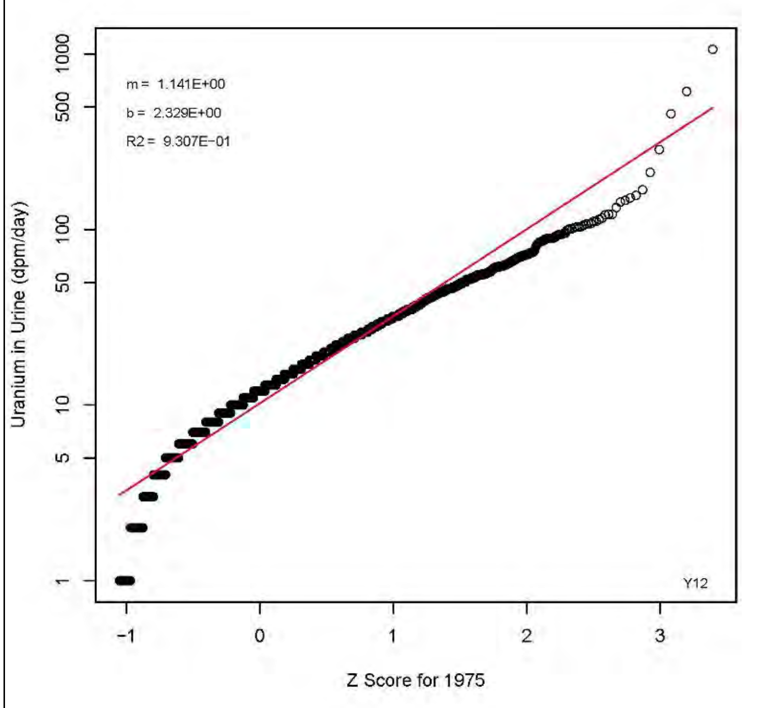

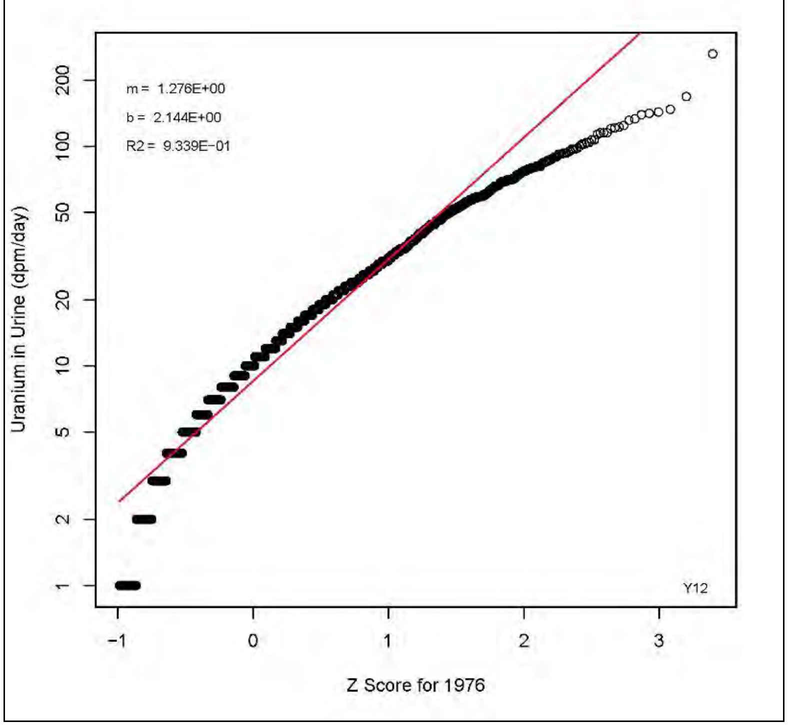

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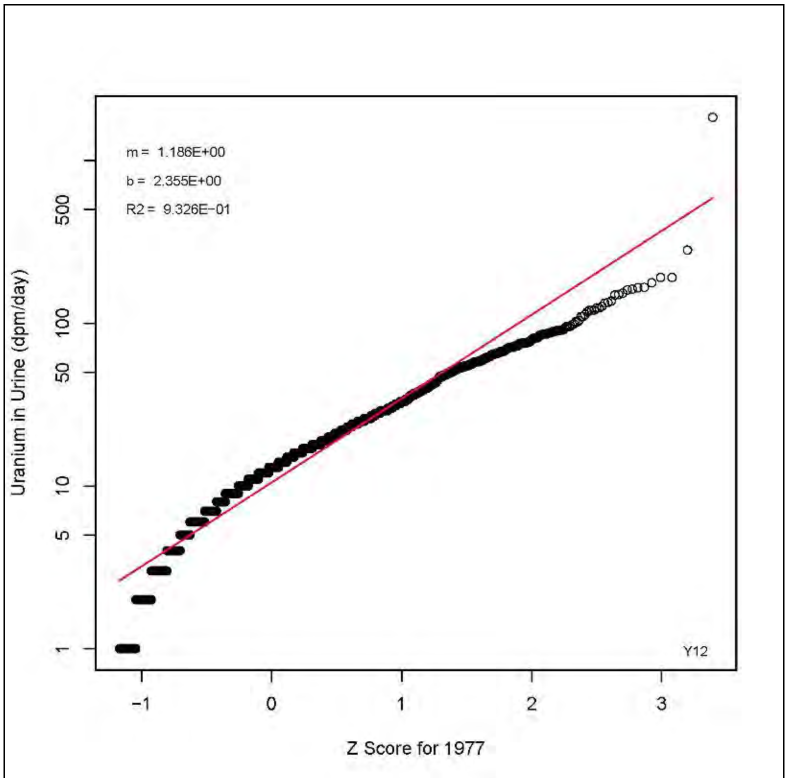

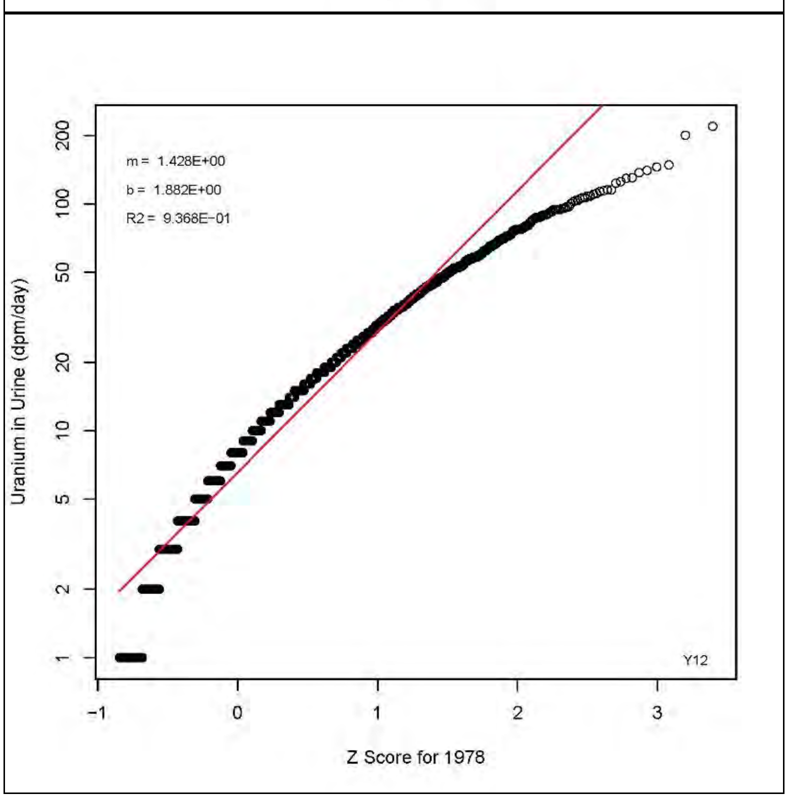

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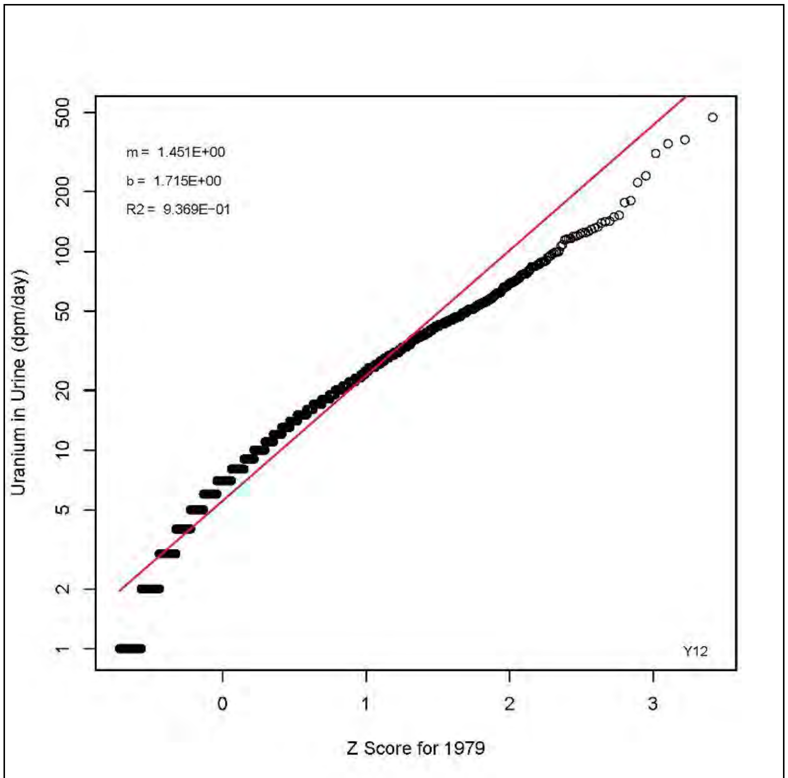

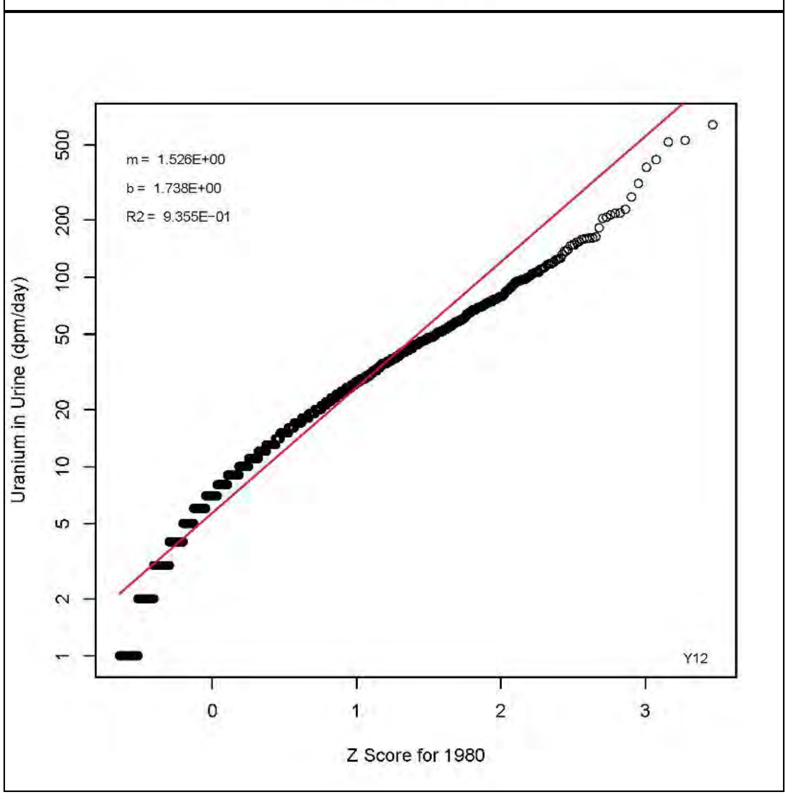

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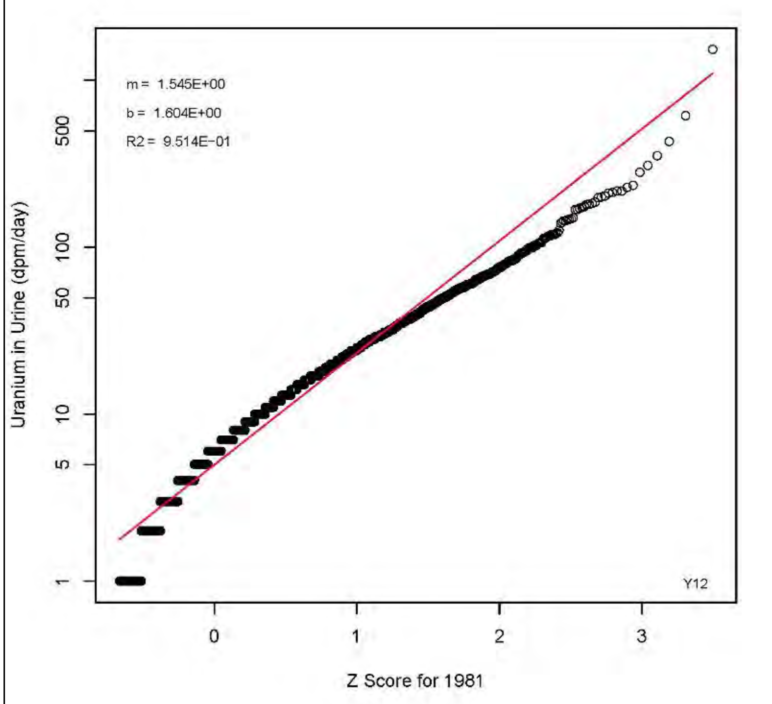

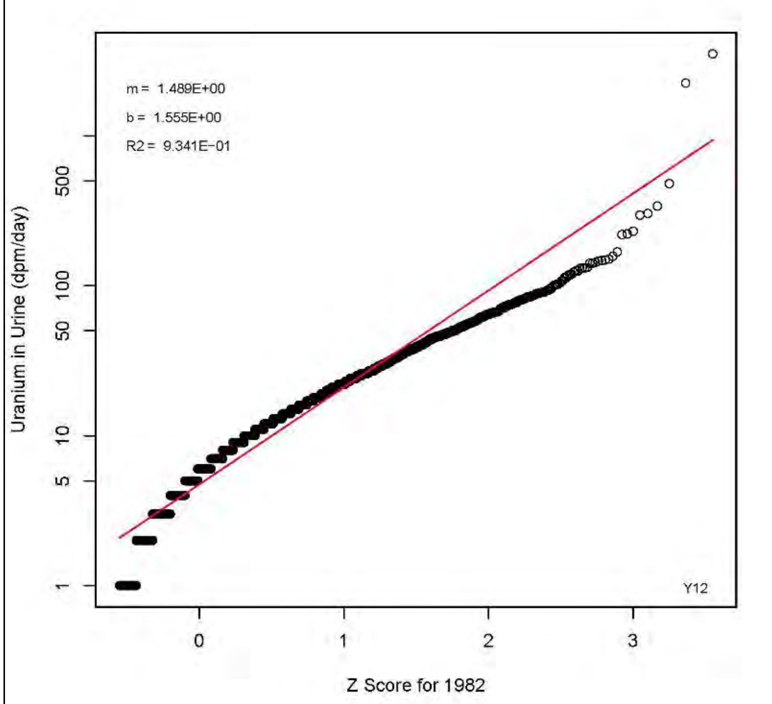

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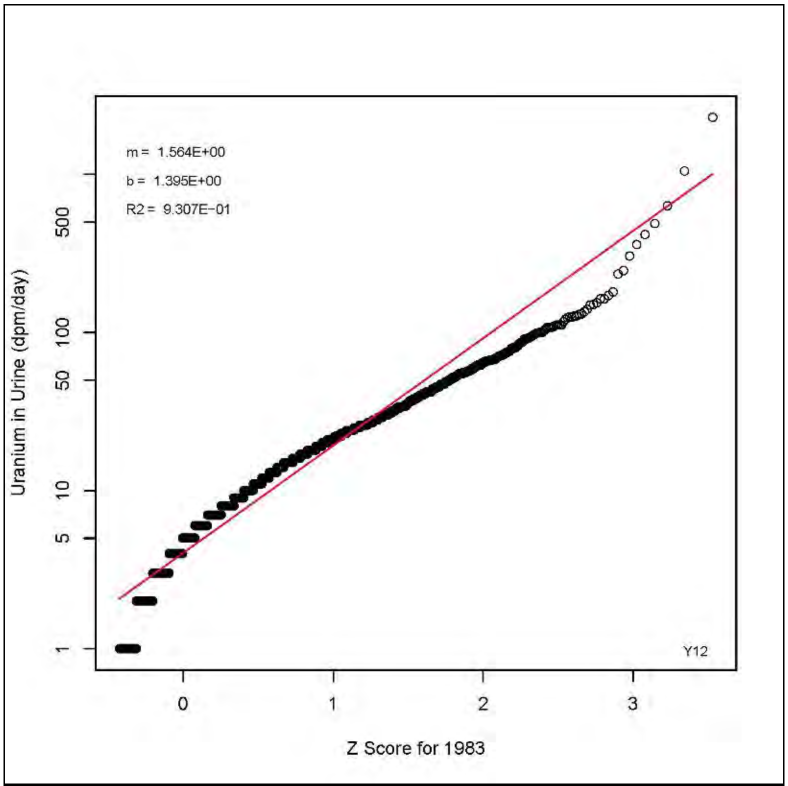

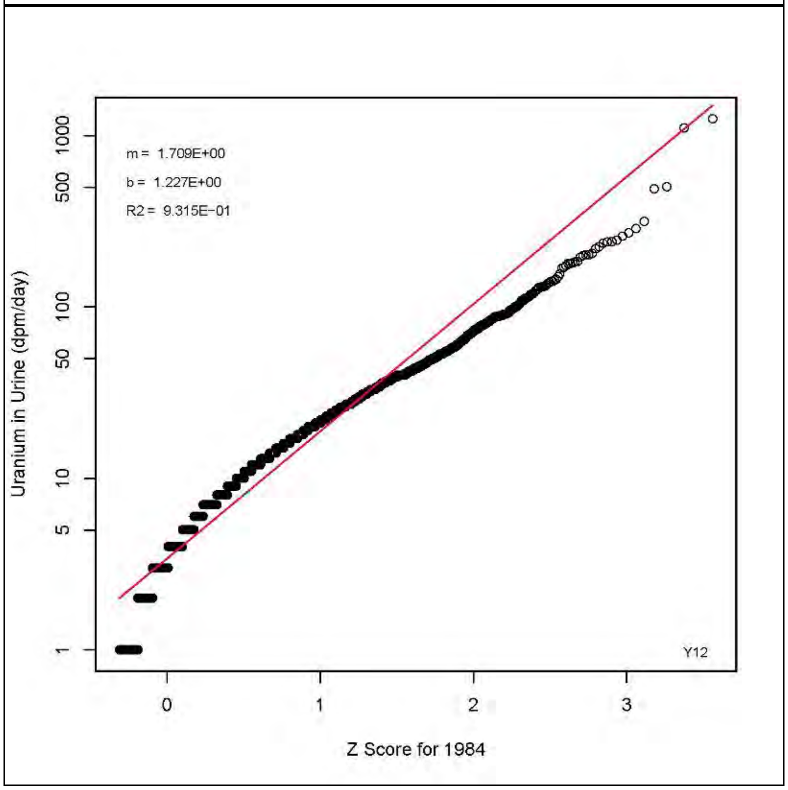

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LOGNORMAL PROBABILITY PLOTS,
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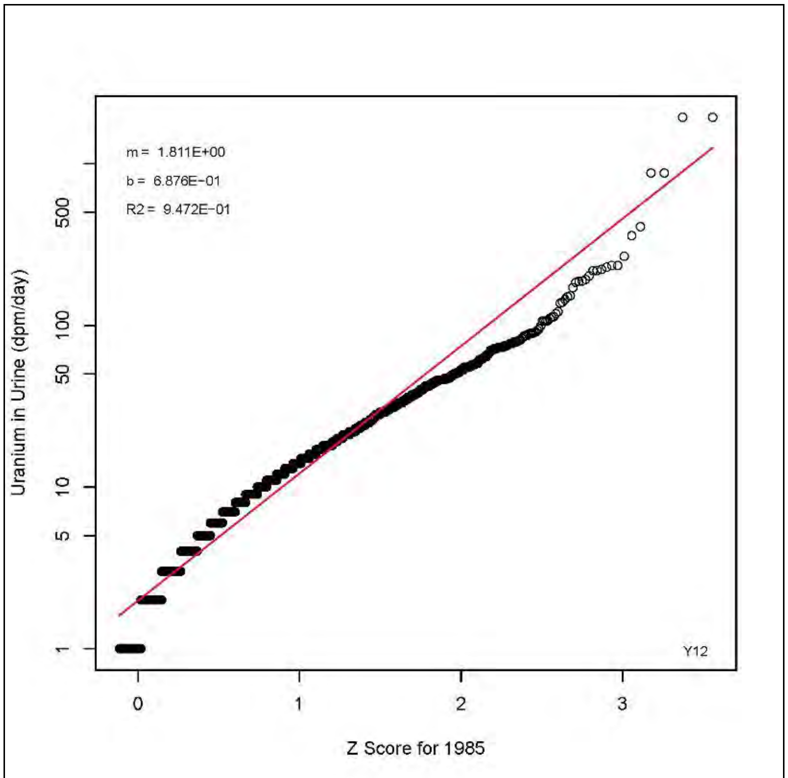

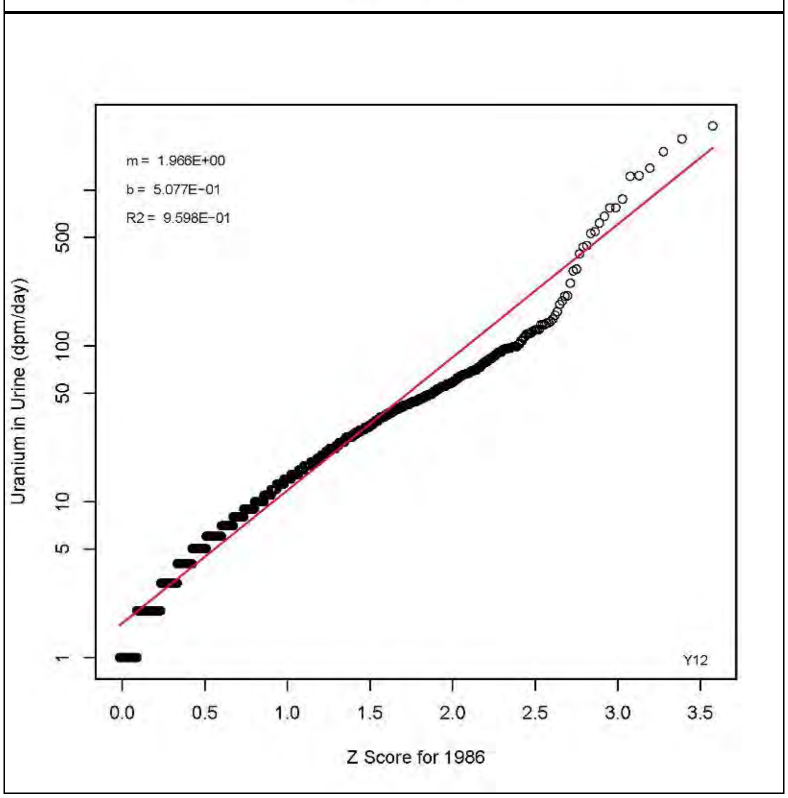

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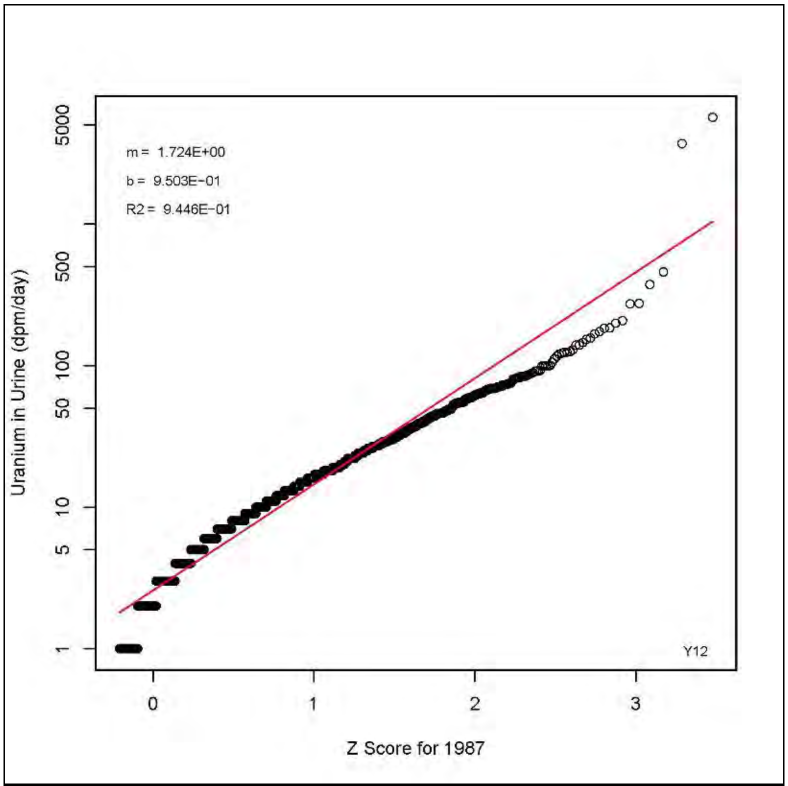

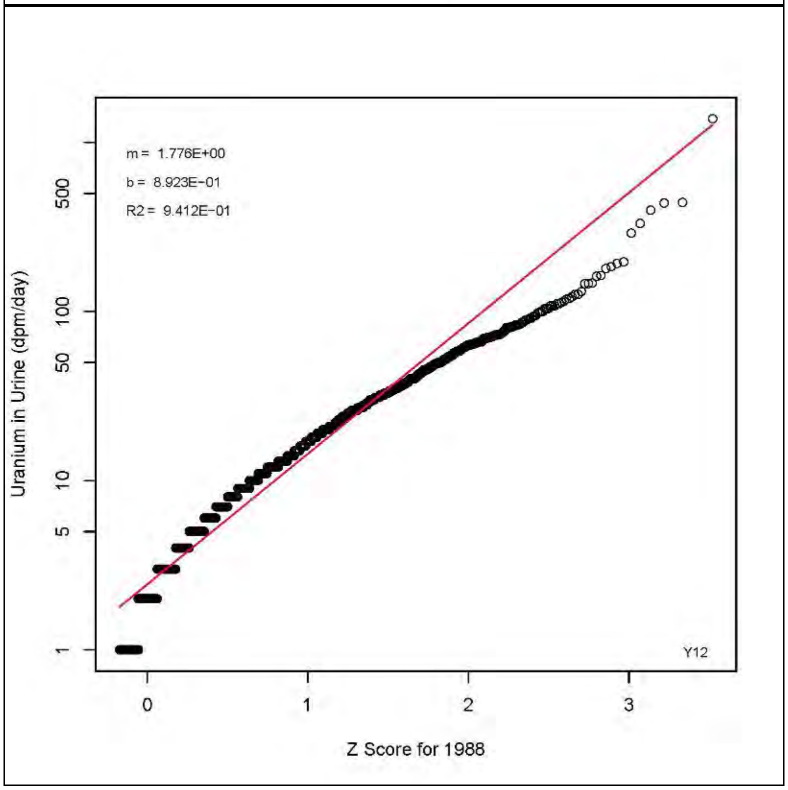

ATTACHMENT B
LOGNORMAL PROBABILITY PLOTS,
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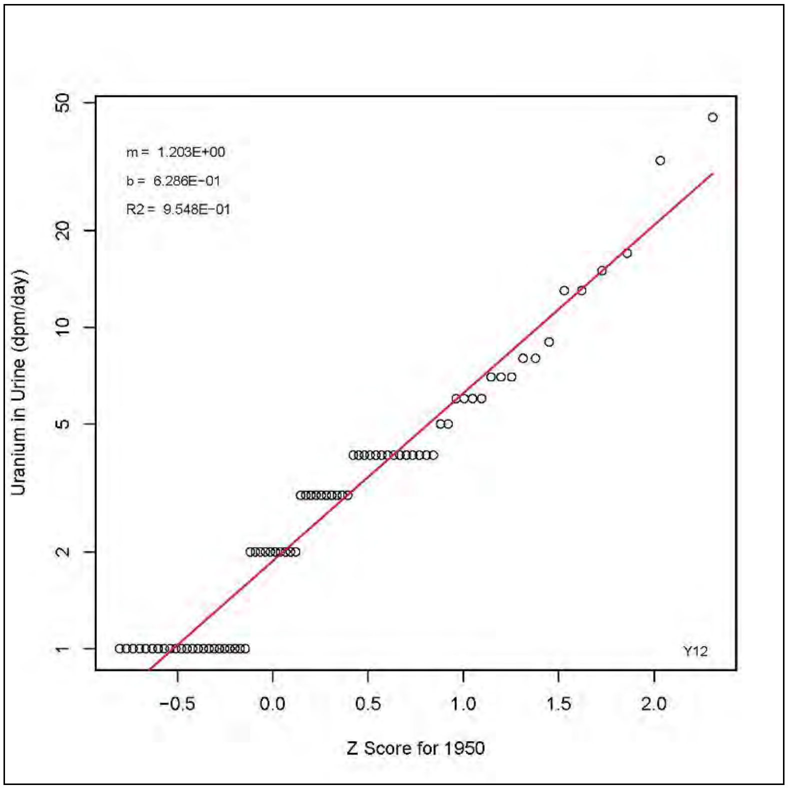
This attachment presents lognormal probability plots for the claimant Y-12 uranium urine bioassay dataset for 1950 to 1988. The slope and intercept for the line of best fit to the data are given on the plot.



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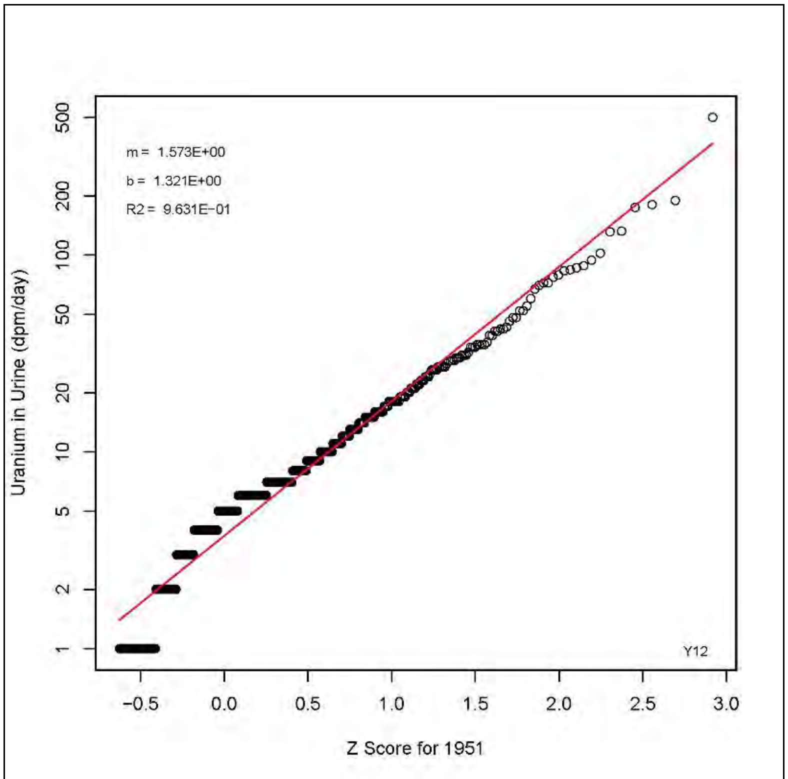

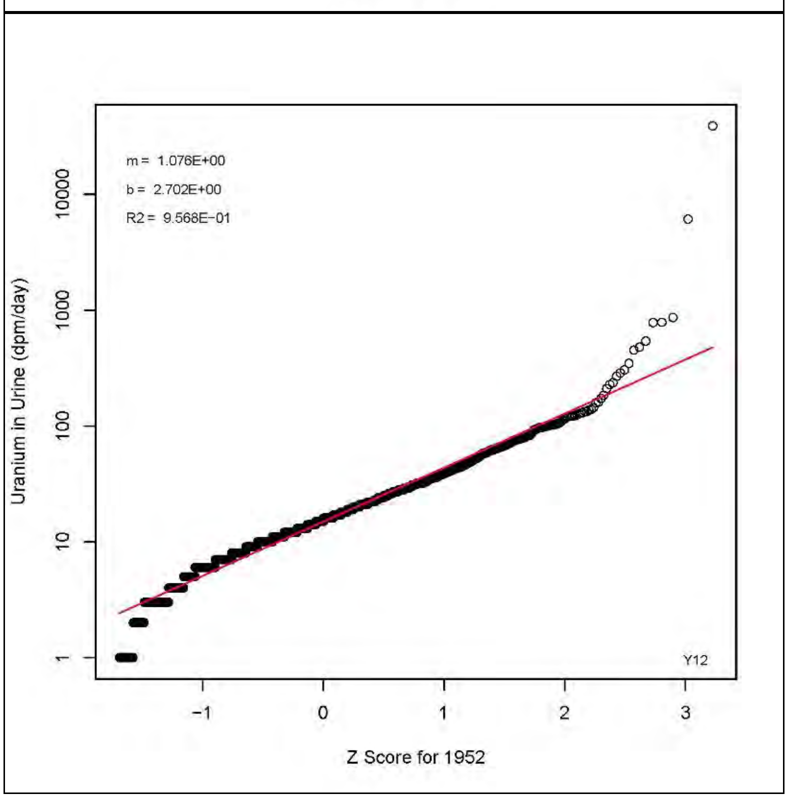

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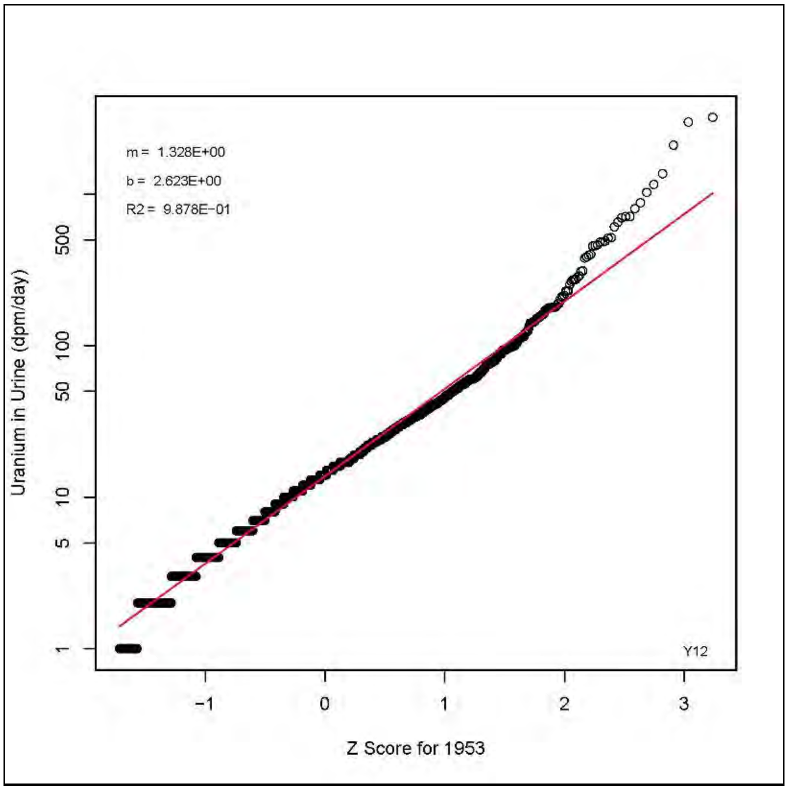

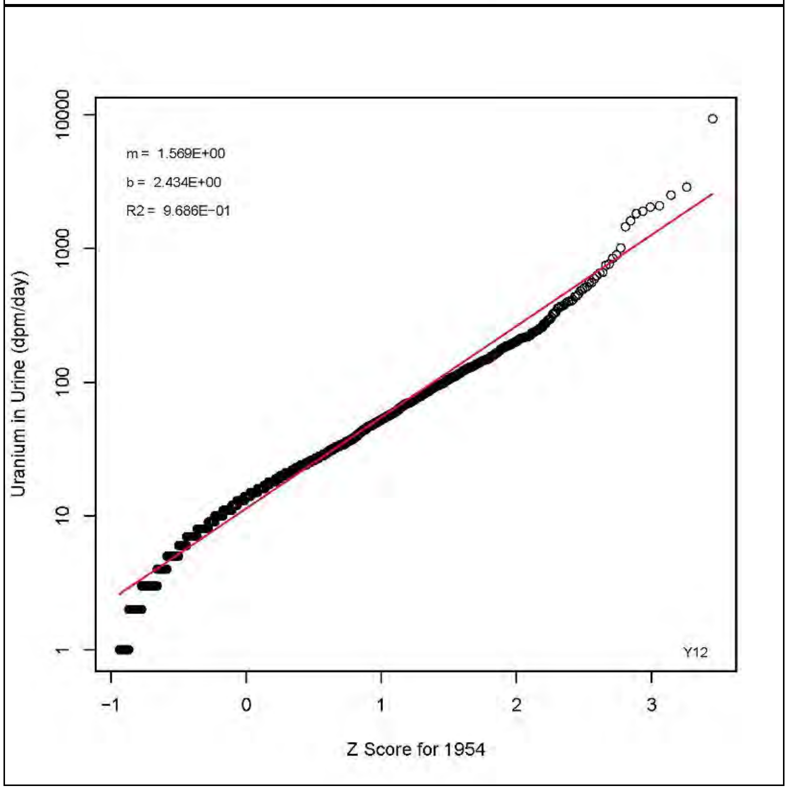

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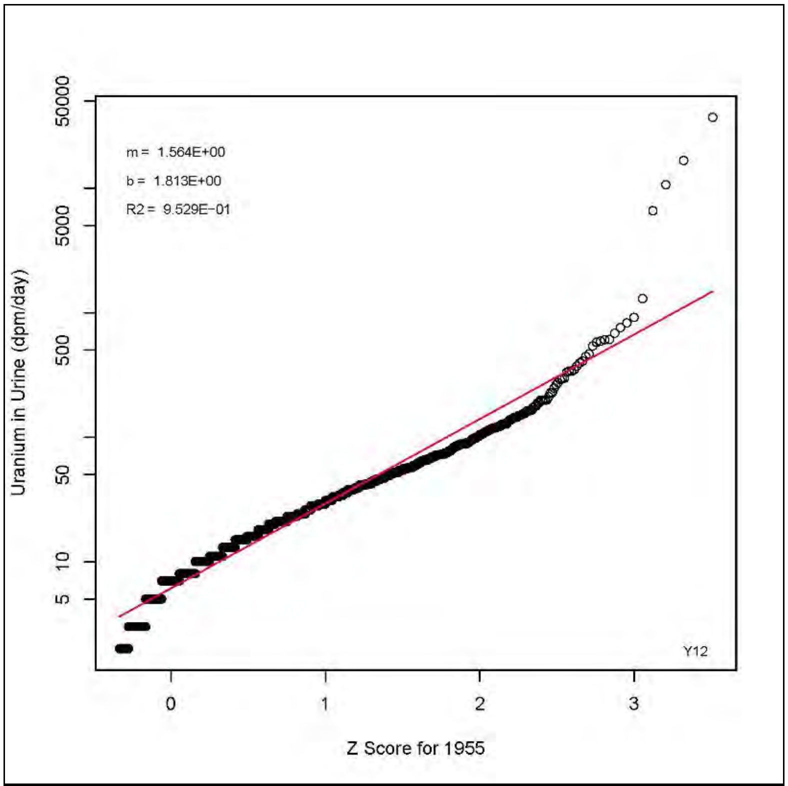

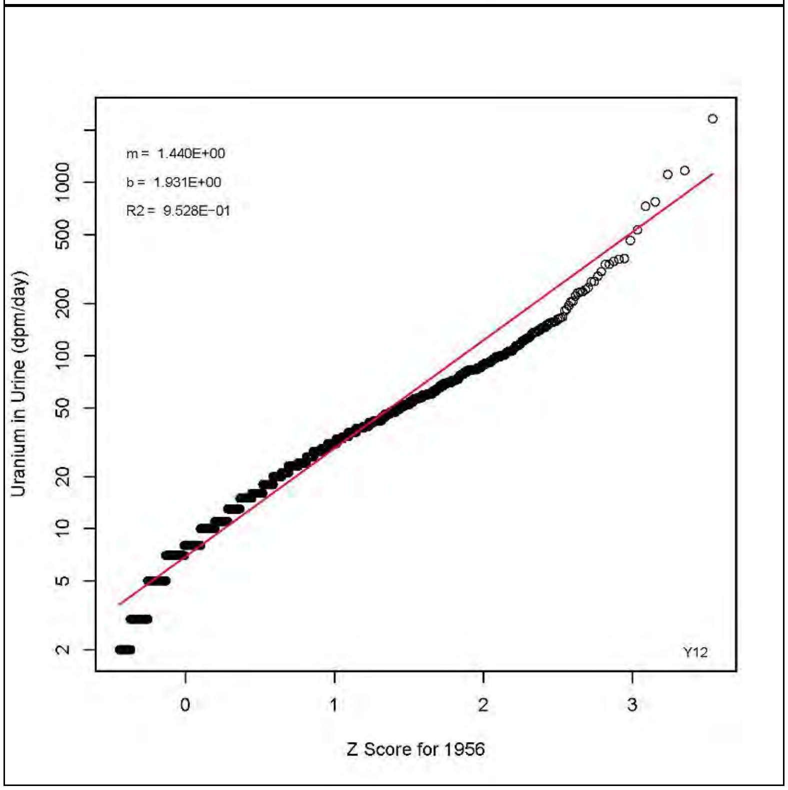

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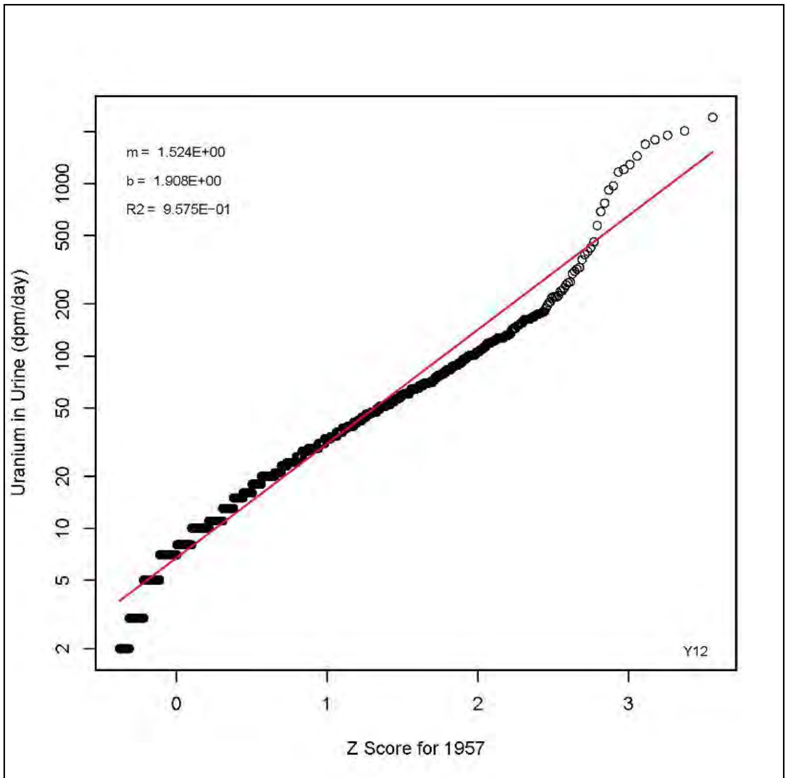

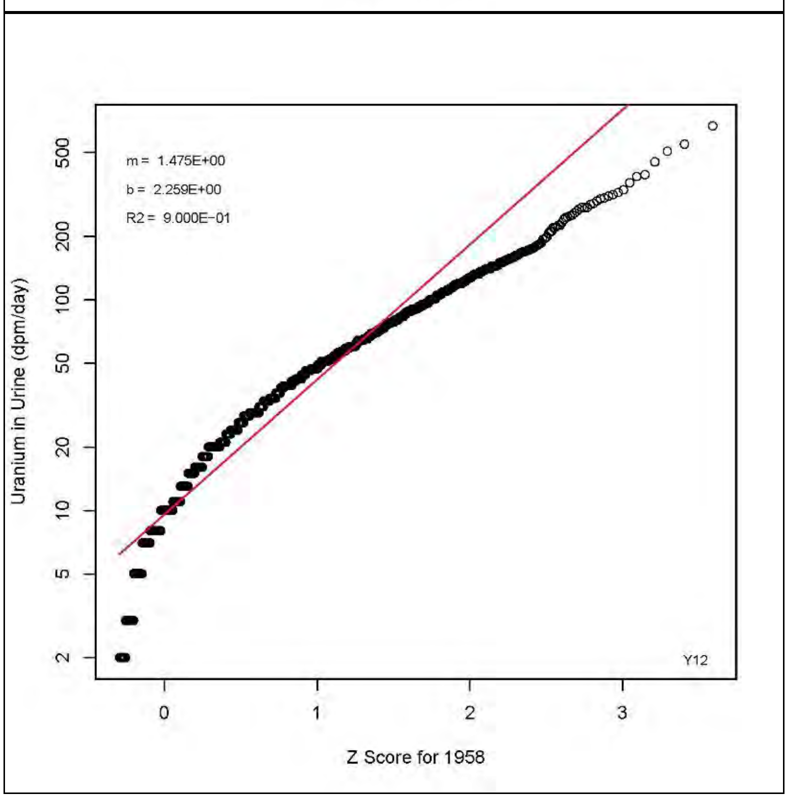

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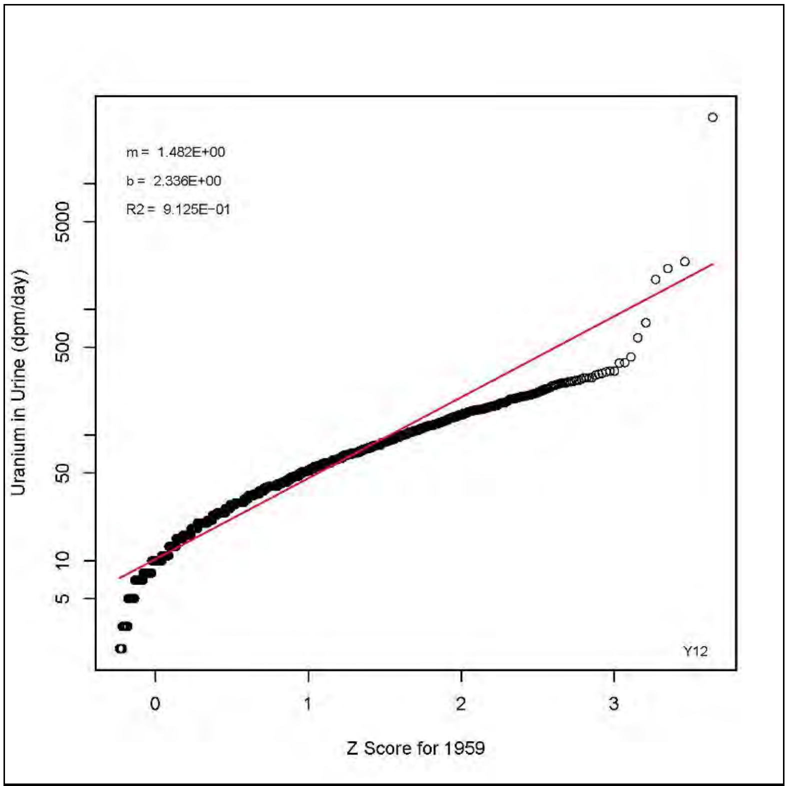

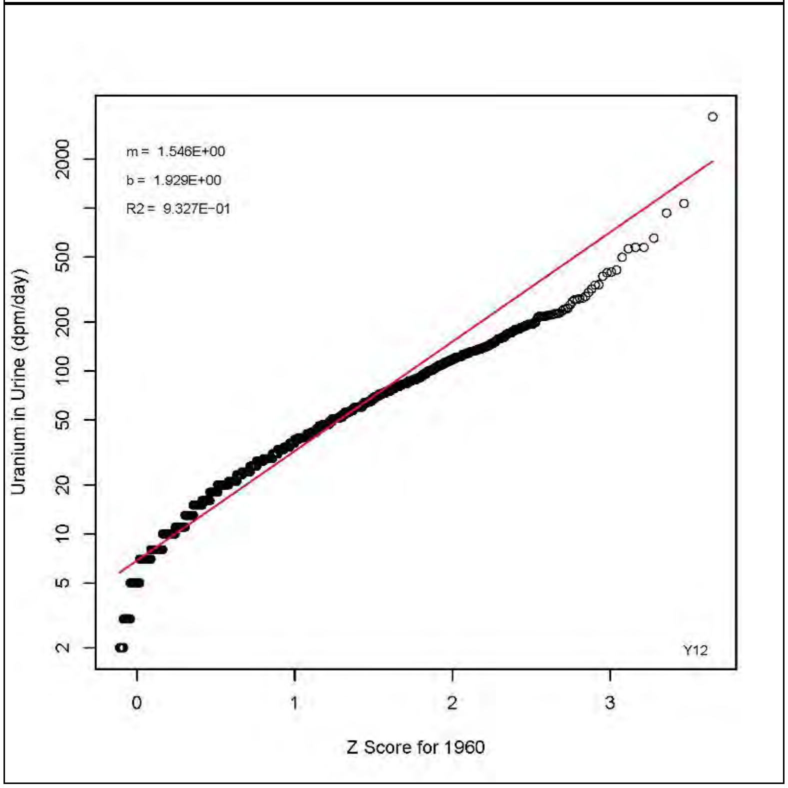

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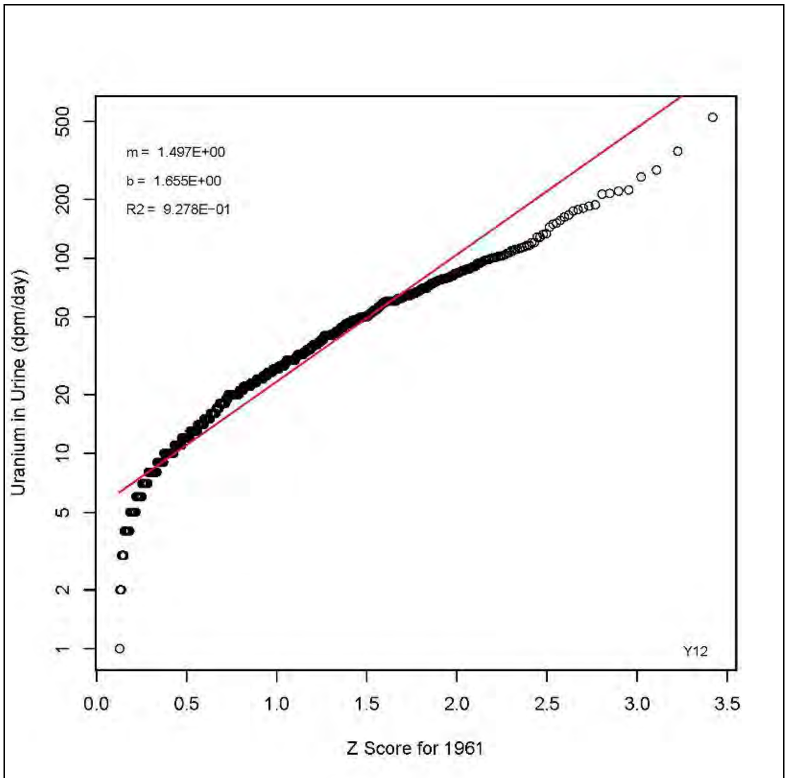

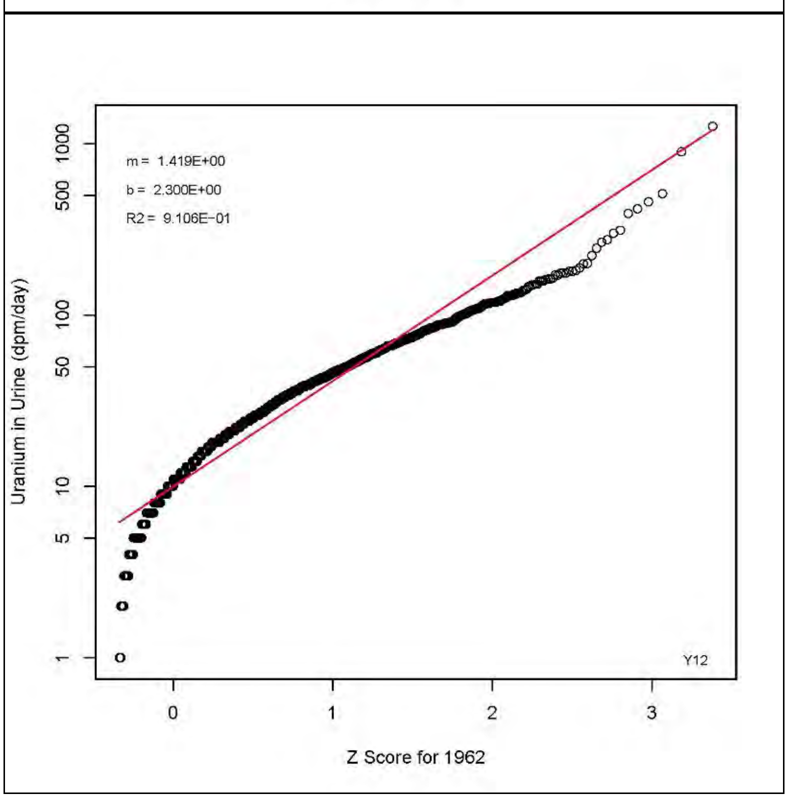

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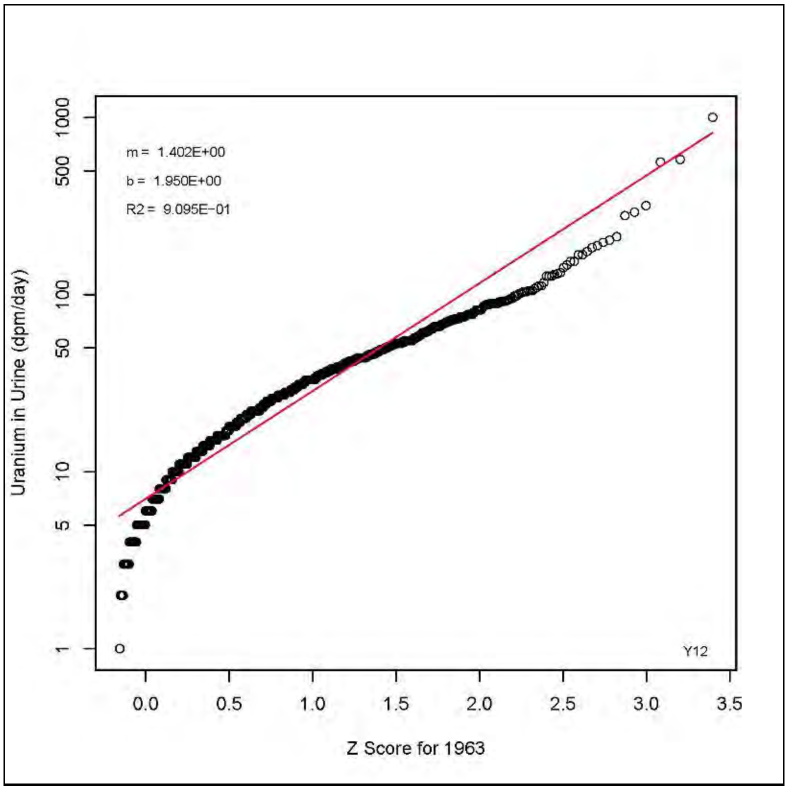

