

APPENDIX E

ESTIMATES FROM URINALYSIS

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Urinalysis results existed for 1,758 samples collected from 1,555 individuals taken over a period extending from a few days to about 2 years following the accident. Earlier samples, collected on site, indicated the strong possibility of contamination. Follow-up samples, collected after personnel returned to their permanent base of assignment, showed dramatically lower concentrations. In 1968, those results demonstrated that no responder received a systemic body burden above a small fraction of the maximum permissible body burden (MPBB) – the standard for comparison at the time. This conclusion support expectations that estimates of intake and dose using currently accepted methods could support similar conclusions. This appendix discusses the urine data, provides preliminary estimates of intake and dose, and draws conclusions about the reliability of the estimates.

Estimates of intake and dose based on urinalysis for plutonium proved to be affected by numerous technical difficulties that made the results unrealistic compared to other plutonium exposure cases from industrial and environmental settings. Nevertheless, review of the extensive urinalyses confirmed the conclusions about the minimal impacts on the health of the responders made during the post-accident evaluations in 1966 through 1968. Furthermore, this effort completed a much-needed organization of the data, consistency checks and revisions, and preparation of the data for use in future evaluations.

E.1 DATA

The Air Force Institute of Environment, Safety, and Occupational Health Risk Analysis (AFIERA) and the Air Force Medical Operations Agency (AFMOA) provided records in the form of:

- Air Force Forms with laboratory analytical and exposure details of the nasal swipe and urine samples submitted and processed.
- Complete case files for the 26 individuals identified for follow-up in 1966 and commonly referred to as the “High 26”.
- A Microsoft Excel spreadsheet prepared by AFIERA staff that contained the data from those Air Force Forms, and some data related specifically to the 26 individuals (referred to as the “High 26” who were considered as having the highest exposures).
- Copies of the accident response reports, USAF RHL documents on the evaluation of exposures by urinalysis, and selected publications from journals and conference proceedings.

Appendix B contains a detailed discussion of the information collected, an evaluation of the information’s suitability for a dose evaluation, and adjustments made to the data for performing intake and dose calculations. The record prepared and maintained by the Air Force consisted of forms, computer spreadsheets, and written correspondence and reports of activities.

E.1.1. Forms

The USAF Radiological Health Laboratory (USAF RHL), the central laboratory for providing radiological services to Air Force units in 1966, recorded the data and results of samples processed on three series of forms: AFLC Form 1165, Internal Dosimetry Data (May 66), AFLC

Form 1165, Radiological Sample Data (May 66), and AFLC Form 1165, Radiological Sample Data (Jul 67). Although similar in design and content, these three forms evolved over the course of the laboratory effort on Palomares. The three forms recorded the data about the individual who submitted the sample, radiation measurement data for urine, radon (breath) (sic), and feces/blood samples, counting data, instrument data, and other factors; and finally the results. The Internal Dosimetry Data (May 66) form apparently served primarily for the samples processed during the initial, or on-site, phase of the response. Figure B-1, Appendix B illustrates that the May 66 version of the form contained information from samples collected in April 1966. The Radiological Sample Data (May 66) form was used to record alpha spectrometry data for most of the follow-up phase. The Radiological Sample Data (Jul 67) form was used during the end of the follow-up phase.

Consistency among the entries on the data forms and the entries in any ultimate data set would be required. The data cards formed the only permanent record available of the actual data generated at the time of the incident. Consequently, they provided the primary means for verifying information from other sources, at least when the data on the cards were unambiguous.

E.1.2. Spreadsheet

AFIERA representatives also provided a copy of a Microsoft EXCEL[®] spreadsheet that contained the basic data transcribed from the hardcopy data forms into the spreadsheet. Figure B-6, Appendix B contains an example of one page of the spreadsheet to illustrate its contents. The spreadsheet contains information on some 1,758 individual entries for 1,555 individuals. The spreadsheet served as a good starting point for evaluating the data contained on the hardcopy records.