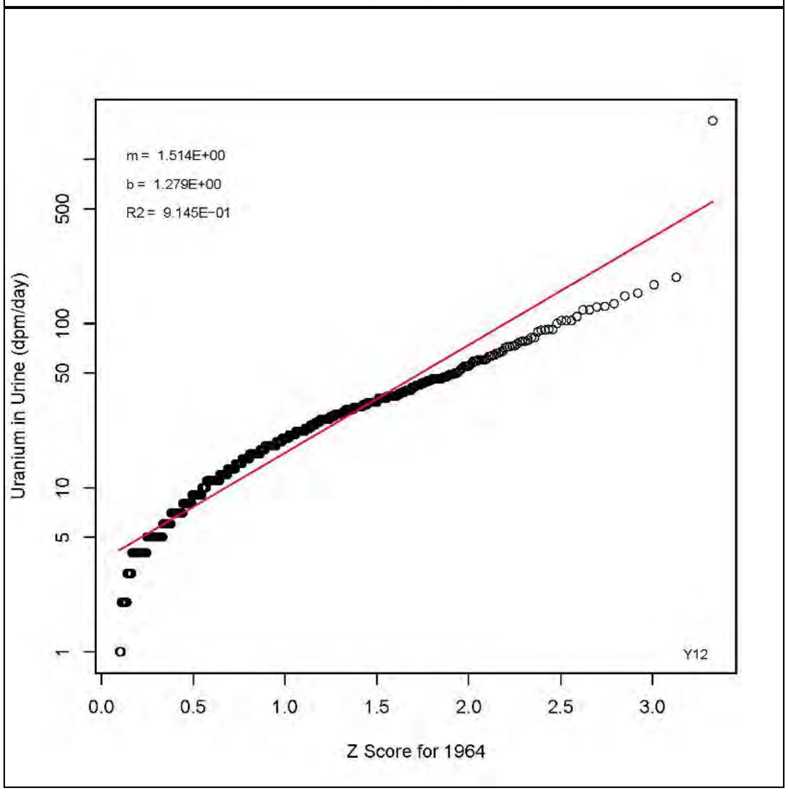

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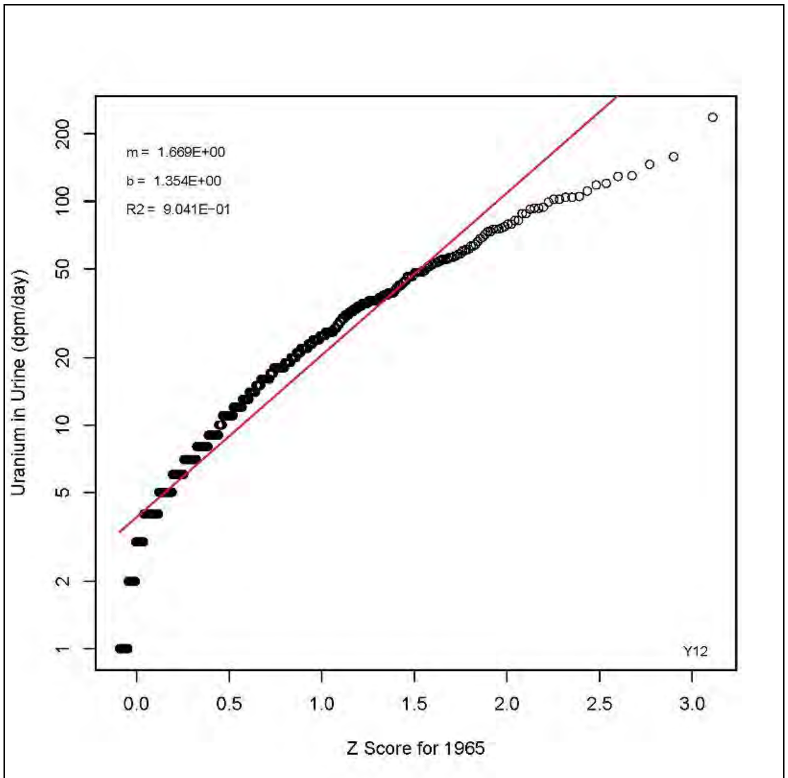

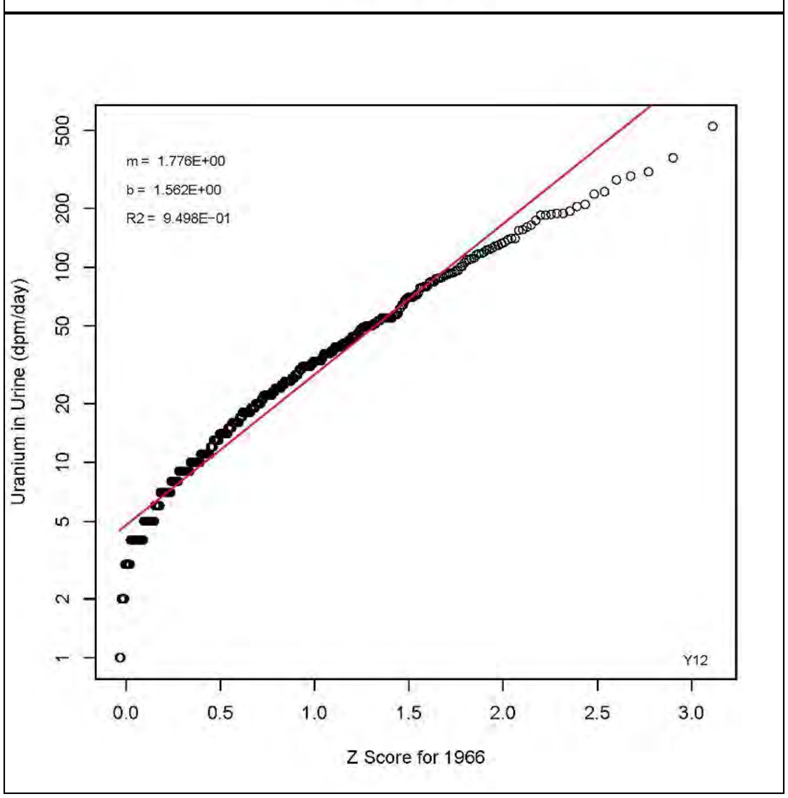

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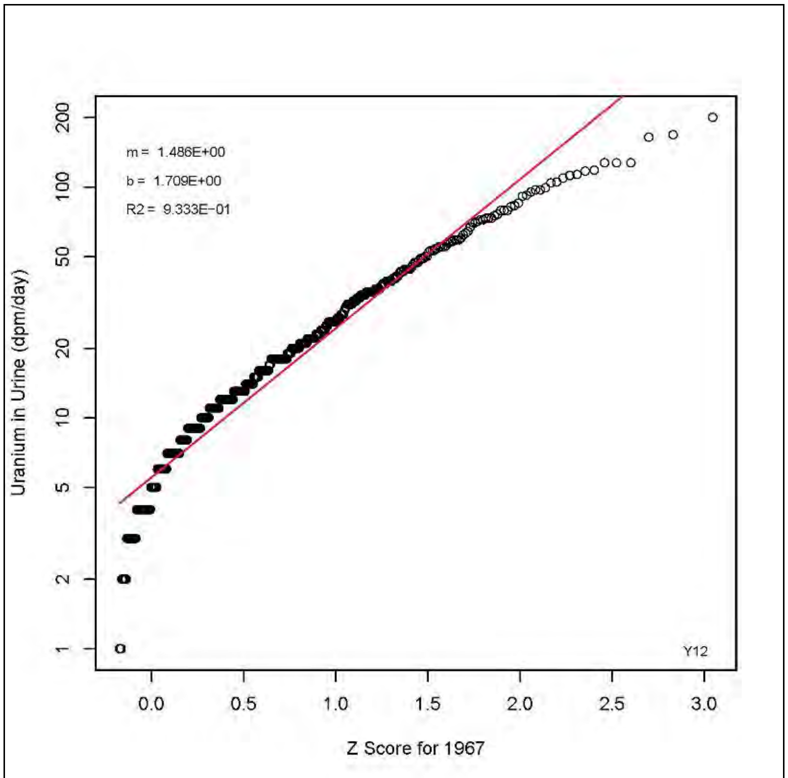

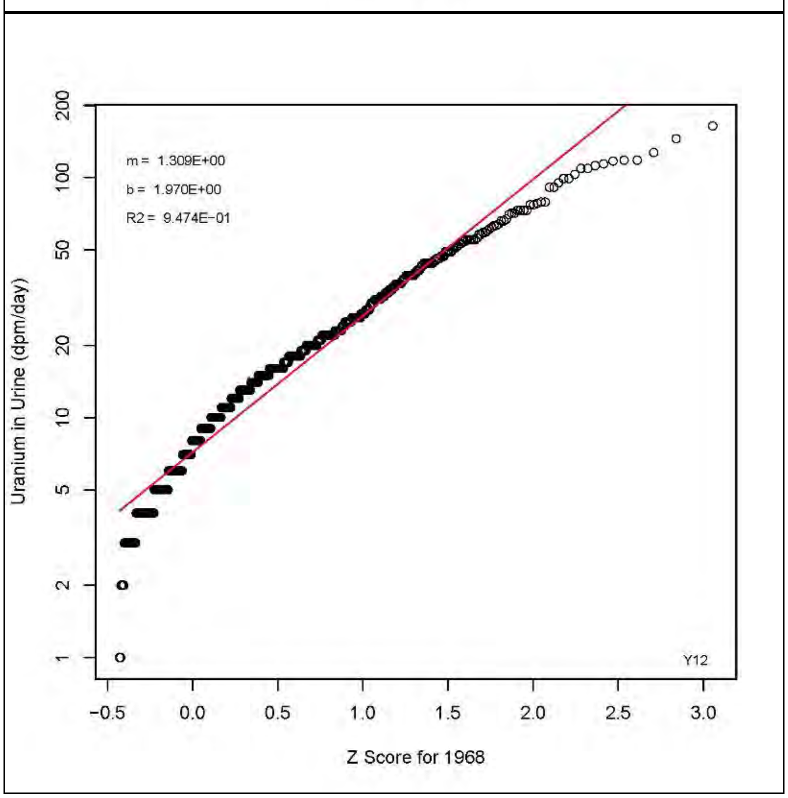

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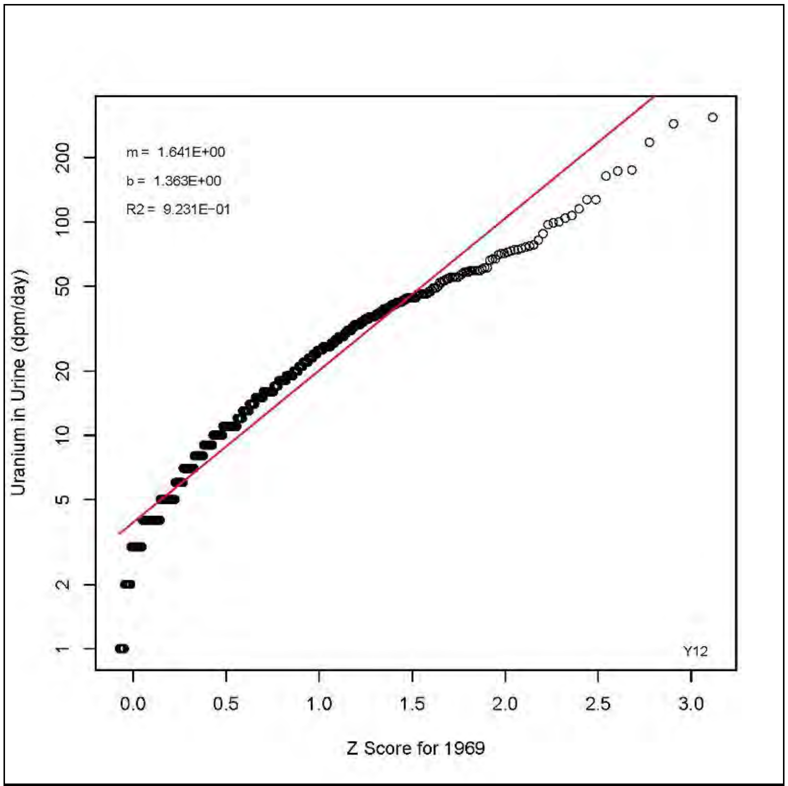

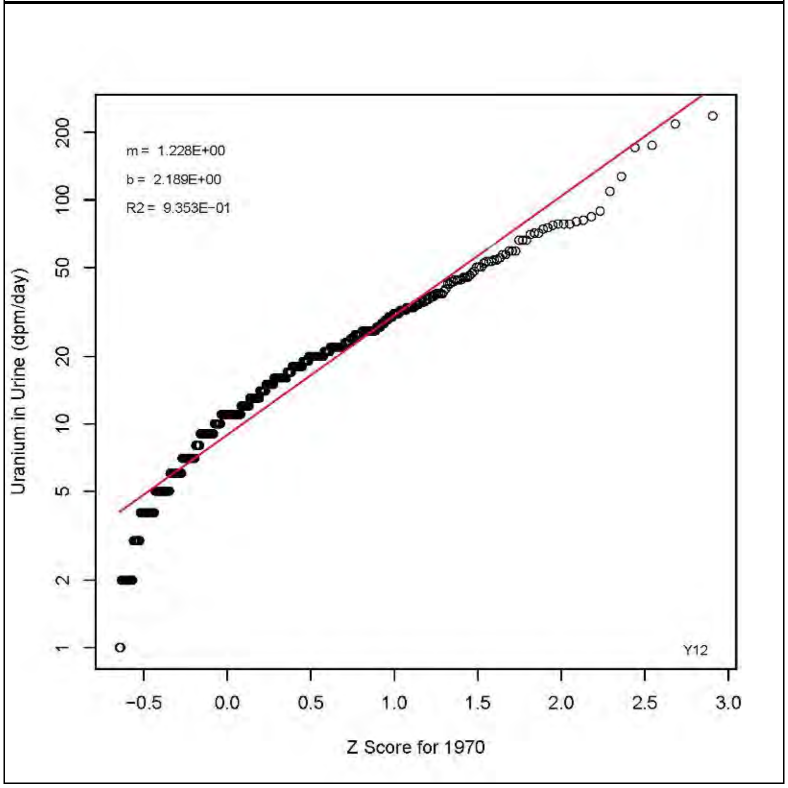

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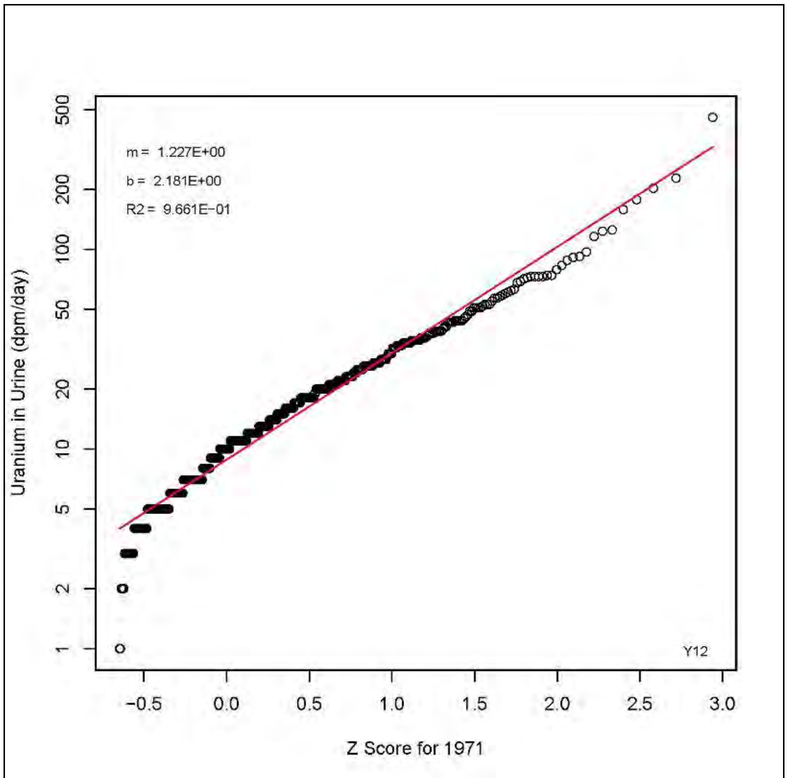

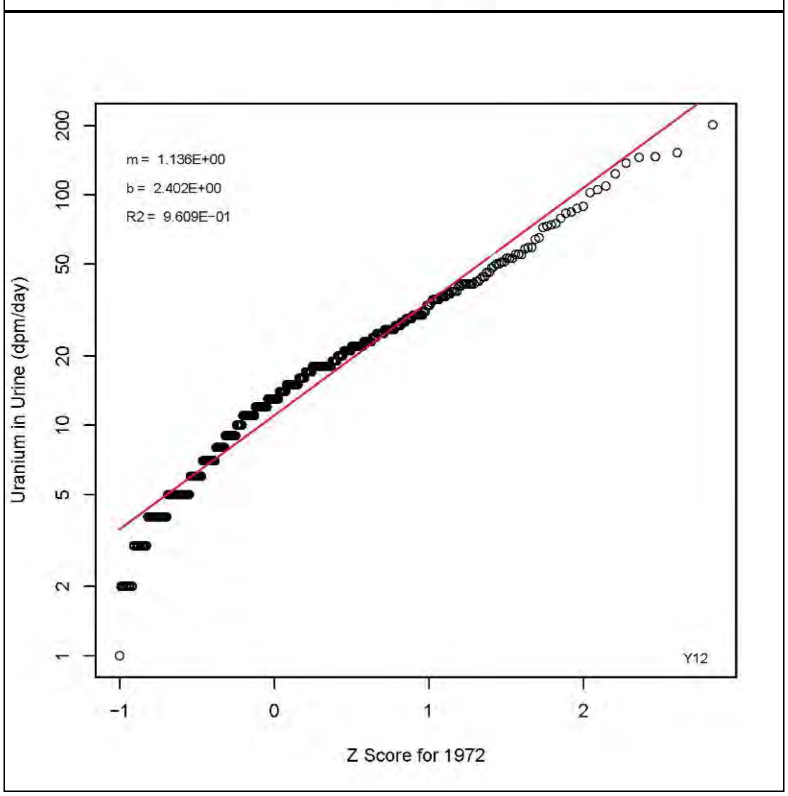

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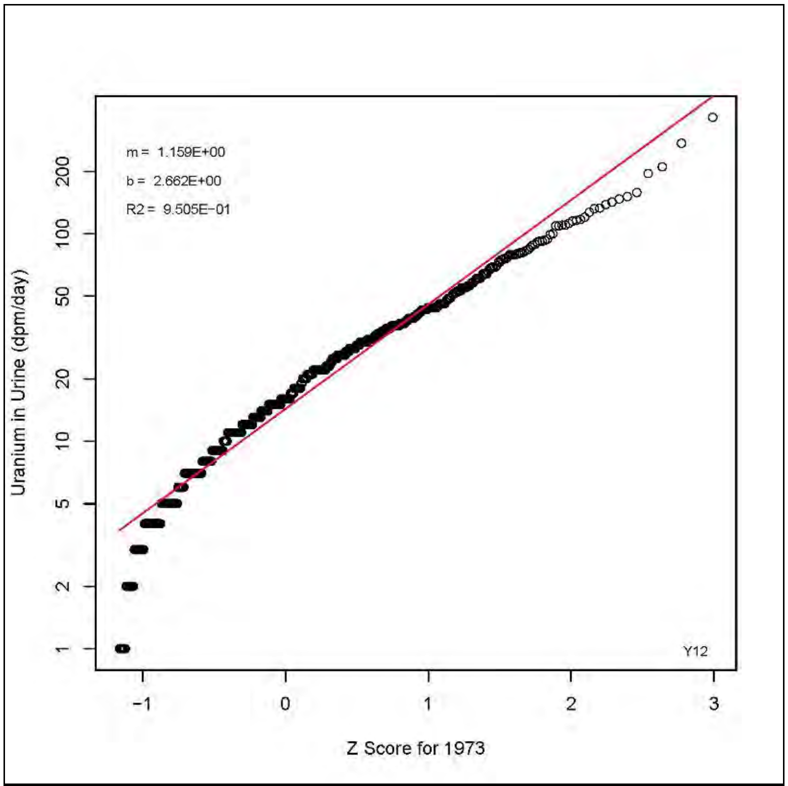

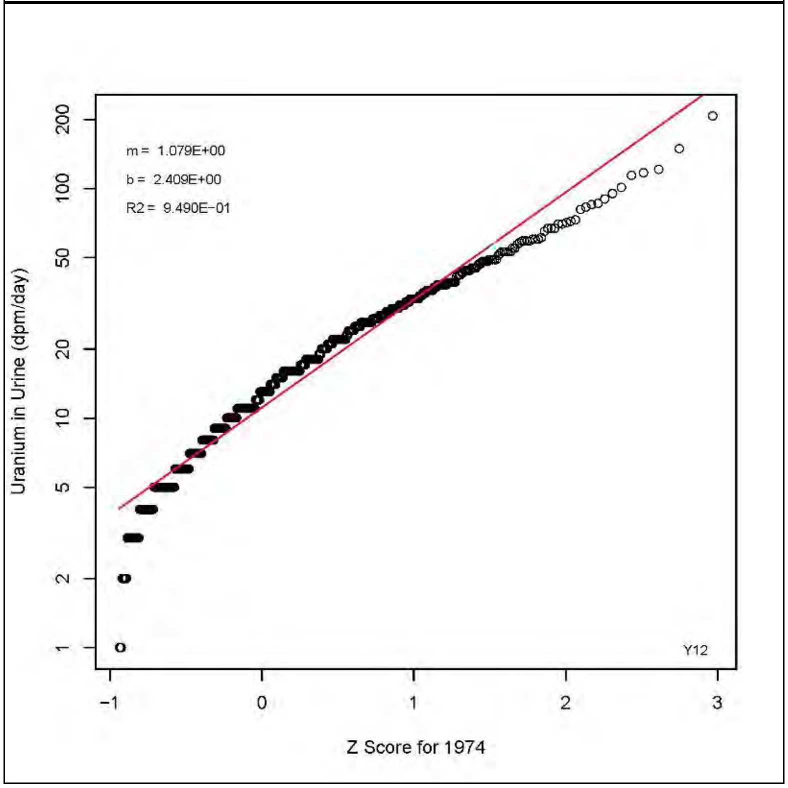

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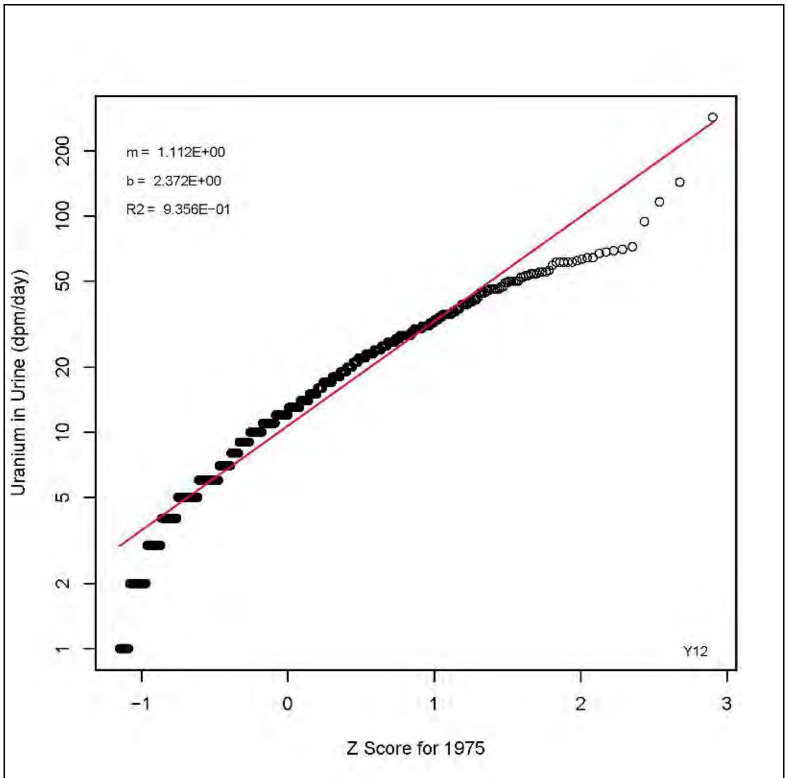

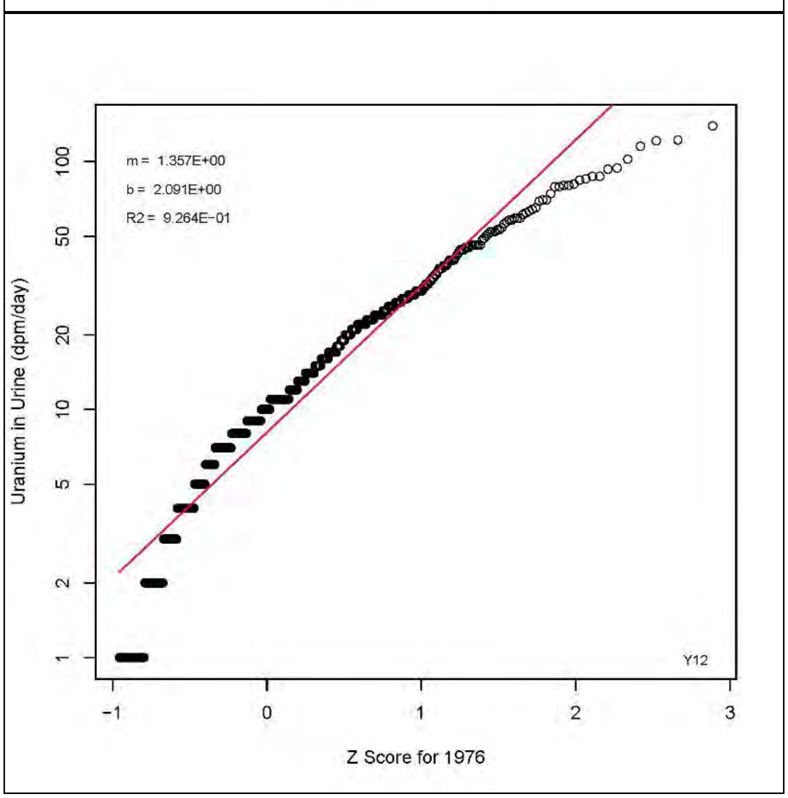

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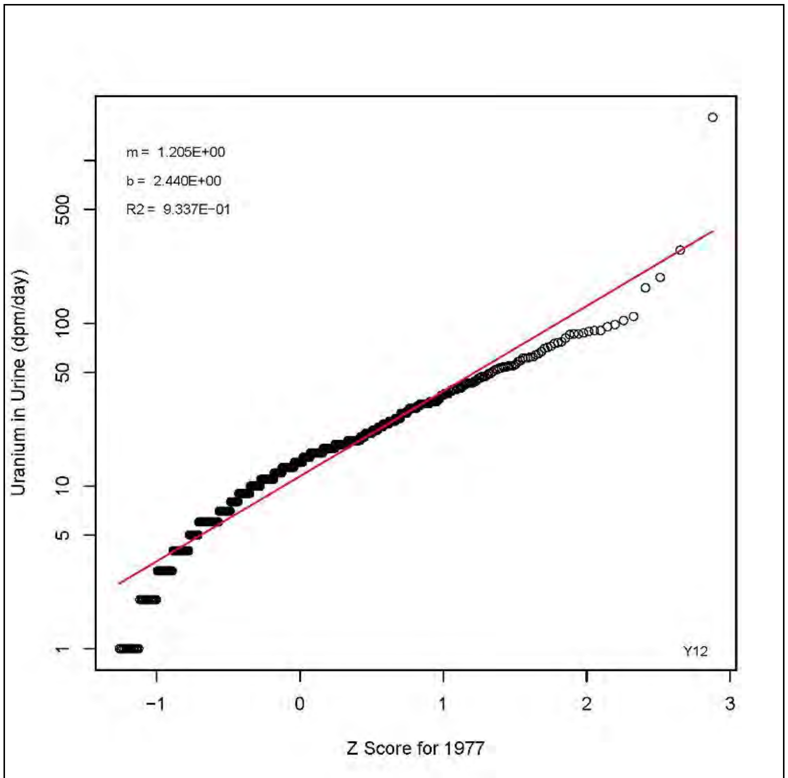

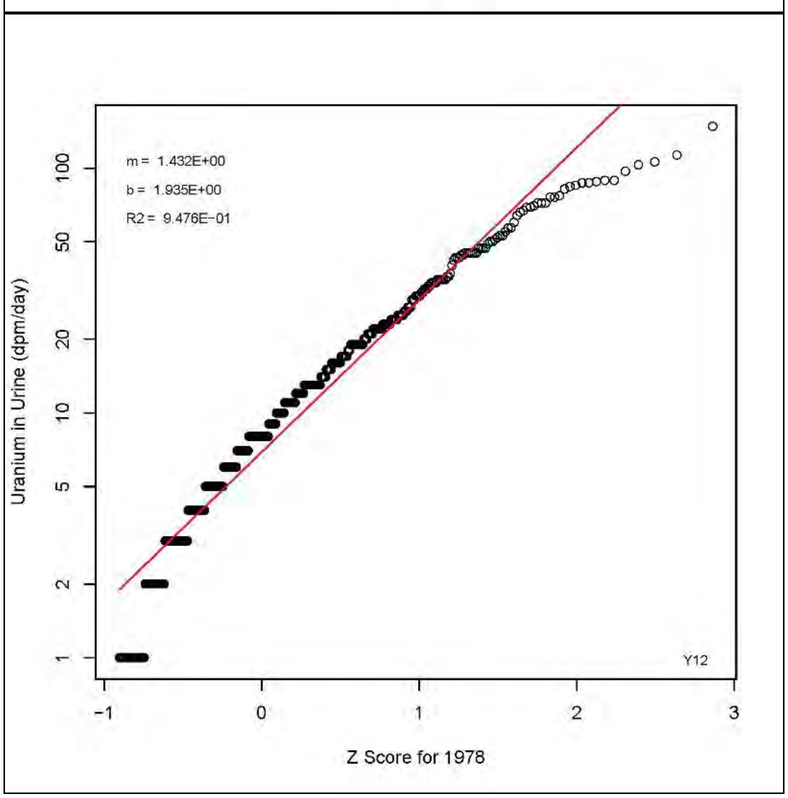

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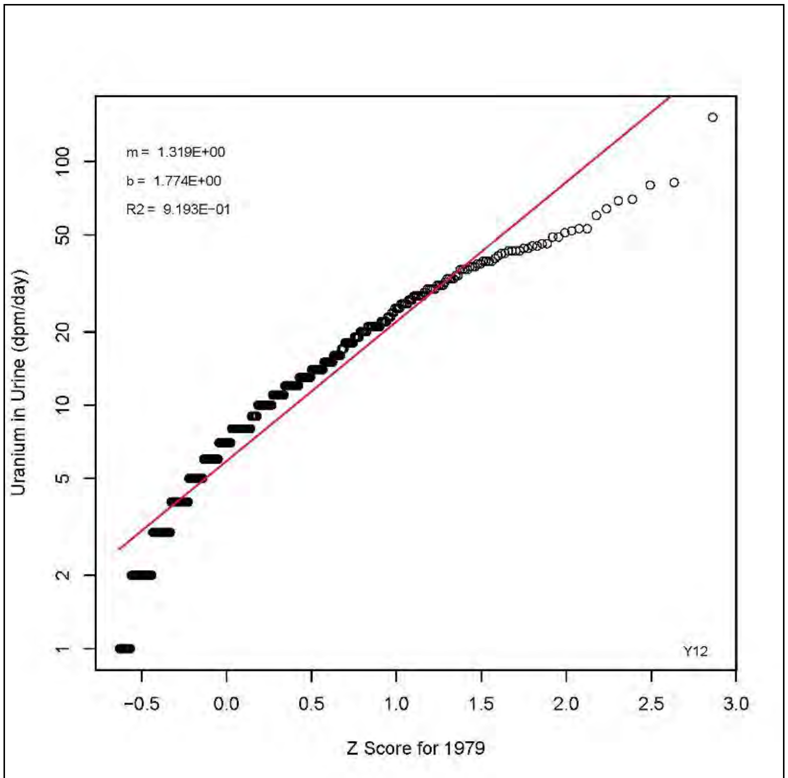

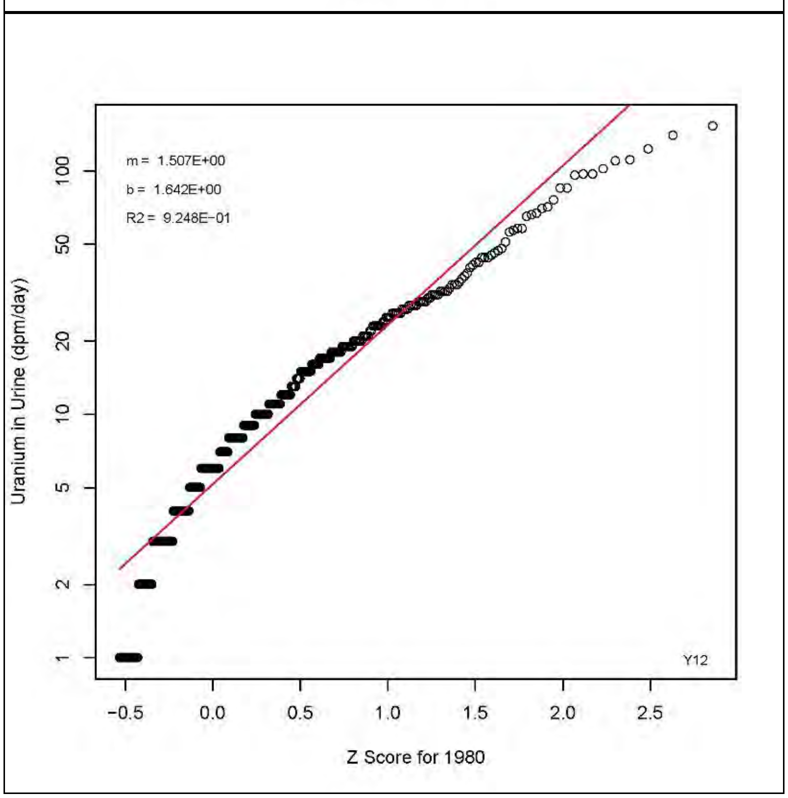

ATTACHMENT B
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT Y-12 DATASET
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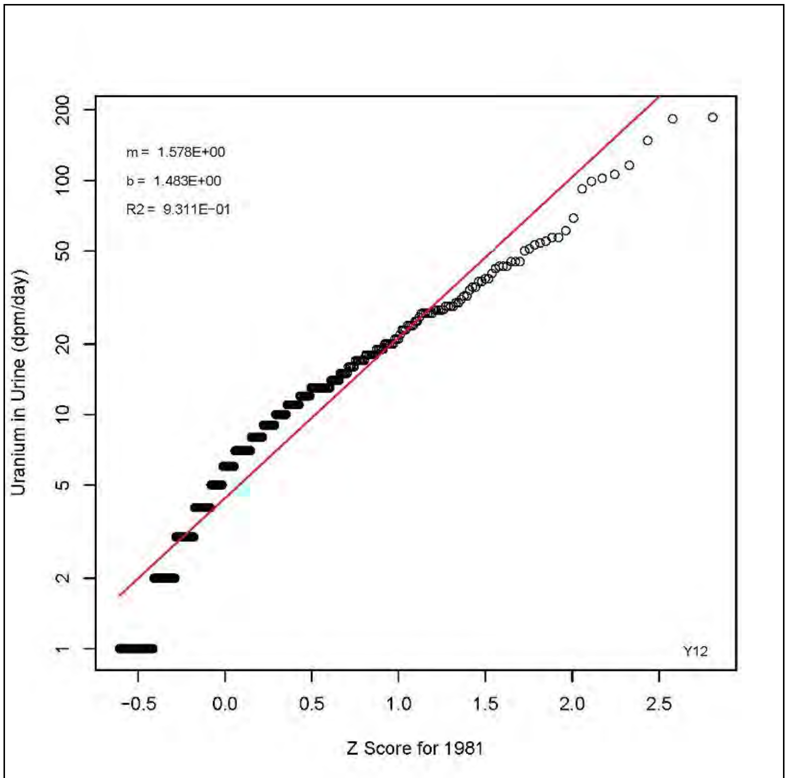

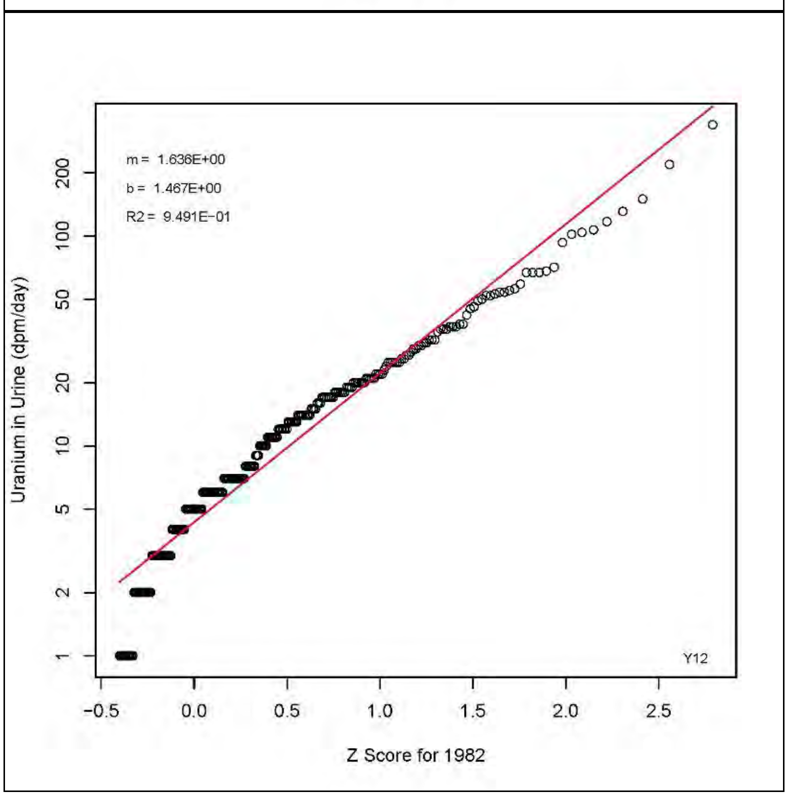

ATTACHMENT B
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT Y-12 DATASET
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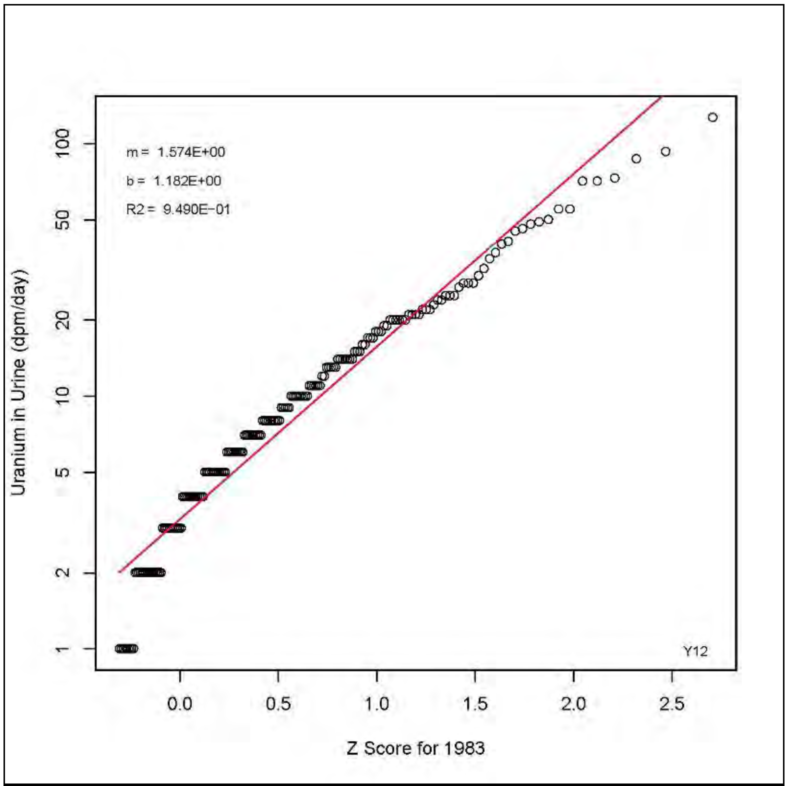
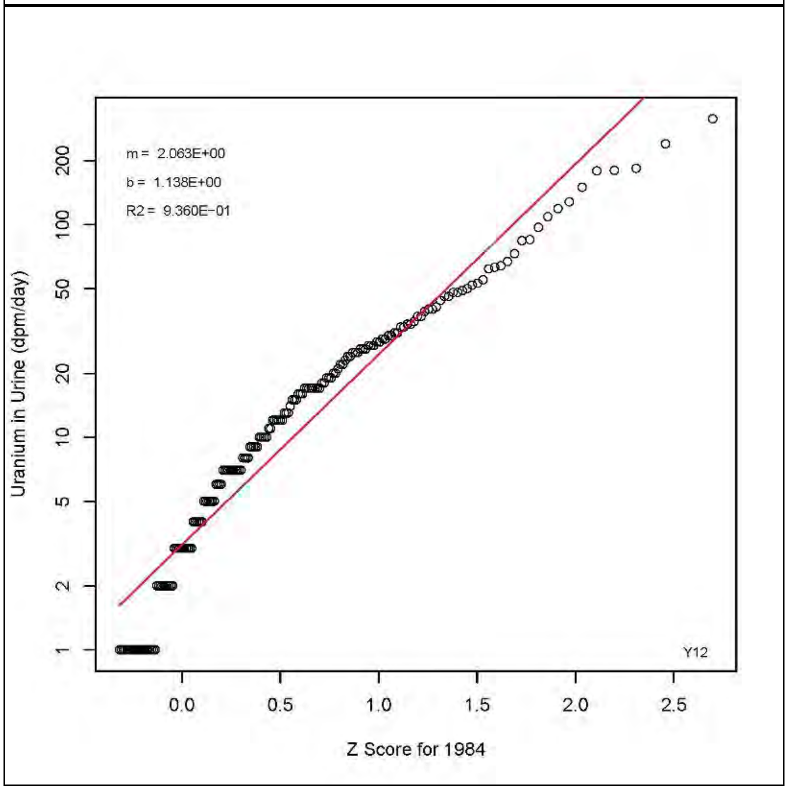
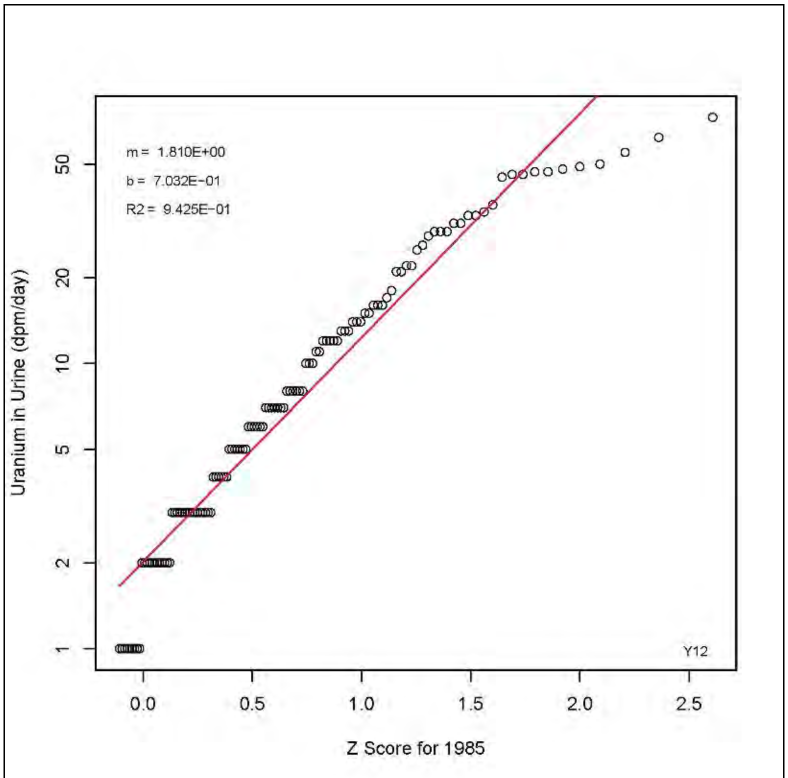
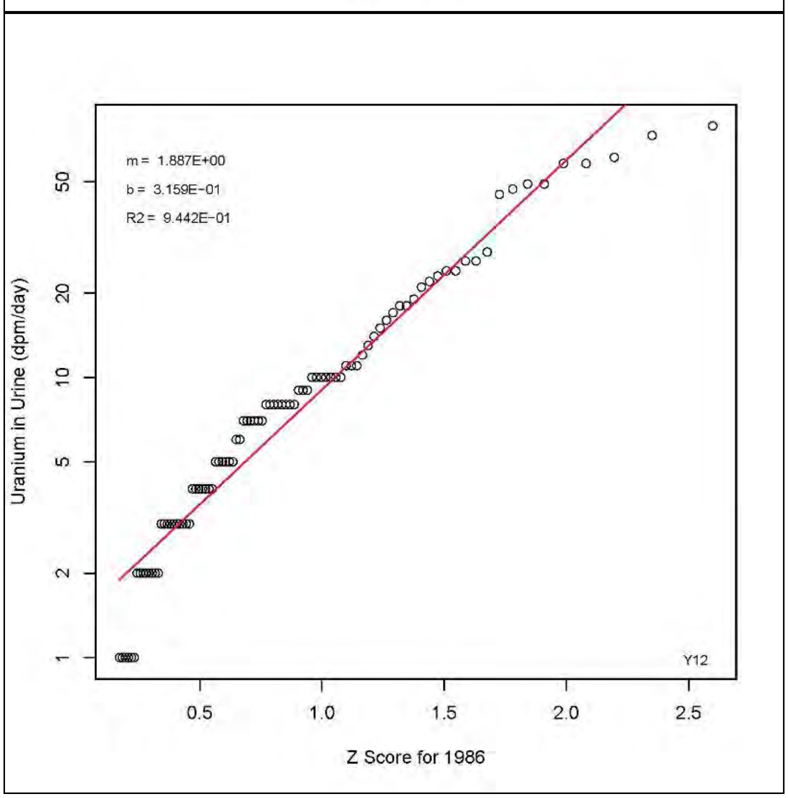


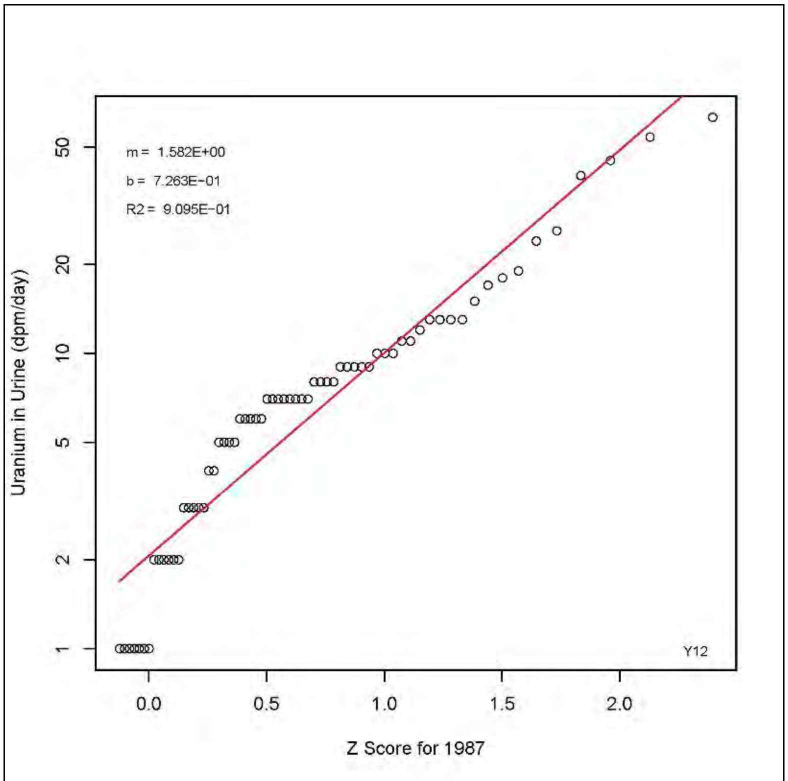


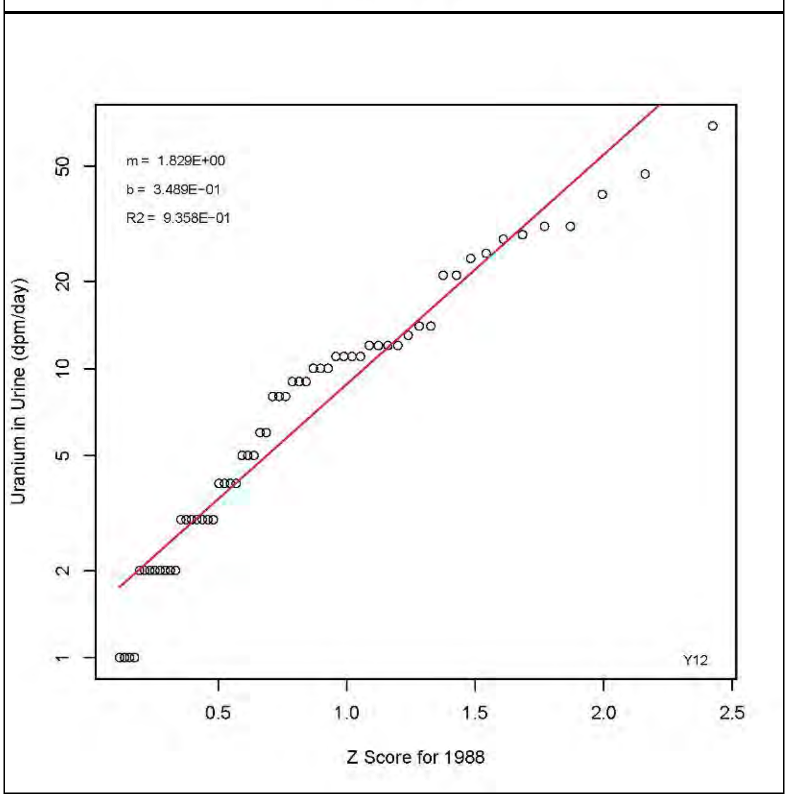
ATTACHMENT B
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT Y-12 DATASET





ATTACHMENT B
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT Y-12 DATASET



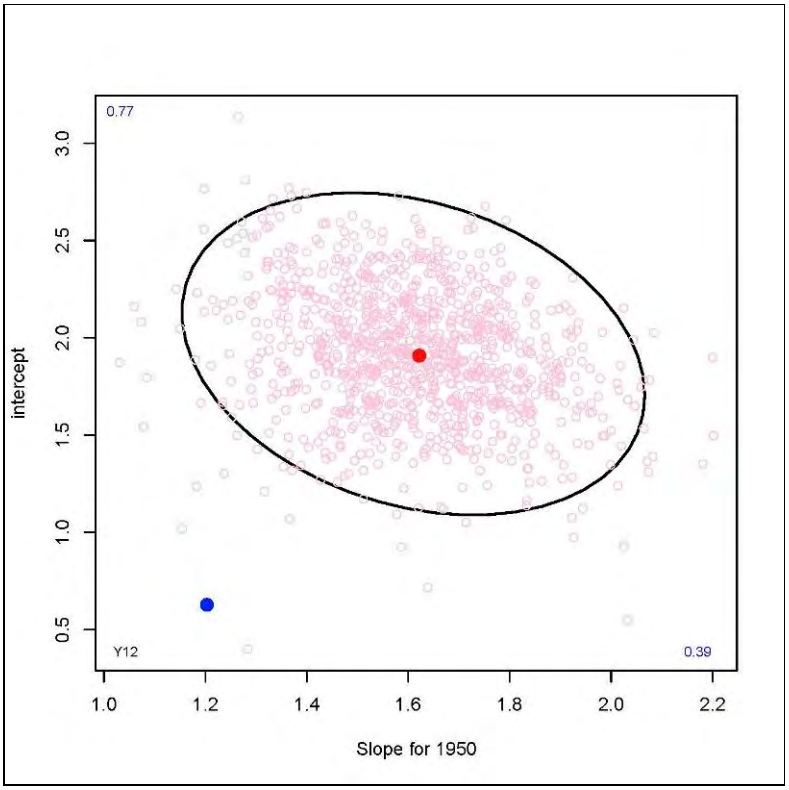


ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS

This attachment presents lognormal probability plots for a sample of 731 unique workers that was drawn at random without replacement from the 7537 workers in the complete dataset. The slope and intercept of the plot for each year from 1950 to 1988 was calculated based on this data. This process was repeated *m* = 1000 times to generate the 95% confidence ellipses. In each plot:

- The solid red point is the slope and intercept of the complete dataset.
- The solid blue point is the slope and intercept of the claimant dataset.
- The open pink points are the slopes and intercepts of the fits to the *m* random sets of 731 workers taken from the complete dataset.
- The ellipse is the 95% joint normal confidence ellipse.
- The numbers in the corners are the full scale of the respective axes in terms of +/- the slope or intercept of the complete dataset.

These plots are presented to support the idea that the claimant dataset is basically no different than a random draw from the complete dataset.



ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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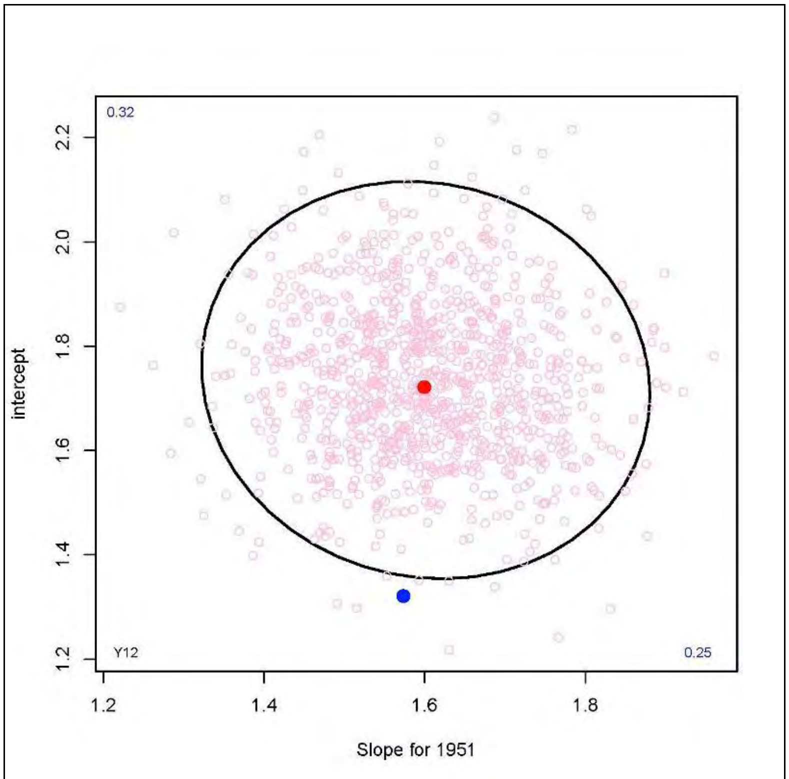

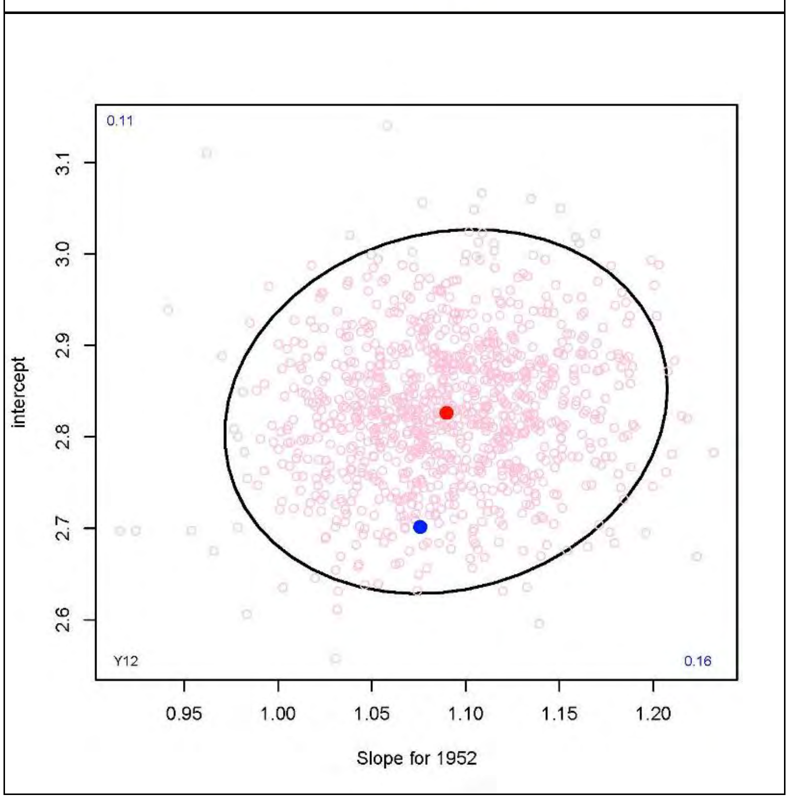

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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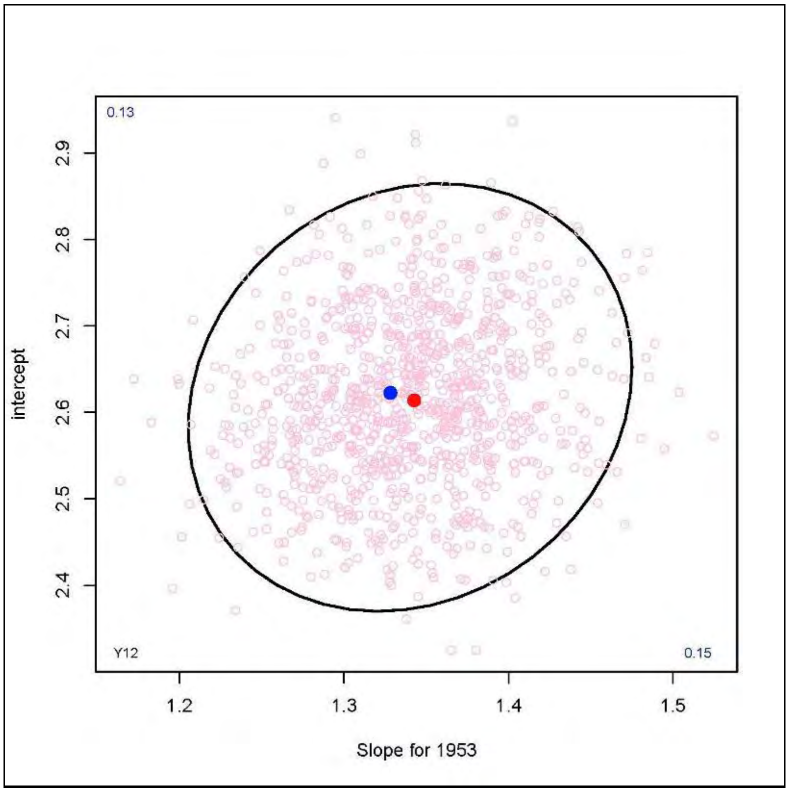

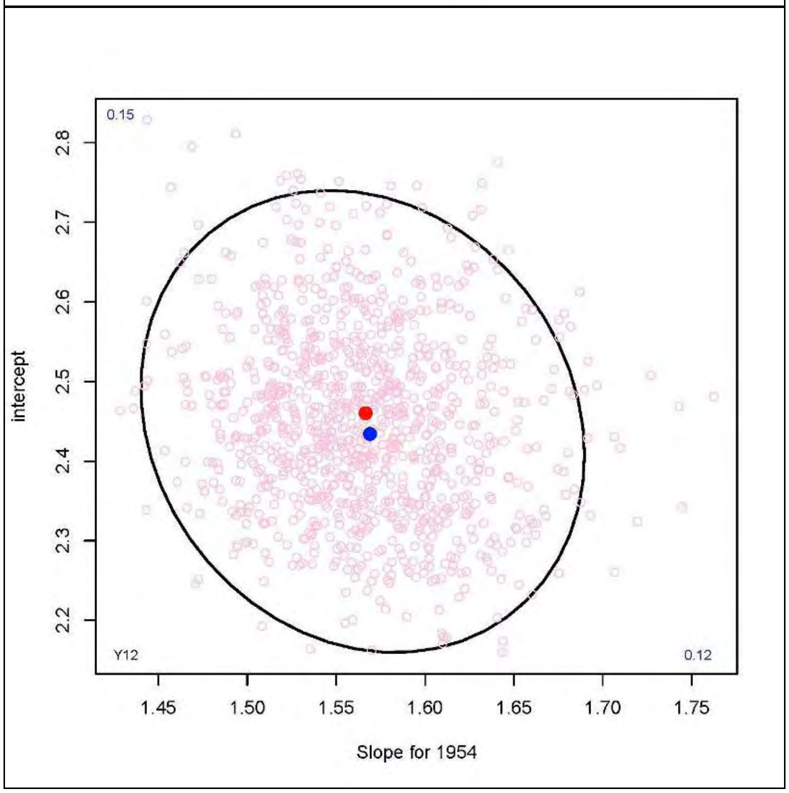

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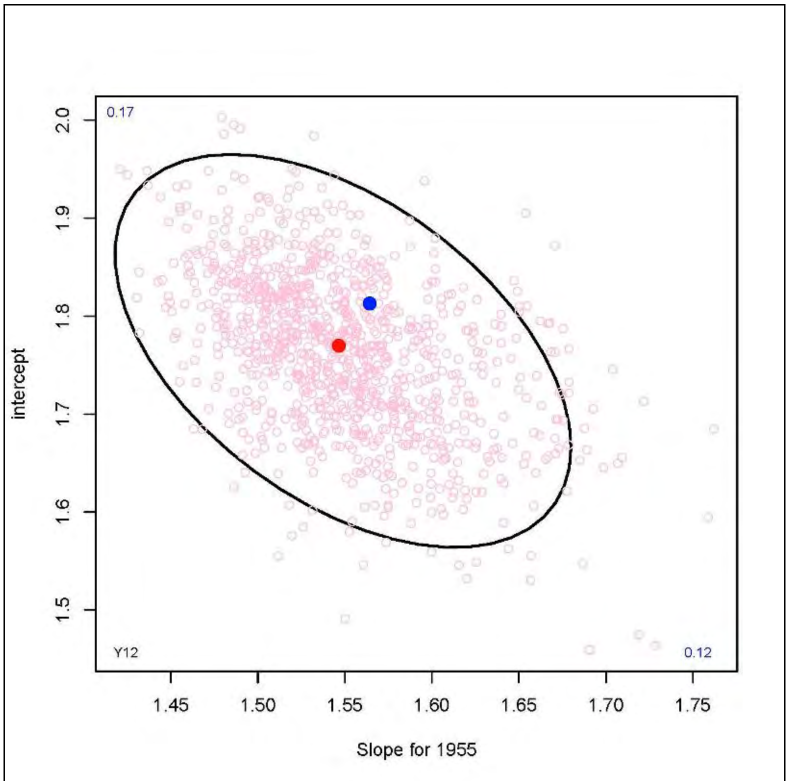
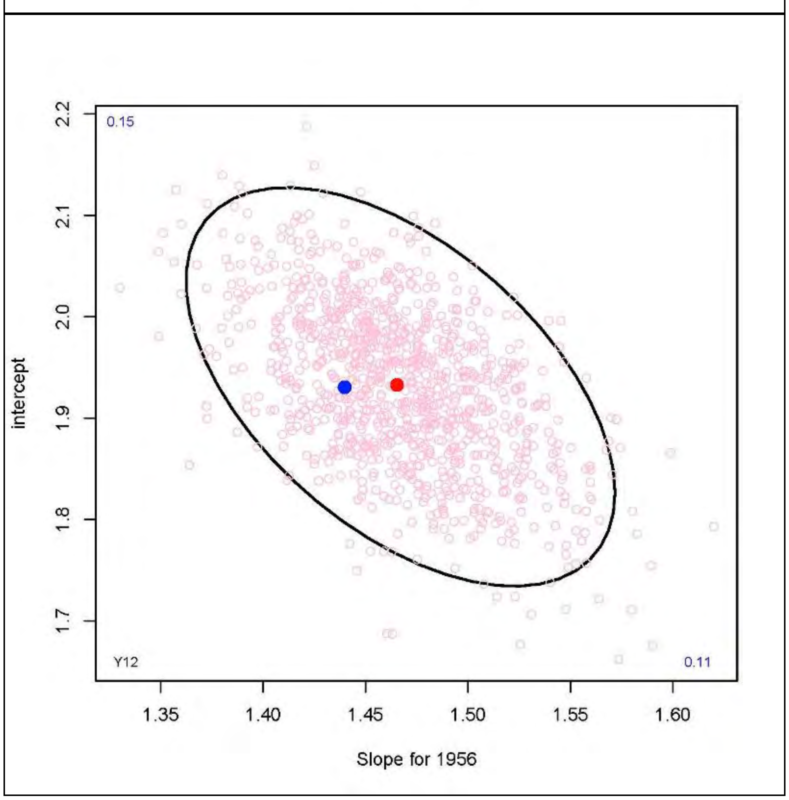
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT,
COMPLETE Y12 DATASET, 731 WORKERS





ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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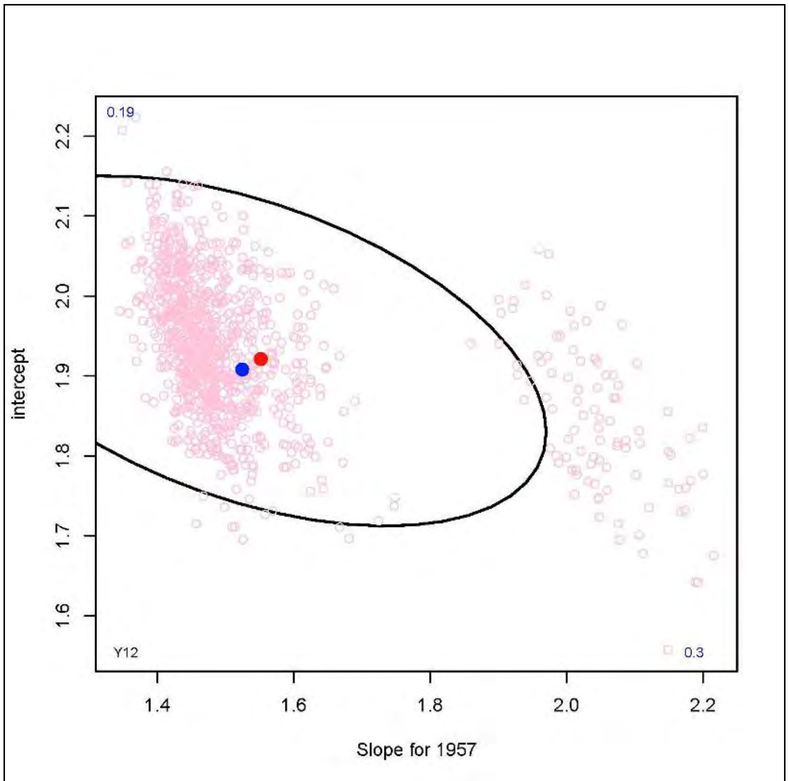

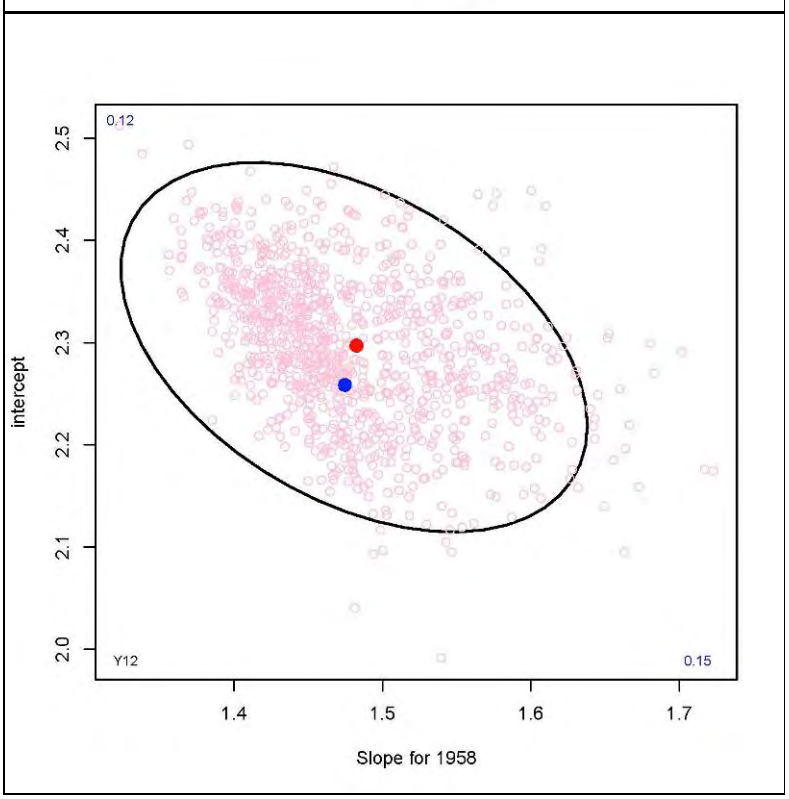

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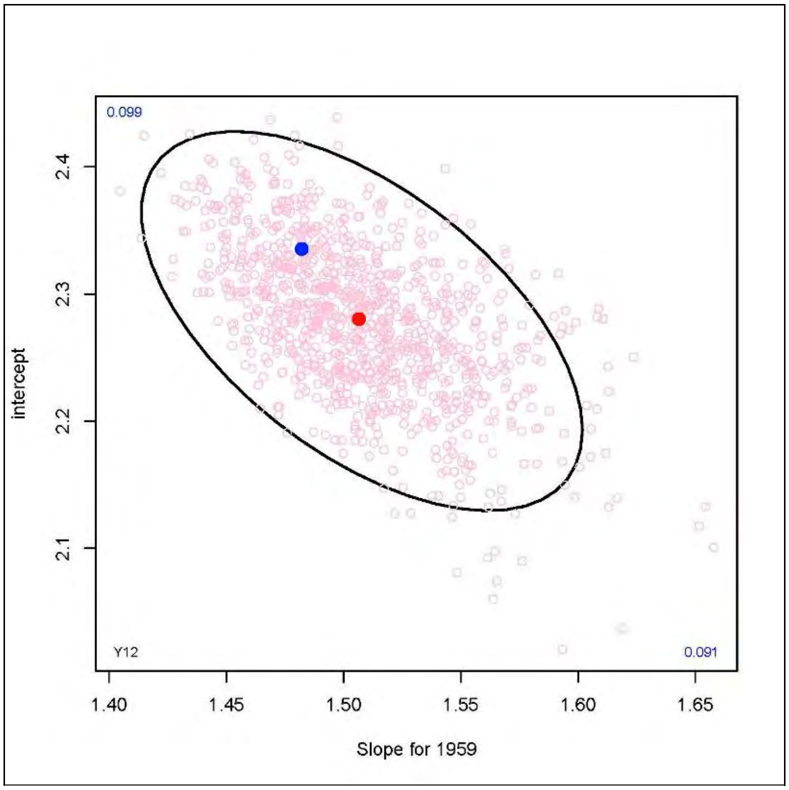
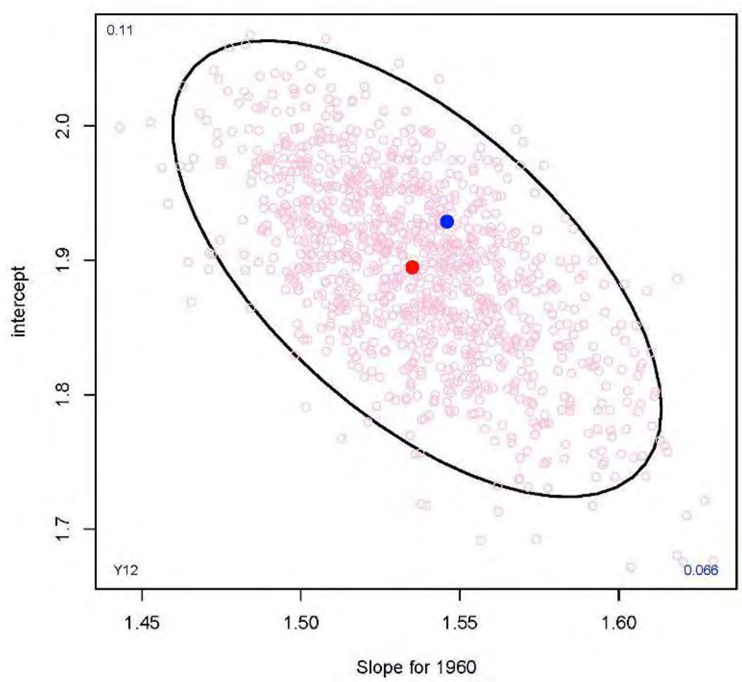
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS





ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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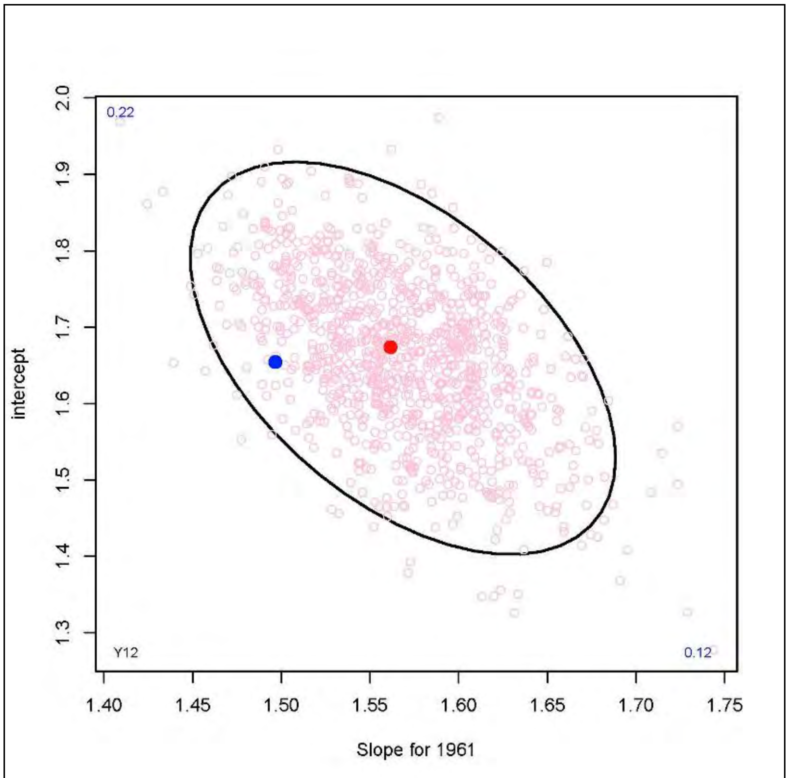

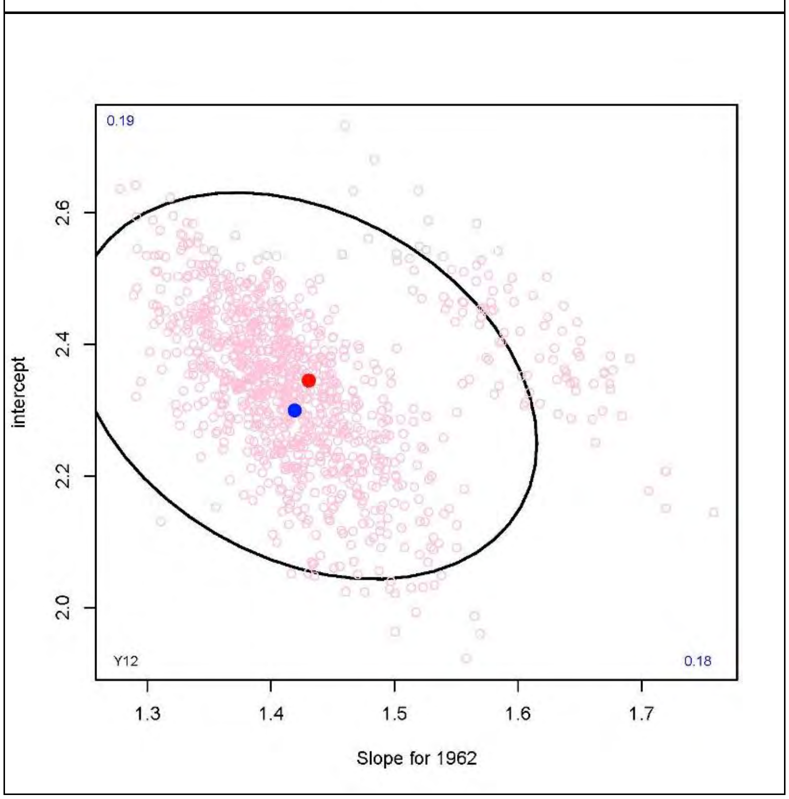

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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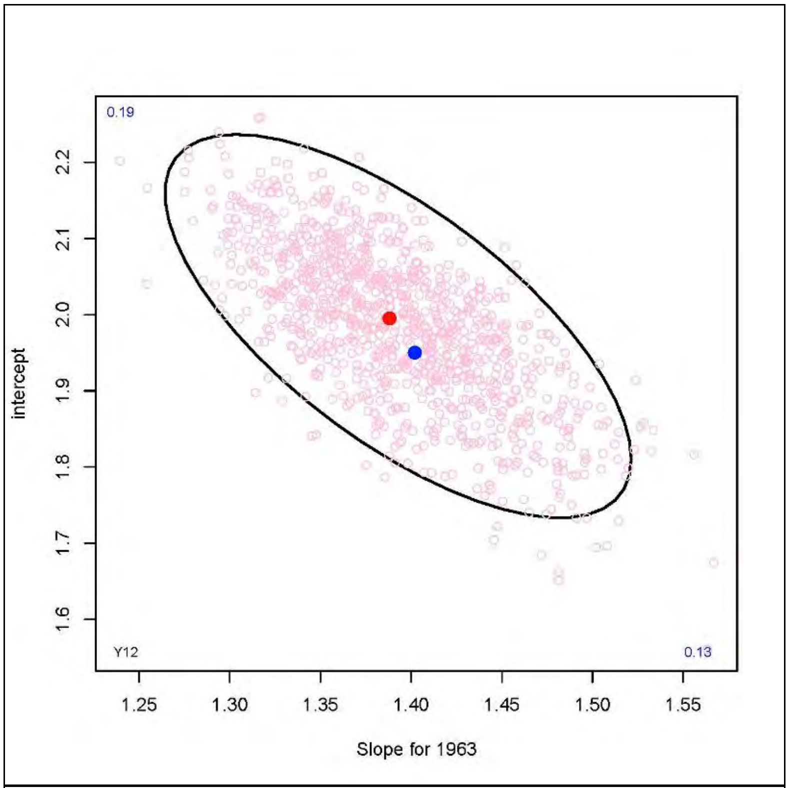

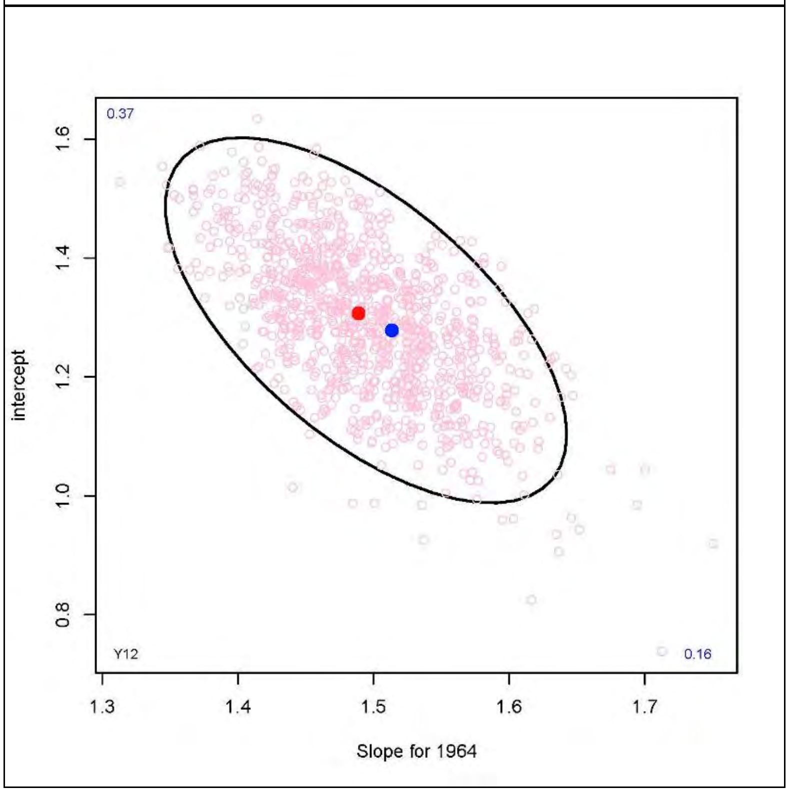

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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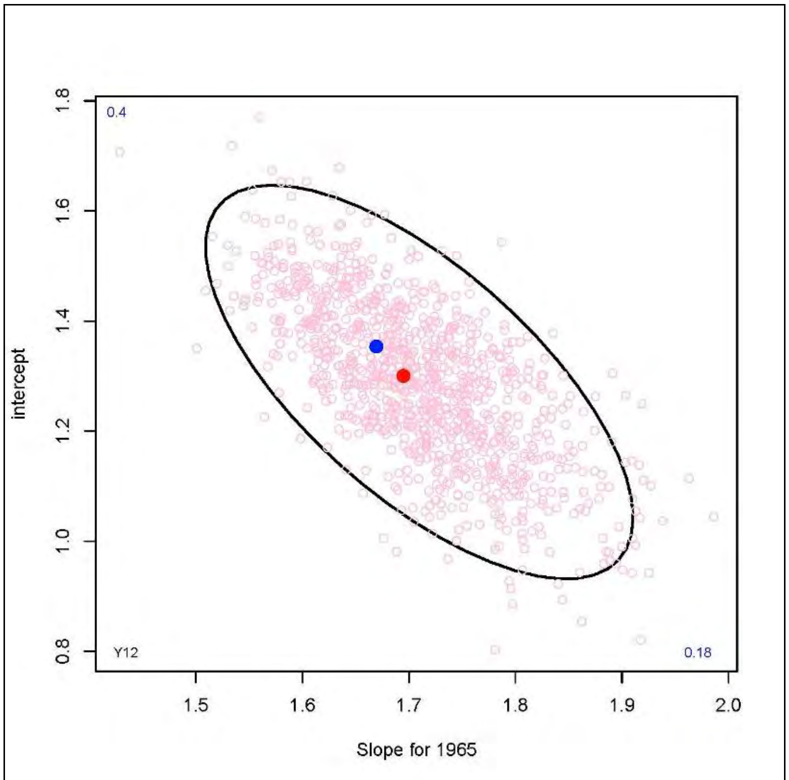

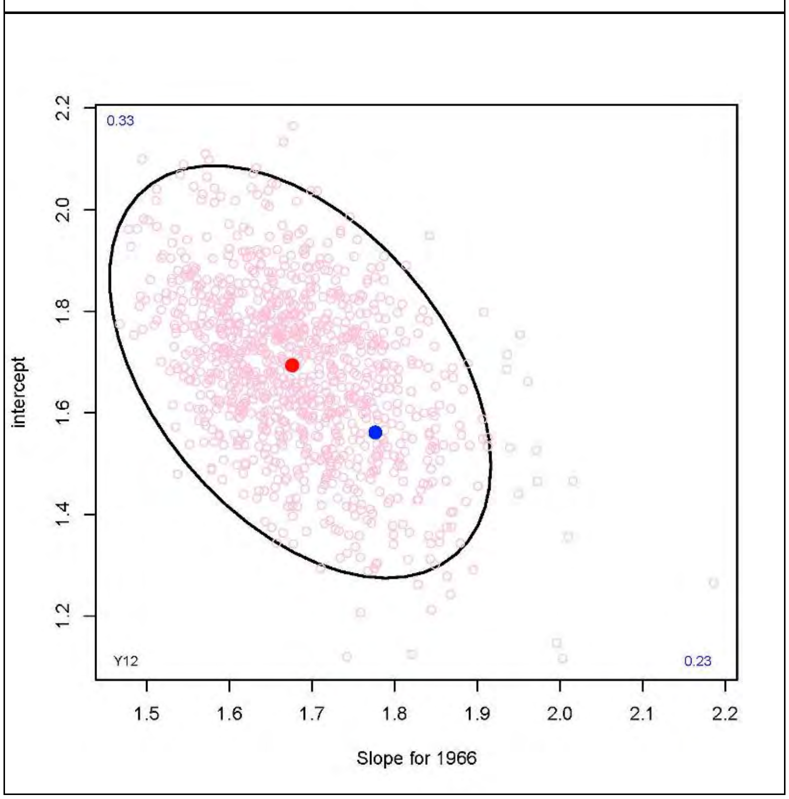

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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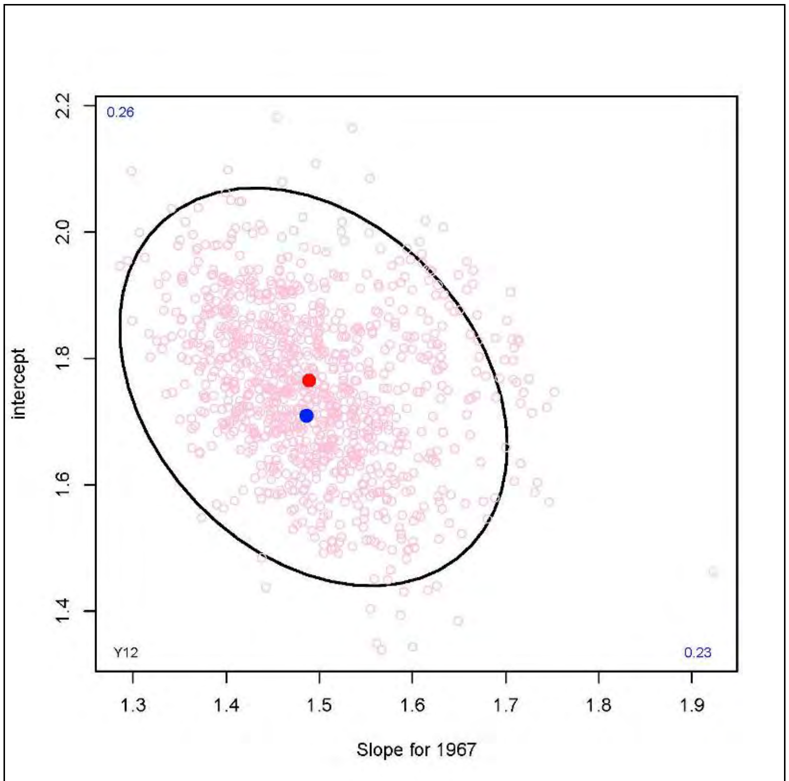

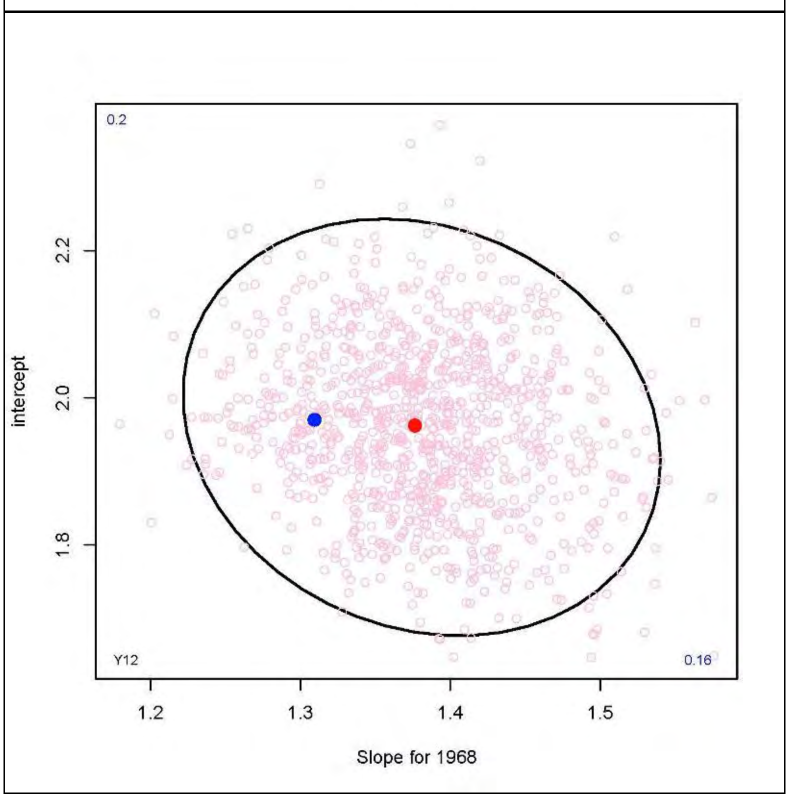

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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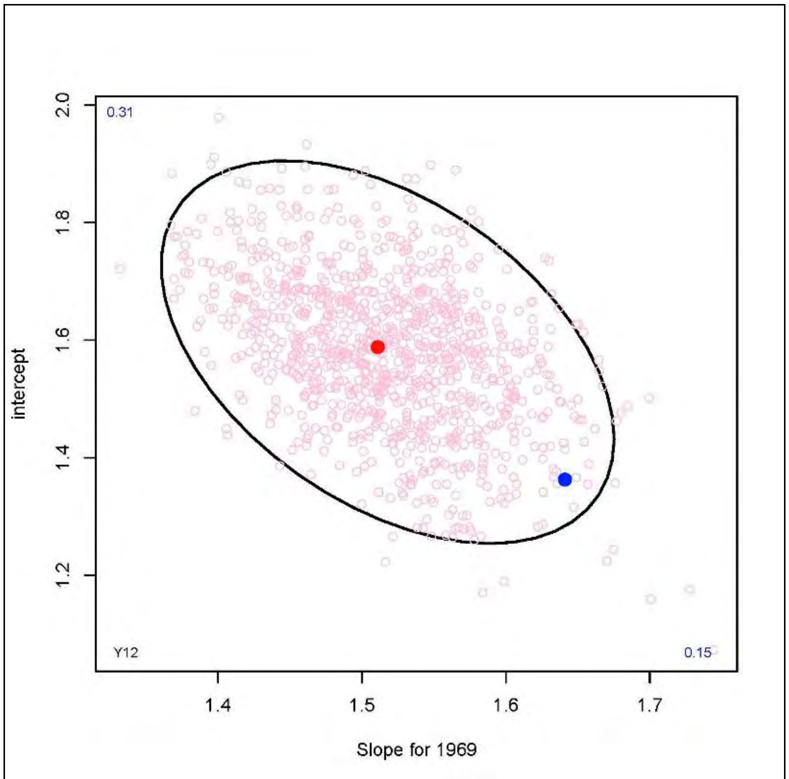

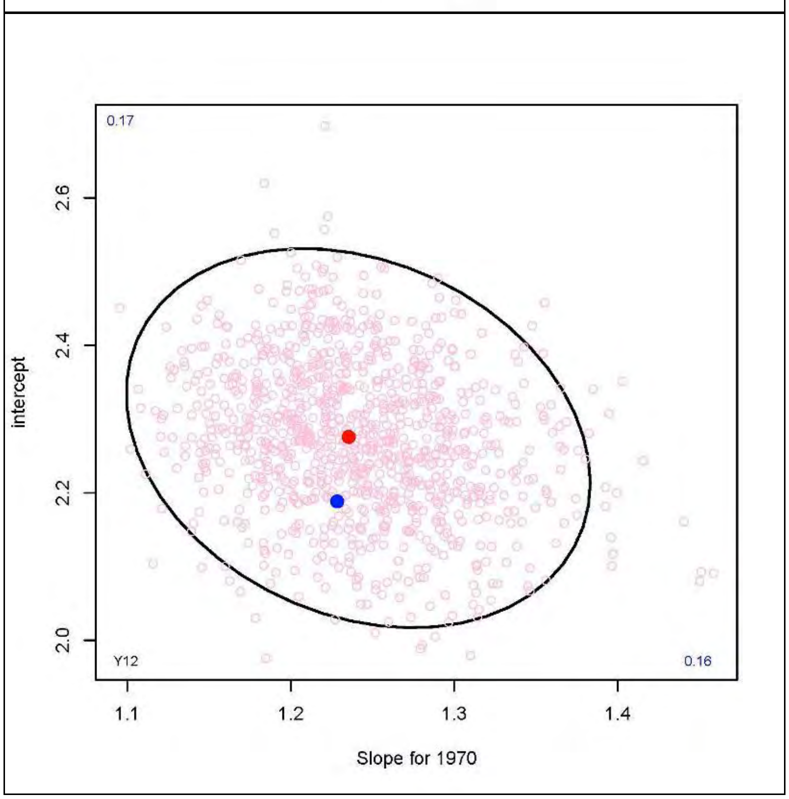

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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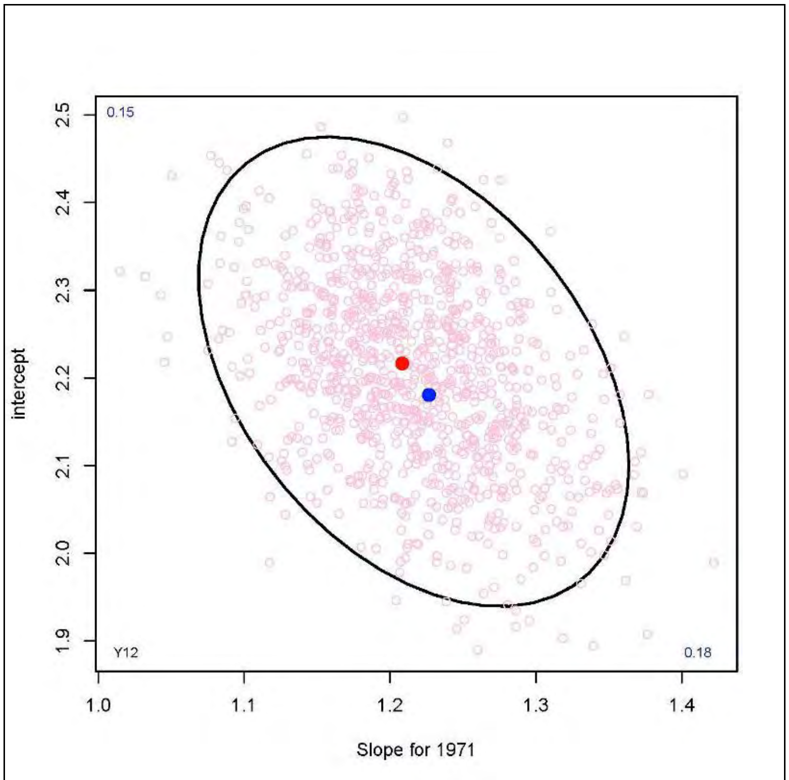

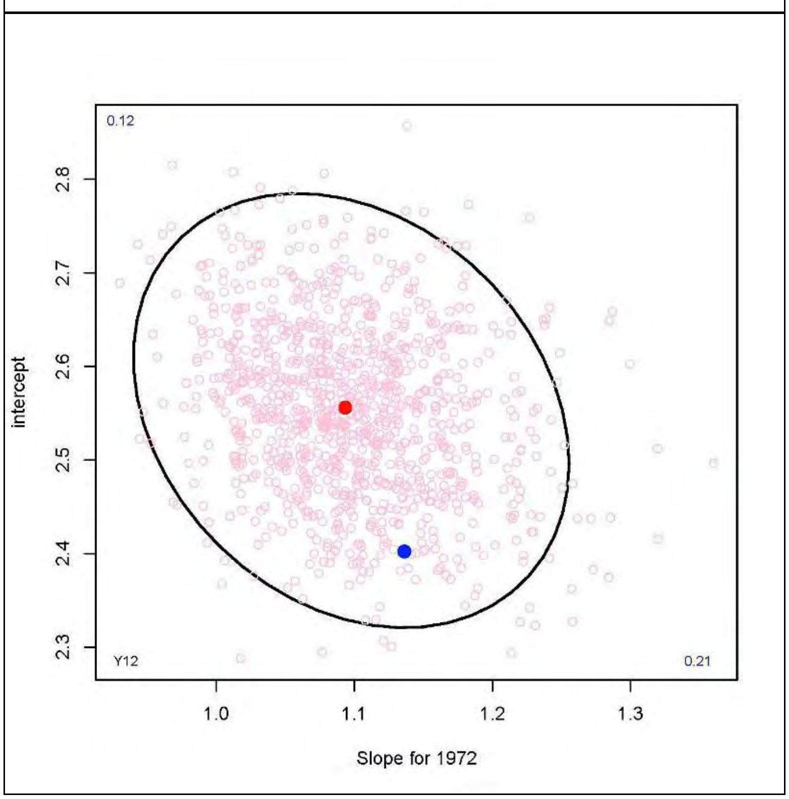

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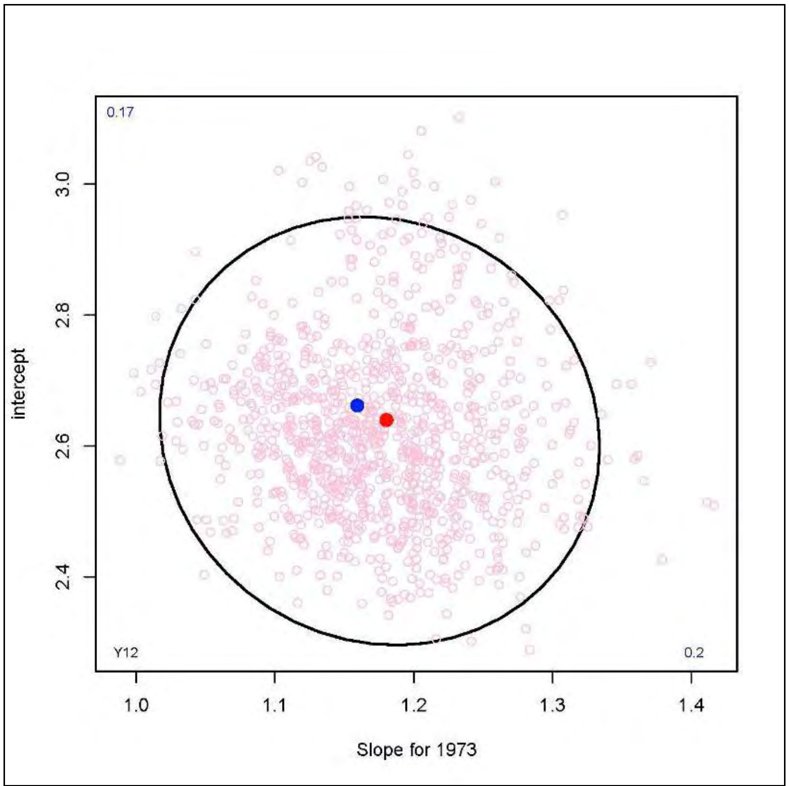

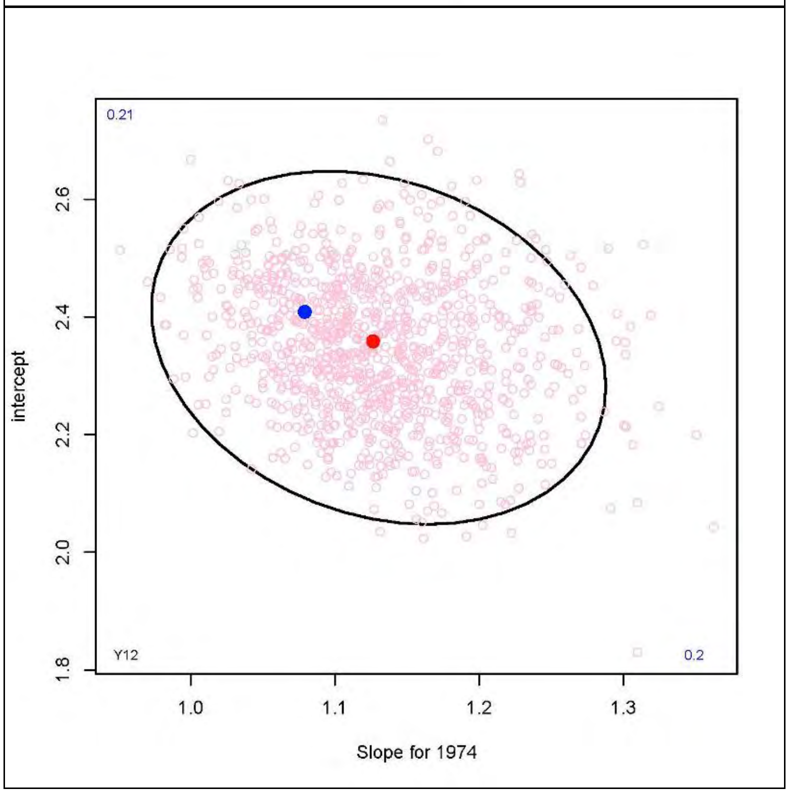

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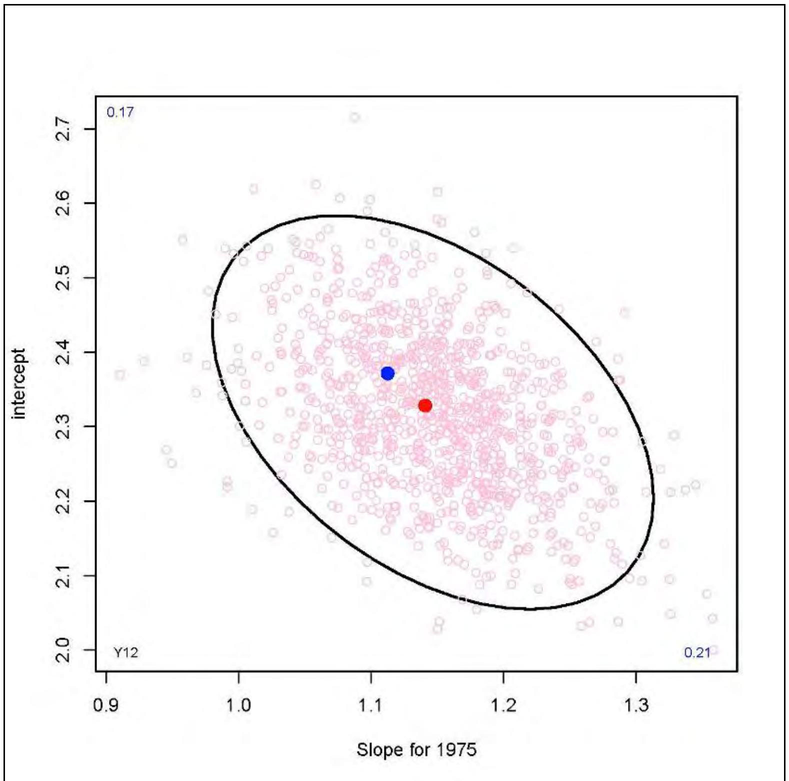

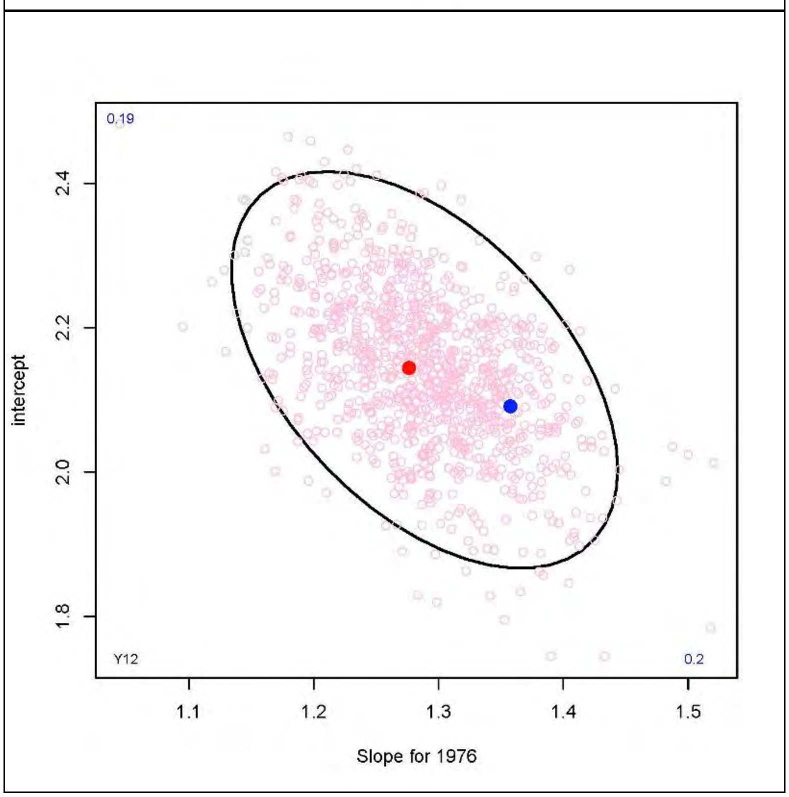

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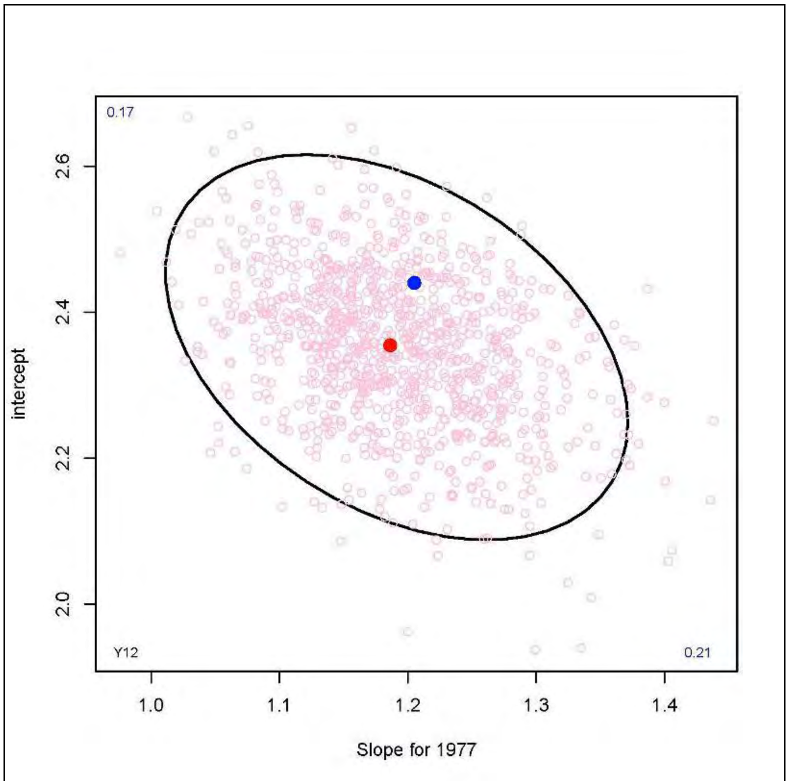
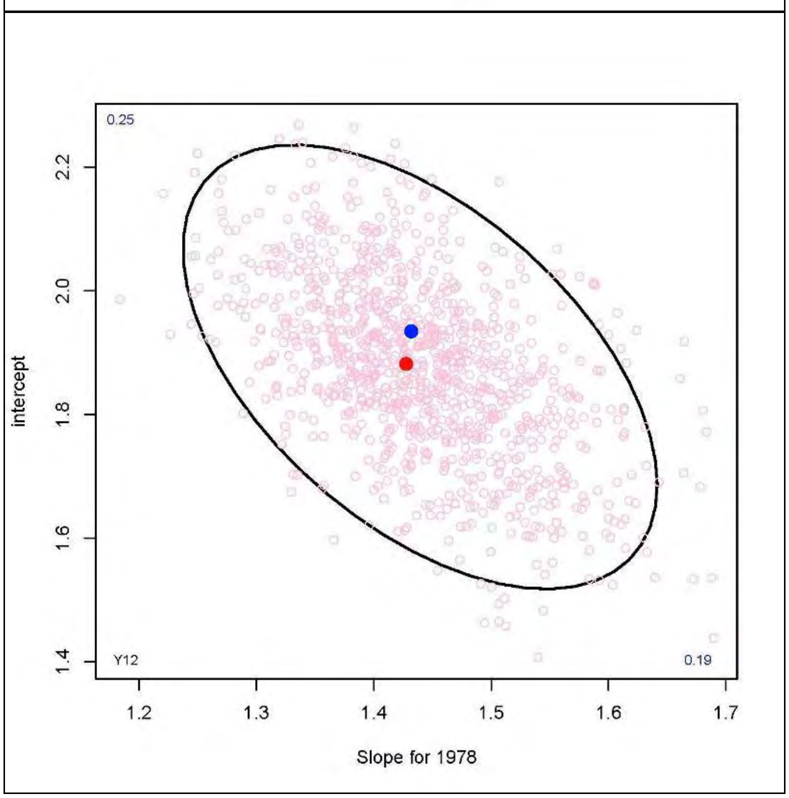
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS





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95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT,
COMPLETE Y12 DATASET, 731 WORKERS
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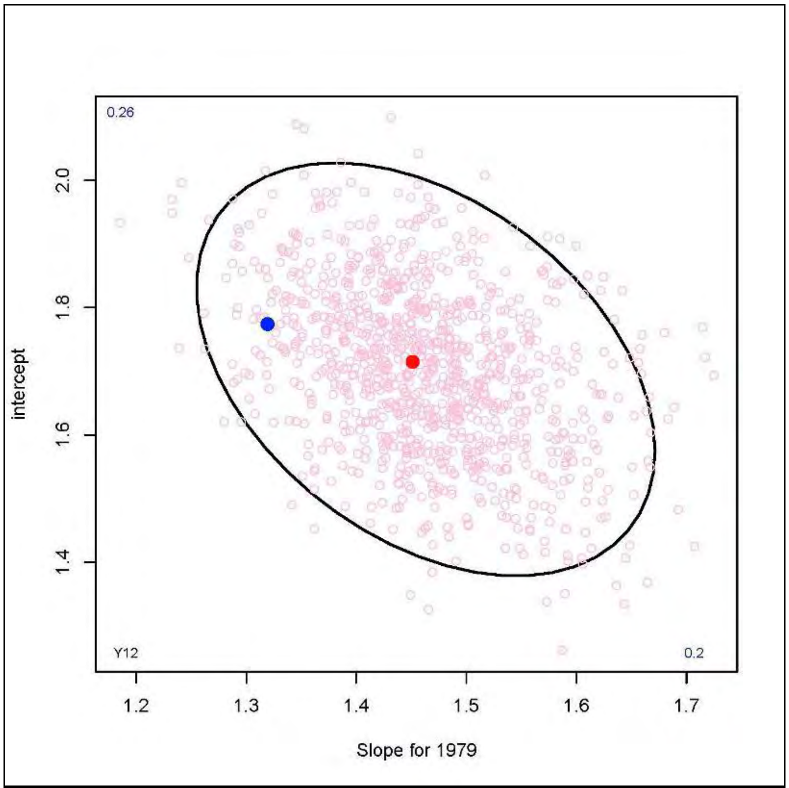

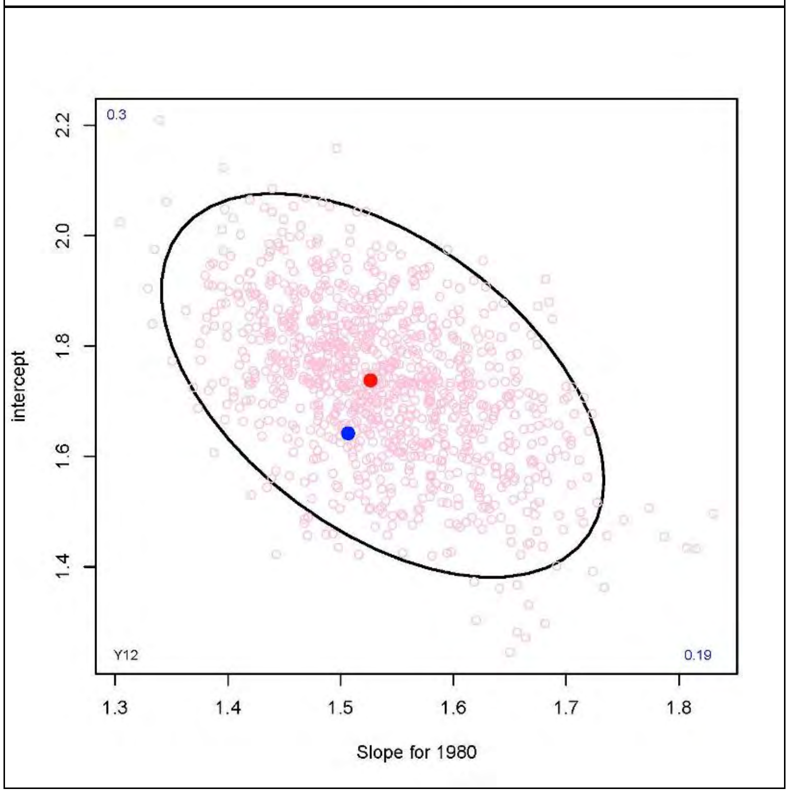

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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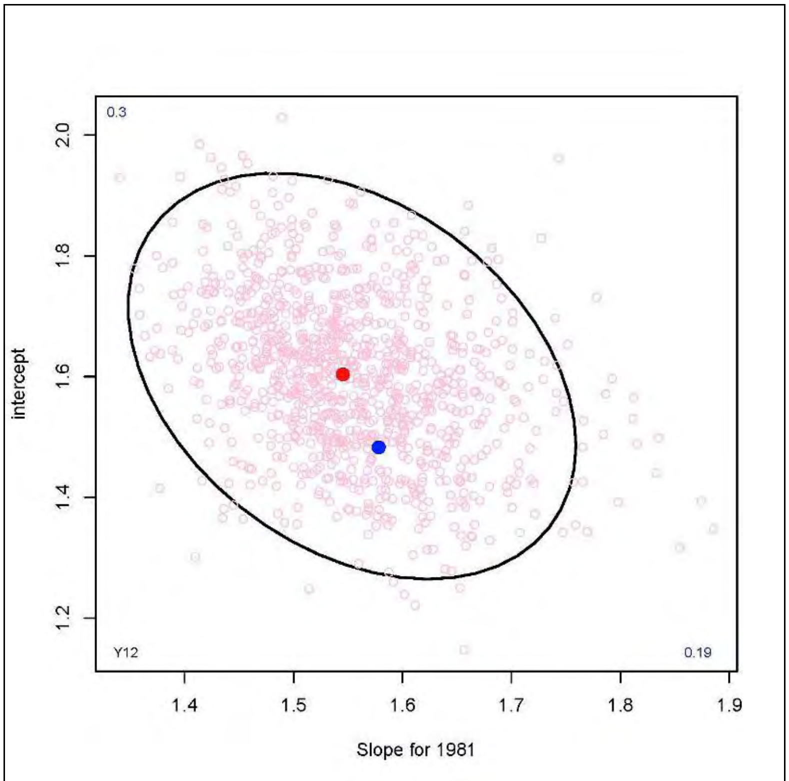

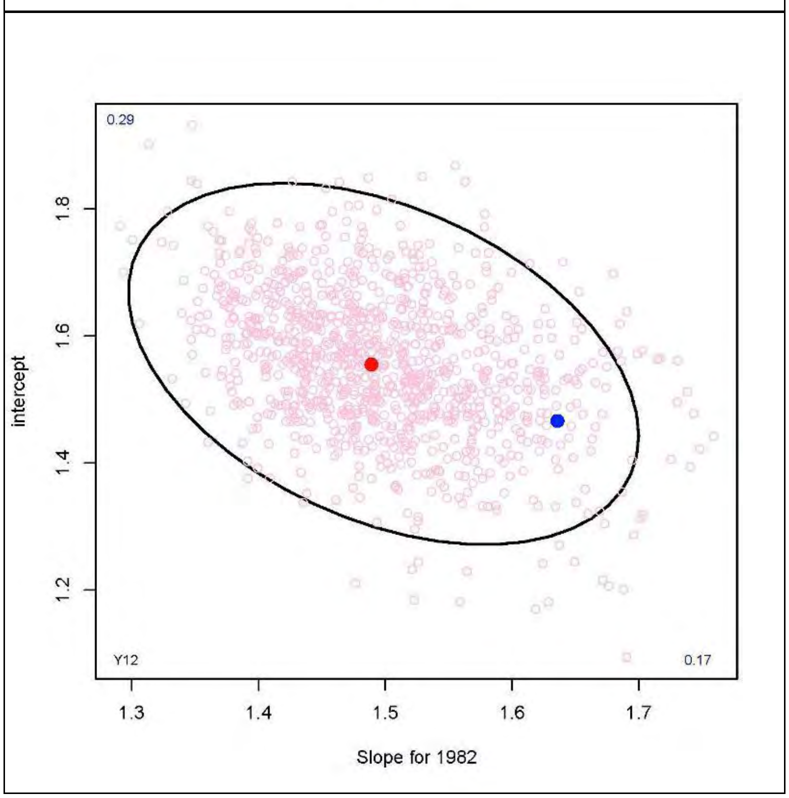

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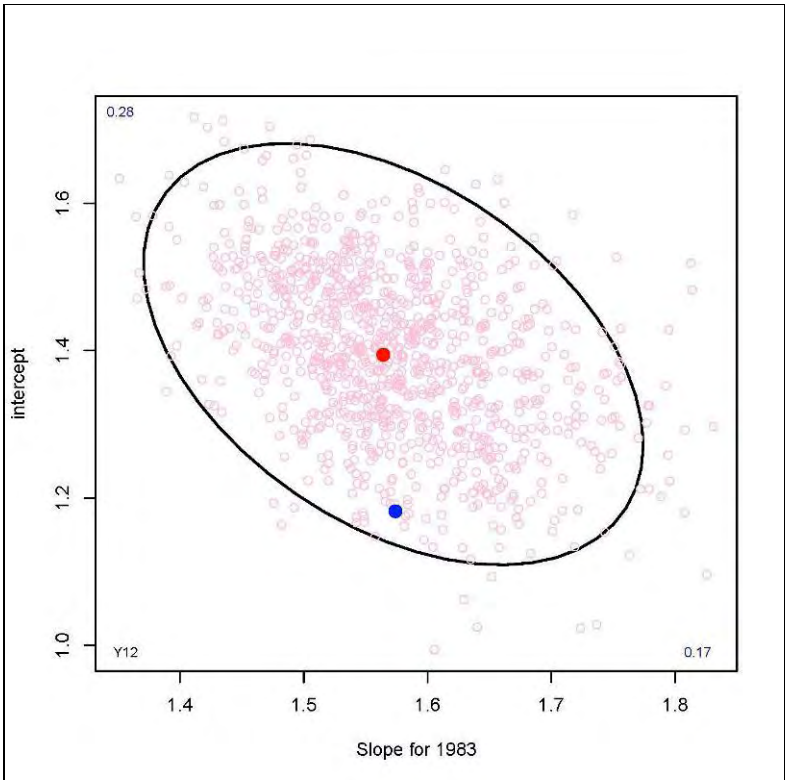
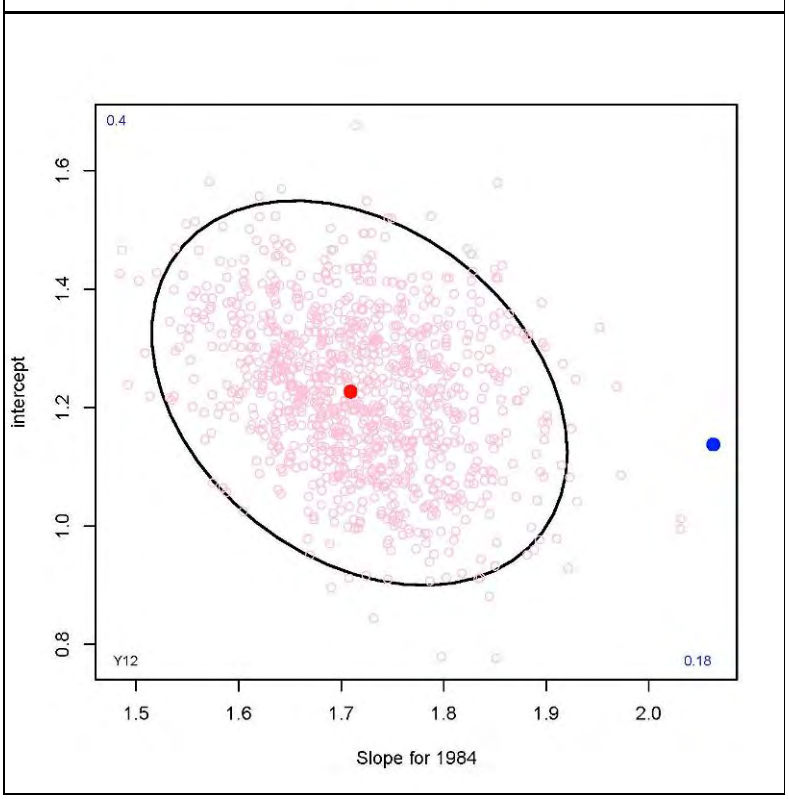
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS





ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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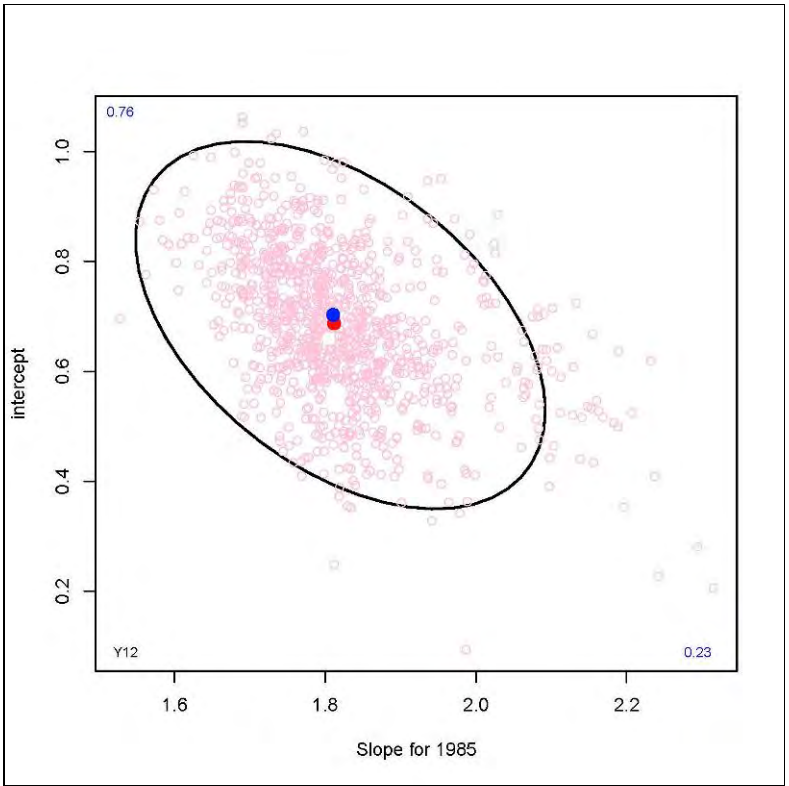

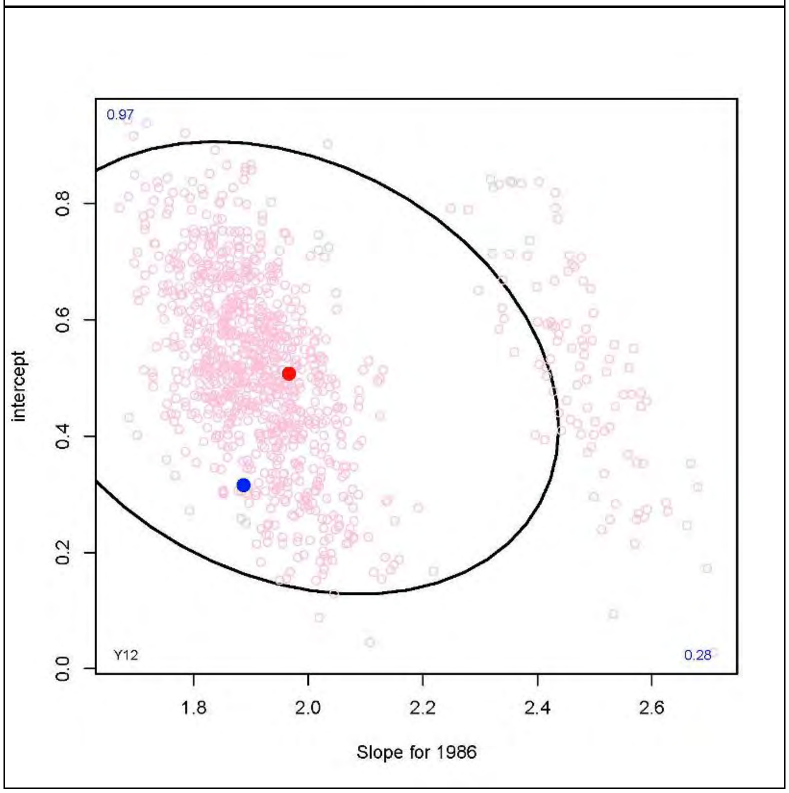

ATTACHMENT C
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE Y12 DATASET, 731 WORKERS
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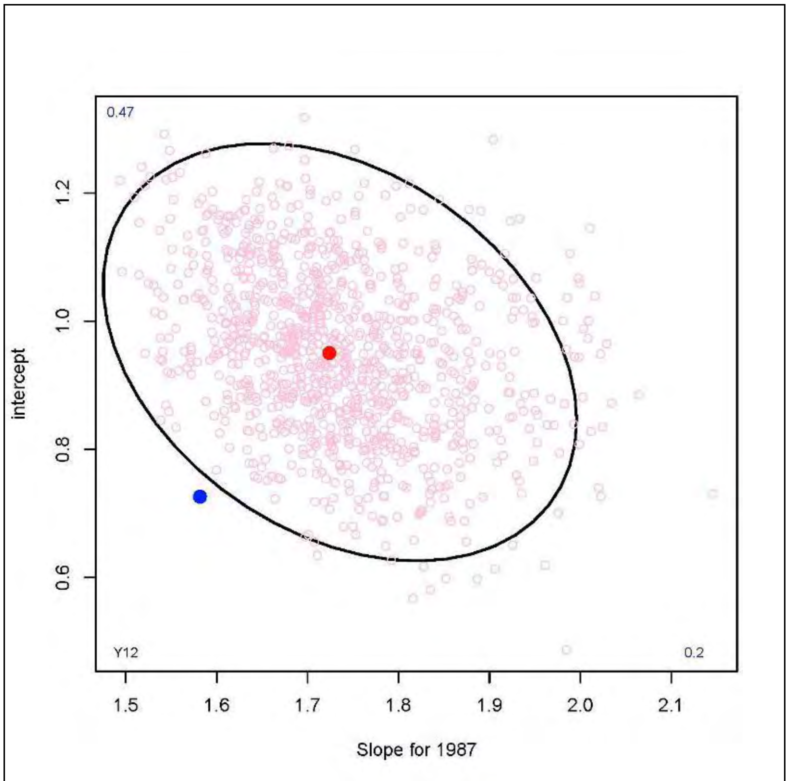
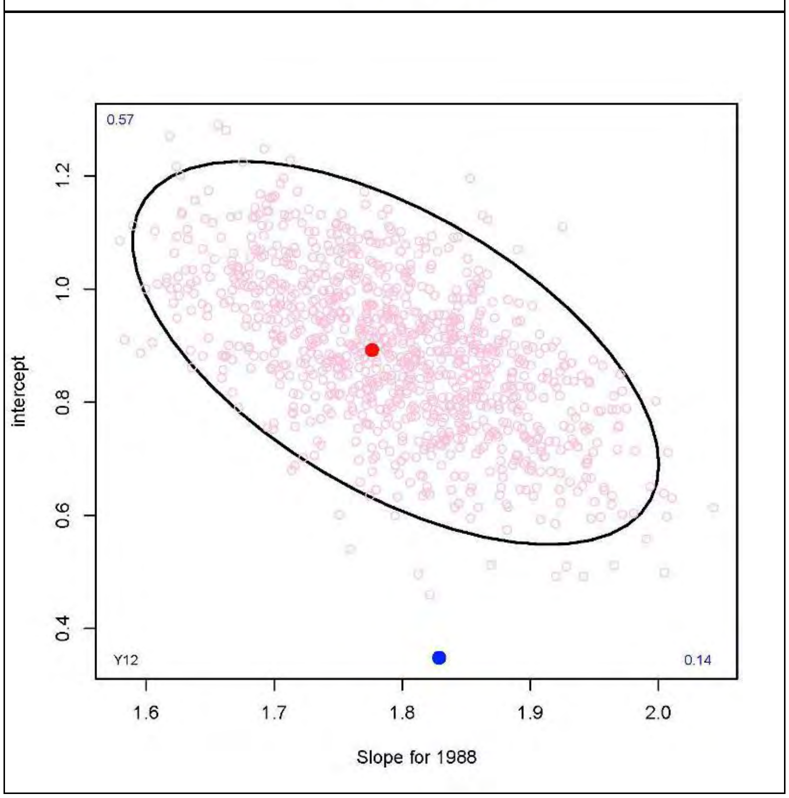
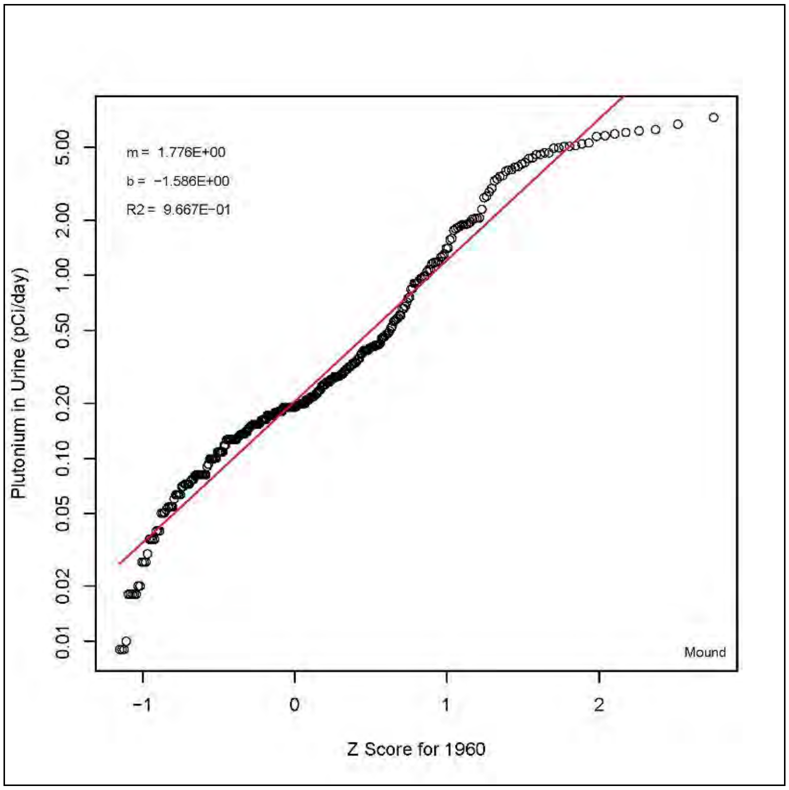




ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET

This attachment presents lognormal probability plots for the complete Mound plutonium urine bioassay dataset for 1960 to 1990. The slope and intercept for the line of best fit to the data are given on the plot.



ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET
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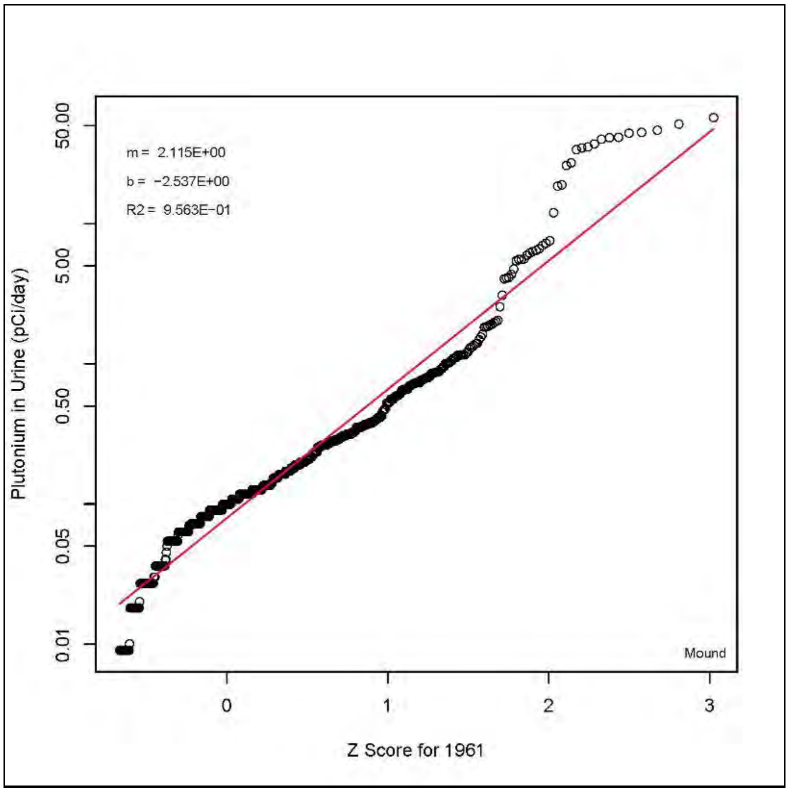

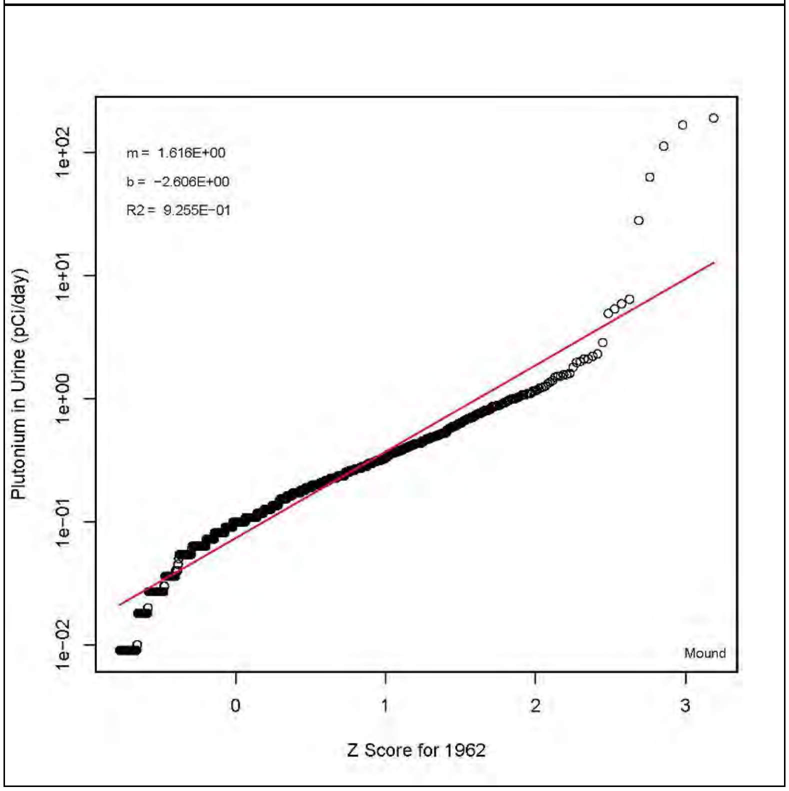

ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET
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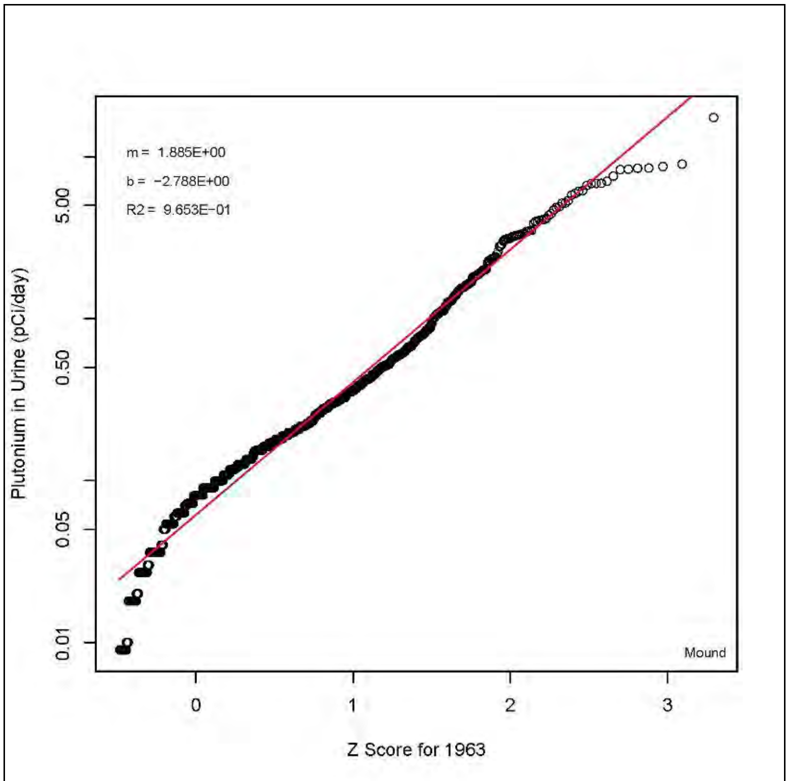
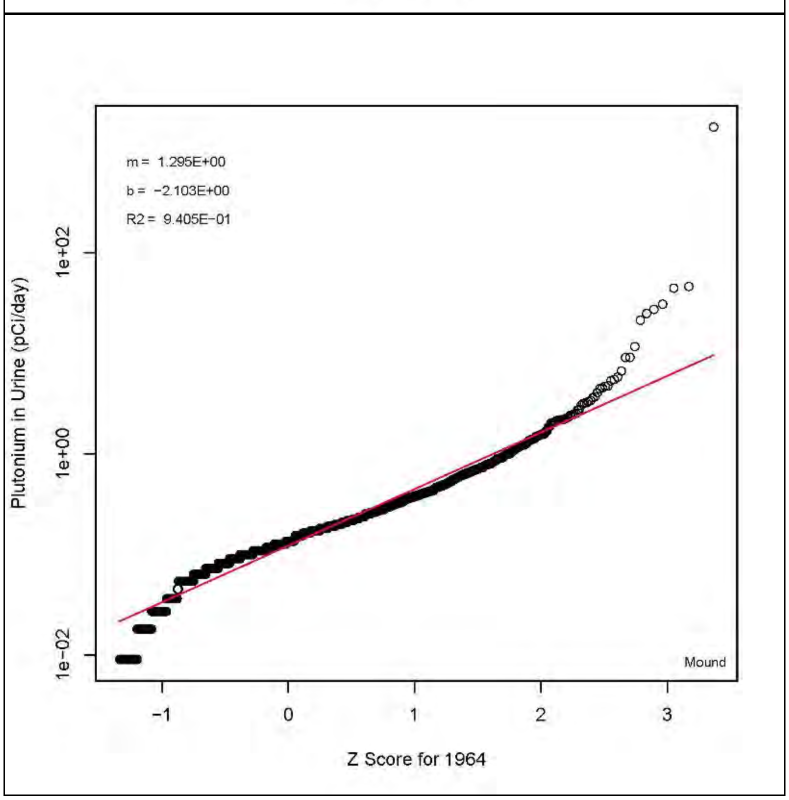
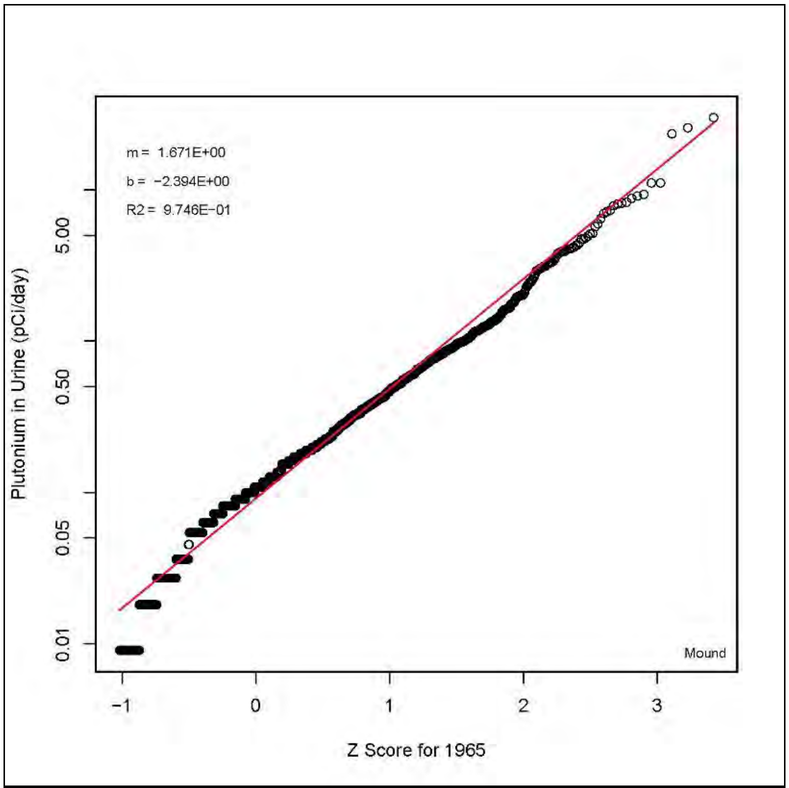
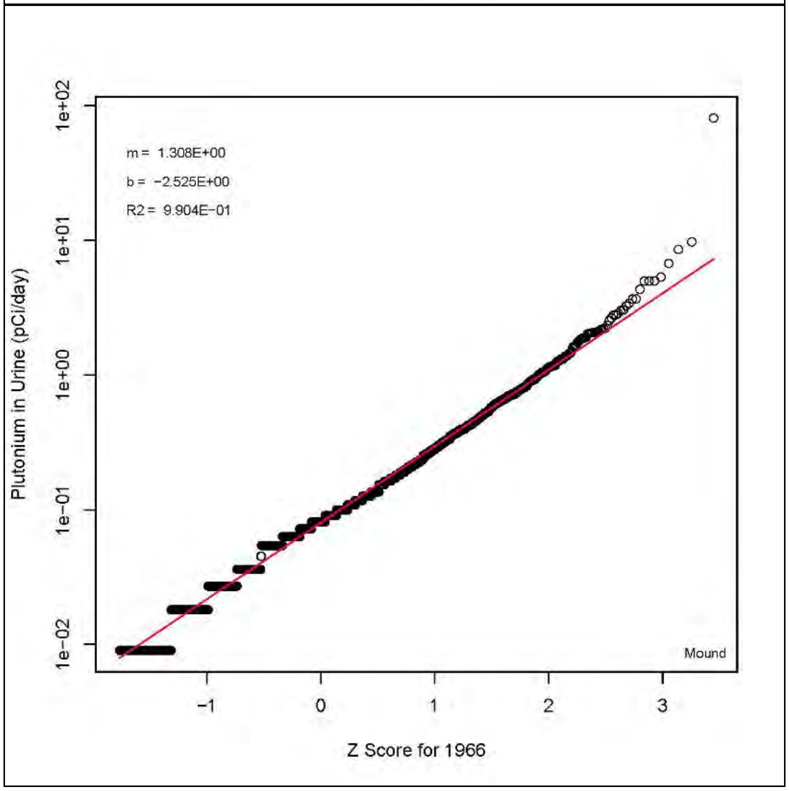


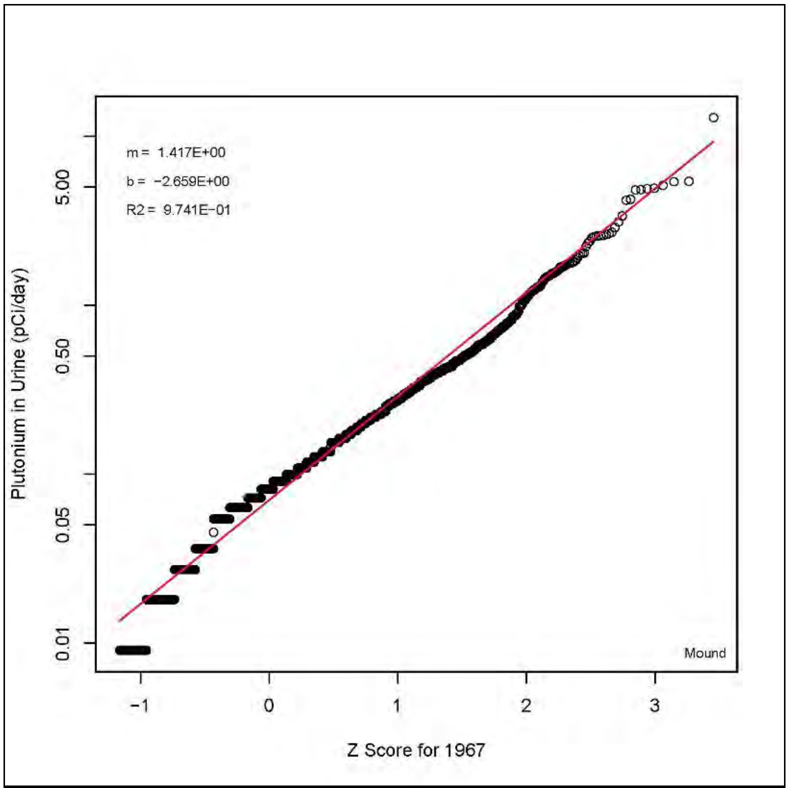


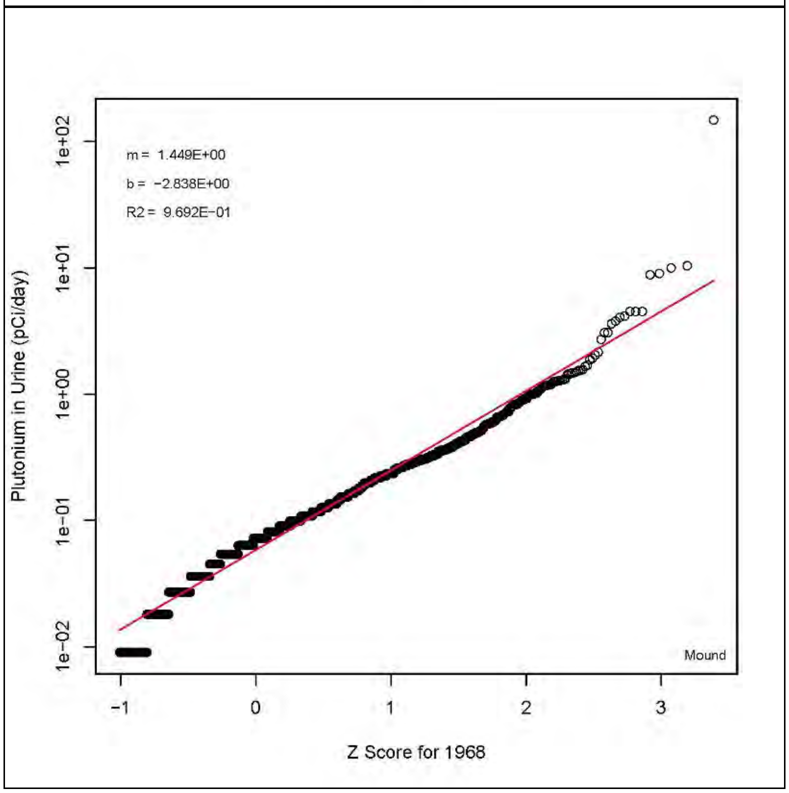
**ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET**





ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET





ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET
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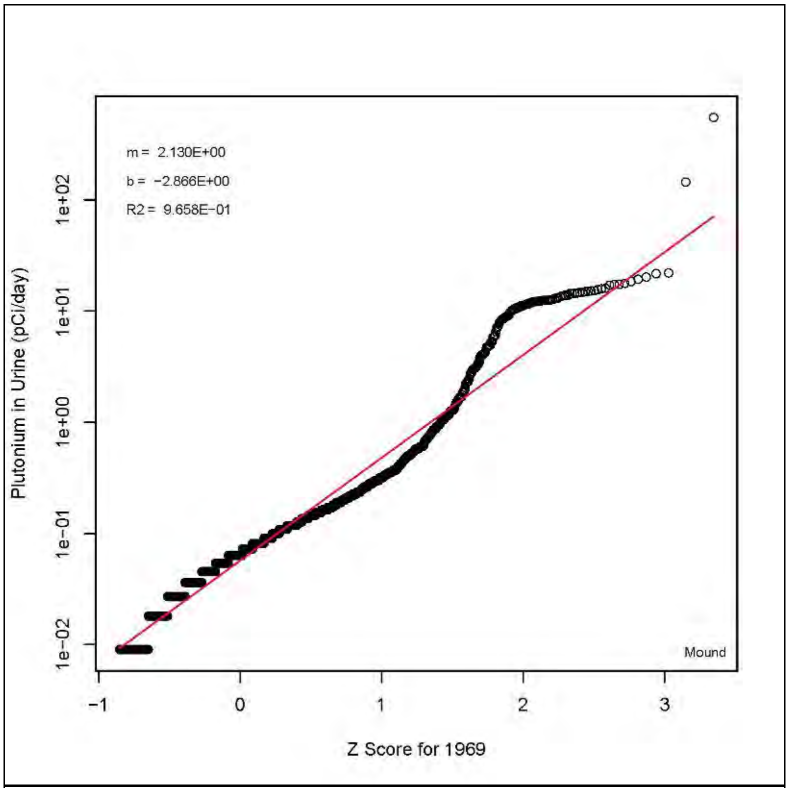

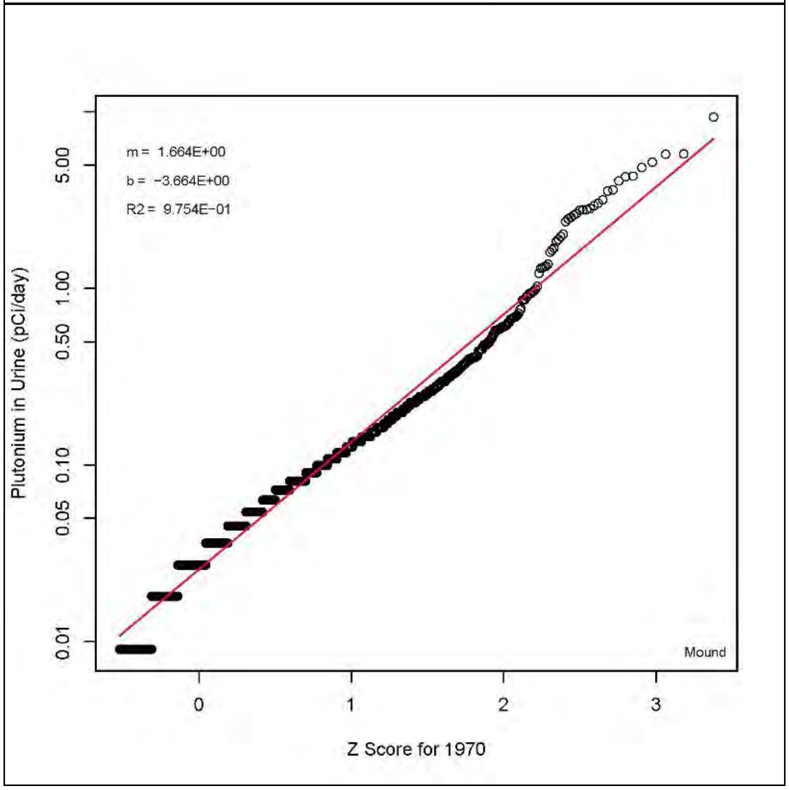

ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET
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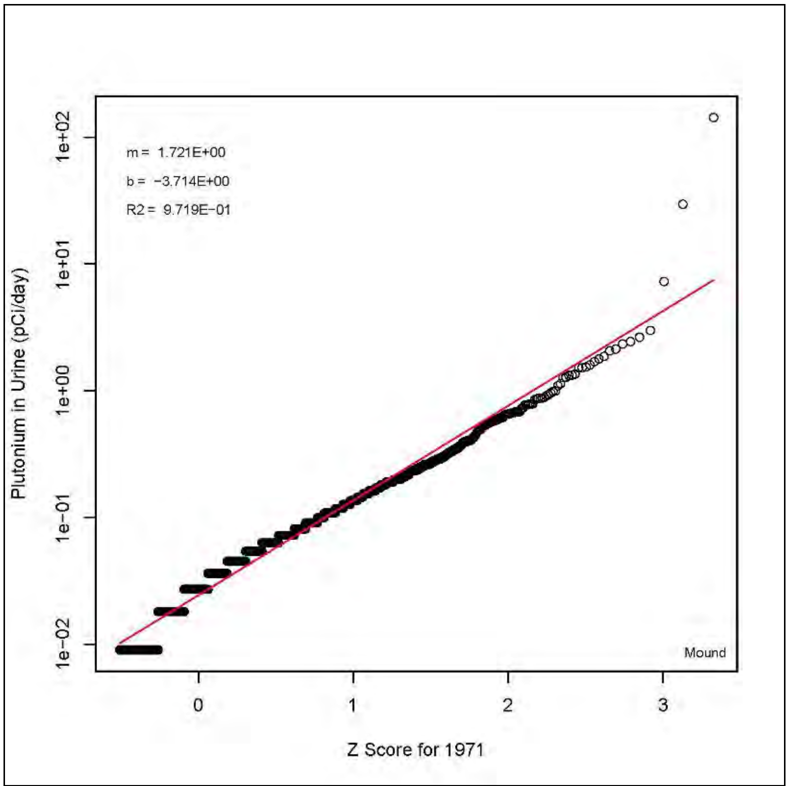

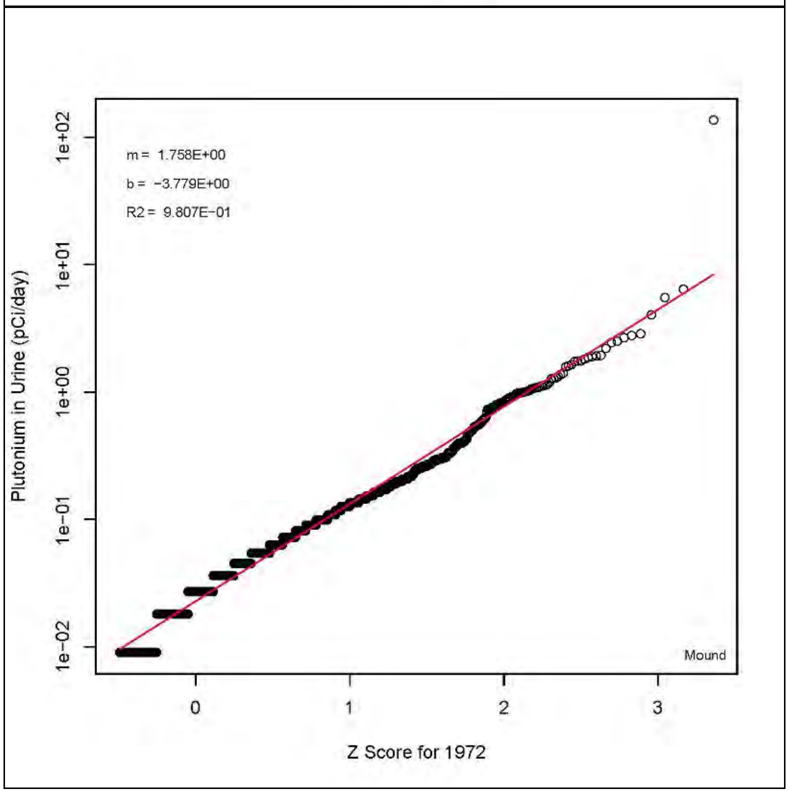

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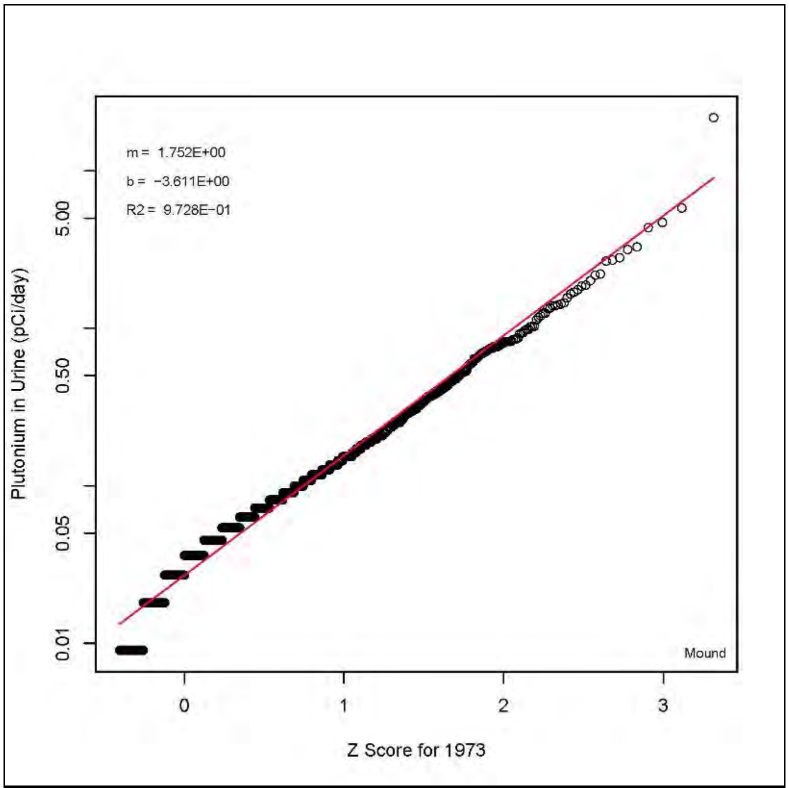
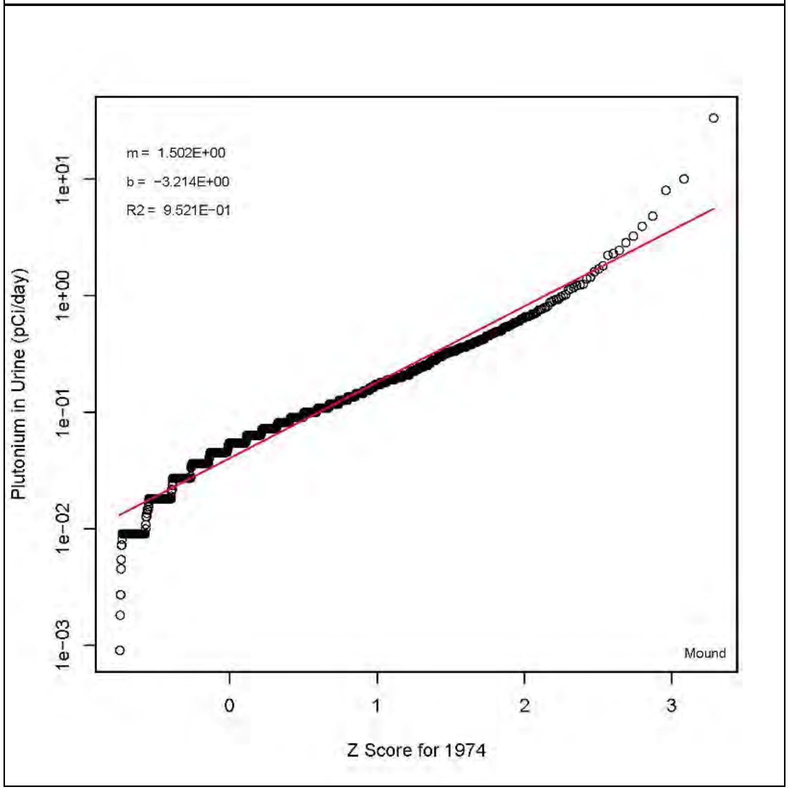
LOGNORMAL PROBABILITY PLOTS, COMPLETE MOUND DATASET





ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS, COMPLETE MOUND DATASET
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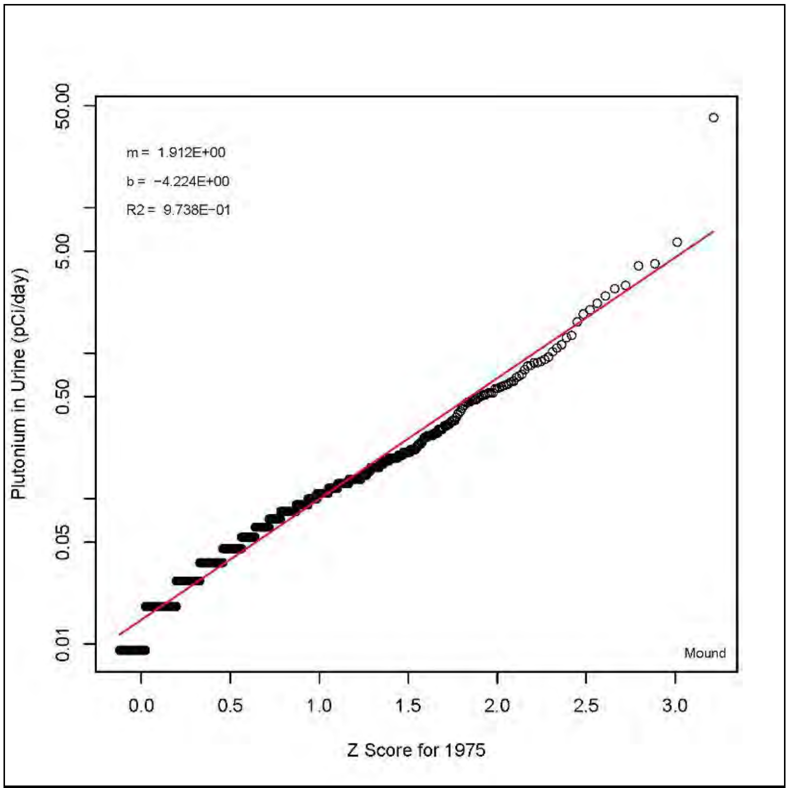