E.1.3. Reports

Several other documents provided essential information about the details of the accident, the response effort, and the approach to evaluating health and safety issues during the response. These documents provided a narrative overview of the approach to assessing possible exposure to plutonium at Palomares. The discussions highlighted the issues faced, the problems encountered, and the rationale that formed the basis for the effort and decisions made throughout the period of on-site activity and subsequent follow-up. These issues are discussed in some detail in Section 2 above. The issues related to possible sample contamination, the sample collection period, and the exposure type and date formed the basis for evaluating the suitability of the data for the evaluation effort.

E.2 EVALUATION OF THE DATA

E.2.1. Condition of the Data

The data were evaluated to assess the availability of the elements required by the internal dosimetry models, including: the type of intake (inhalation, ingestion, skin contact), the date or dates the exposure occurred, the date of collection of nasal swab or urine samples, the duration of the urine sample collection, and the results of the sample analysis. Review indicated that the exposure date or dates, sample date, and results were not completely recorded for all cases. The

collection of information was reviewed by comparing the spreadsheet and data forms to determine whether all forms were present in the spreadsheet and whether the entries were correct. The initial evaluation identified a number of problems with the spreadsheet and supporting forms as shown in Table E-1.

This initial review indicated that substantial numbers of samples lacked one or more important pieces of data and identified 115 data forms that apparently represented a repeat analysis of a sample or a follow-up sample for an individual. Following the initial review, many of the missing entries were corrected through careful analysis of the information and reasonable assumptions about the missing information.

The duration of sample collection is critical to estimating the daily excretion rate of plutonium in urine. Air Force reports indicated that sample collection lasted 12 hours for many samples collected at Camp Wilson. The Air Force corrected the result for any urine sample of less than 1200 milliliters to 1200 milliliters. This conservative procedure would tend to overestimate urinary excretion. Our review indicated that 12-hour samples were clearly designated in 42 of the samples; however, attempts to duplicate the Air Force estimate of systemic body burden revealed that the sample volume correction might have been applied inconsistently. However, this did not adversely affect any conclusions about the individuals tested. Our review concluded that adjustments to samples that were not designated as 12-hour samples presented were unnecessary. Therefore, recorded sample volumes were assumed to represent 24-hour output unless specifically designated as 12-hour samples.

Table E- 1. Issues with dose records.

Issue	Number of Entries	Percentage
Exposure Date Not Available	402	22.7
Sample Date Not Available	445	25.1
No SSN Available	385	21.8
No Air Force ID Available	2	0.11
Sample Vol. < 600 mL	323	18.3
Sample Vol. > 1000 mL	434	24.5
Number with Additional Sampling Data (2nd page)	115	6.50
Number of Cards Marked Out	2	0.11
Number of Cards Not Found	5	0.28
Total Number of Samples = 1768		

Missing or incorrect entries for Exposure and Sample Date also hinder a reasonable estimate of intake and radiation dose. Additional analysis would be required to establish these parameters.

Other observed issues included missing Social Security Numbers (SSNs), Air Force Service Numbers (AFSNs), and other entries. Many of those records pertained to a broad spectrum of responders – from Air Force to other Services (Army, Navy, Marines); other US agencies (State

Department, Bureau of Mines), possible Spanish civilian employees of Torrejon Air Base or local citizens, and at least one media representative.

E.2.2. Sample Collection and Handling

Urine sampling was begun within three days of the accident. Urine sample collection on site was subject to several compromises. First, isolation of responders for 24 hours was desired and attempted but operational requirements limited the period to 12 hours or less. Opportunities for sample contamination from strong winds frequently spread dust over the base camp; decontamination procedures were not always followed; make-shift sample containers were used, and even when preferred containers were obtained, storage areas were frequently contaminated by blowing winds.

Nasal swabs were also collected and submitted to the laboratory, however, records indicated that of the 122 nasal swab records reviewed, 109 did not contain a result, 13 contained a result (8 were 0 pCi, 4 had values all below 1.5 pCi, and 1 was reported as NDA). Therefore, the nasal swab records were not used in this analysis.

Laboratory personnel observed alpha particle contamination on the outside of sample containers from the operational site very early in the program. This immediately raised issues about whether any alpha activity detected in urine represented material excreted by responders. Follow-up sampling was recognized as one means for resolving issues of possible contamination for persons with urine levels indicating significant exposure.