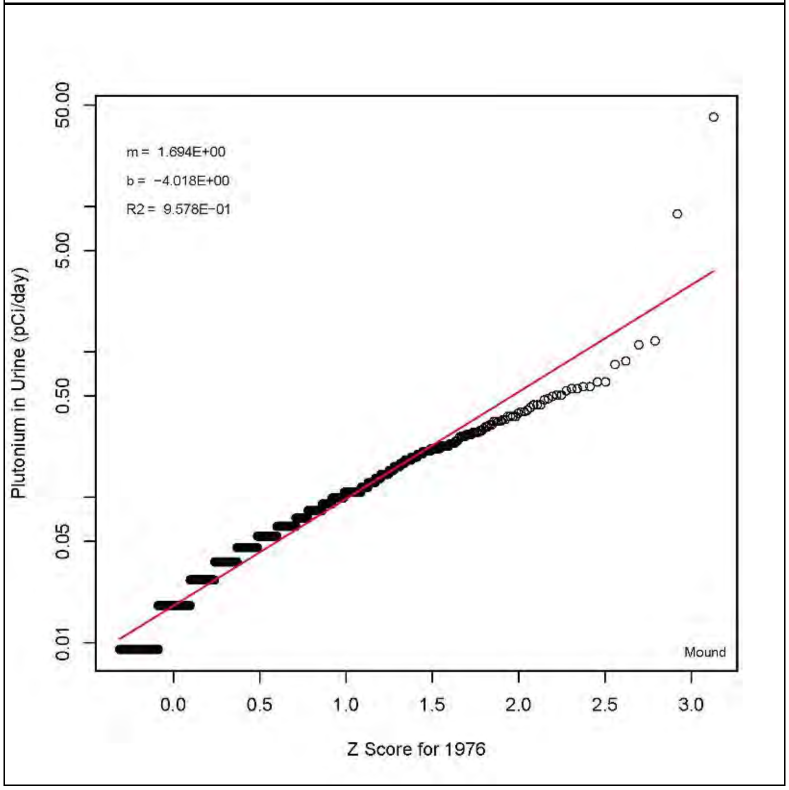

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LOGNORMAL PROBABILITY PLOTS,
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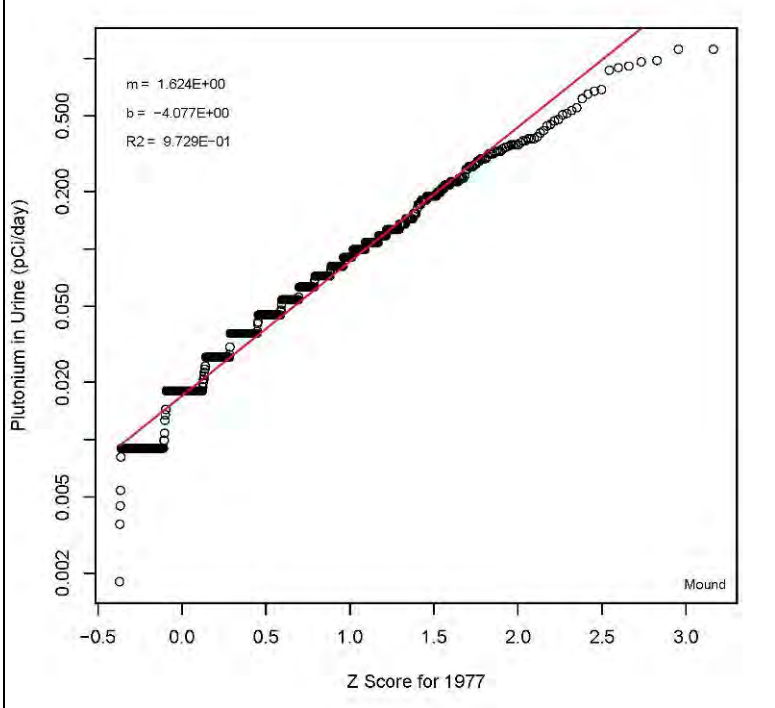

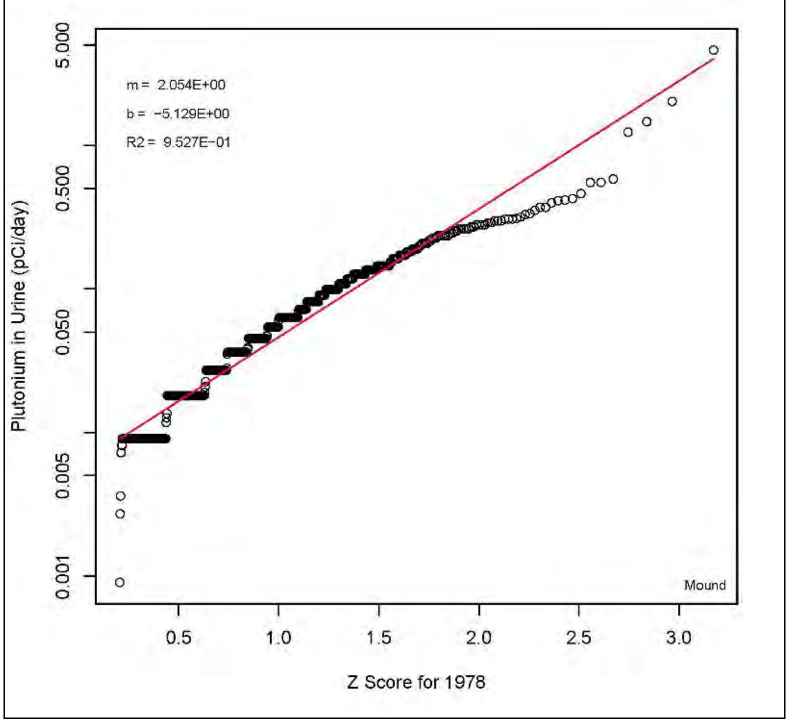

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LOGNORMAL PROBABILITY PLOTS,
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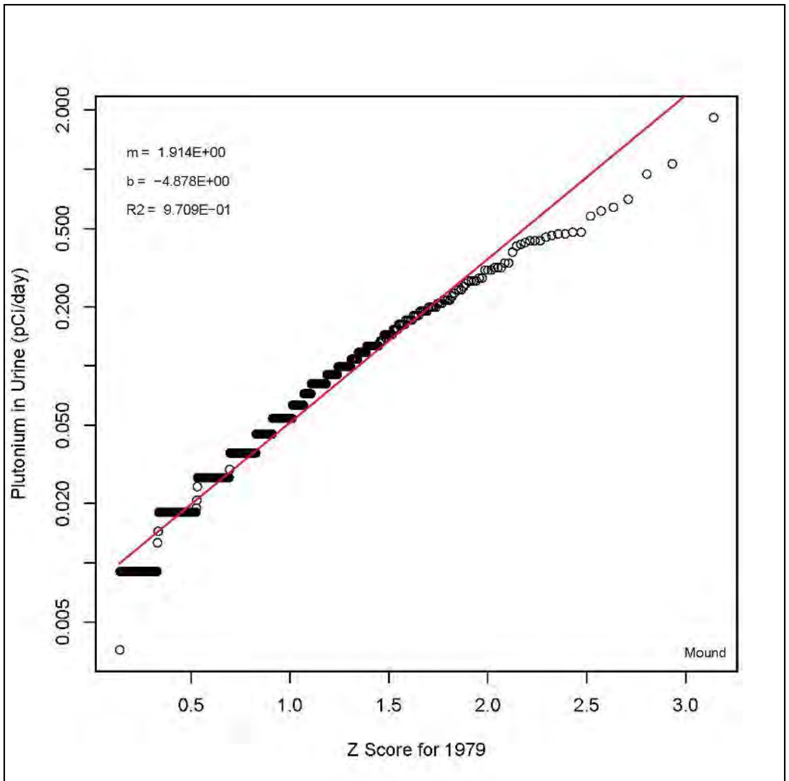

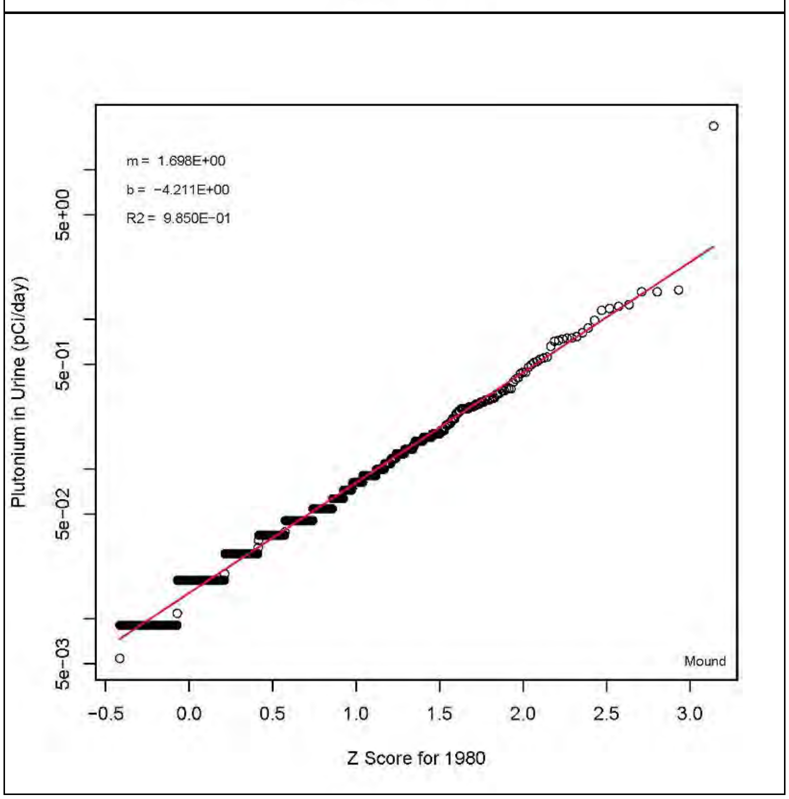

ATTACHMENT D
LOGNORMAL PROBABILITY PLOTS,
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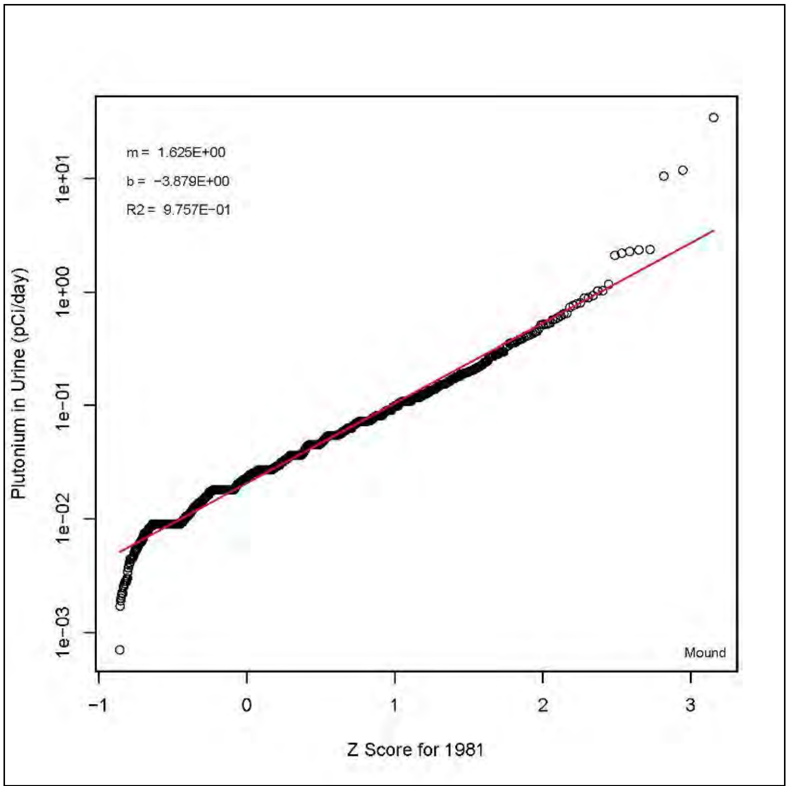

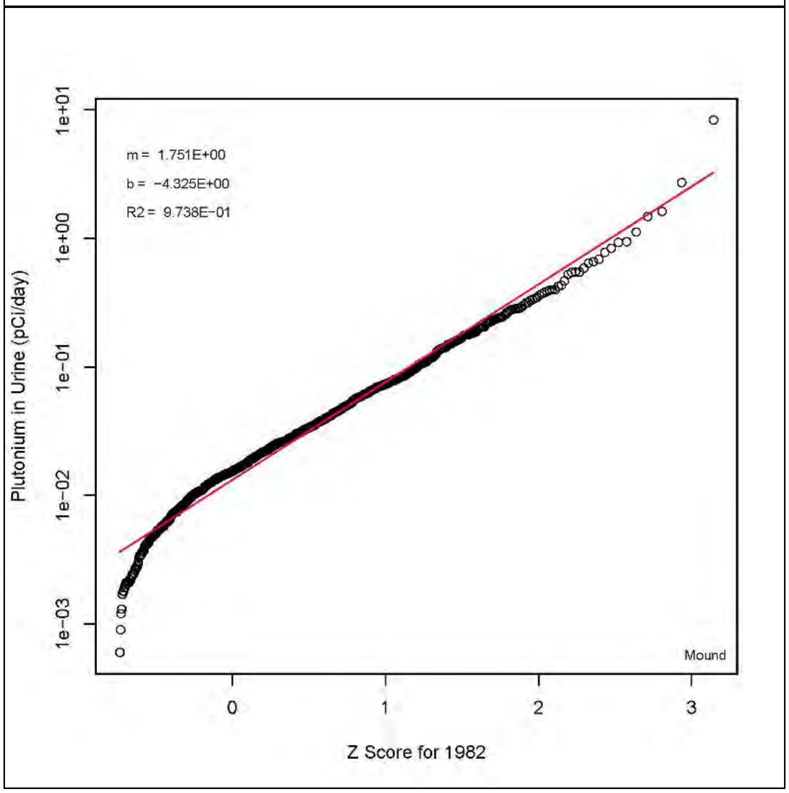

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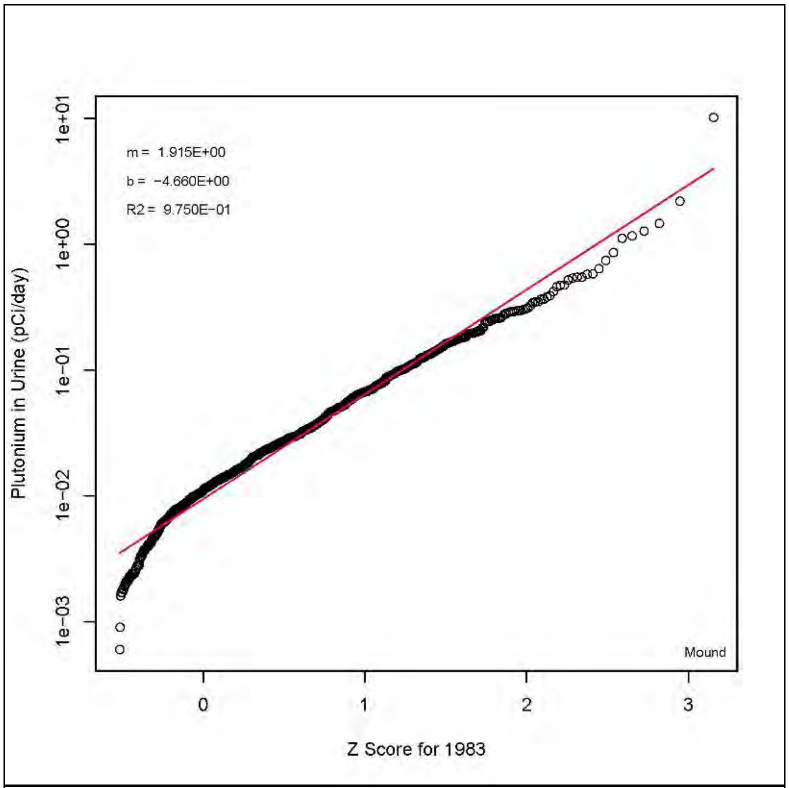
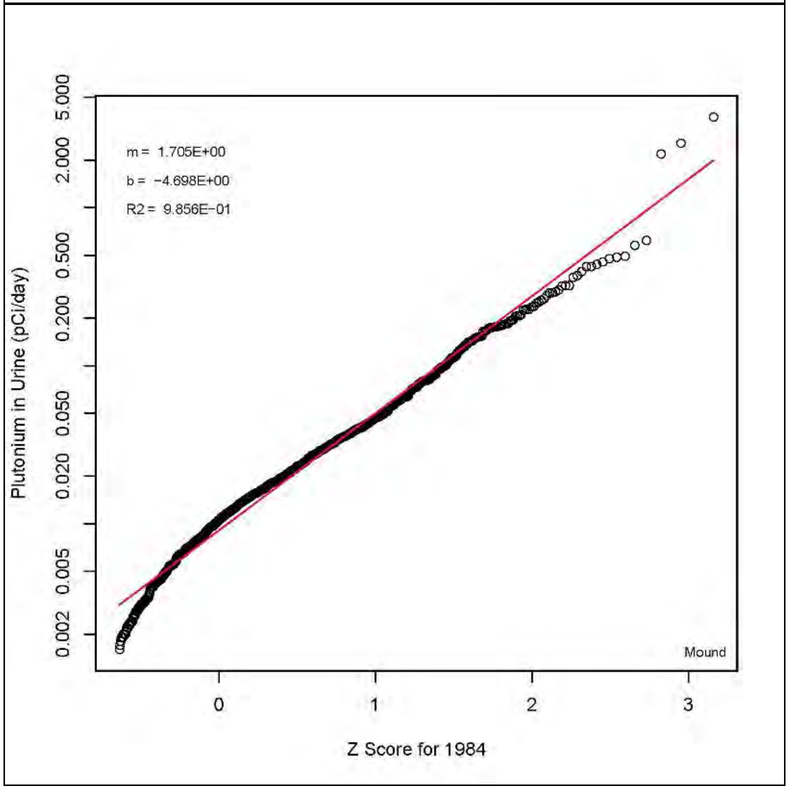
LOGNORMAL PROBABILITY PLOTS,
COMPLETE MOUND DATASET





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LOGNORMAL PROBABILITY PLOTS,
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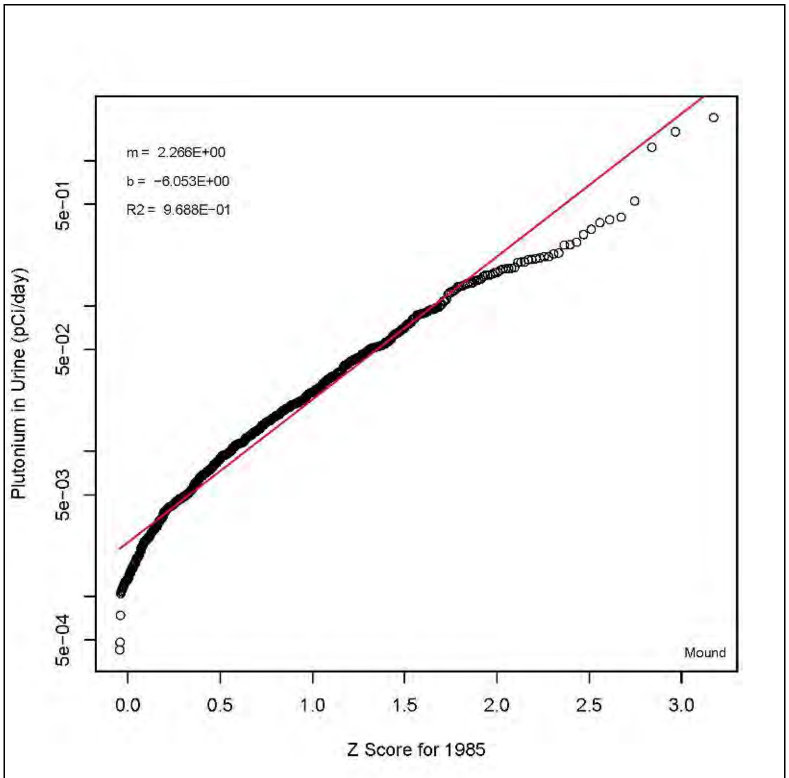

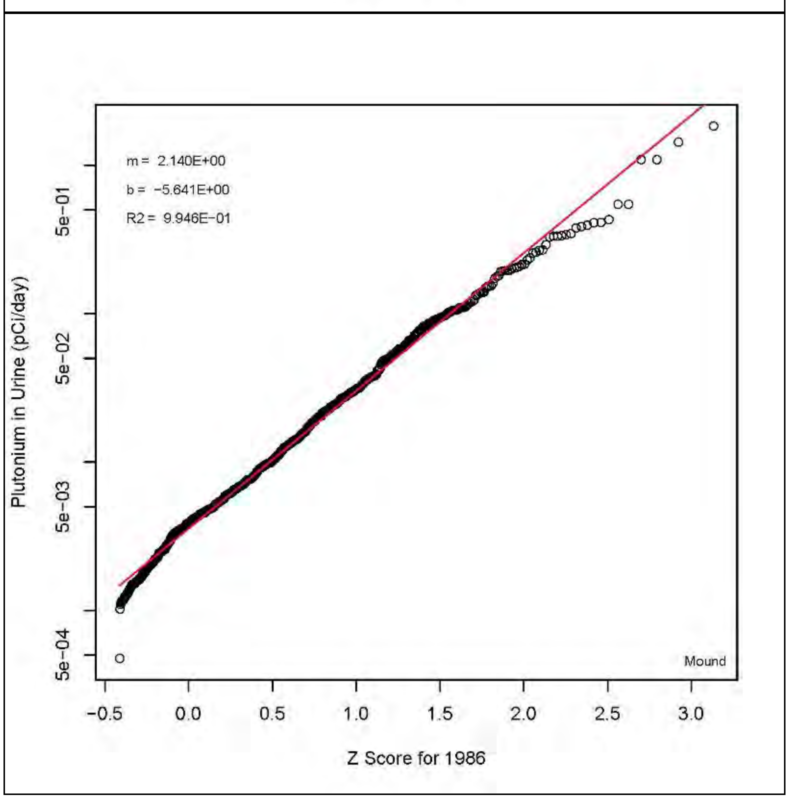

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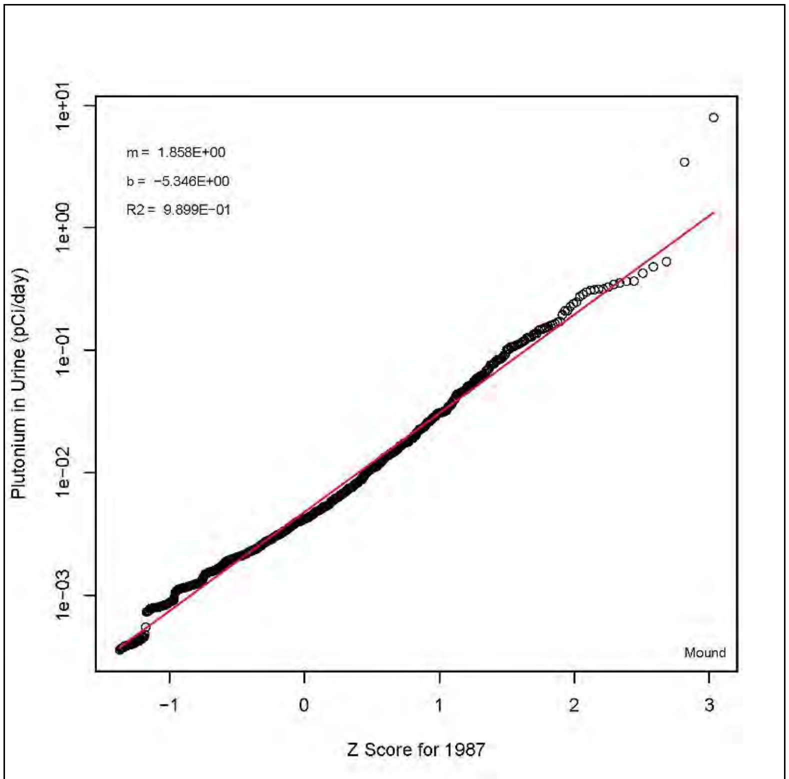

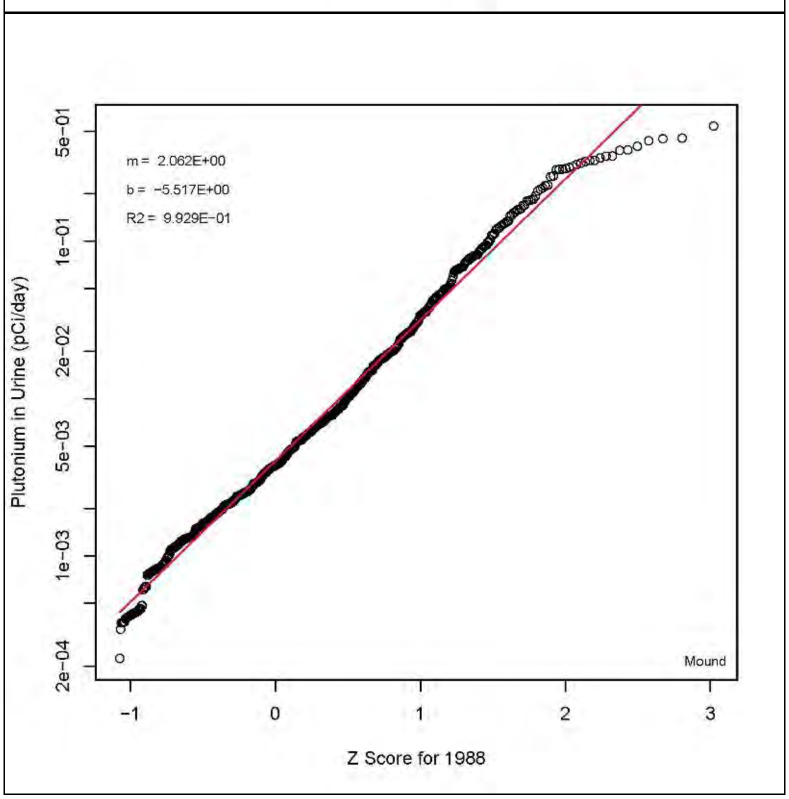

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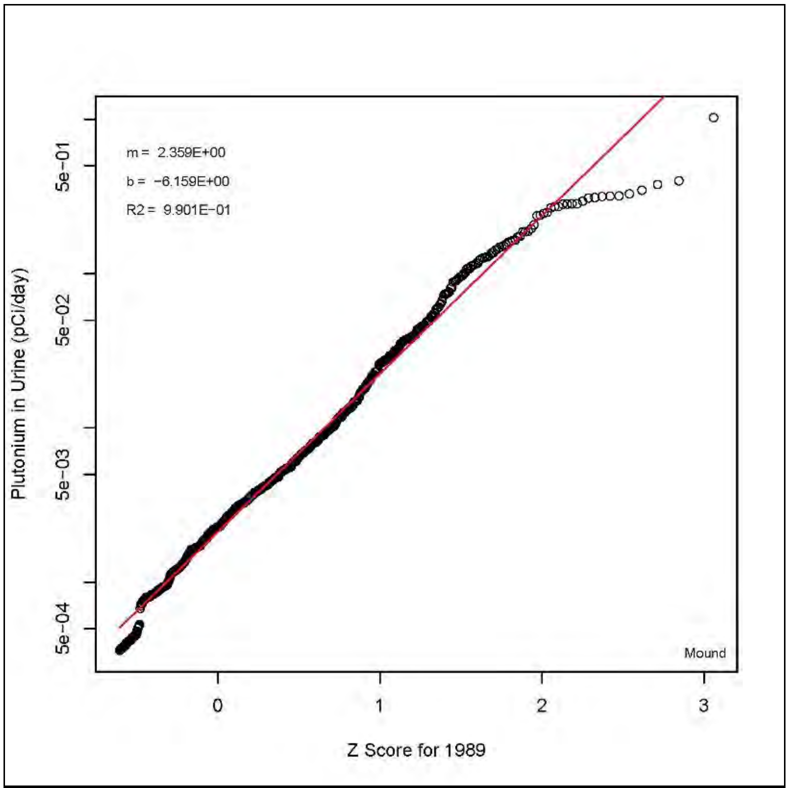

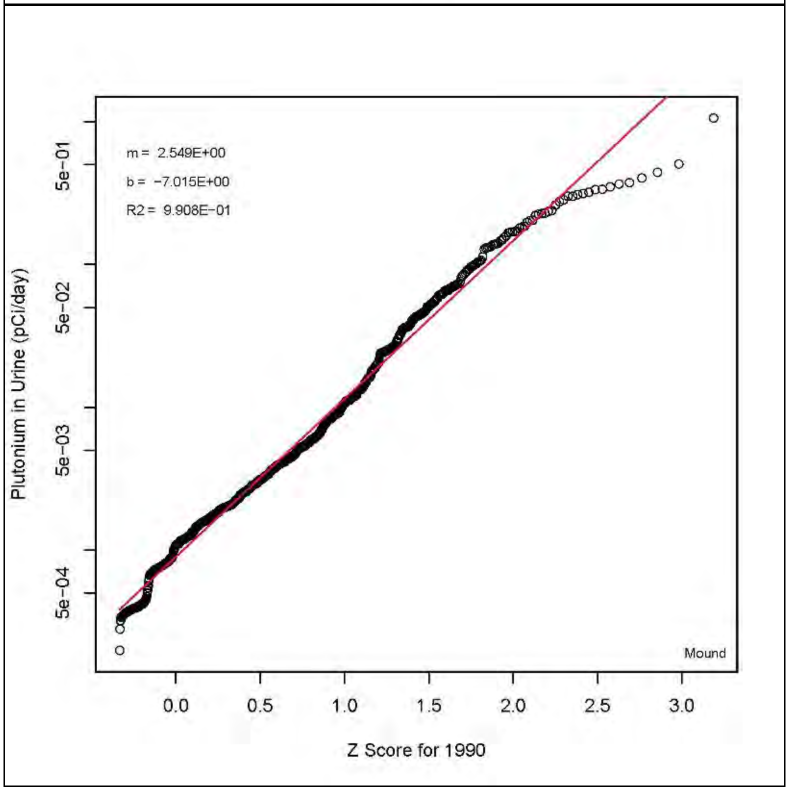

ATTACHMENT E
LOGNORMAL PROBABILITY PLOTS,
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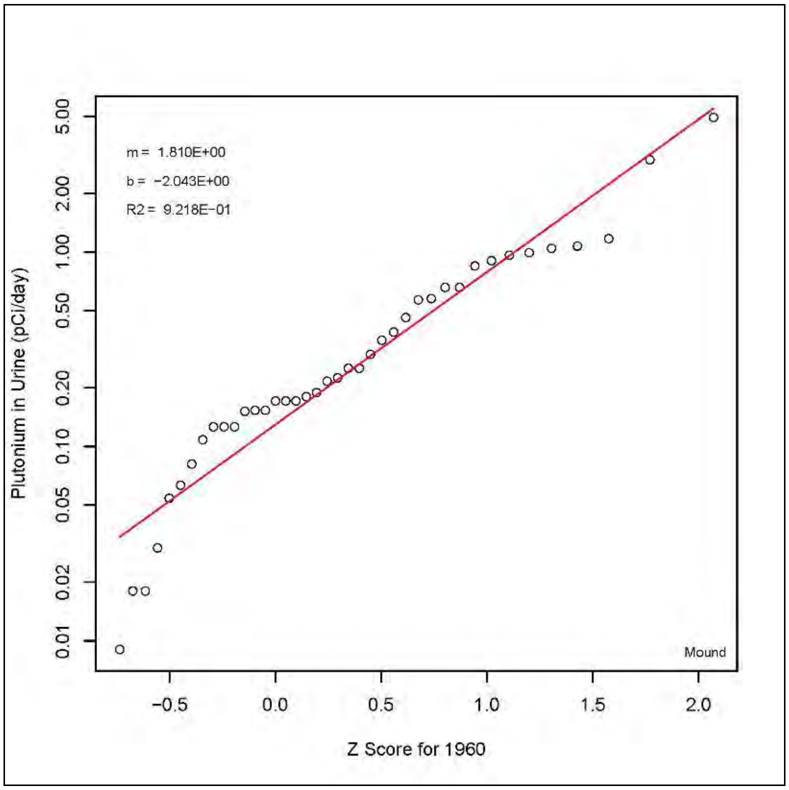
This attachment presents lognormal probability plots for the claimant Mound plutonium urine bioassay dataset for 1960 to 1990. The slope and intercept for the line of best fit to the data are given on the plot.



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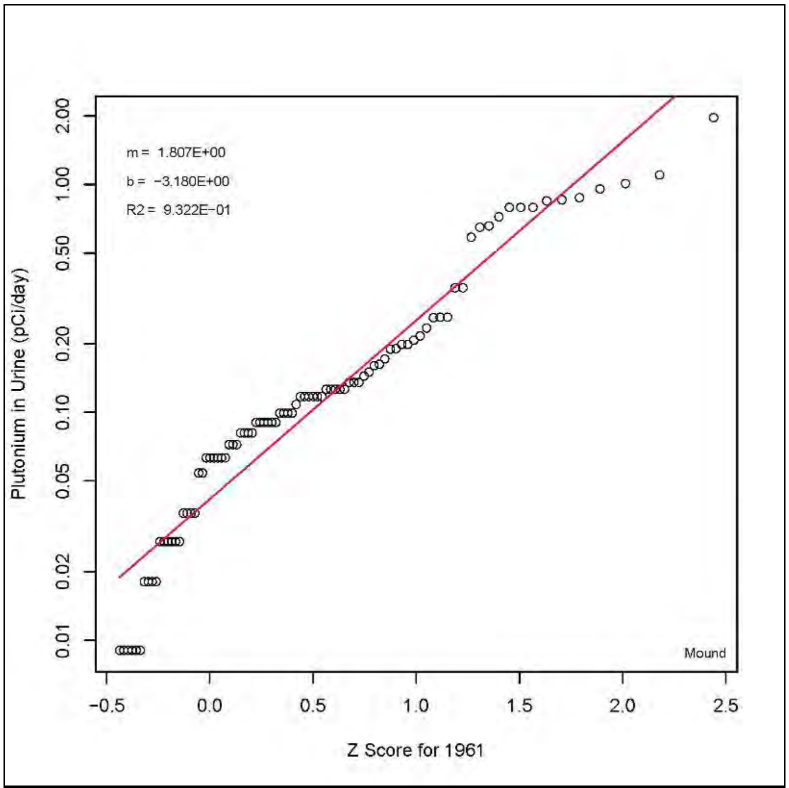

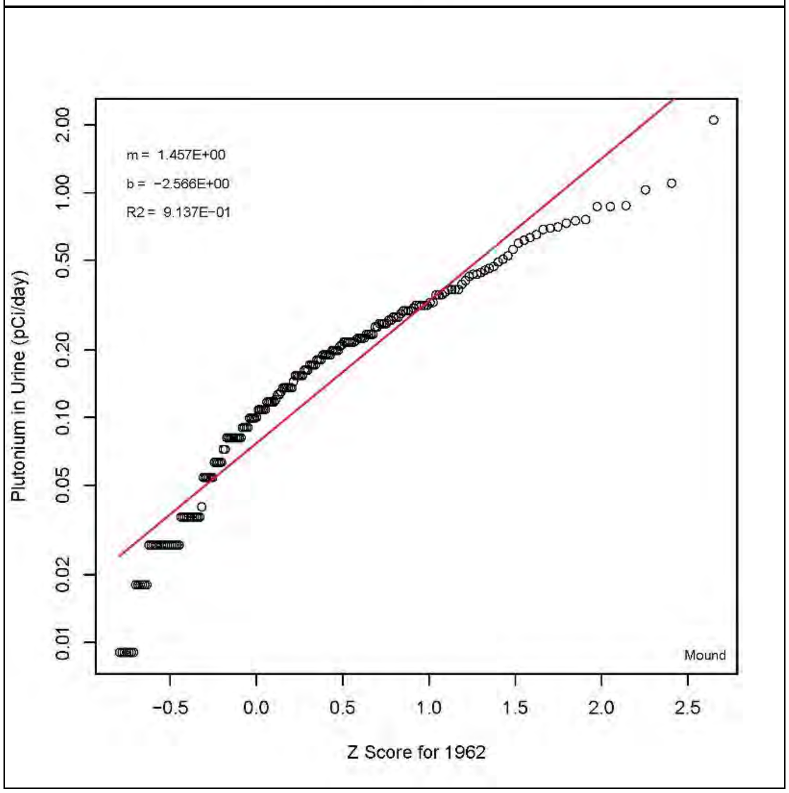

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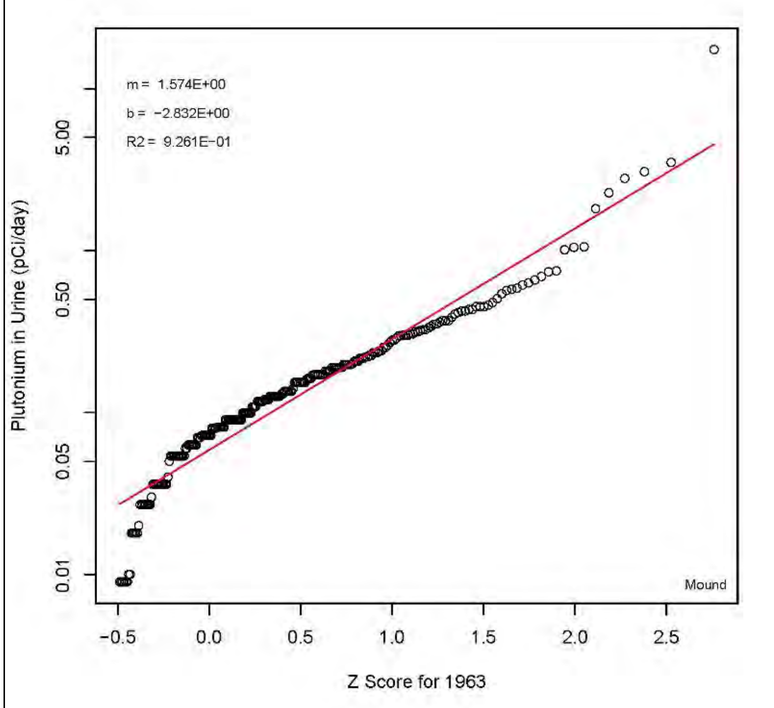

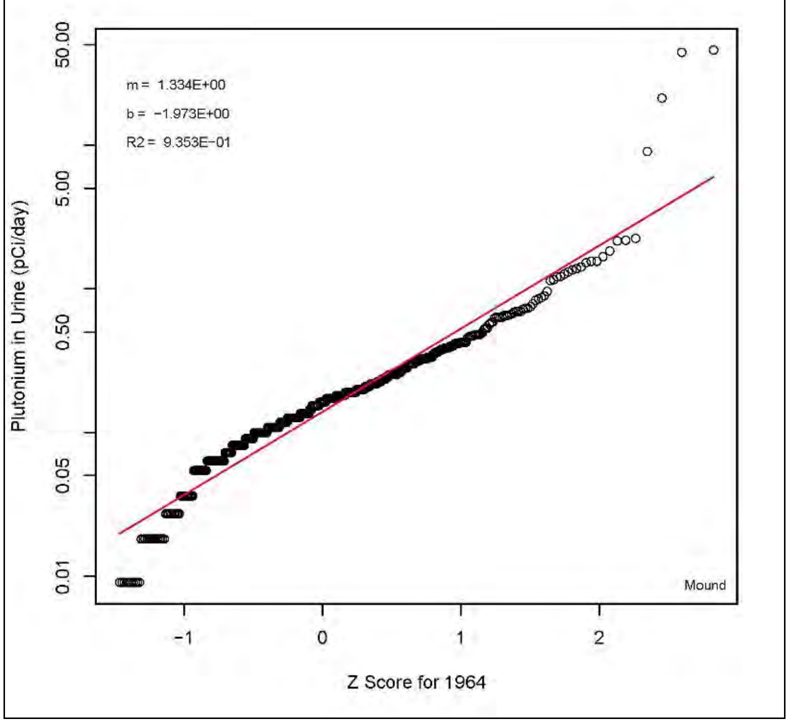

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LOGNORMAL PROBABILITY PLOTS,
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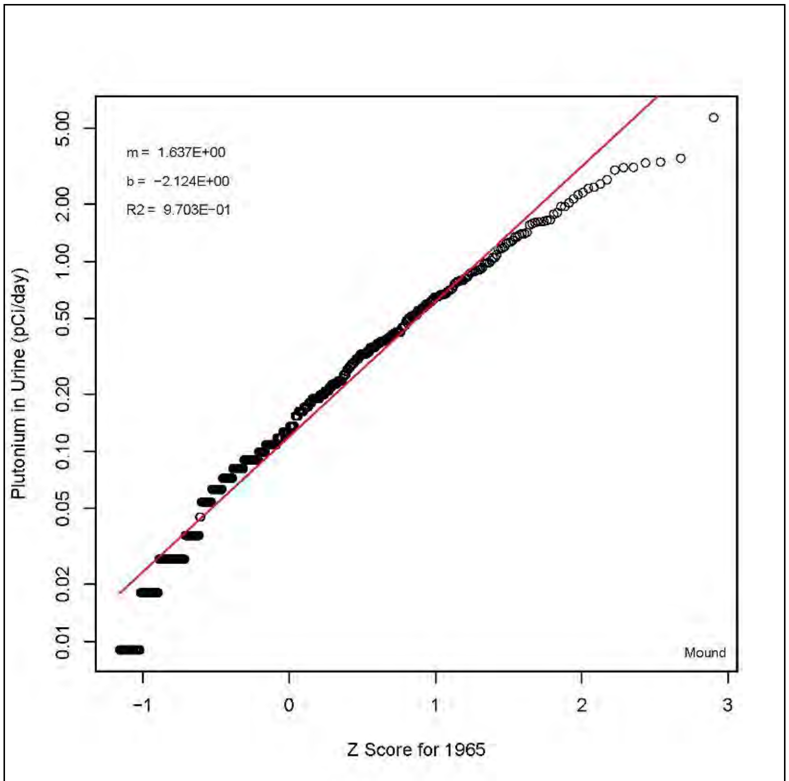

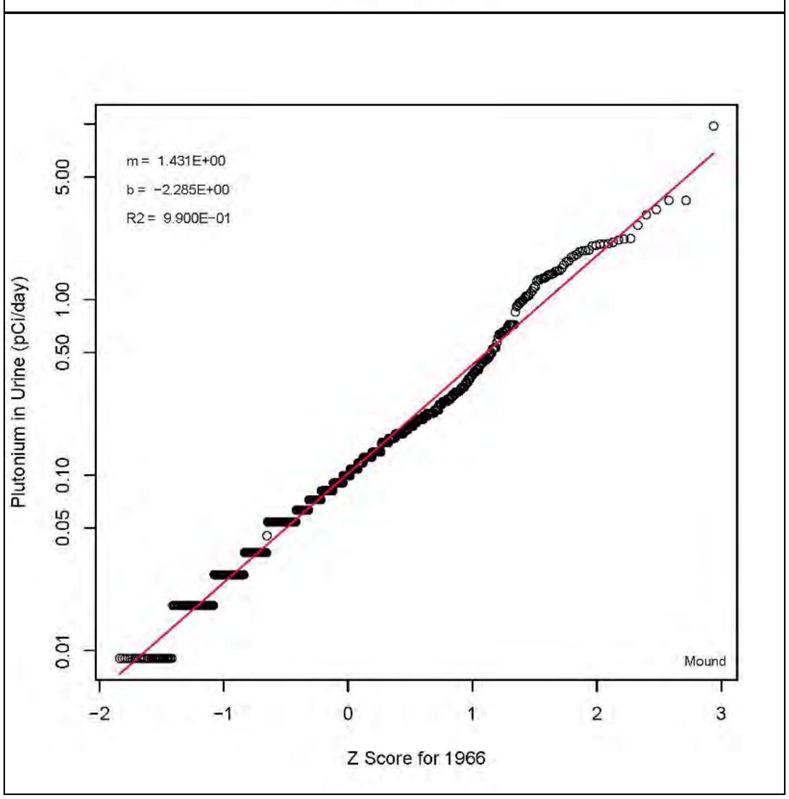

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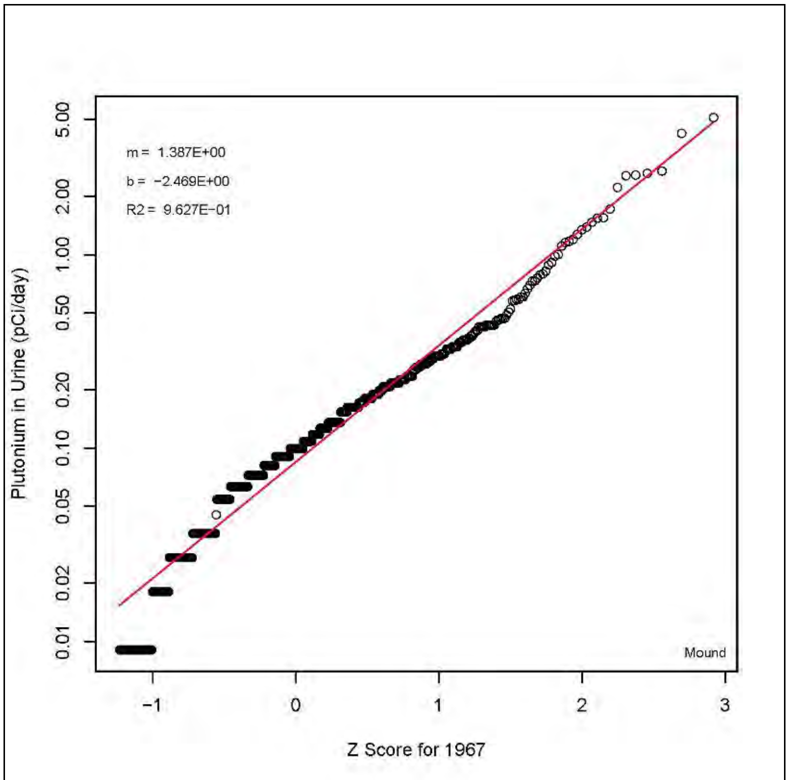

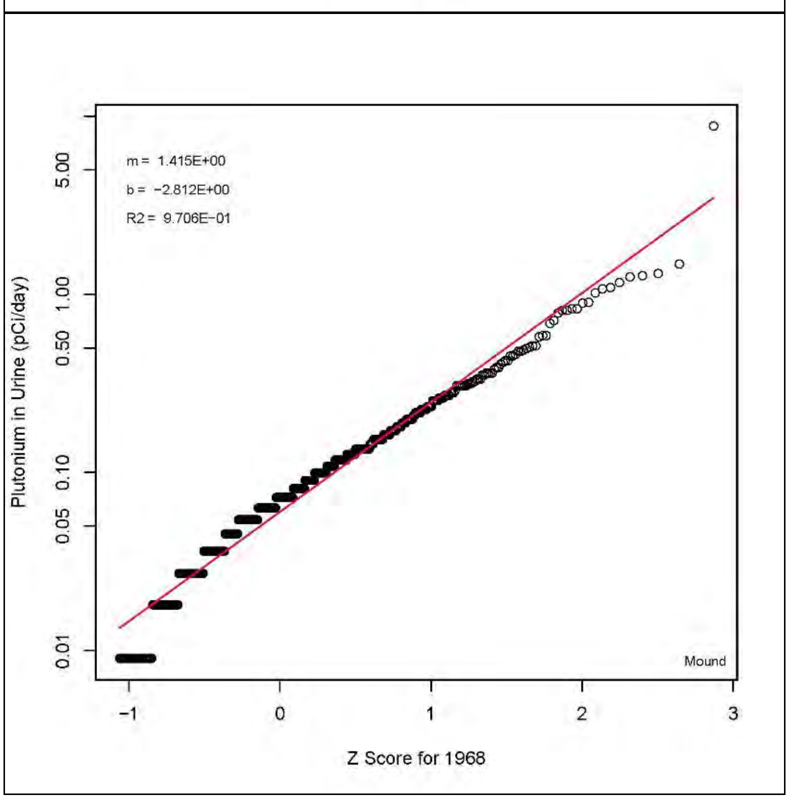

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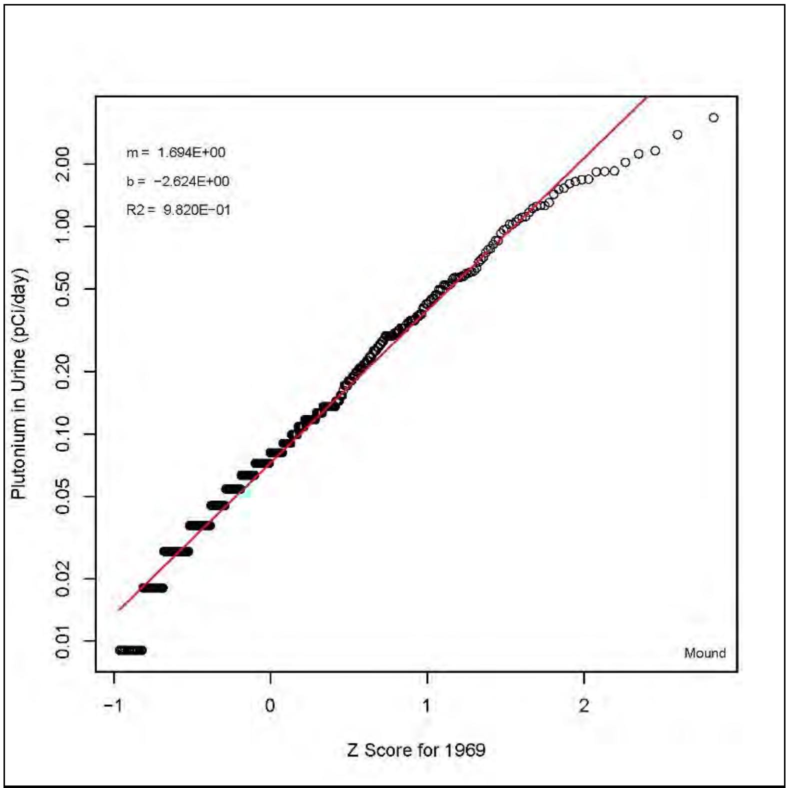

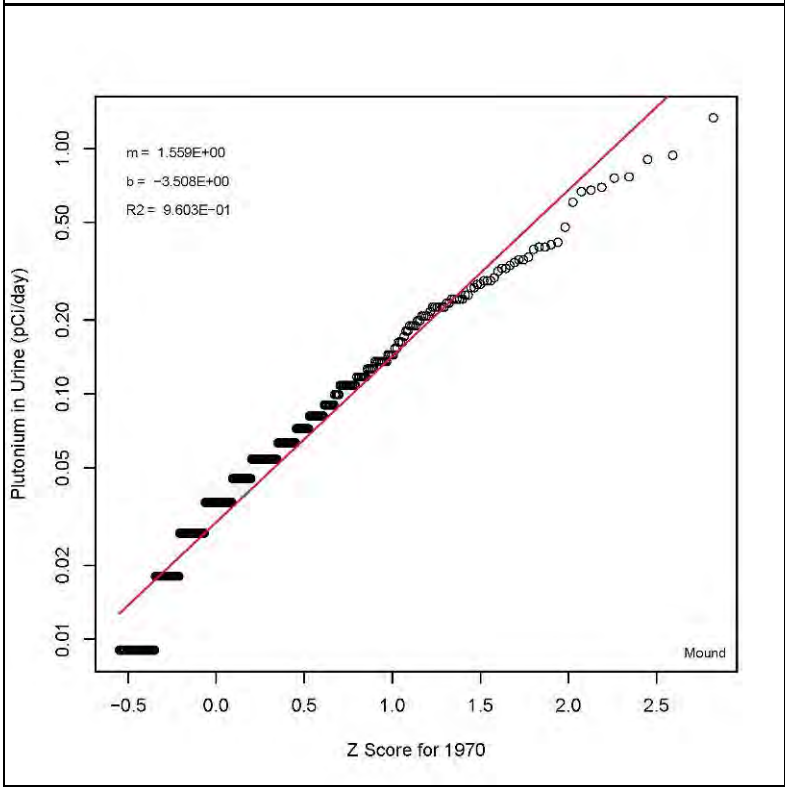

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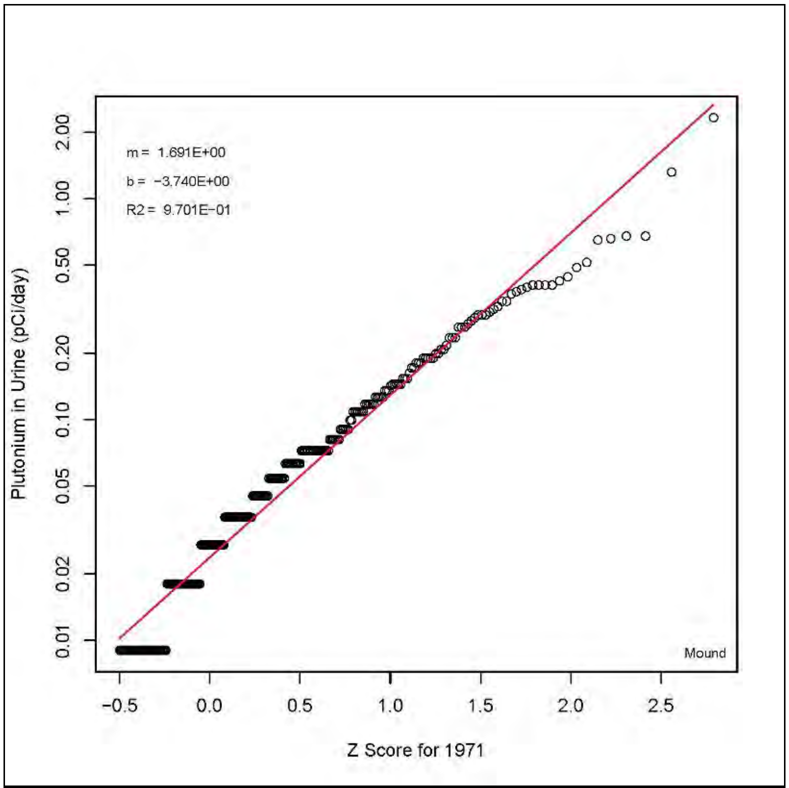

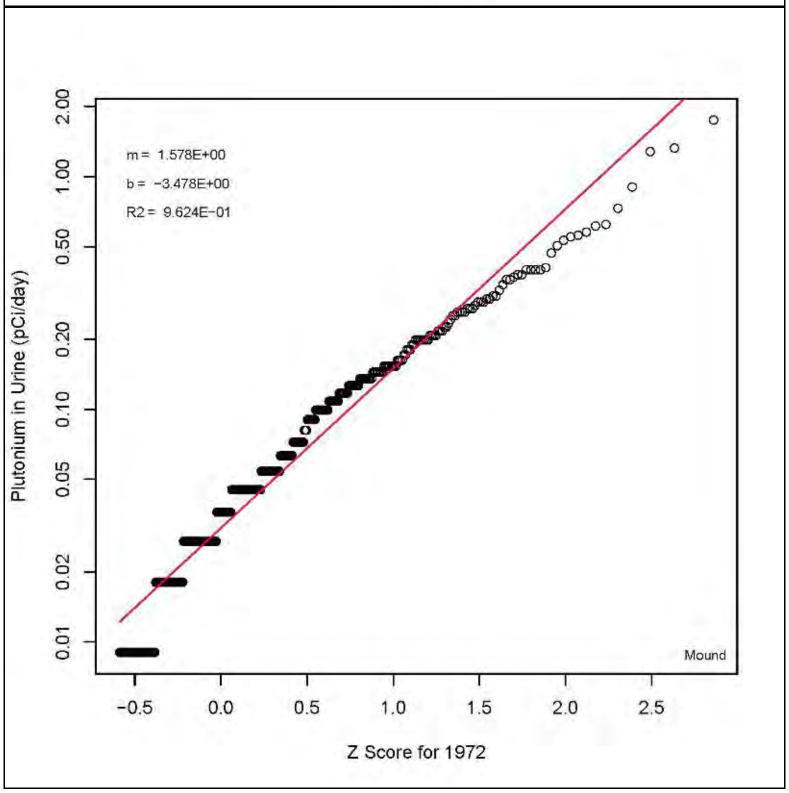

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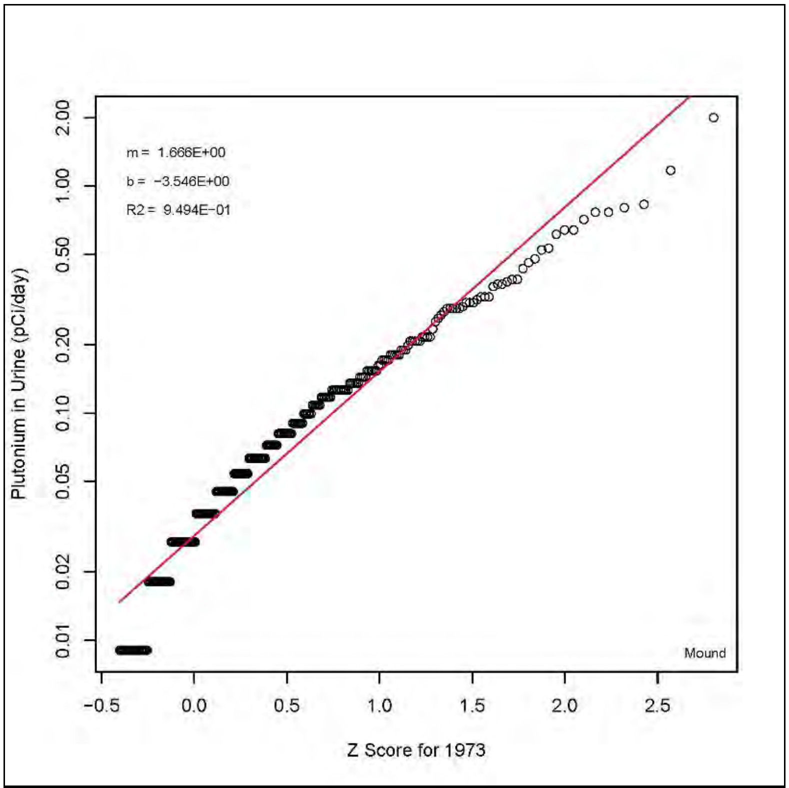

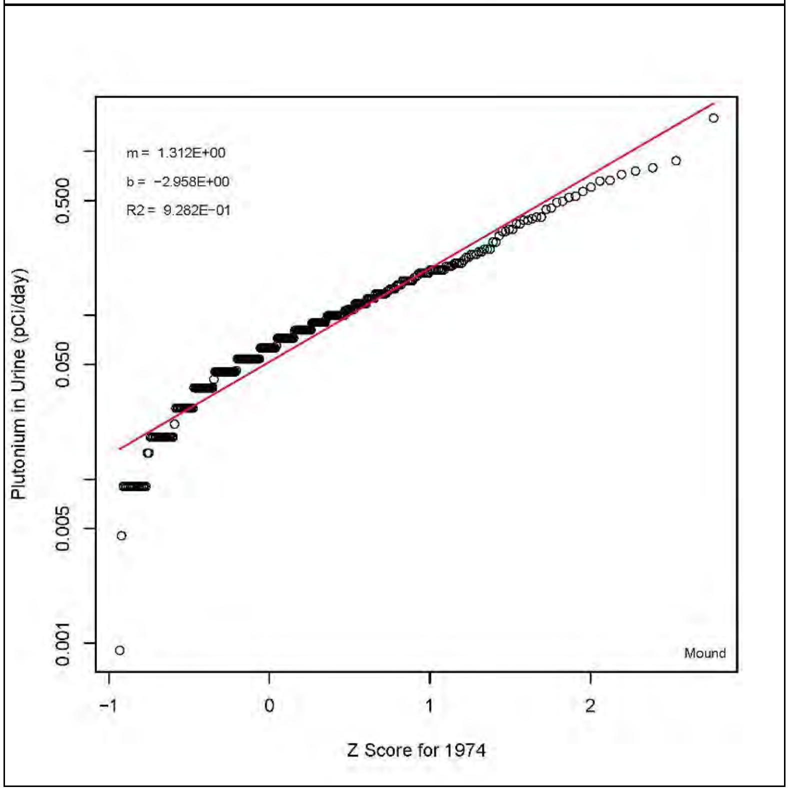

ATTACHMENT E
LOGNORMAL PROBABILITY PLOTS,
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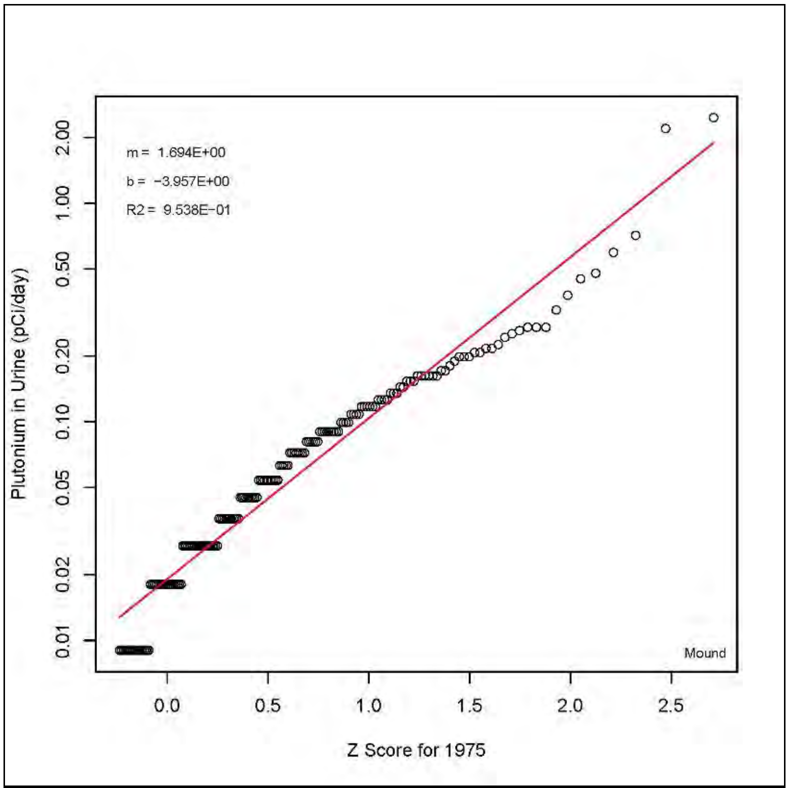

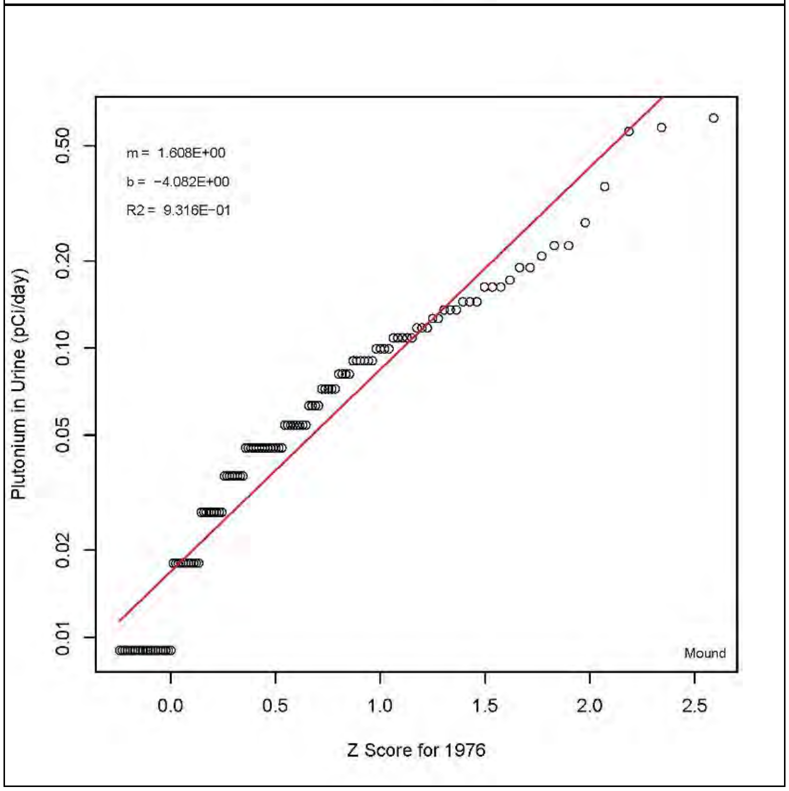

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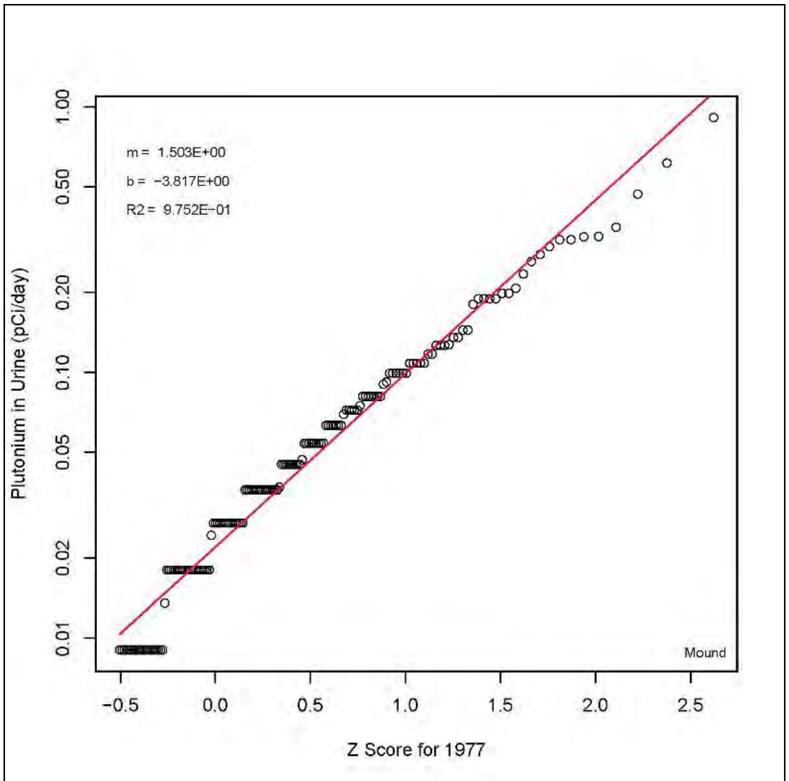

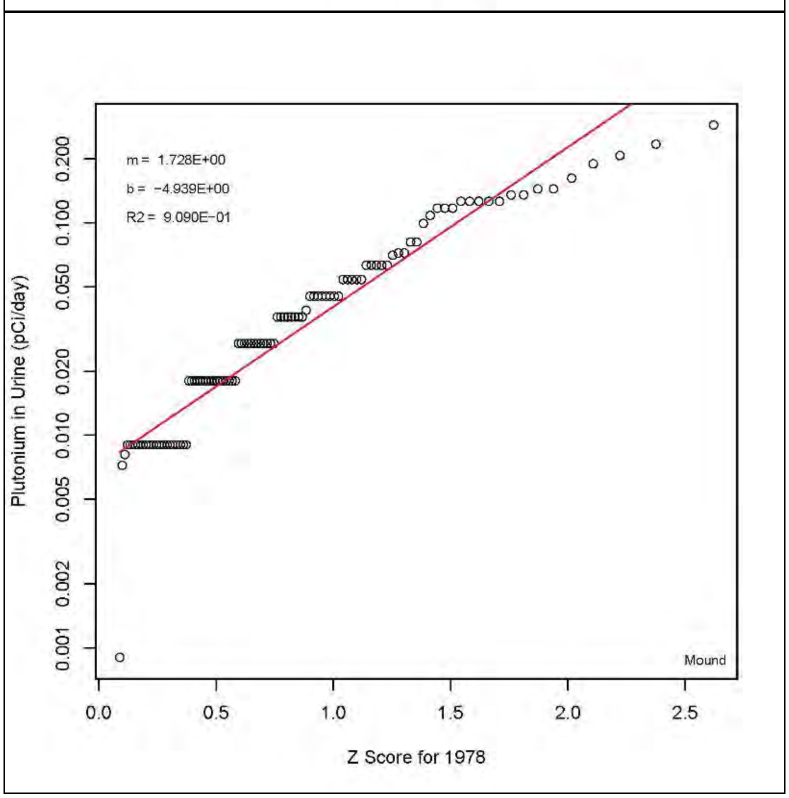

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LOGNORMAL PROBABILITY PLOTS,
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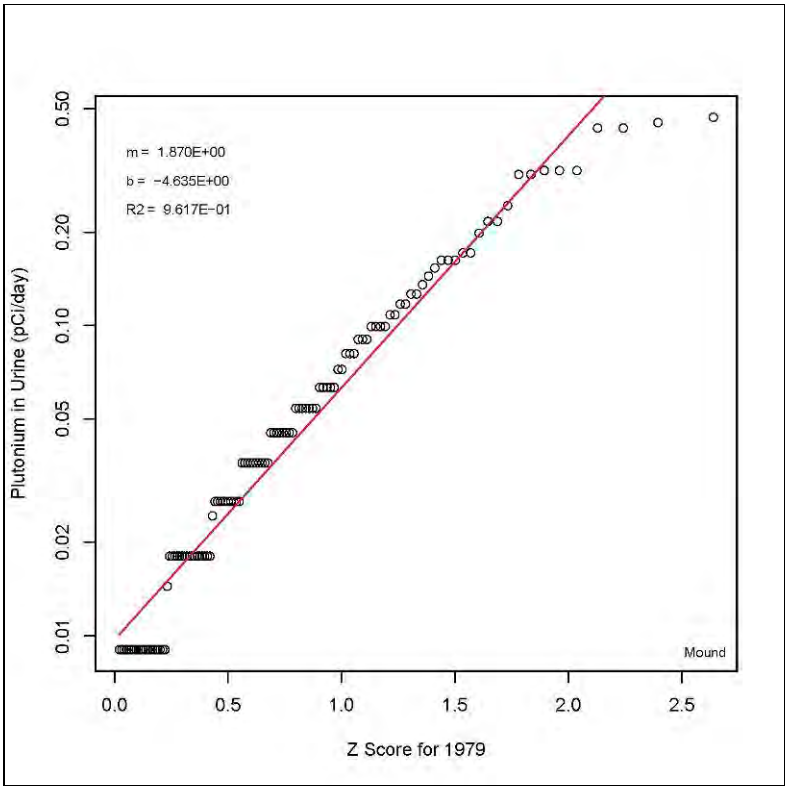

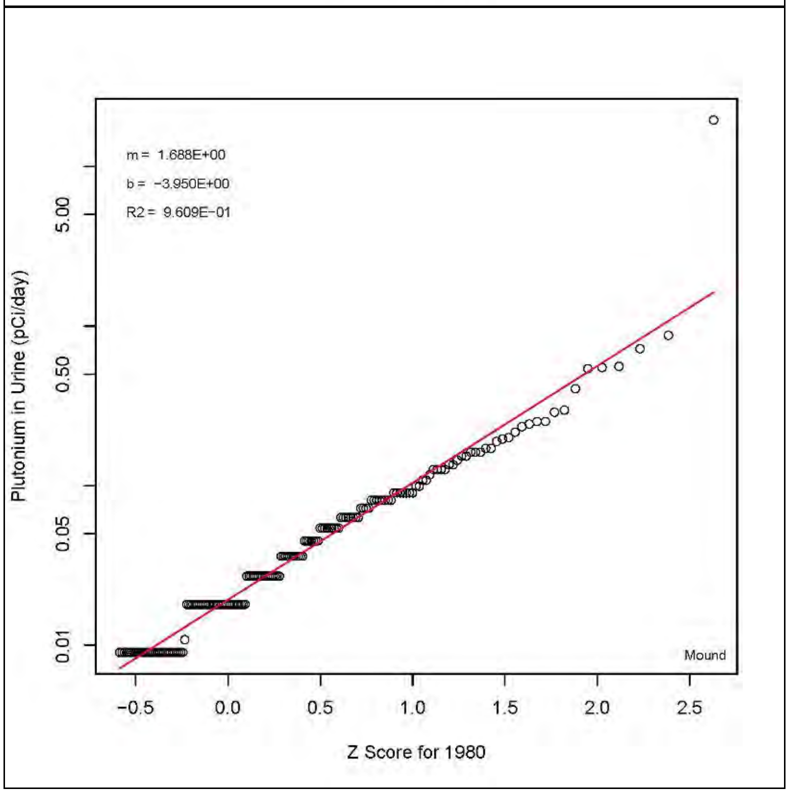

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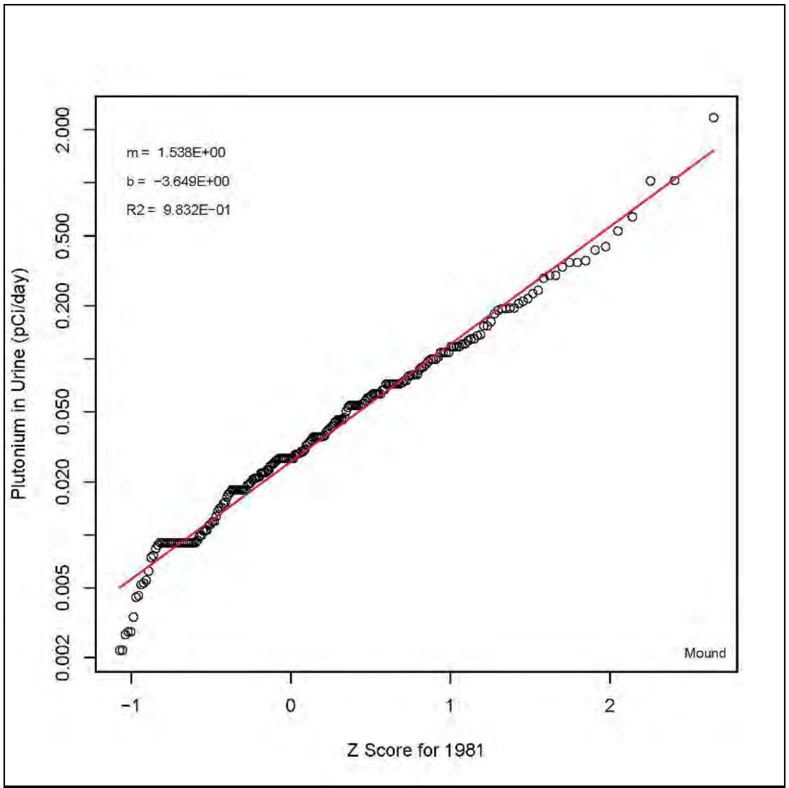
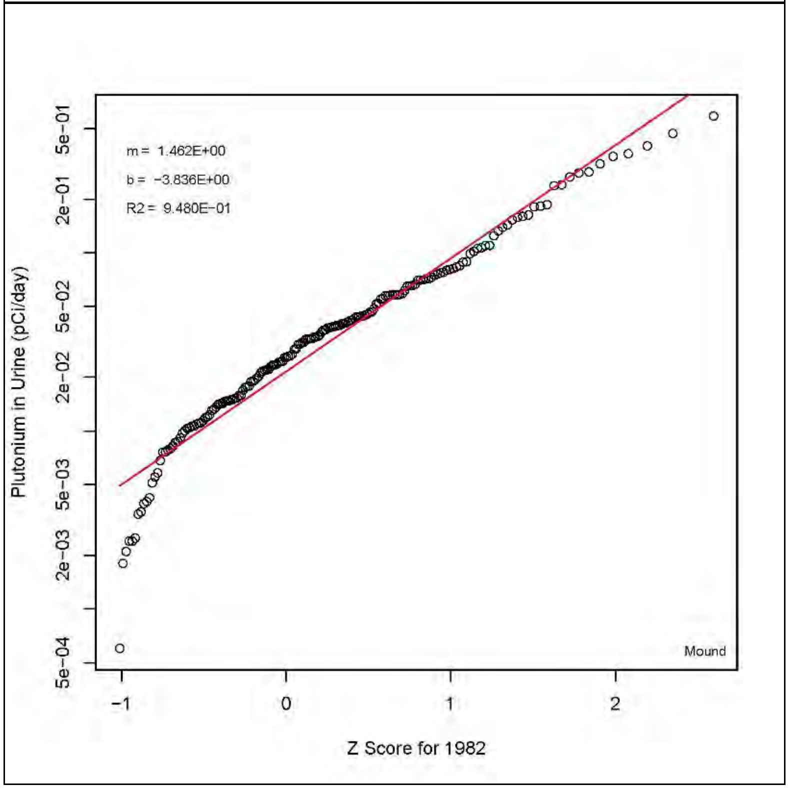
LOGNORMAL PROBABILITY PLOTS, CLAIMANT MOUND DATASET





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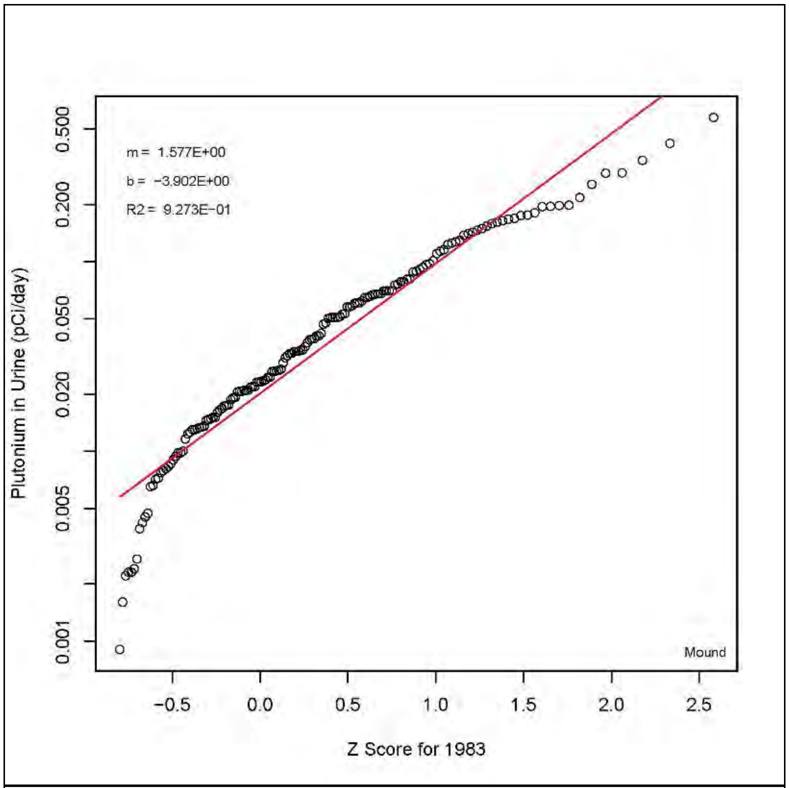

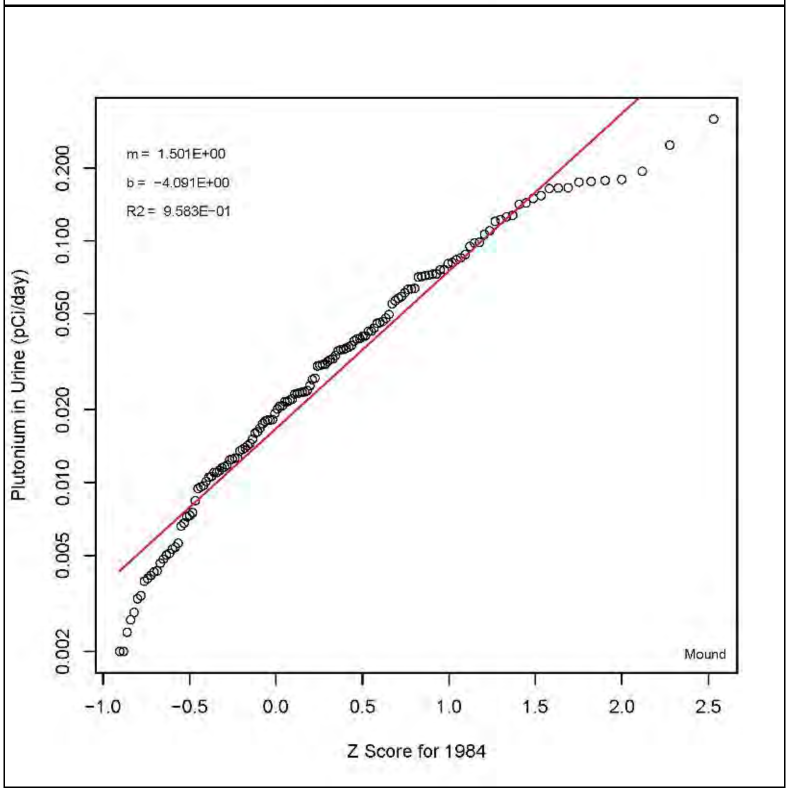

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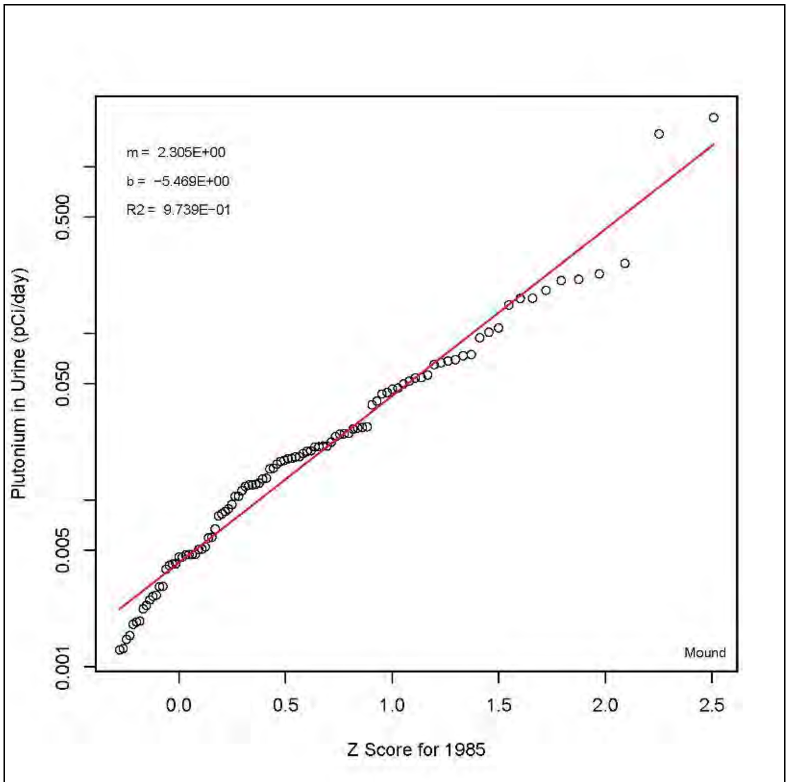

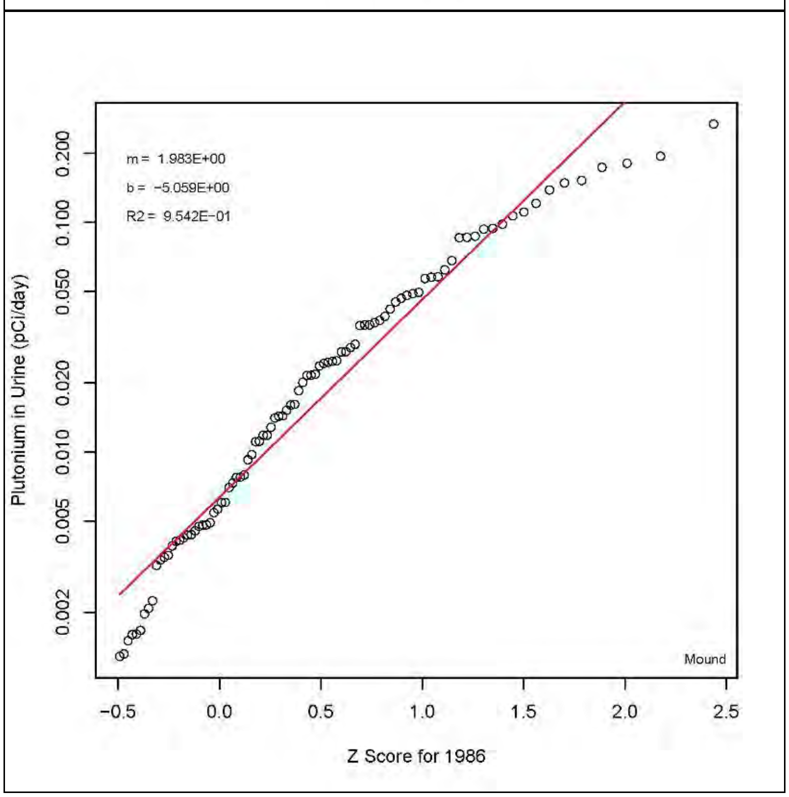

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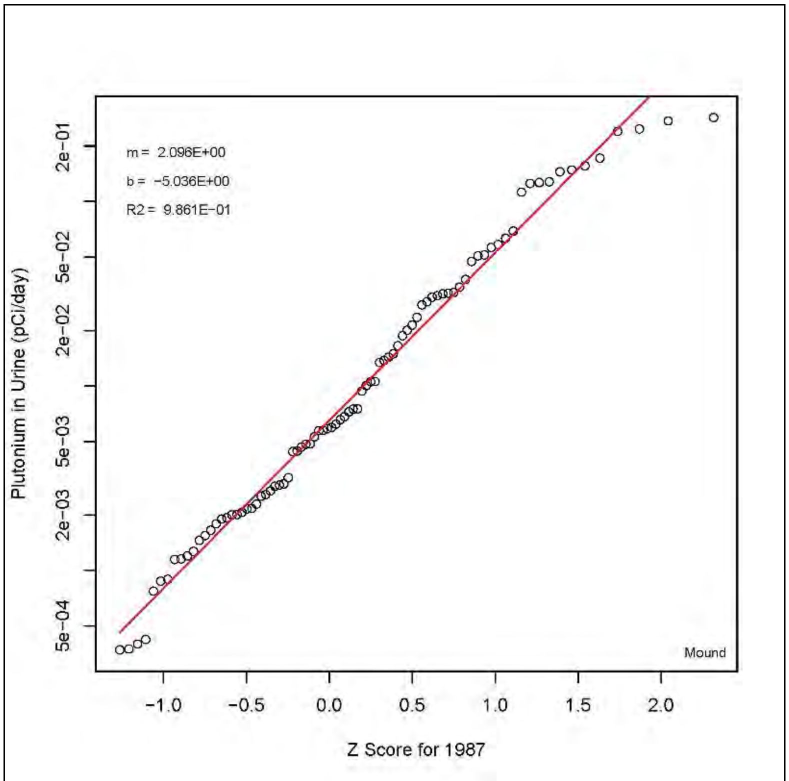

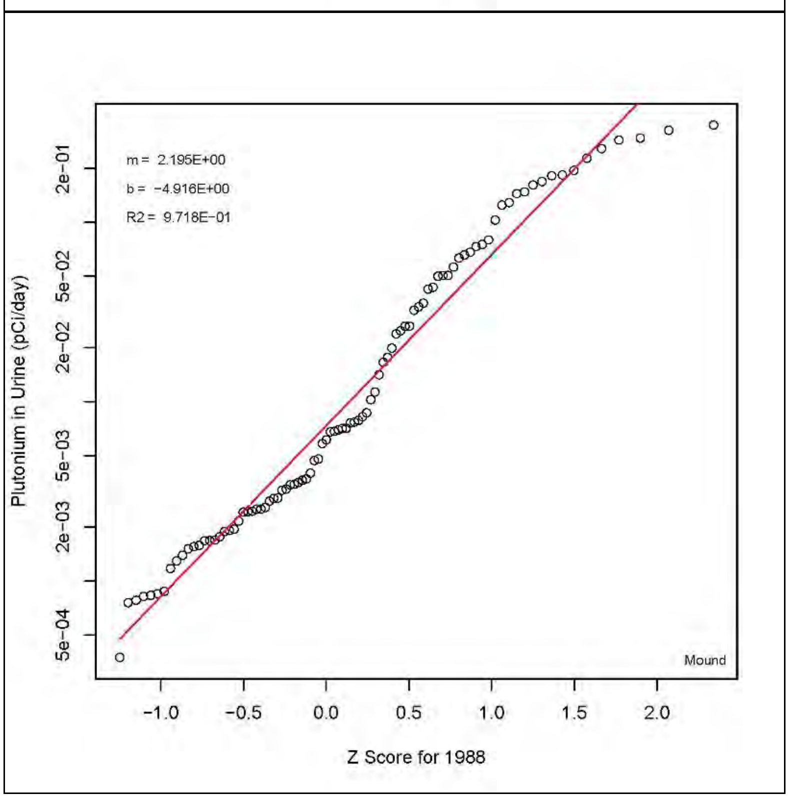

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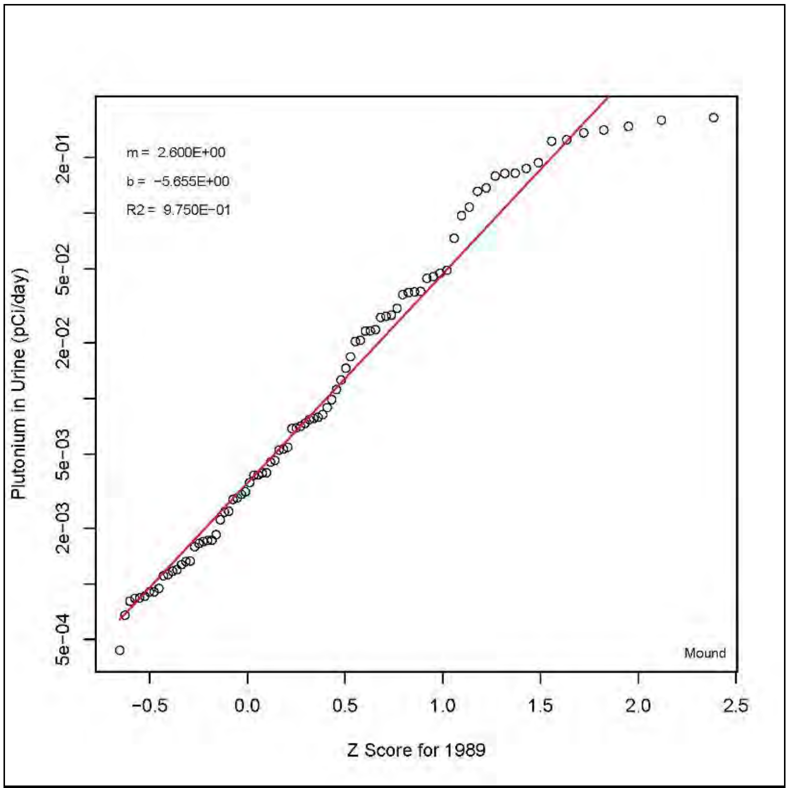
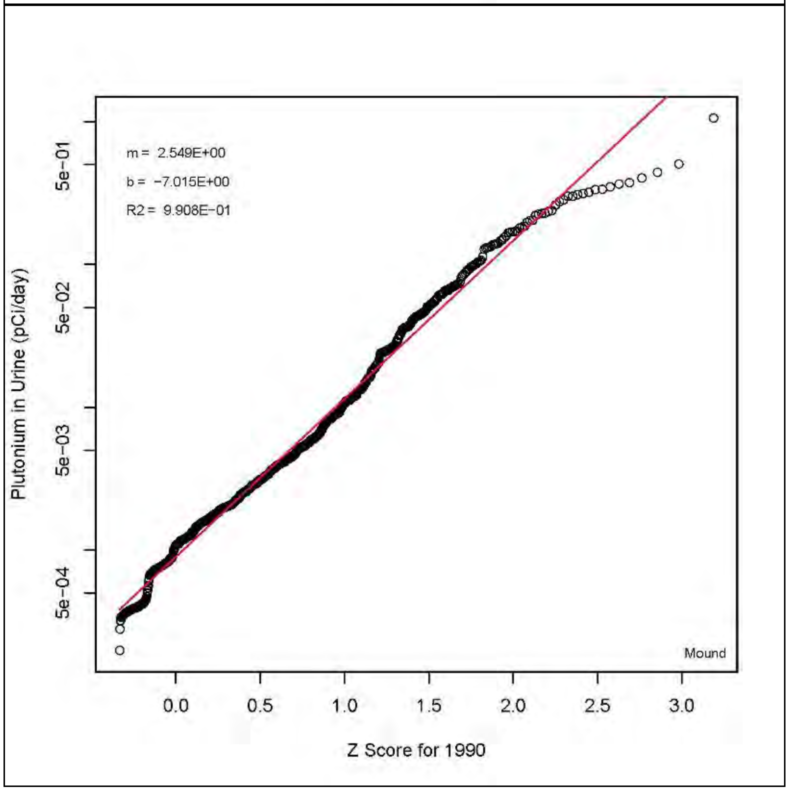


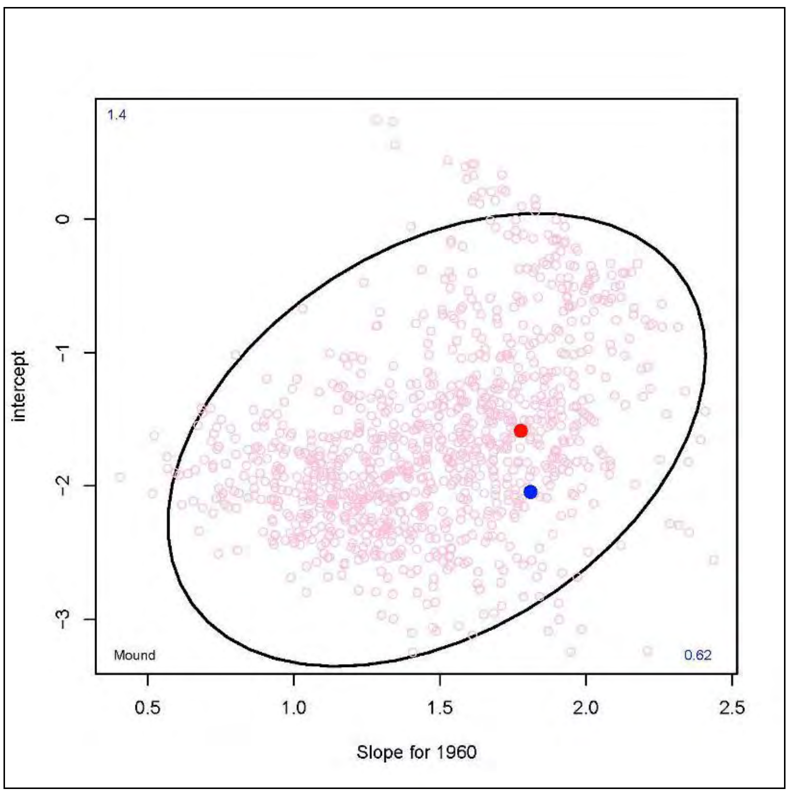


ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT,
COMPLETE MOUND DATASET, 225 WORKERS

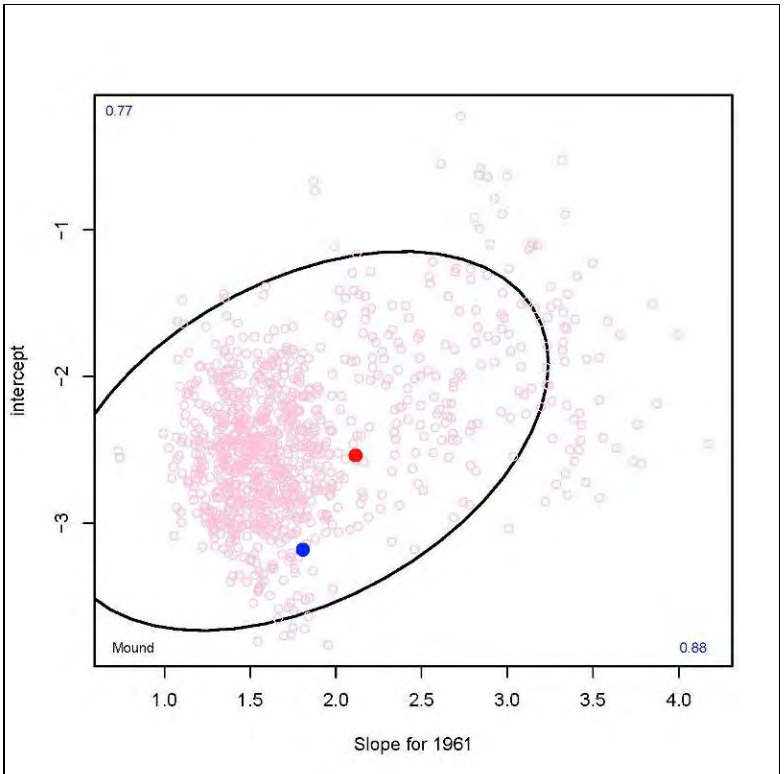
This attachment presents lognormal probability plots for a sample of 225 unique workers that was drawn at random without replacement from the 2070 workers in the complete dataset. The slope and intercept of the plot for each year from 1960 to 1990 was calculated based on this data. This process was repeated *m* = 1000 times to generate the 95% confidence ellipses. In each plot:

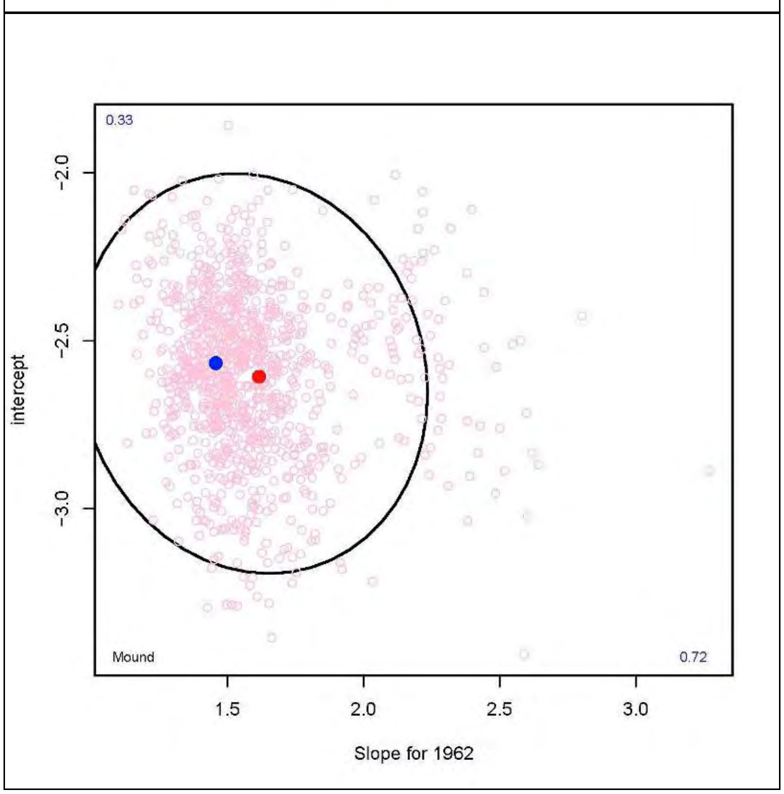
- The solid red point is the slope and intercept of the complete dataset.
- The solid blue point is the slope and intercept of the claimant dataset.
- The open pink points are the slopes and intercepts of the fits to the *m* random sets of 225 workers taken from the complete dataset.
- The ellipse is the 95% joint normal confidence ellipse.
- The numbers in the corners are the full scale of the respective axes in terms of +/- the slope or intercept of the complete dataset.

These plots are presented to support the idea that the claimant dataset is basically no different than a random draw from the complete dataset.



ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS





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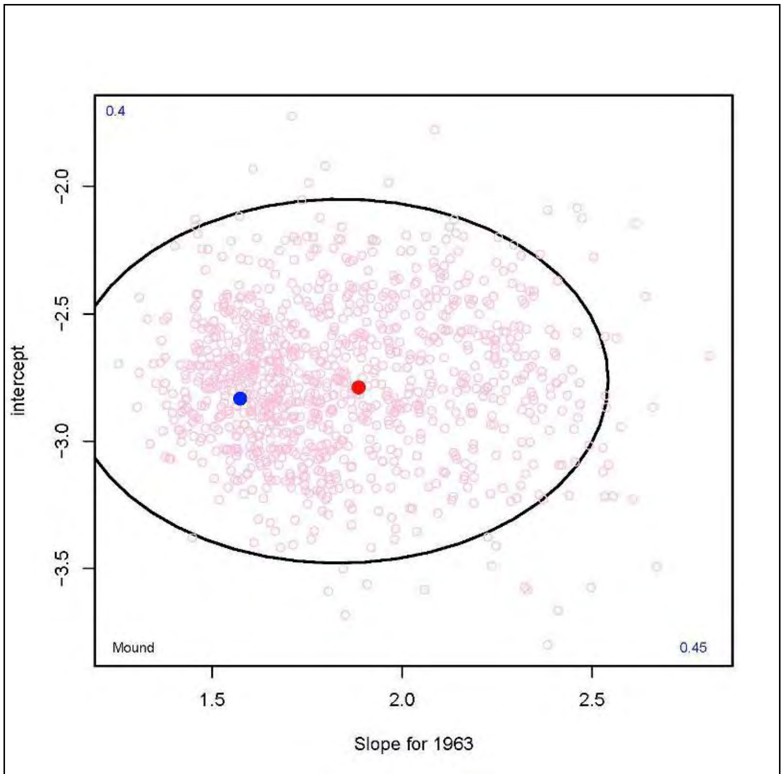

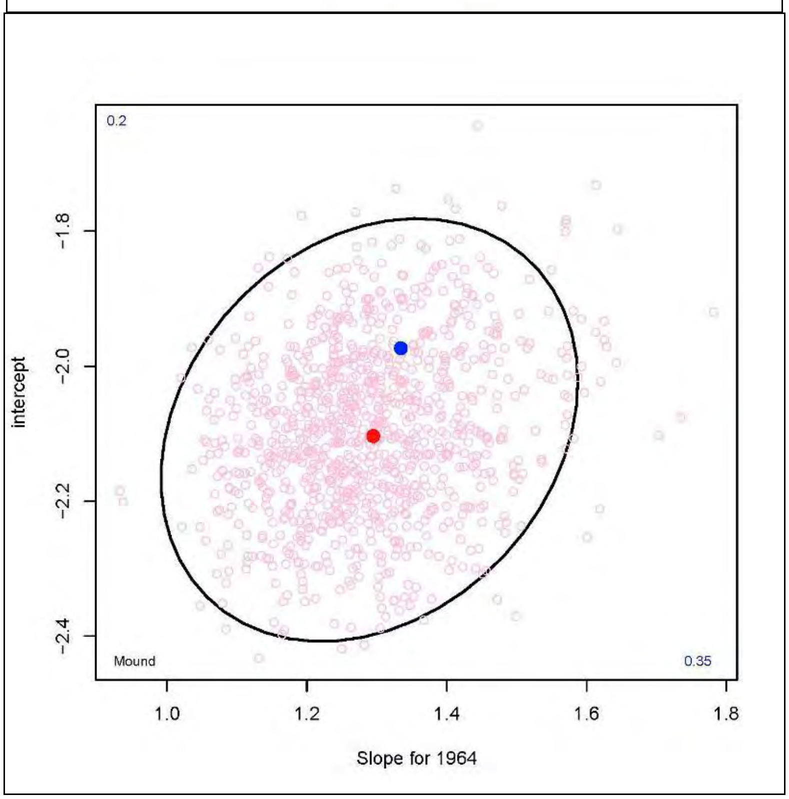

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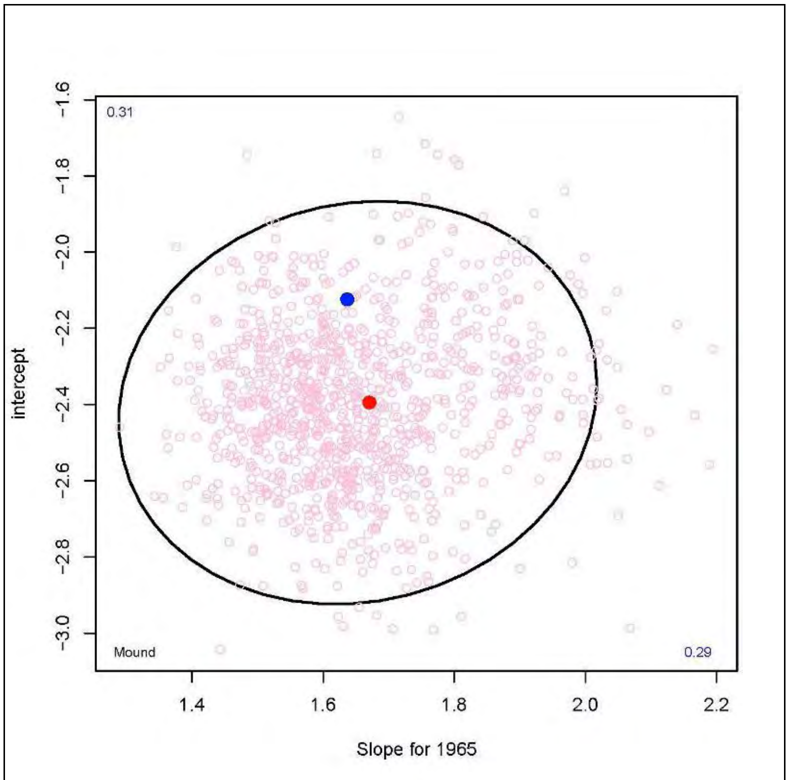

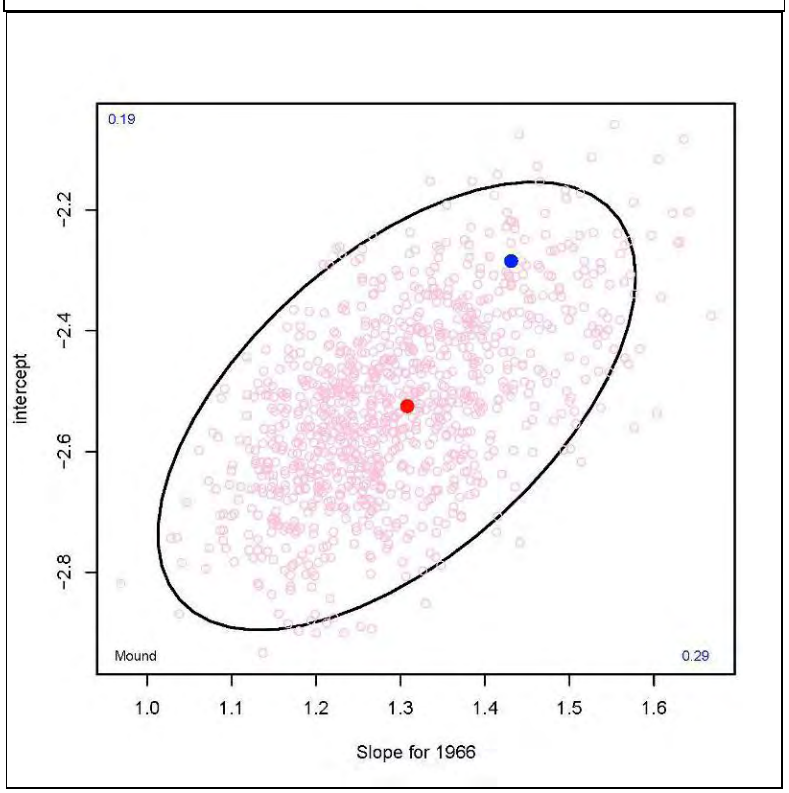

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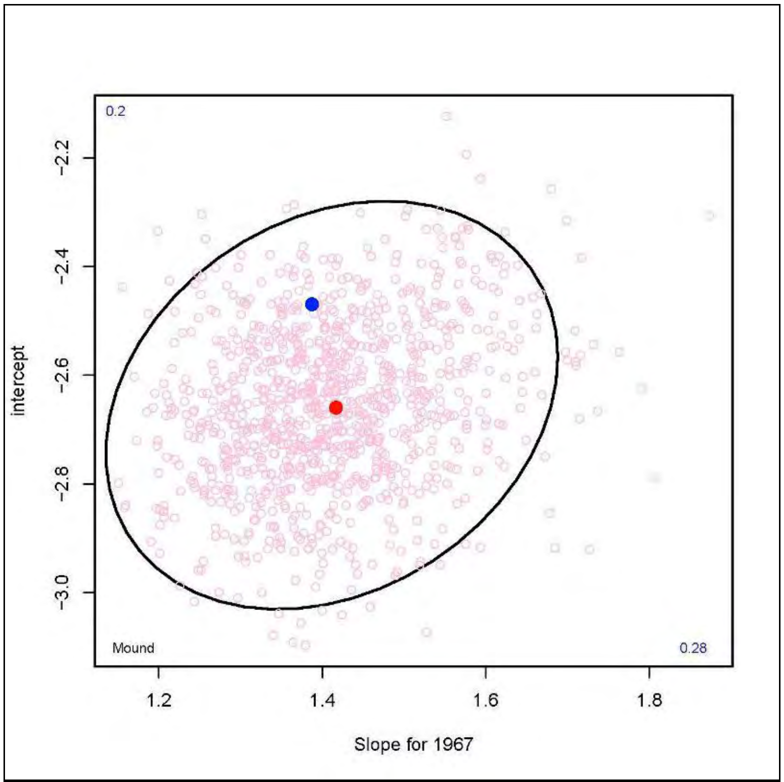

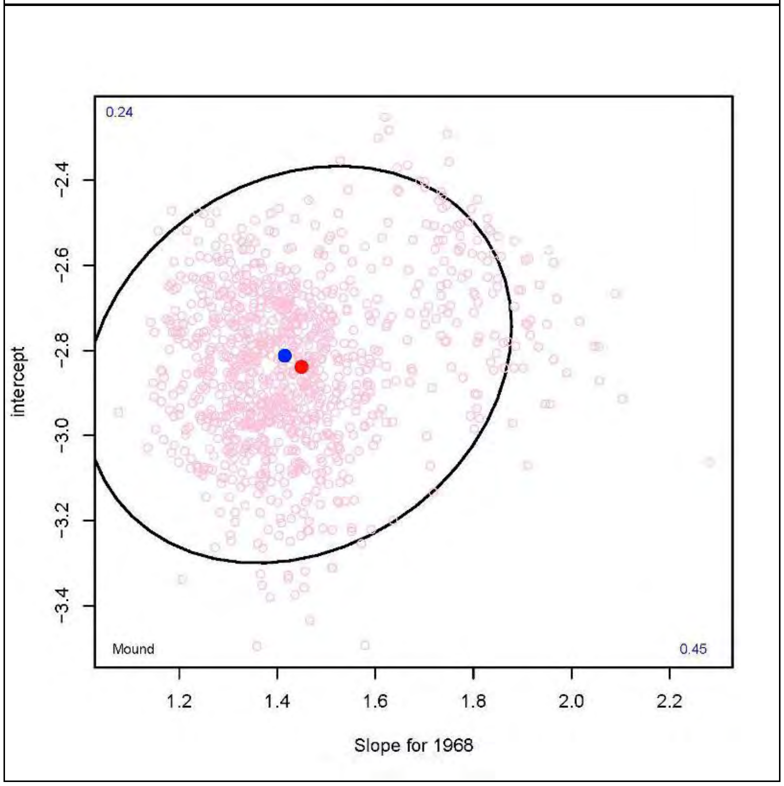

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95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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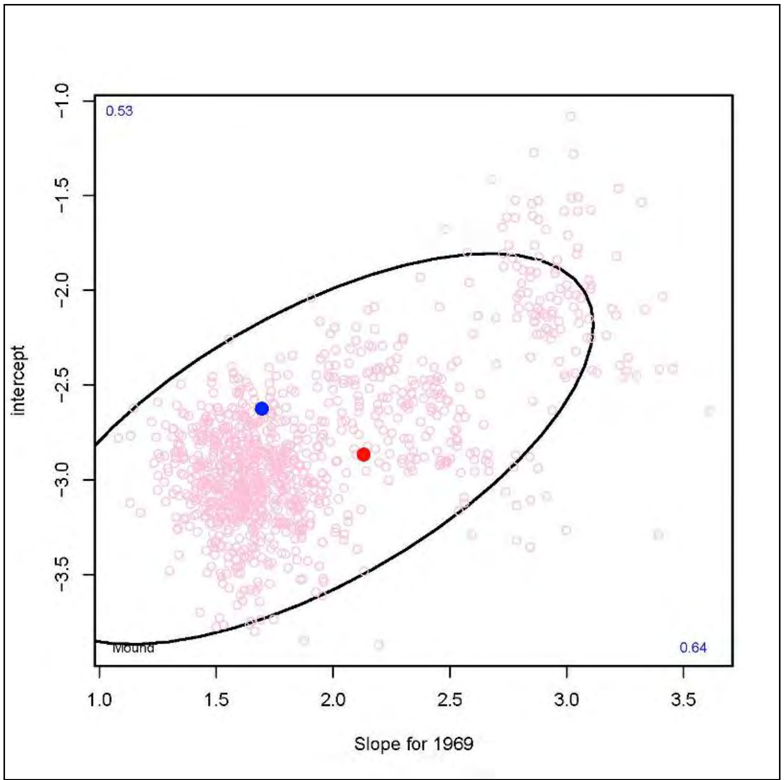

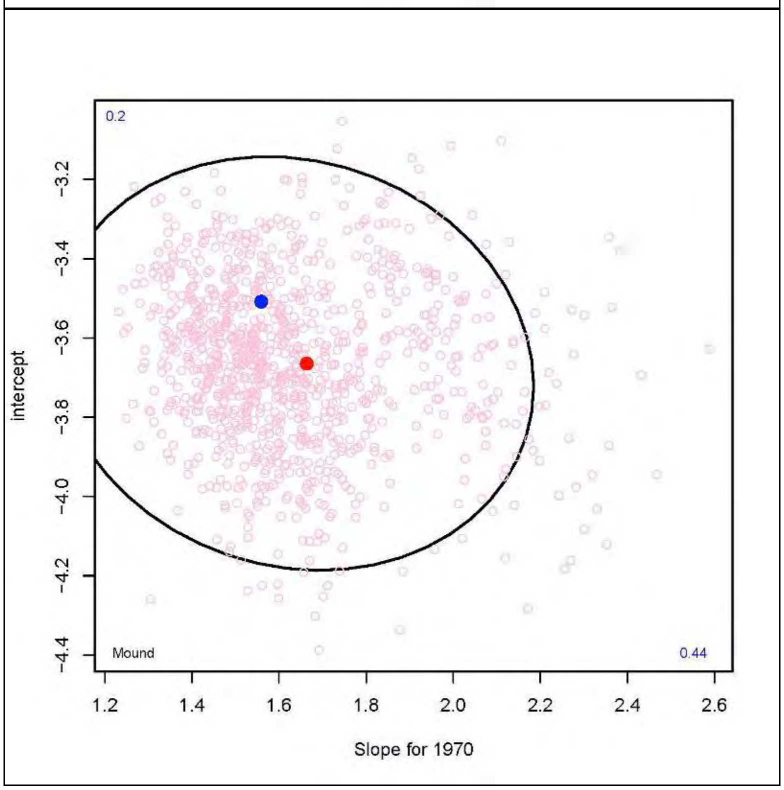

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95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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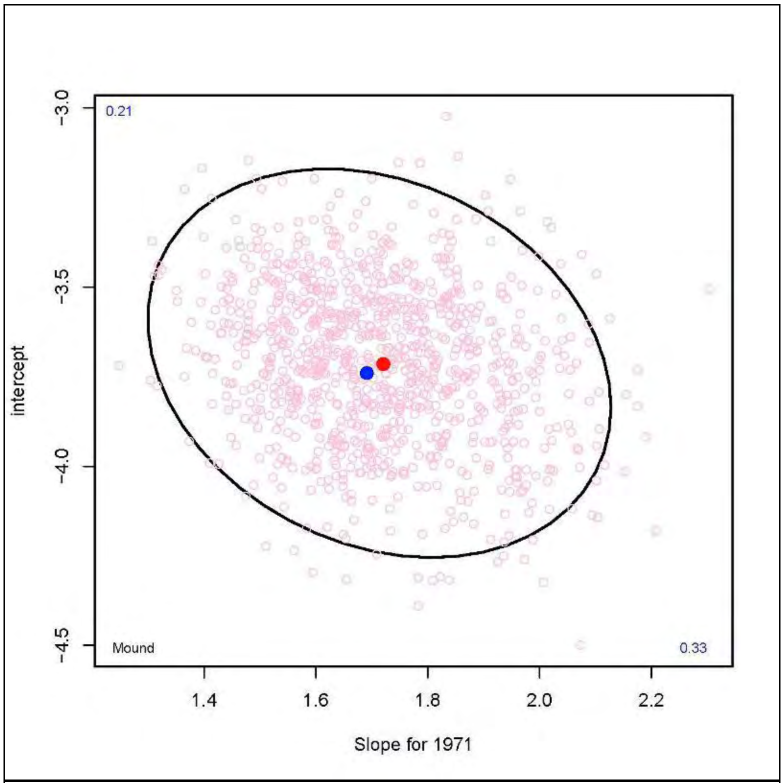

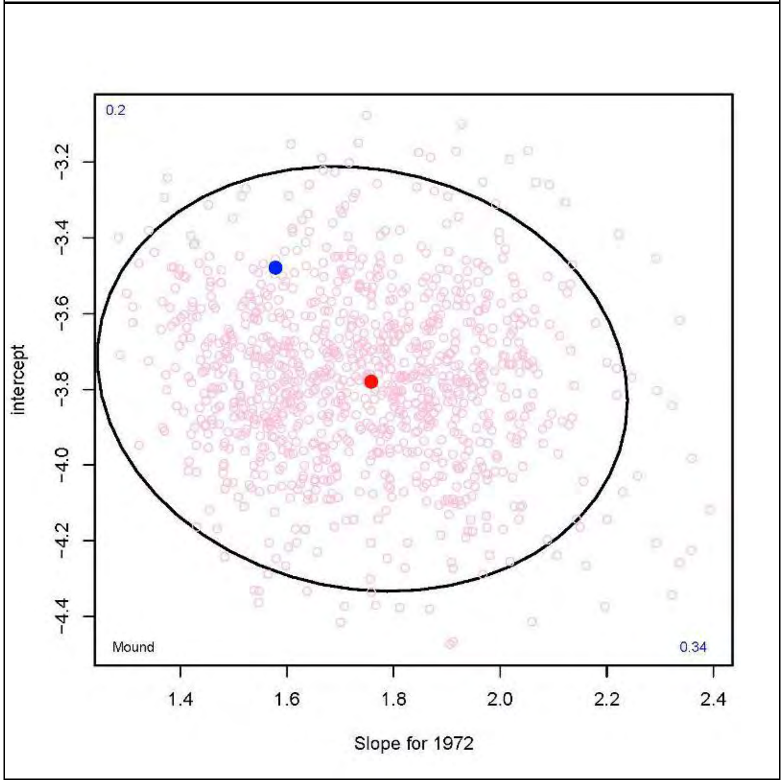

ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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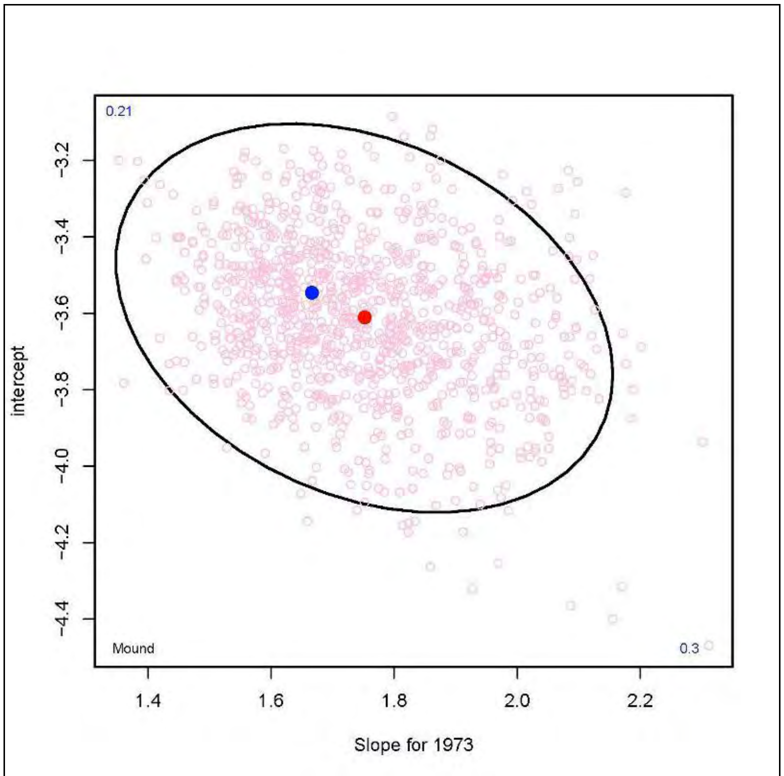

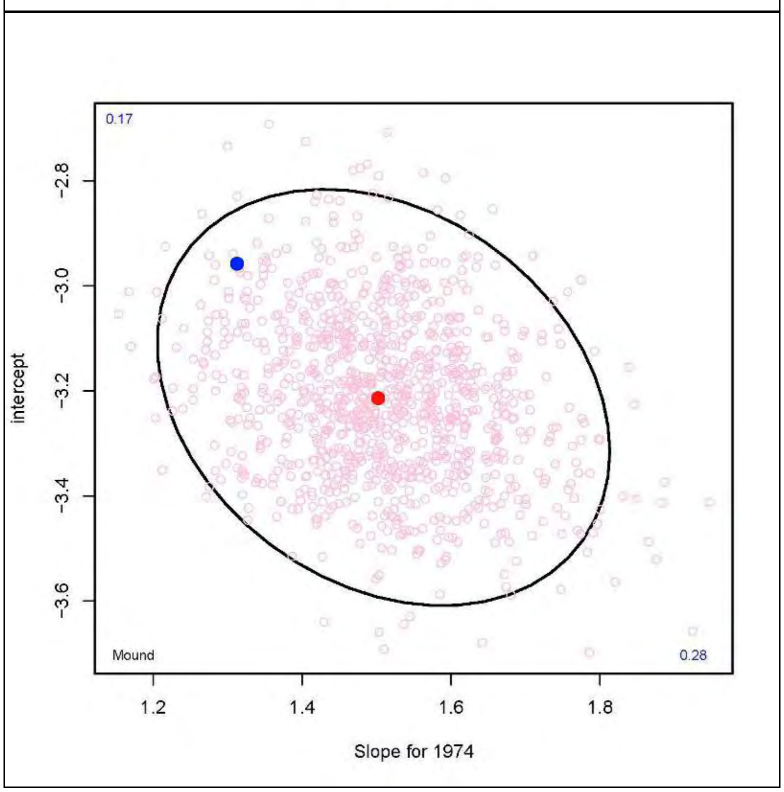

ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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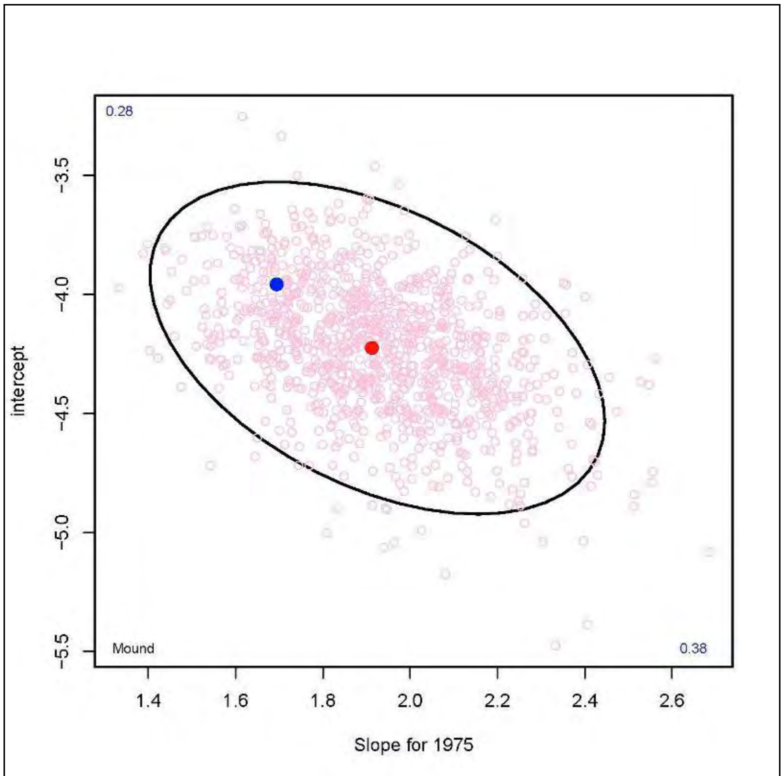

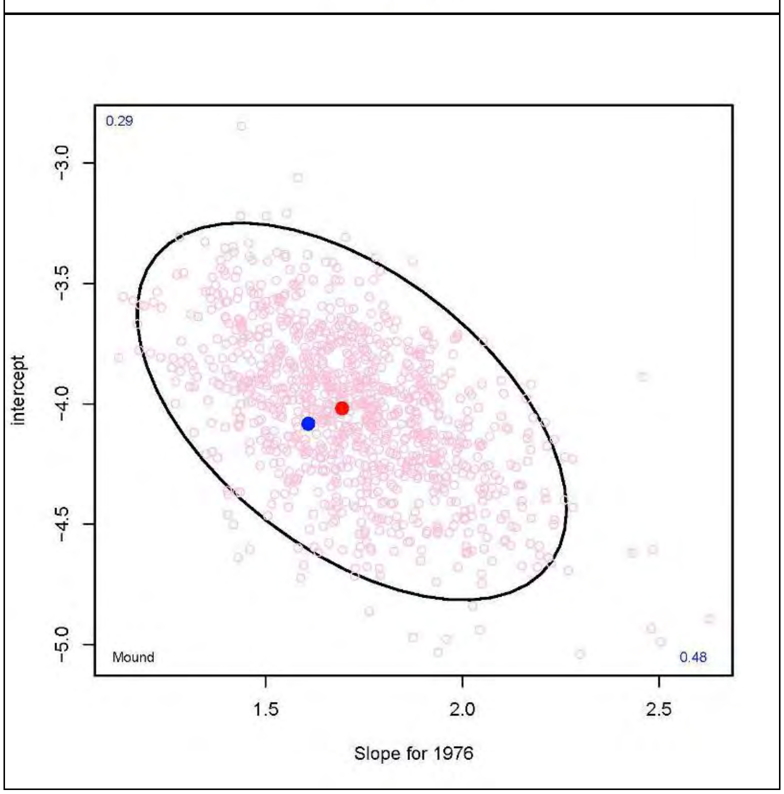

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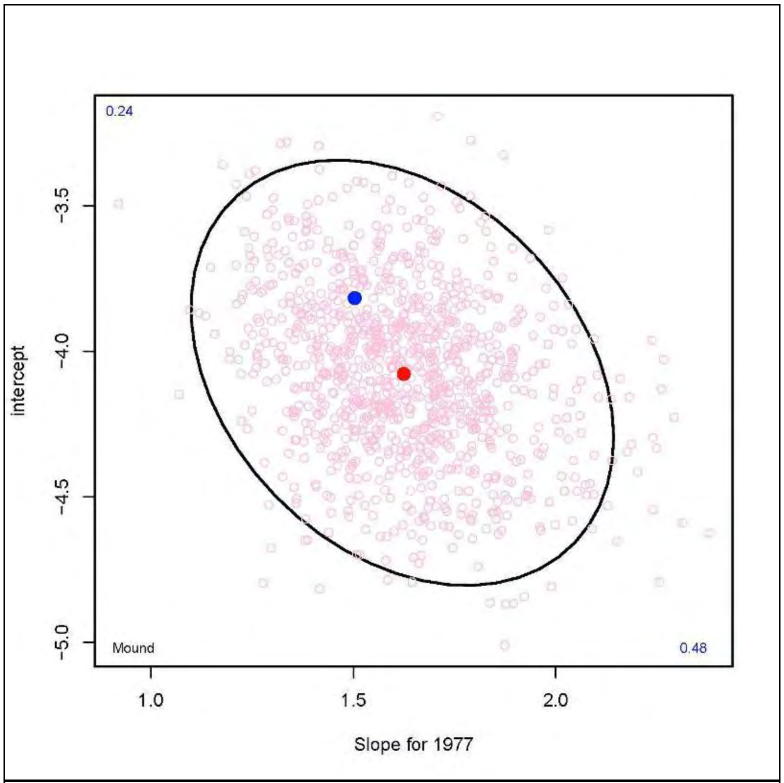

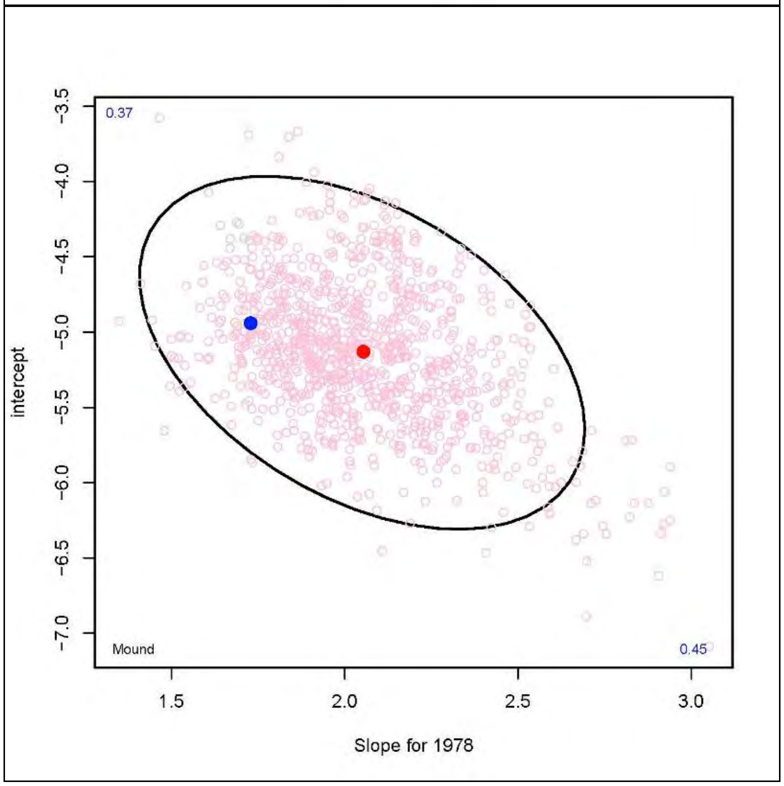

ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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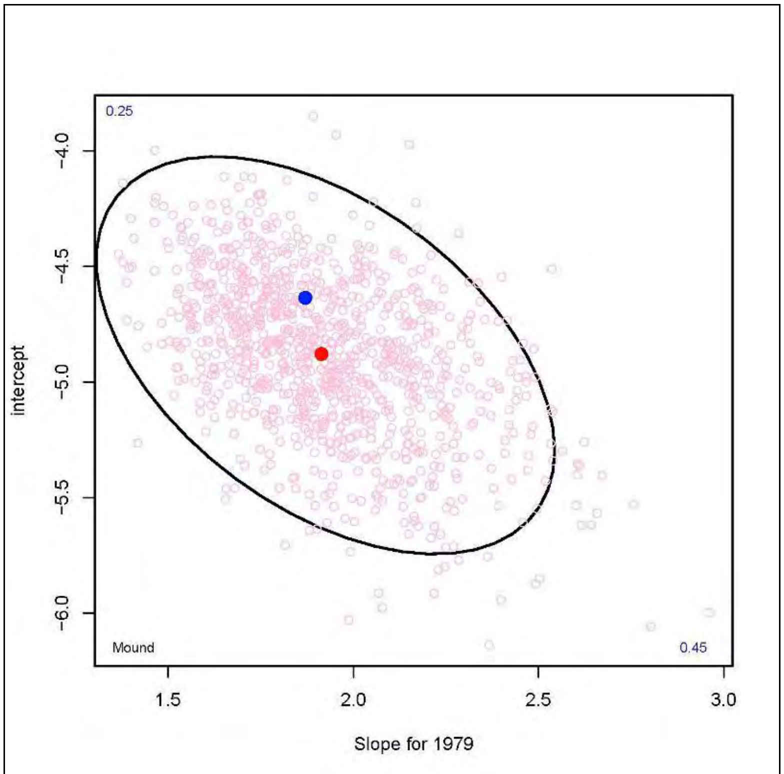

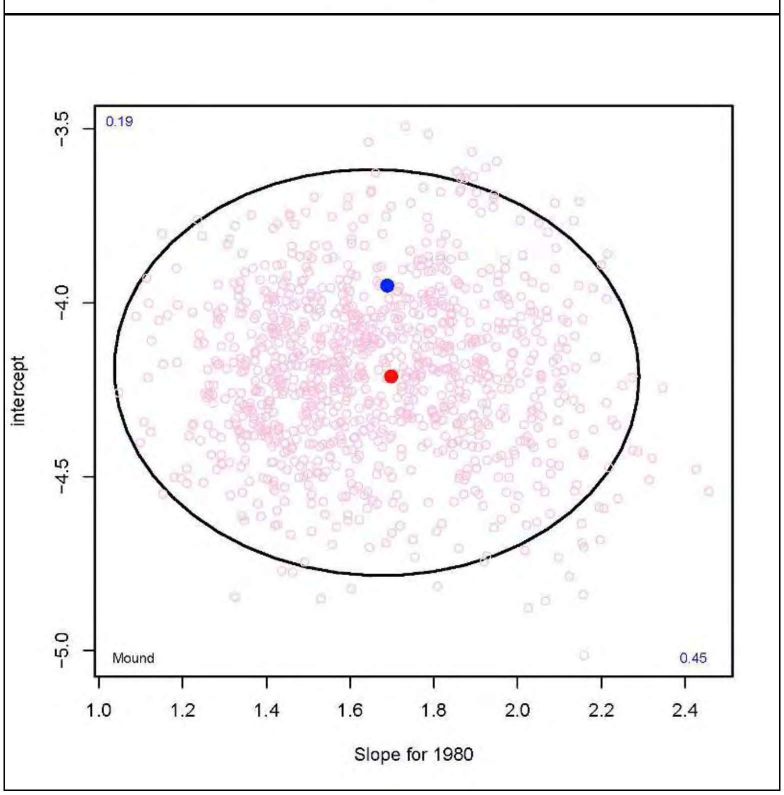

ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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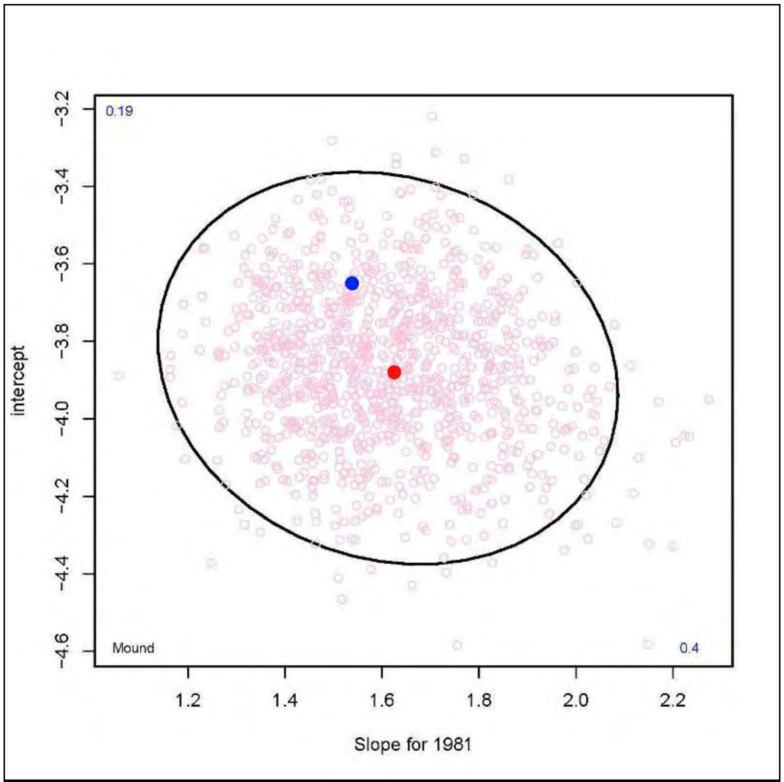
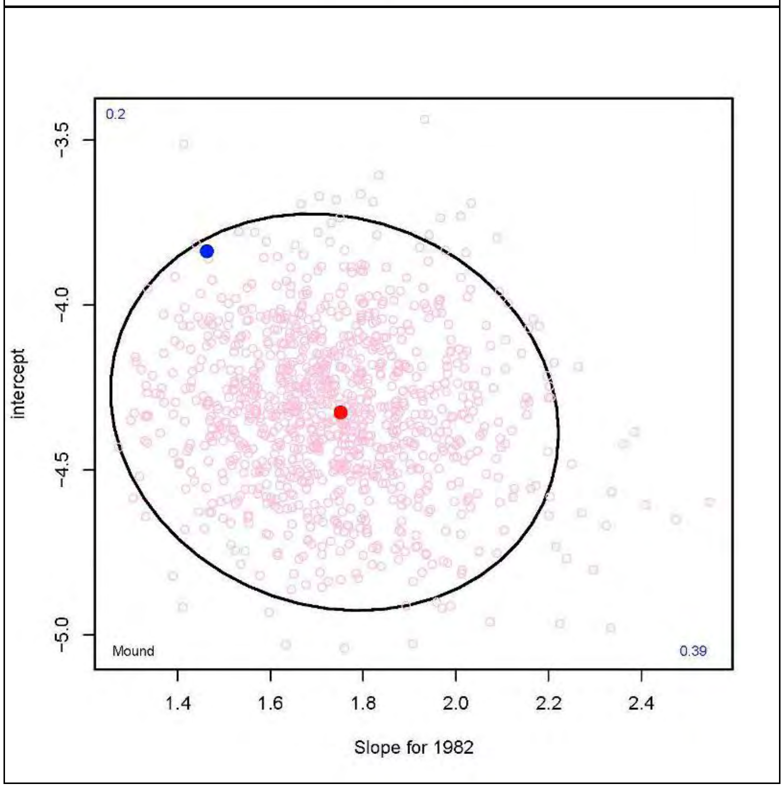
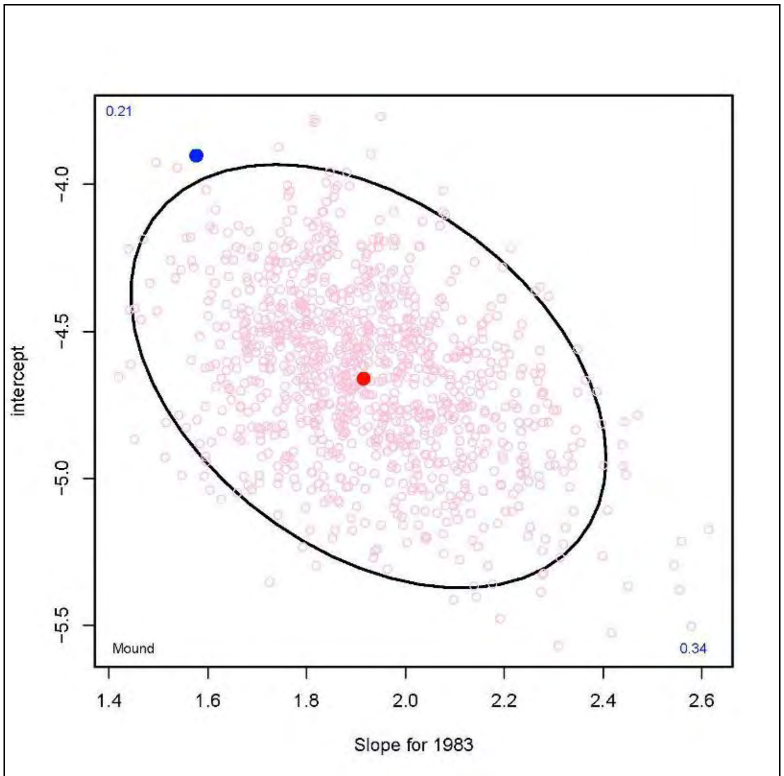
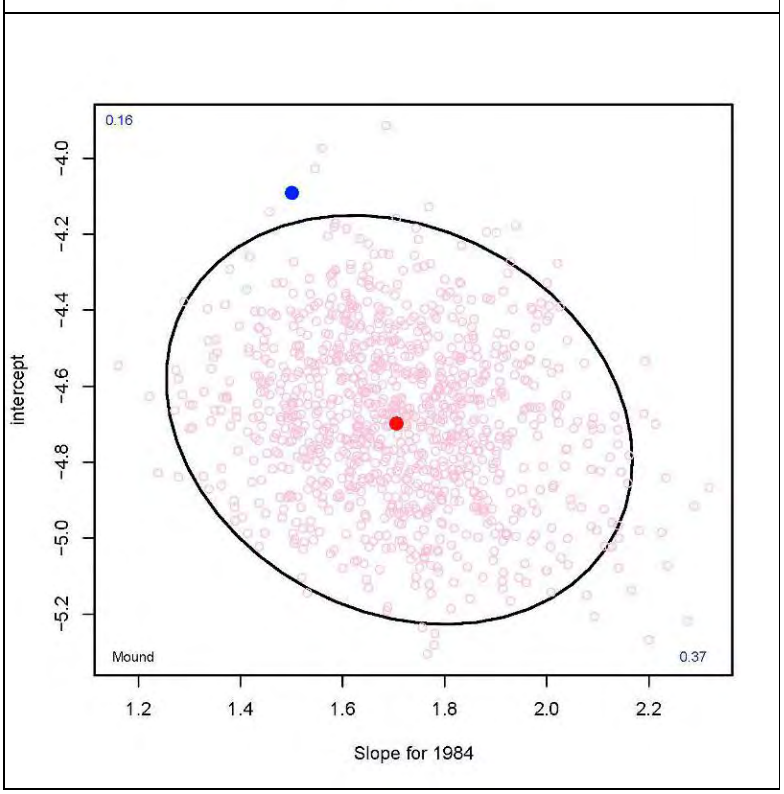


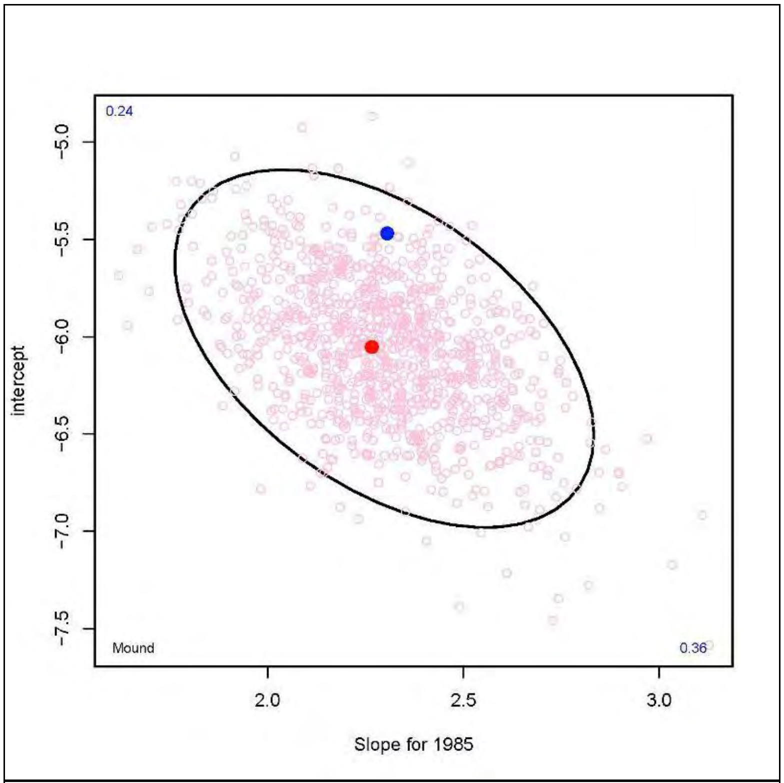


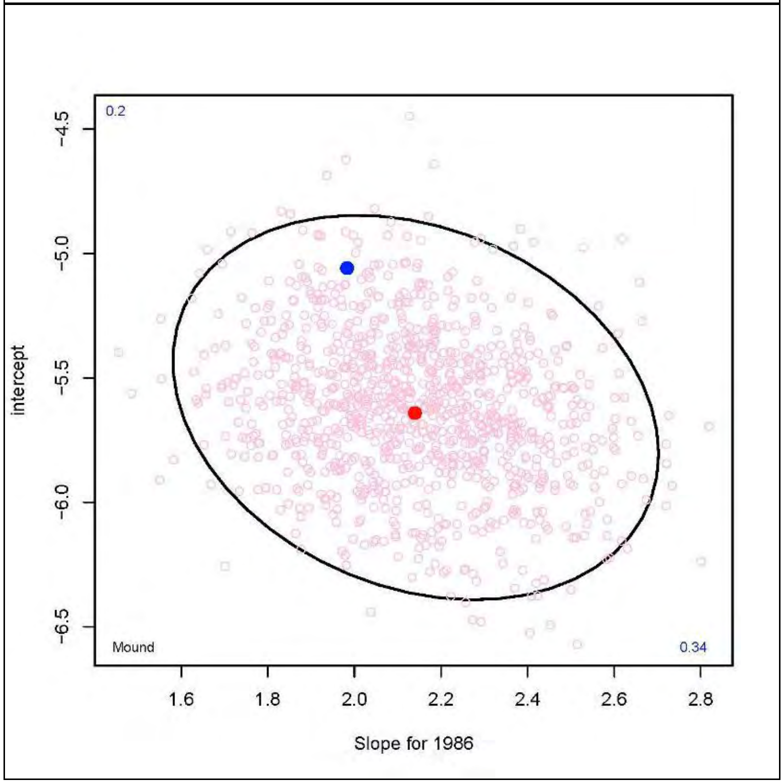
ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS





ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS





ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS
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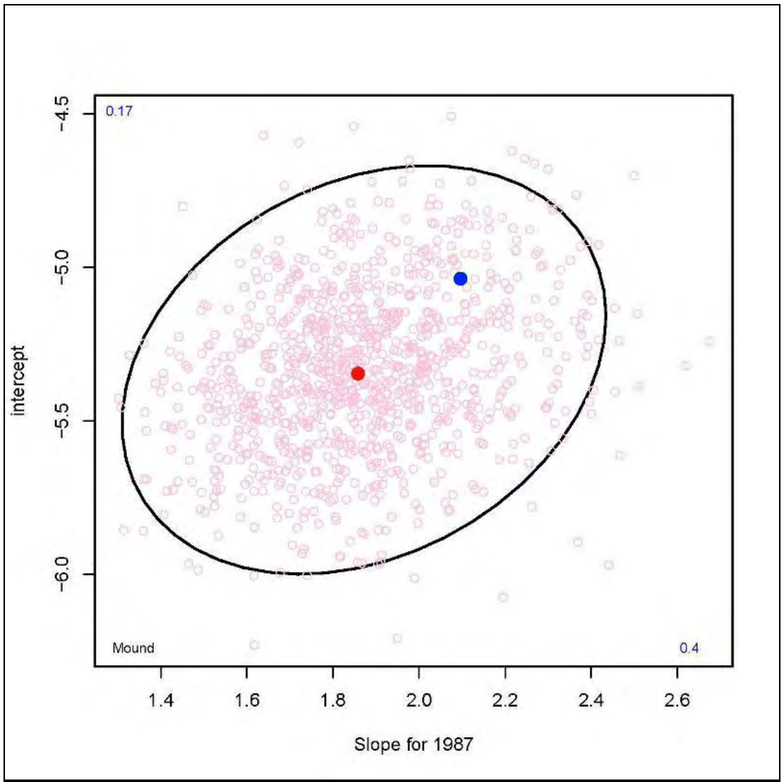
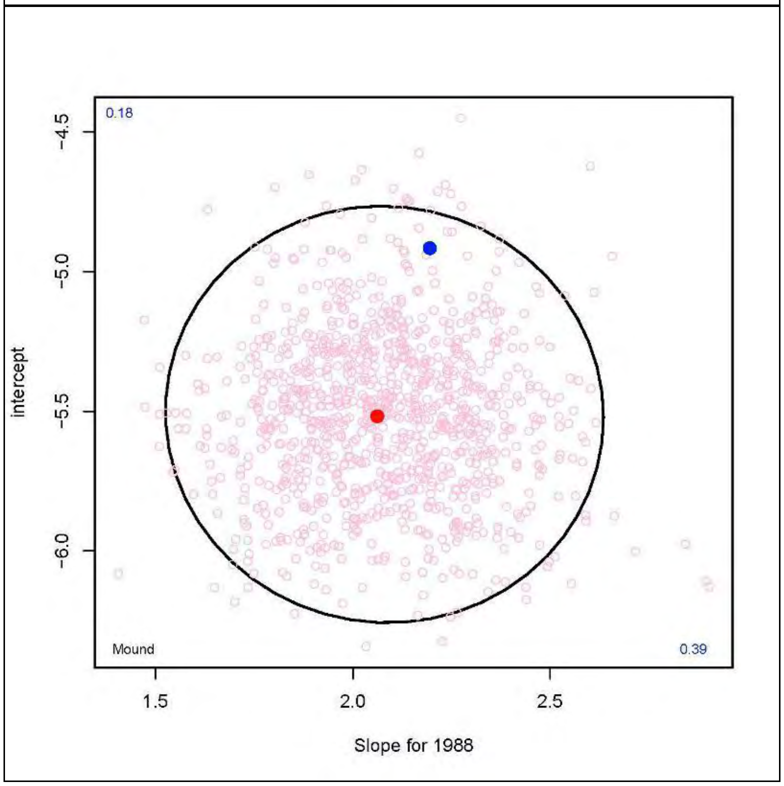
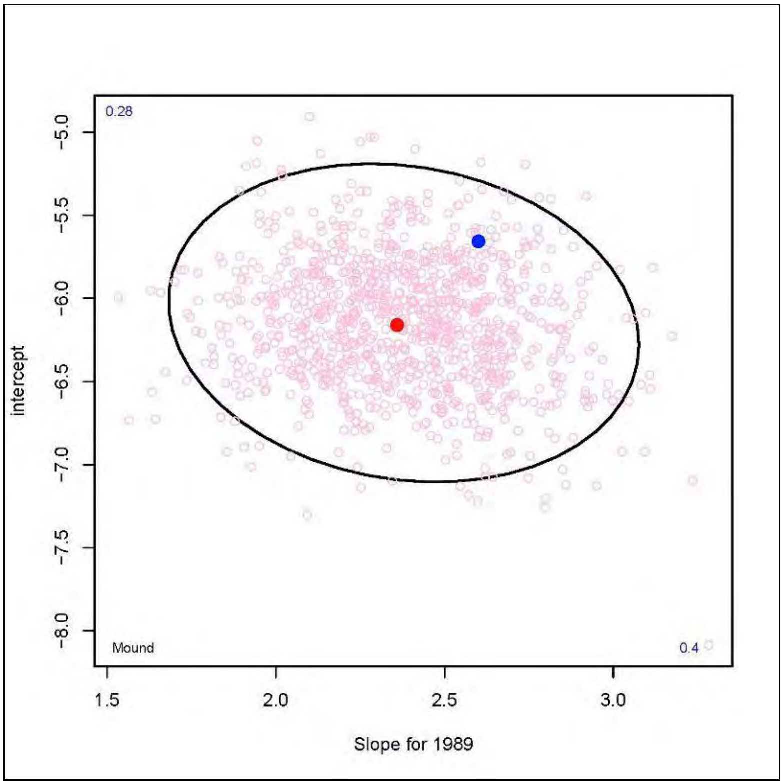
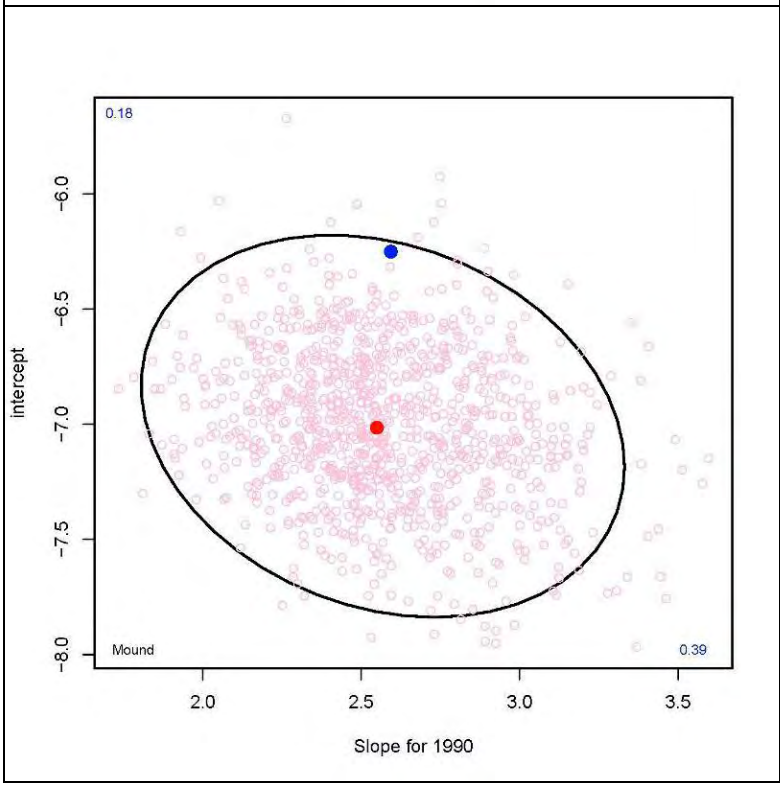




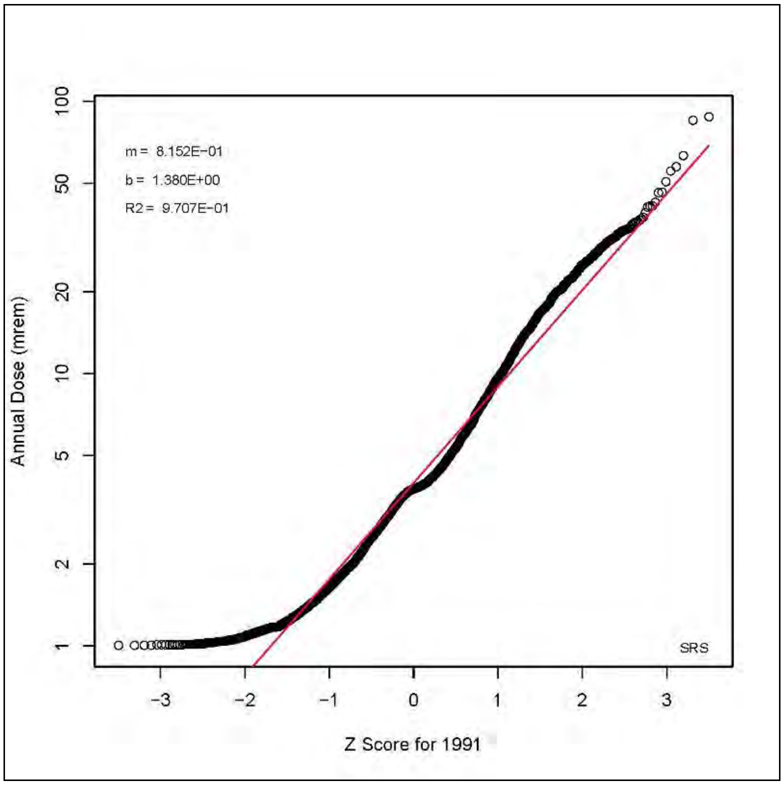
ATTACHMENT F
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE MOUND DATASET, 225 WORKERS





ATTACHMENT G
LOGNORMAL PROBABILITY PLOTS, COMPLETE SRS DATASET

This attachment presents lognormal probability plots for the complete SRS tritium dose dataset for 1991 to 2001. The slope and intercept for the line of best fit to the data are given on the plot.



ATTACHMENT G
LOGNORMAL PROBABILITY PLOTS,
COMPLETE SRS DATASET
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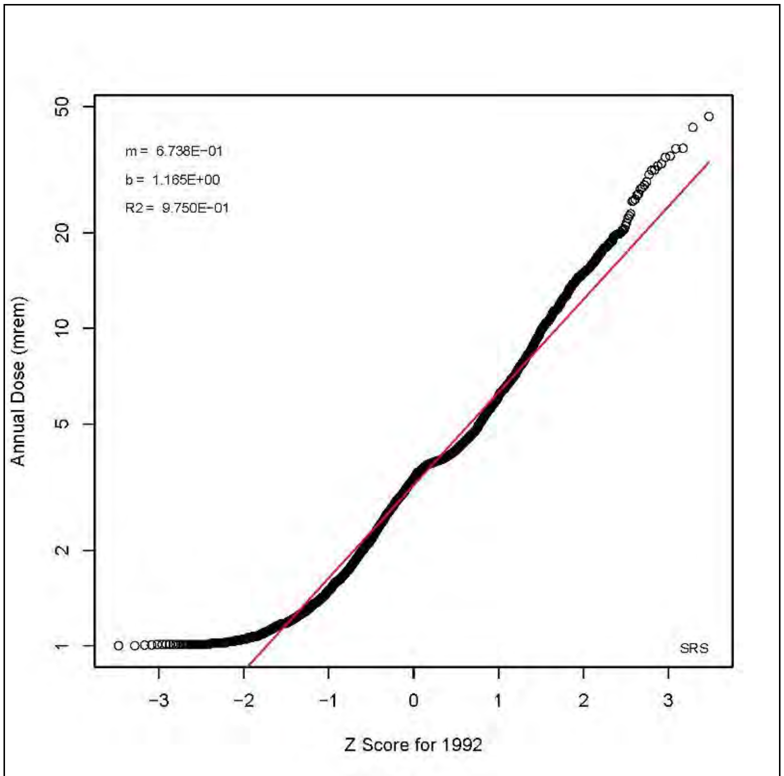

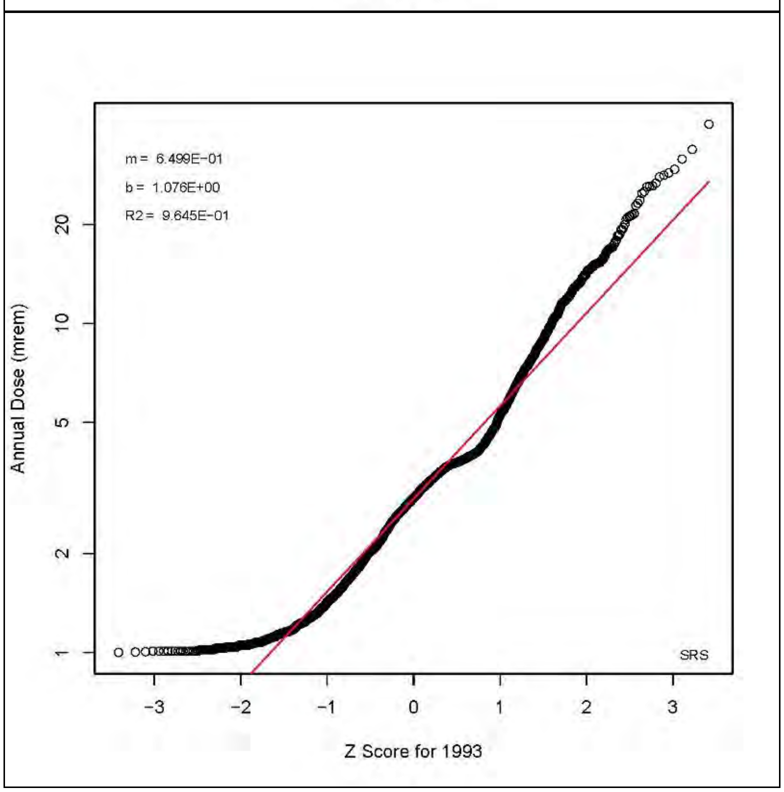

ATTACHMENT G
LOGNORMAL PROBABILITY PLOTS, COMPLETE SRS DATASET
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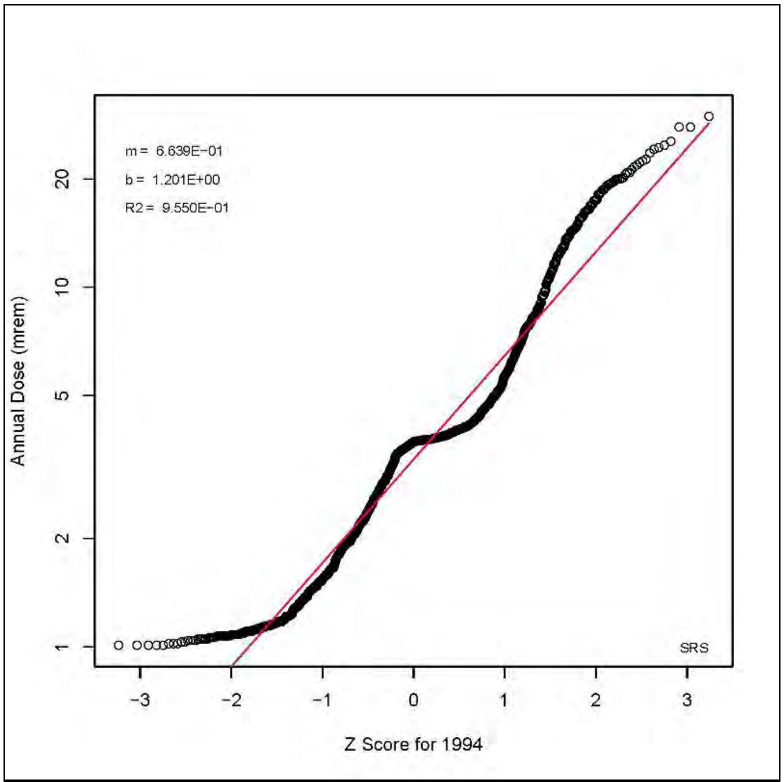

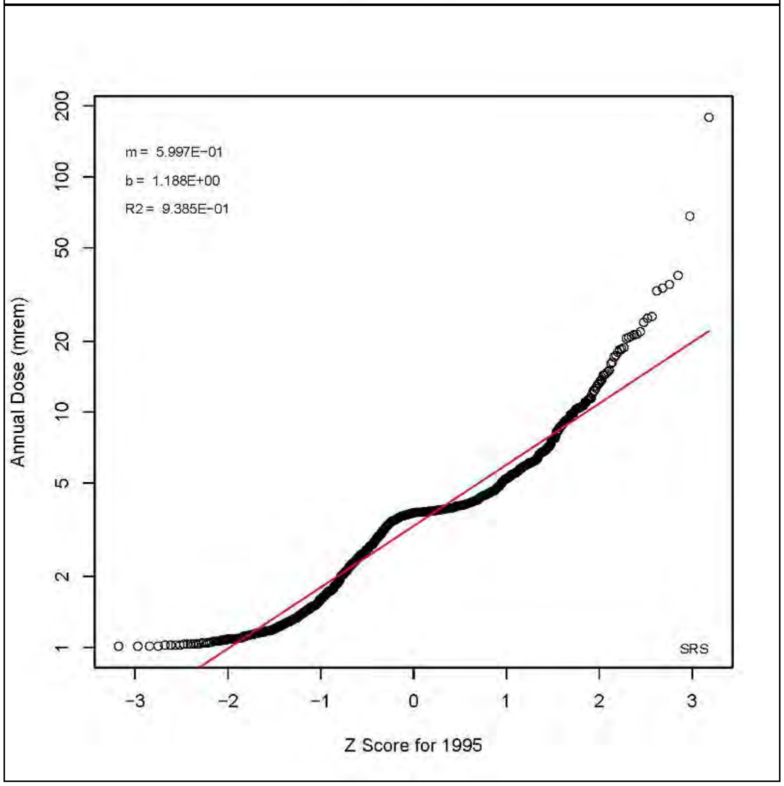

ATTACHMENT G
LOGNORMAL PROBABILITY PLOTS, COMPLETE SRS DATASET
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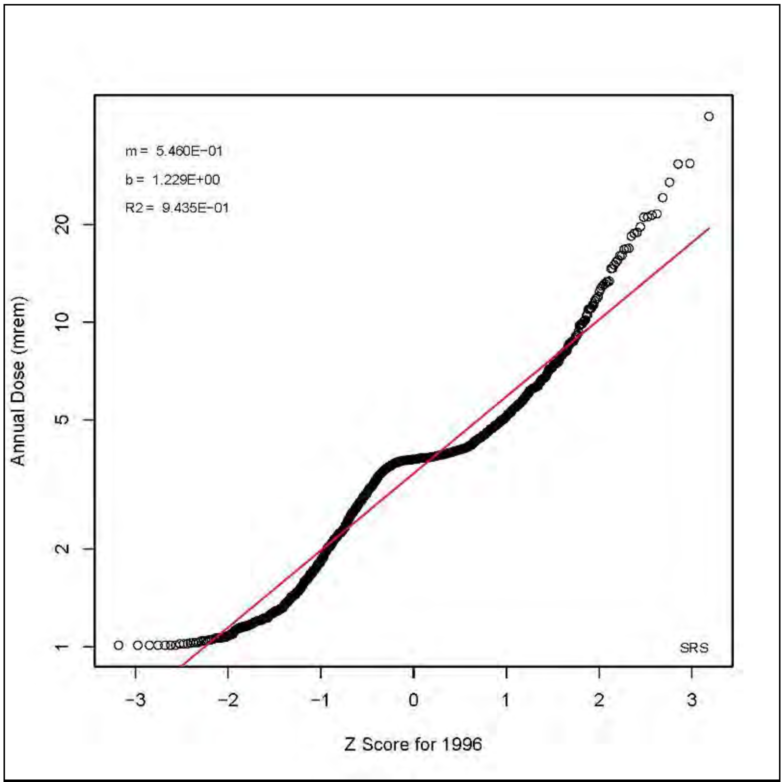

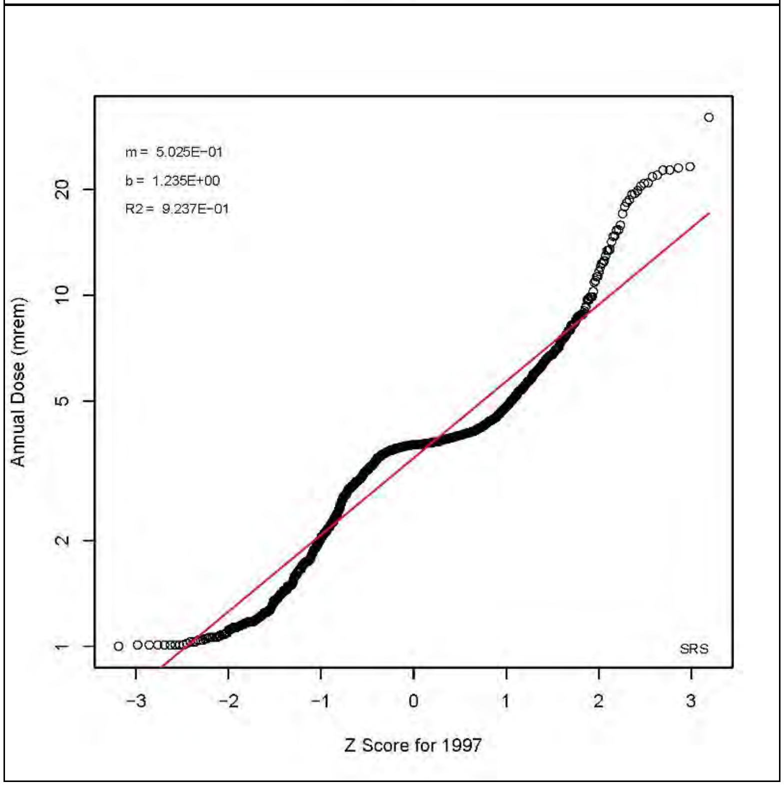

ATTACHMENT G
LOGNORMAL PROBABILITY PLOTS,
COMPLETE SRS DATASET
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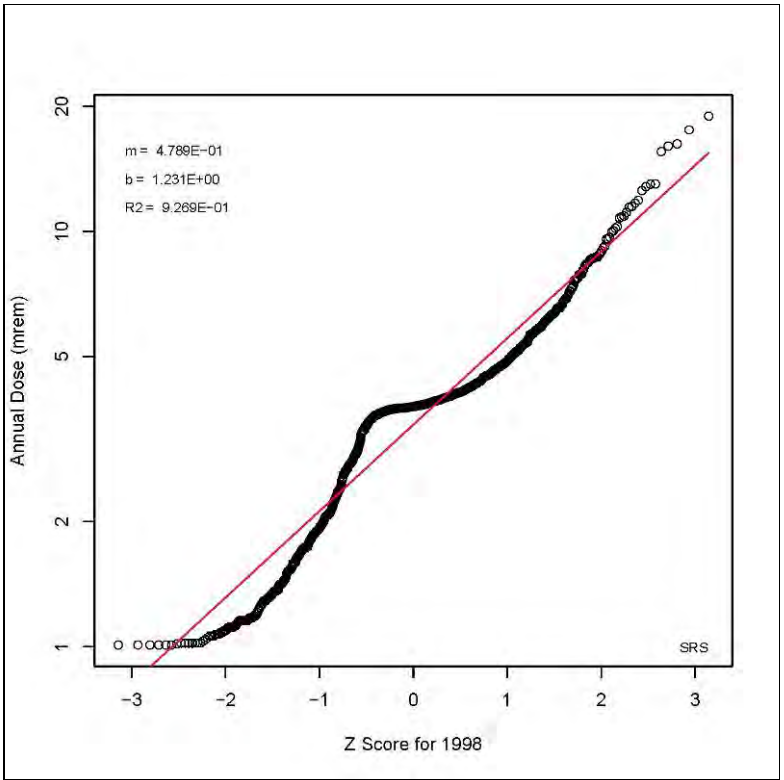

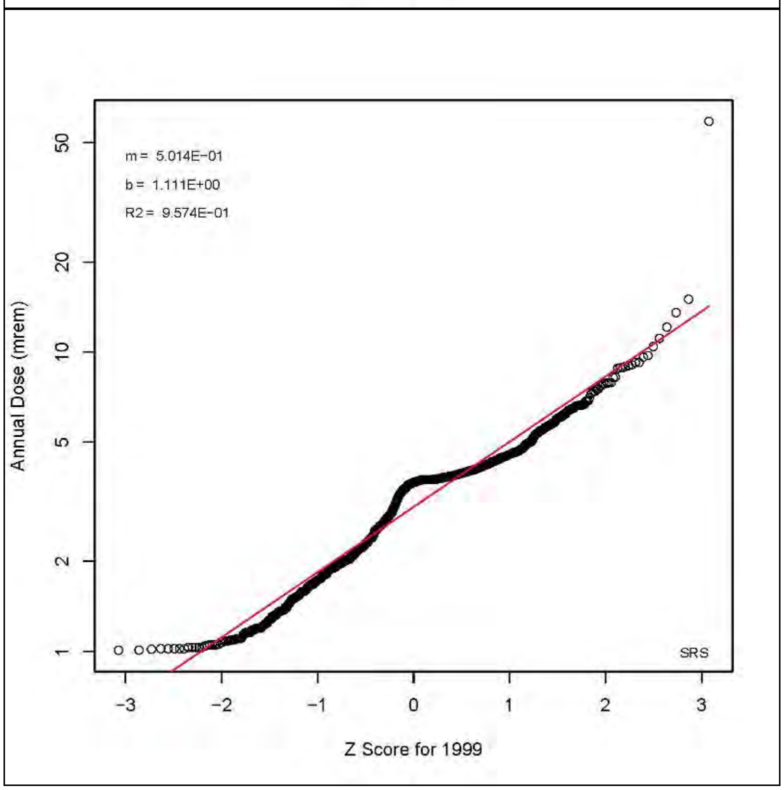

ATTACHMENT G
LOGNORMAL PROBABILITY PLOTS,
COMPLETE SRS DATASET
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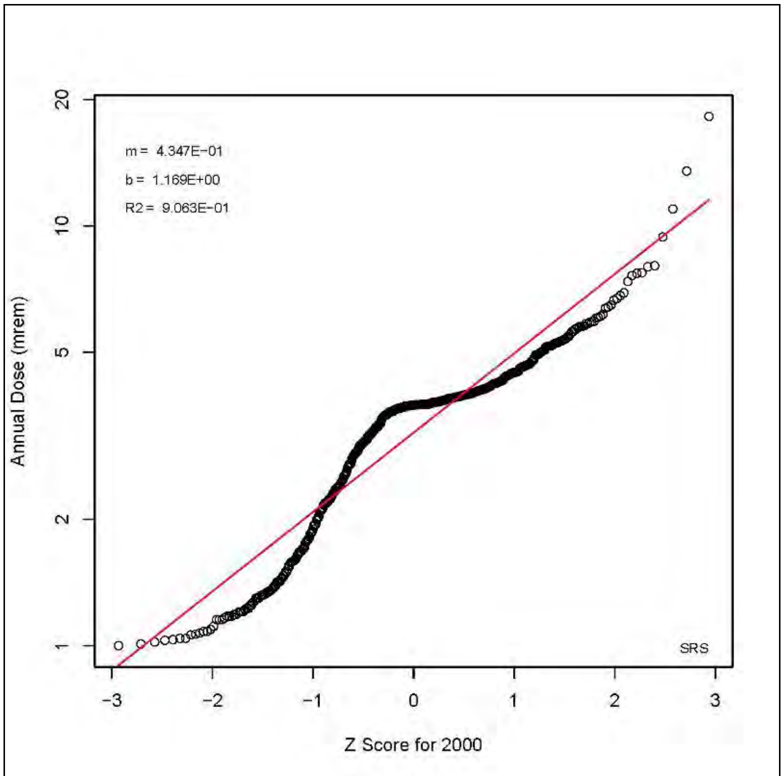
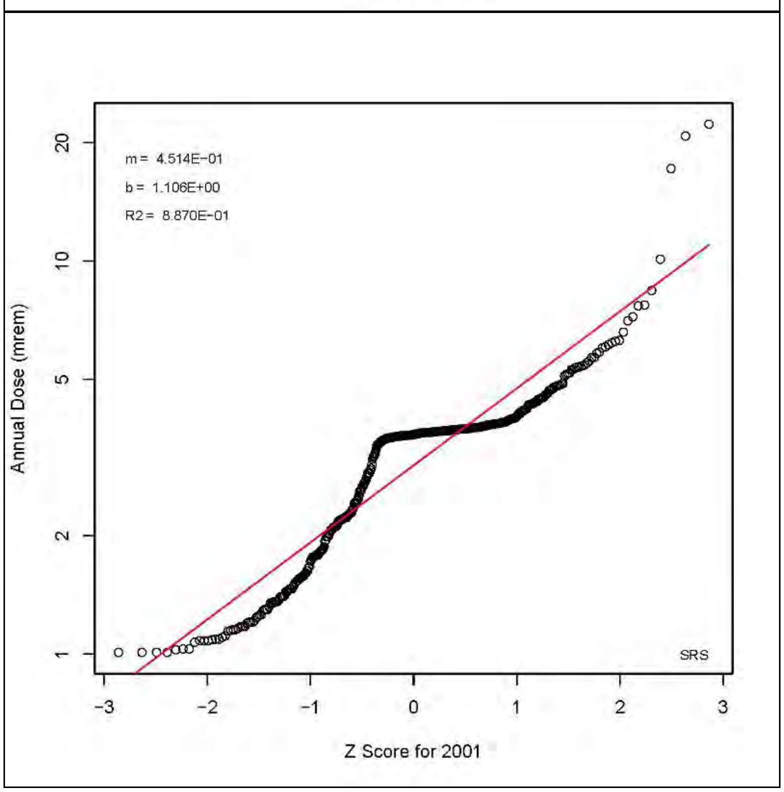
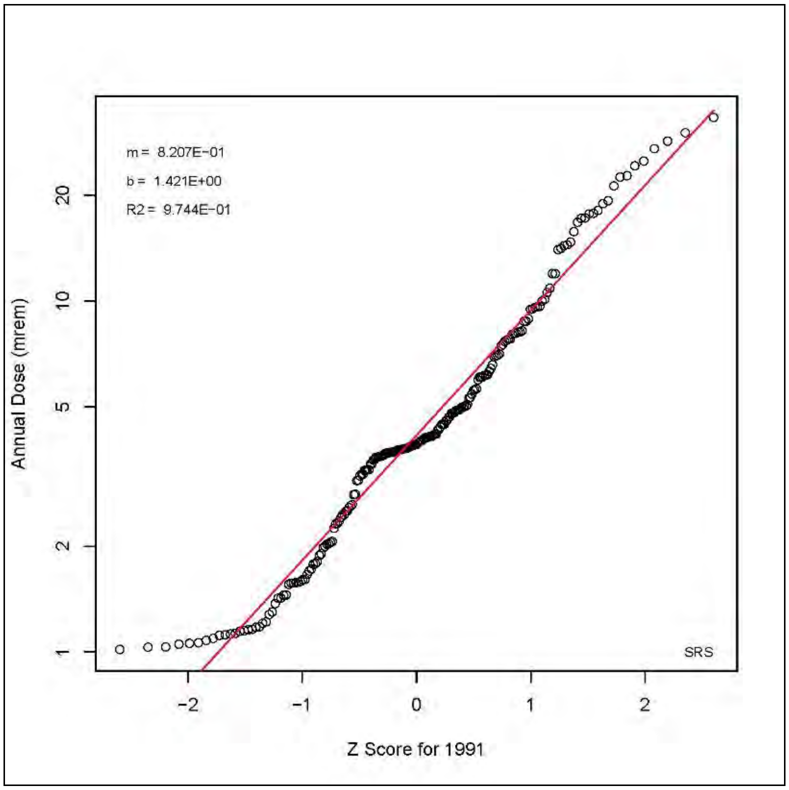




ATTACHMENT H
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT SRS DATASET

This attachment presents lognormal probability plots for the claimant SRS tritium dose dataset for 1991 to 2001. The slope and intercept for the line of best fit to the data are given on the plot.



ATTACHMENT H
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT SRS DATASET
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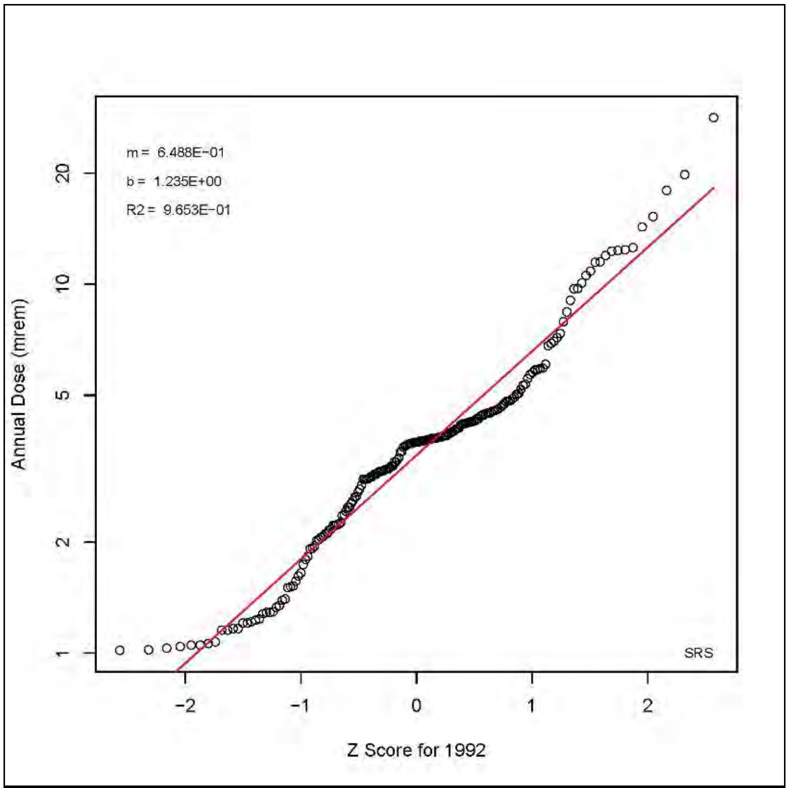

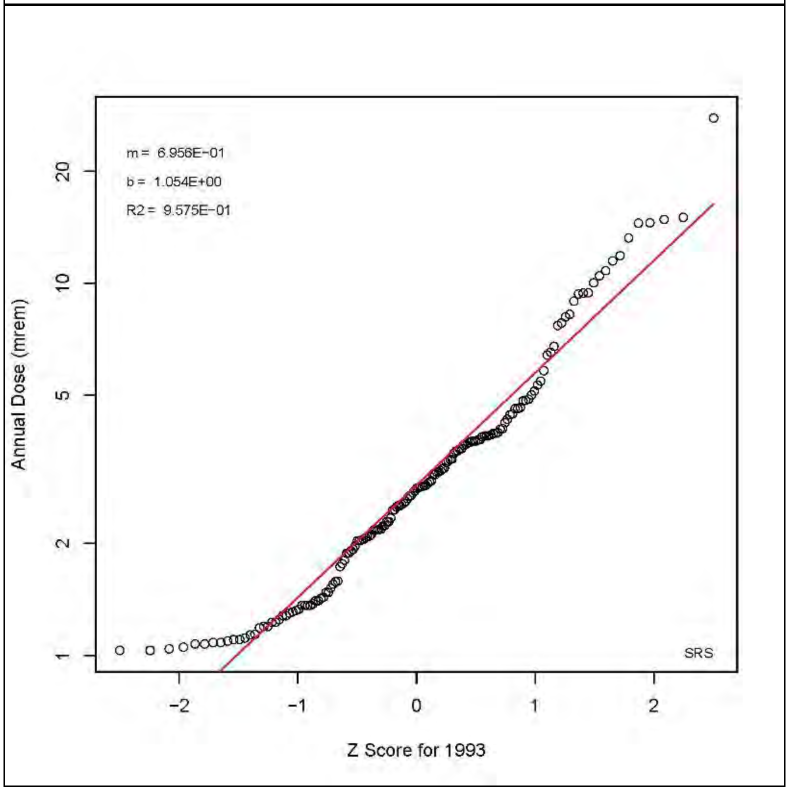

ATTACHMENT H
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT SRS DATASET
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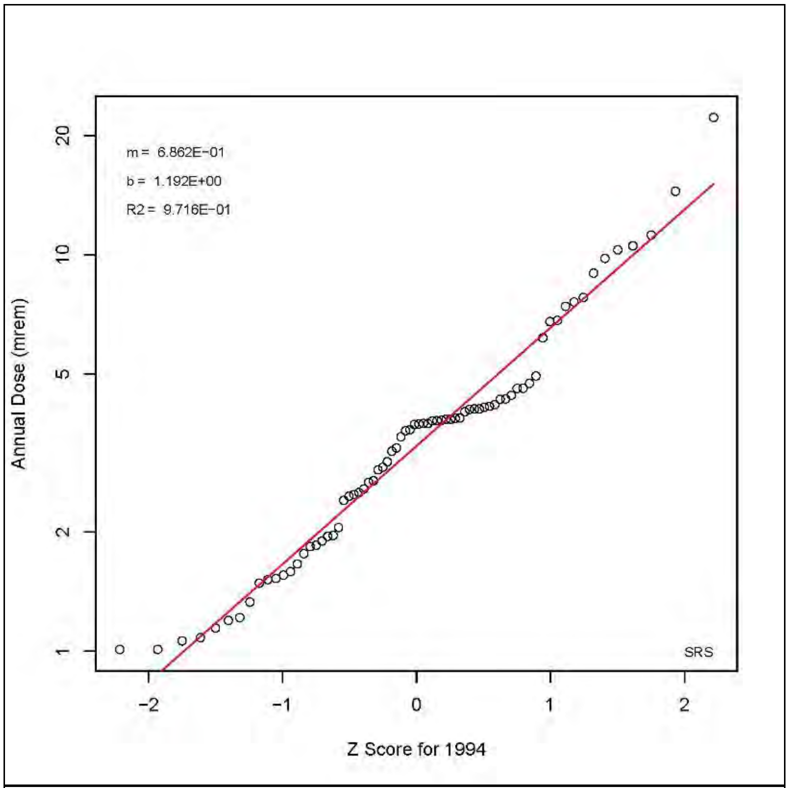

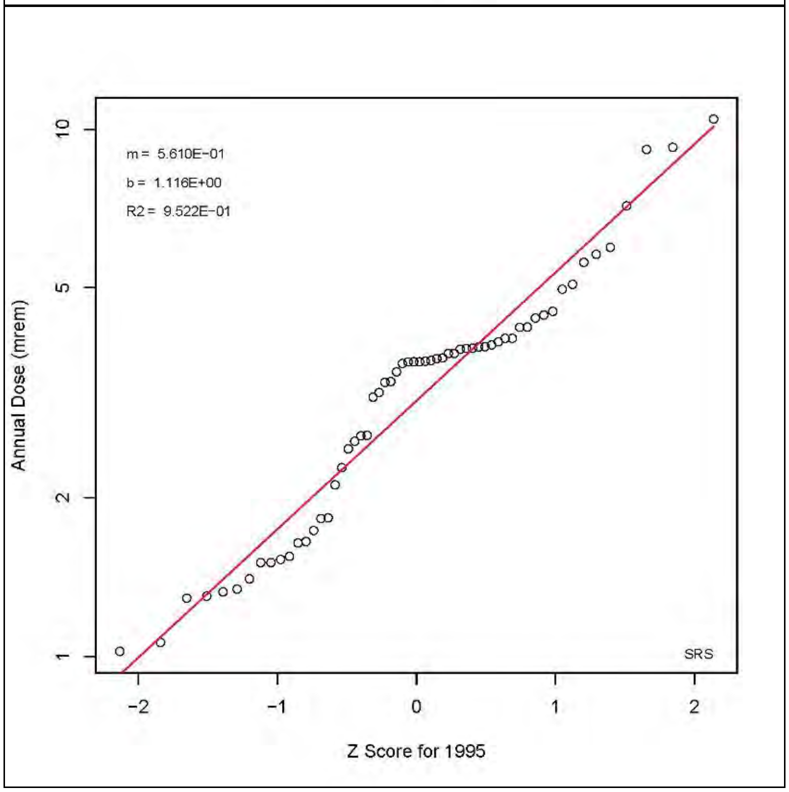

ATTACHMENT H
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT SRS DATASET
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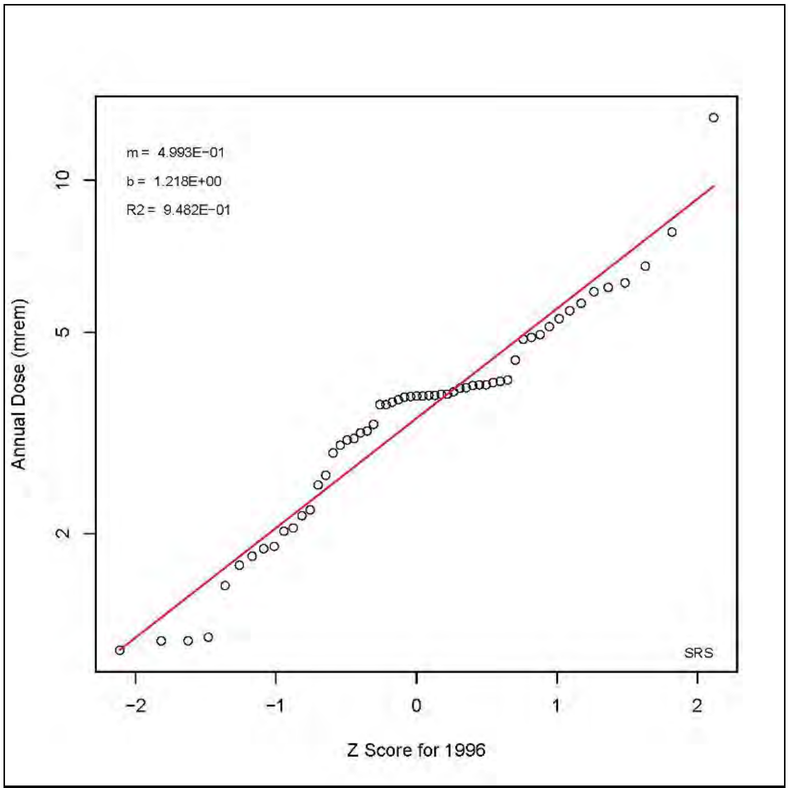

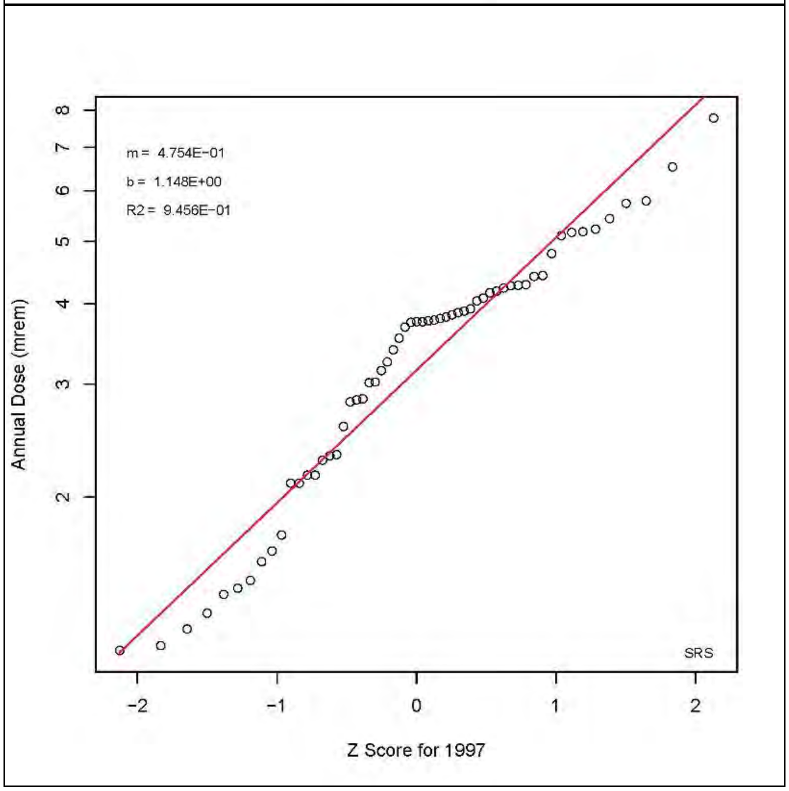

ATTACHMENT H
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT SRS DATASET
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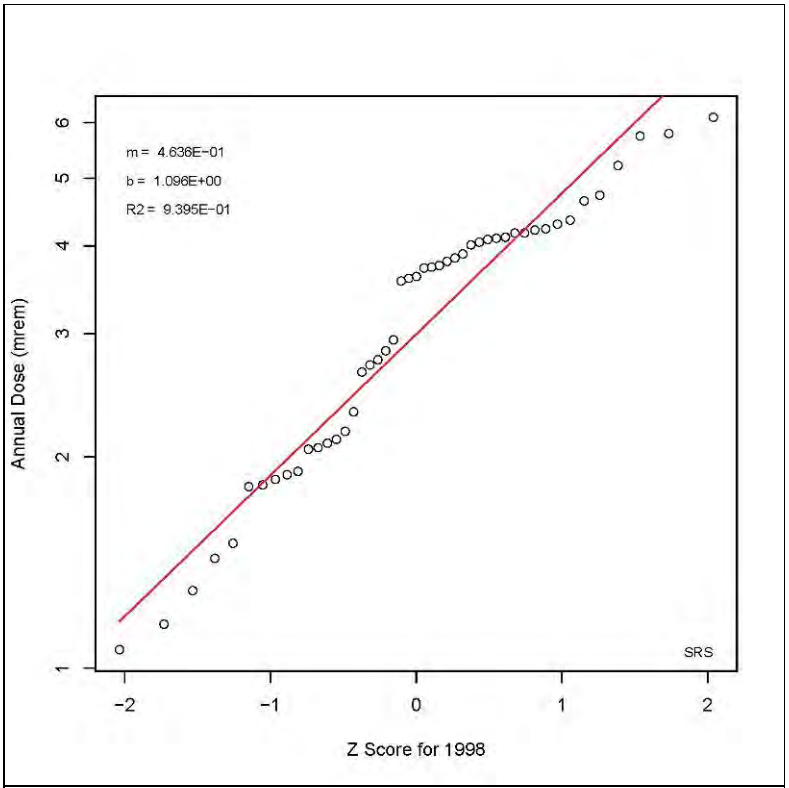

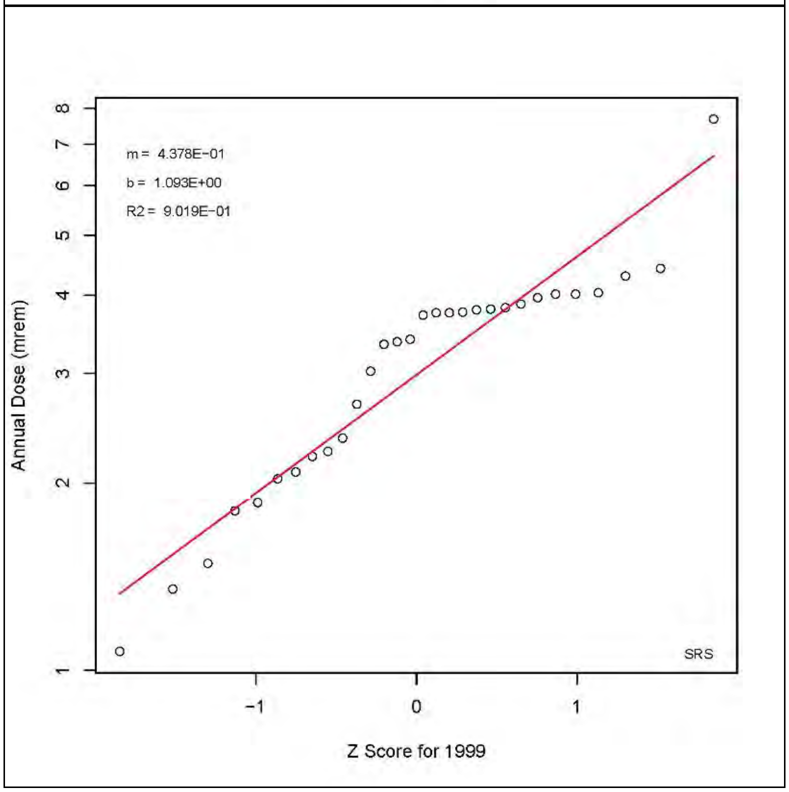

ATTACHMENT H
LOGNORMAL PROBABILITY PLOTS,
CLAIMANT SRS DATASET
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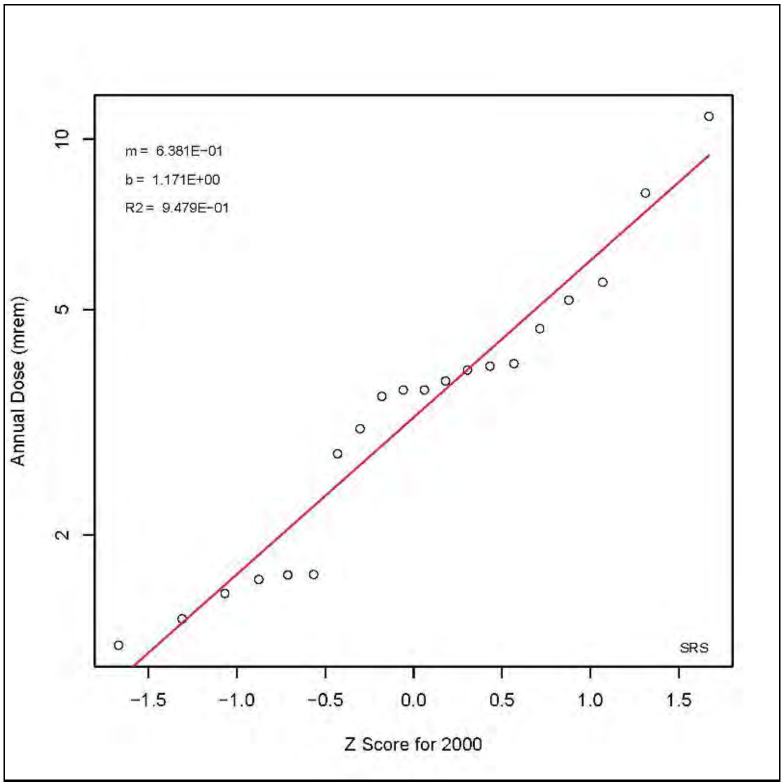
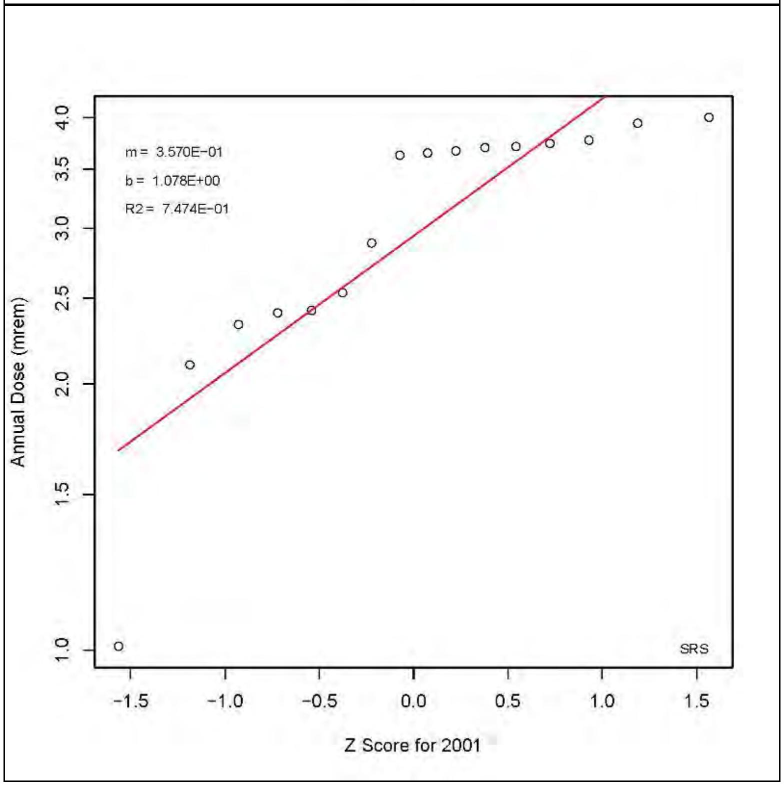


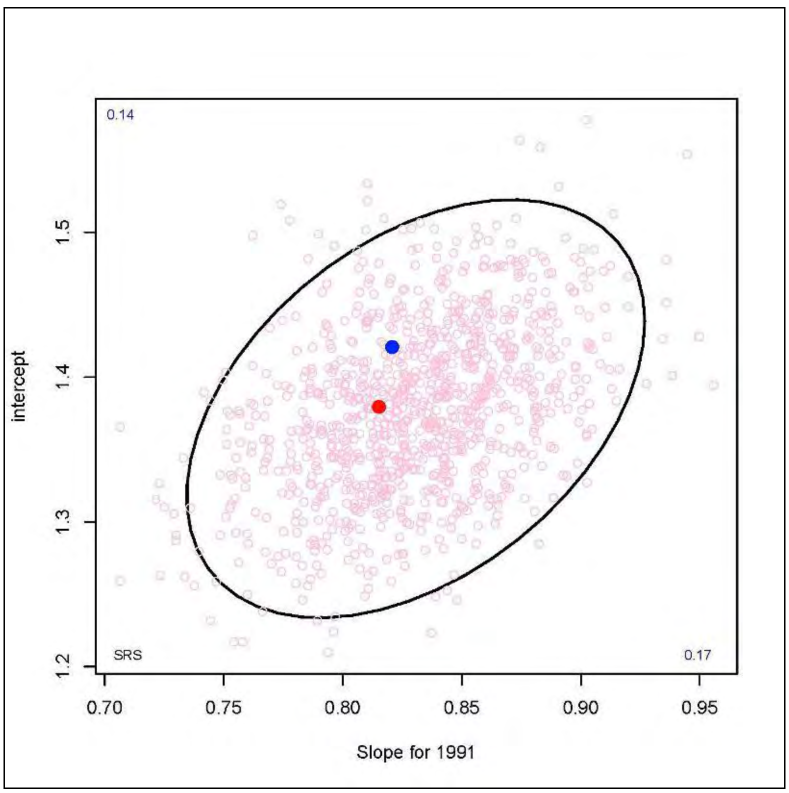


ATTACHMENT I
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE SRS DATASET, 451 WORKERS
Page 1 of 6

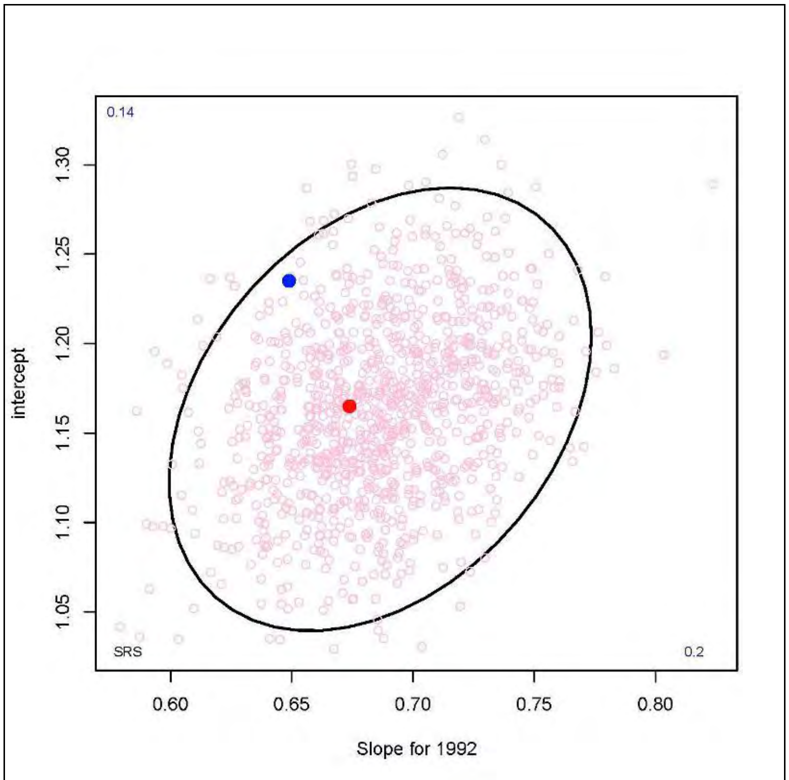
This attachment presents lognormal probability plots for a sample of 451 unique workers that was drawn at random without replacement from the 10711 workers in the complete dataset. The slope and intercept of the plot for each year from 1991 to 2001 was calculated based on this data. This process was repeated *m* = 1000 times to generate the 95% confidence ellipses. In each plot:

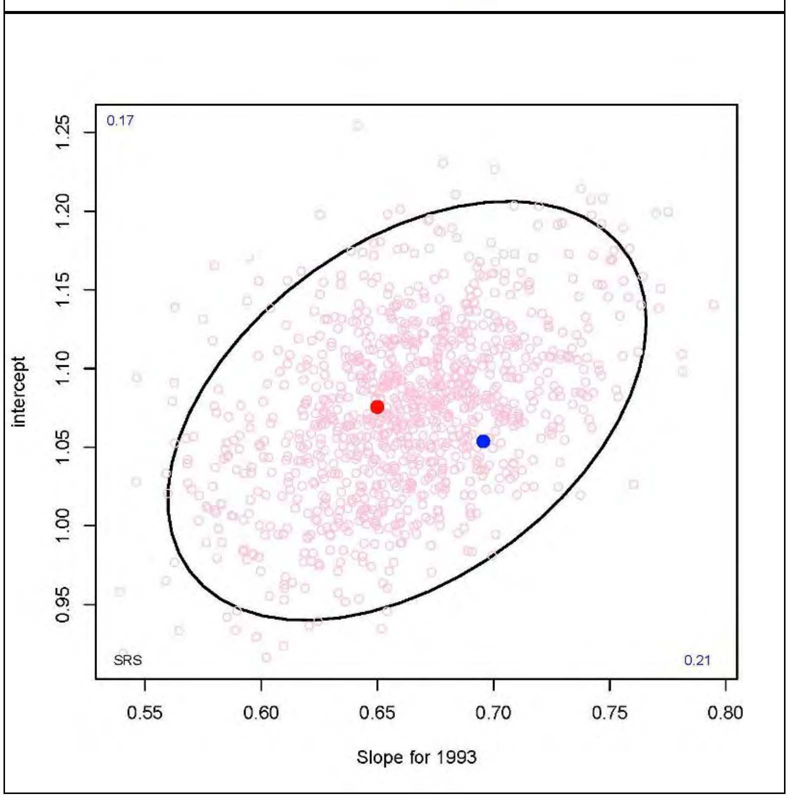
- The solid red point is the slope and intercept of the complete dataset.
- The solid blue point is the slope and intercept of the claimant dataset.
- The open pink points are the slopes and intercepts of the fits to the *m* random sets of 451 workers taken from the complete dataset.
- The ellipse is the 95% joint normal confidence ellipse.
- The numbers in the corners are the full scale of the respective axes in terms of +/- the slope or intercept of the complete dataset.

These plots are presented to support the idea that the claimant dataset is basically no different than a random draw from the complete dataset.



ATTACHMENT I
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE SRS DATASET, 451 WORKERS
Page 2 of 6





ATTACHMENT I
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE SRS DATASET, 451 WORKERS
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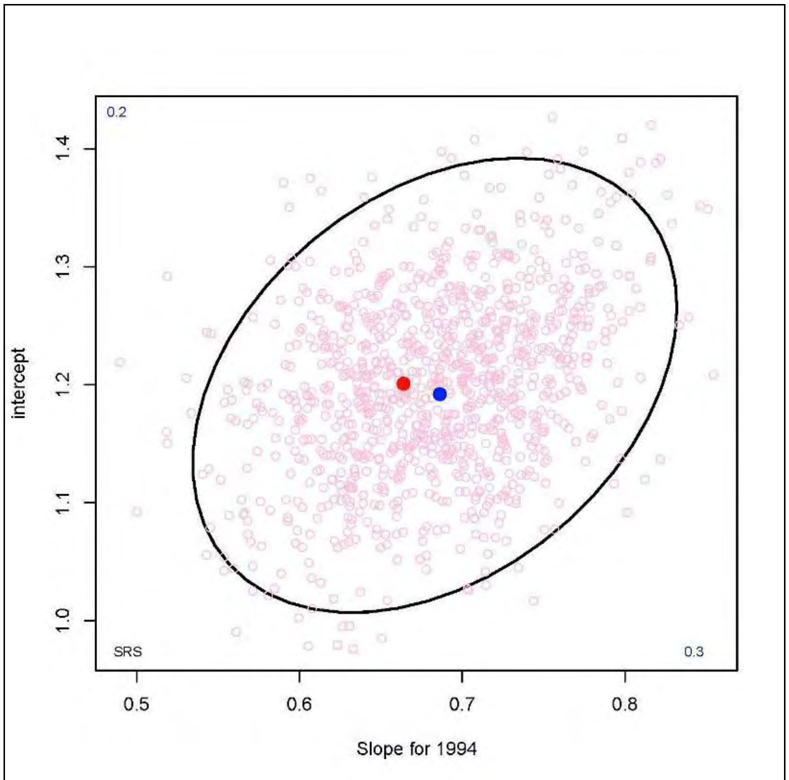

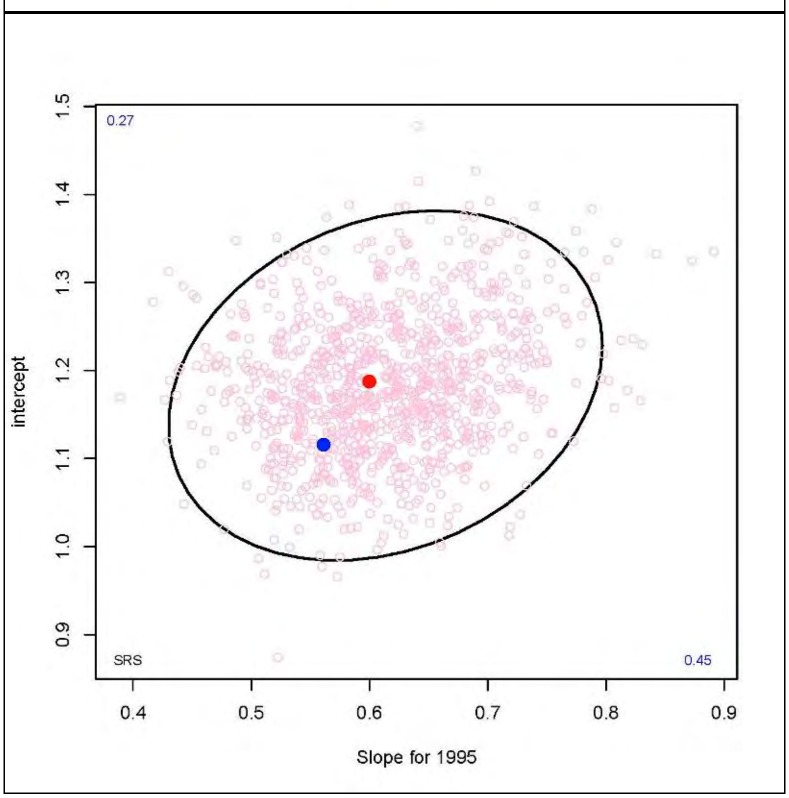

ATTACHMENT I
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE SRS DATASET, 451 WORKERS
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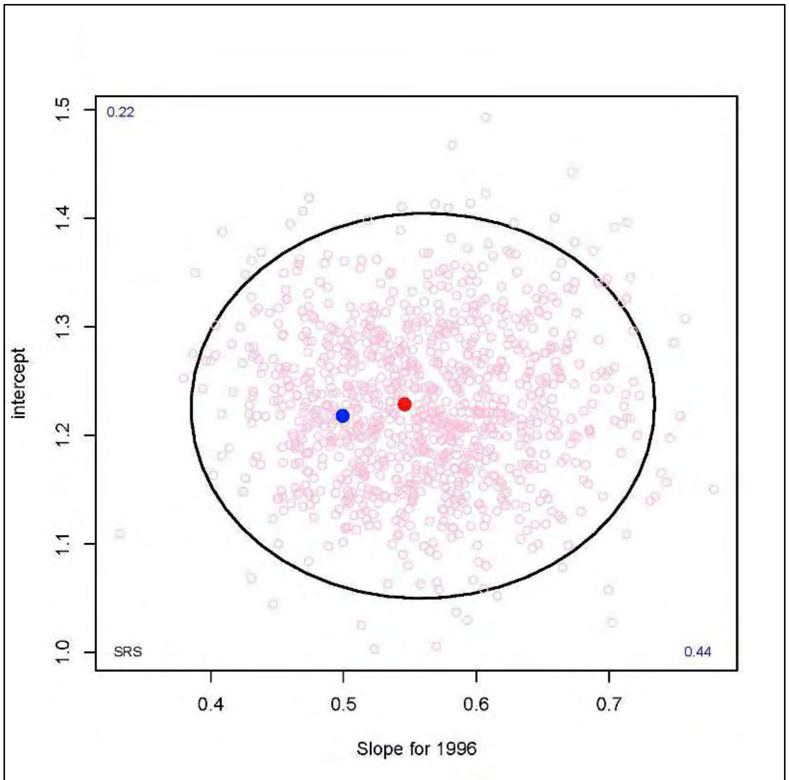

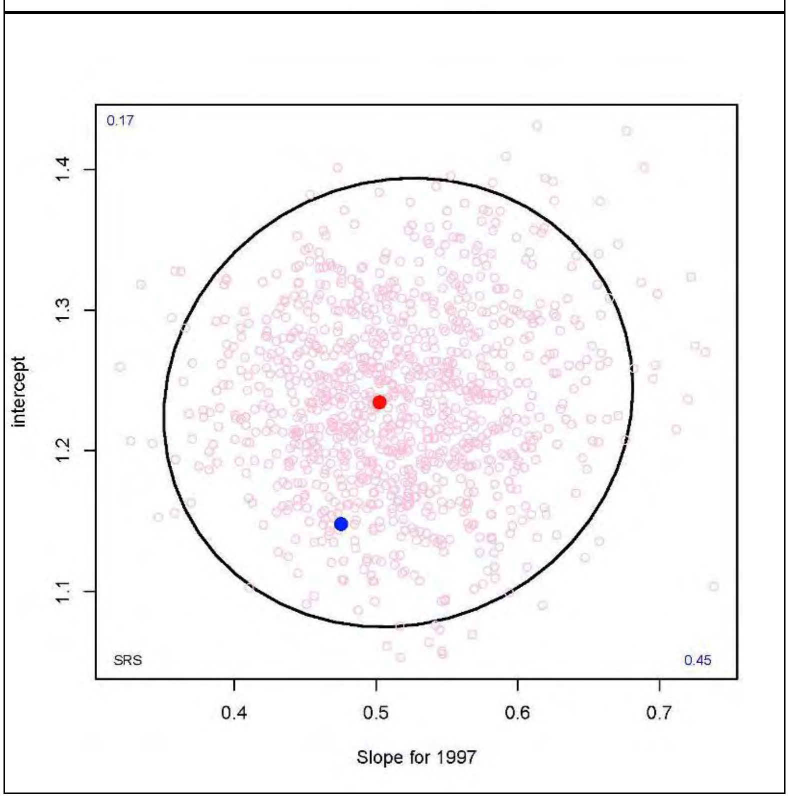

ATTACHMENT I
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE SRS DATASET, 451 WORKERS
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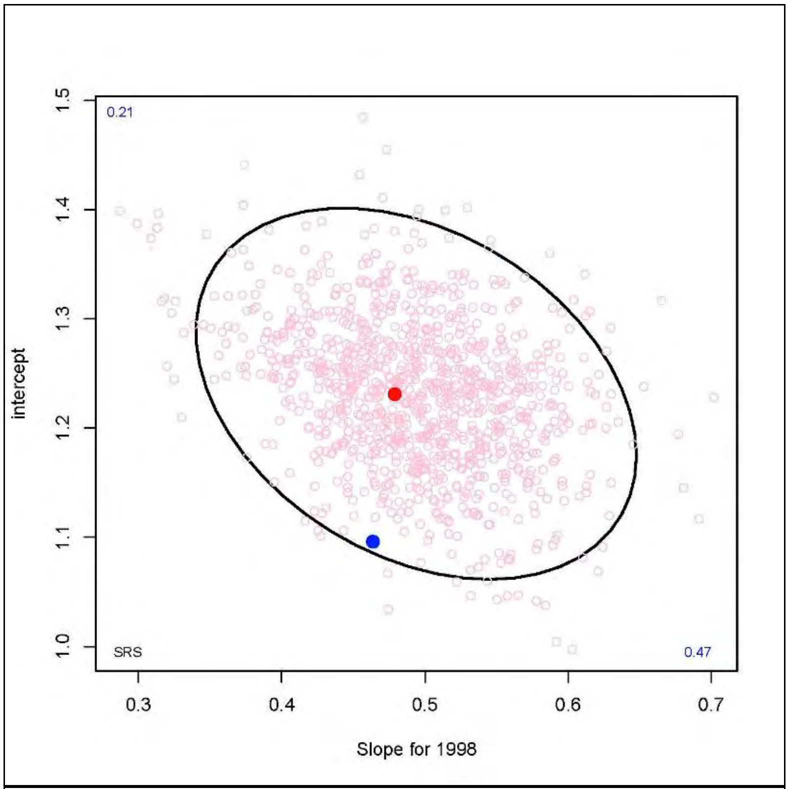

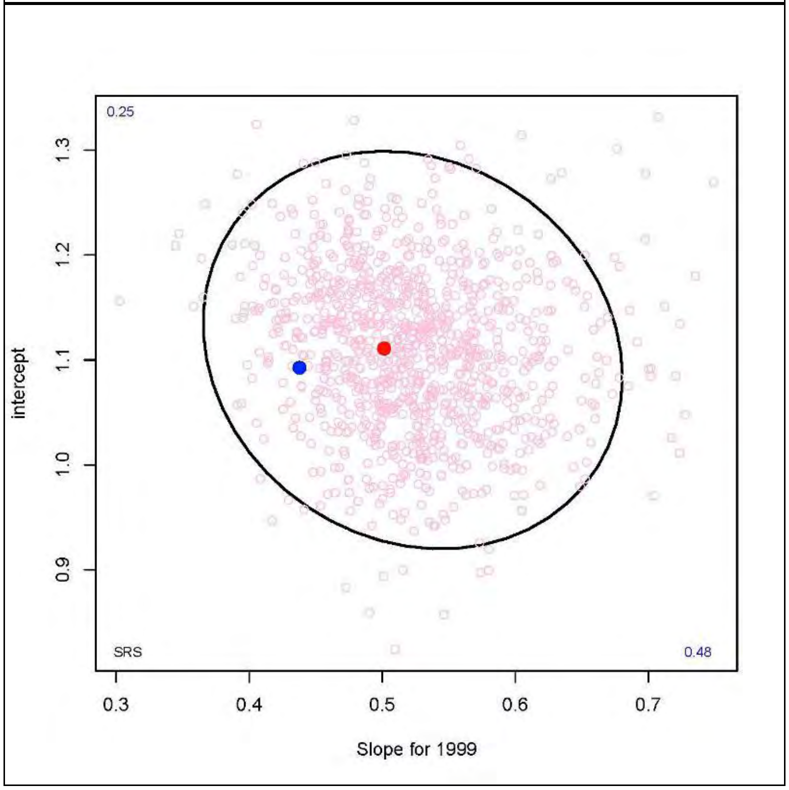

ATTACHMENT I
95% CONFIDENCE ELLIPSES FOR SLOPE AND INTERCEPT, COMPLETE SRS DATASET, 451 WORKERS
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