Upon receipt at the laboratory, a unique sample number was assigned, the samples were recorded into a sample logbook, and the AFLC Forms, discussed above, were completed. Attempts to locate the logbook(s) were unsuccessful. Samples were then submitted for the selected radioactivity analysis procedure.

During the follow-up sampling effort, sample containers obtained specifically for the purpose and tested for contamination were used to collect urine specimens from individuals. Whenever possible, sample collection was conducted at an Air Force medical facility under controlled conditions to reduce the likelihood of mishandling and to fulfill the need for a legitimate 24-hour collection period.

E.2.3. Sample Analysis Procedures

The USAF Radiological Health Laboratory processed the urine samples in a two-phased program – an initial phase and a resample phase. During the initial phase, samples collected on site were processed by a gross alpha counting procedure with preliminary chemical processing to extract any alpha emitting radionuclides from the bulk urine sample (Odland 1968a).

E.2.3.1. Initial Phase Procedures

During the initial phase, samples were processed for counting by: digesting a portion of the urine sample with nitric acid and hydrogen peroxide to a white residue; dissolving the residue and coprecipitation of plutonium with bismuth salts; dissolving the salts with hydrochloric acid, addition of lanthanum carrier, and coprecipitation of plutonium on lanthanum fluoride; and direct

mounting of the precipitate onto 2" stainless steel planchets for gross alpha counting (Odland 1966).

A small amount of ^{239}Pu tracer was added to pooled urine and processed in the same batch as Palomares samples. The added tracer served as an indicator of the effectiveness of plutonium recovery, which was reported to average $75.6 \pm 19.6\%$ (68% confidence) (Odland 1966).

The samples were counted in internal proportional counters optimized for detecting alpha particles. Daily checks monitored instrument response, and daily background counts were done. According to reports (Odland 1966), samples were counted for 120 minutes, and background was counted for 960 minutes. Review of the initial data indicated that samples were often counted for 55 minutes. Background was reported to range from 0.02 to 0.06 count per minute and counting chambers were decontaminated whenever the background count exceeded 0.1 count per minute.

Gross alpha results were reported in pCi/sample, where:

$$\text{pCi/sample} = \frac{(\text{gross counts/gross ctg time}) - (\text{background counts/bkgrd ctg time})}{(\text{counting efficiency})(2.22)(\text{procedural yield})}$$

Analysis of selected samples from the initial phase indicated that the results and estimated errors were calculated, recorded, and reported. The estimated errors were determined from counting data only and were reported at the 95% confidence level.

Procedural yield was determined from the results of the traced urine sample for each batch of urine processed.

E.2.3.2. Resample Phase Procedures

During the resample phase, the laboratory derived its procedures from those used for monitoring workers at other facilities handling significant quantities of plutonium. The process involved nitric acid digestion, coprecipitation of alkaline earth and plutonium phosphates, precipitation with cerium, ion exchange to remove interfering ions, and electrodeposition onto stainless steel planchets for radioactivity counting. A small quantity of ^{236}Pu was added to each sample before chemical processing to evaluate radiochemical recovery.

Radioactivity counting was conducted using alpha particle spectrometry with solid-state surface-barrier detectors in a vacuum. Count data were collected with a multichannel pulse-height analyzer. Detector efficiency and background were monitored daily. Background was counted for 800 minutes duration and samples for 100 minutes. Review of results indicated that samples were counted for 100, 200, or 400 minutes, perhaps in attempts to achieve lower detectability.

Data were accumulated in 255 storage positions. Total events in a 236-Pu band and in a 239-Pu band were determined. The activity in the counting sample was determined from the following equation:

$$\text{pCi/sample} = \frac{(\text{net cpm in } 239\text{-Pu band}) \times (\text{dpm } 236\text{-Pu added})}{(\text{net cpm in } 236\text{-Pu band}) \times 2.22}$$

$$\text{where net cpm in 239 - Pu band} = \left[\begin{array}{c} \frac{\text{gross cts in 239 - Pu band}}{\text{gross ctg time}} - \\ \frac{\text{bkg cts in 239 - Pu band}}{\text{bkg ctg time}} \end{array} \right]$$

$$\text{and net cpm in 236 - Pu band} = \left[\begin{array}{c} \frac{\text{gross cts in 236 - Pu band}}{\text{gross ctg time}} - \\ \frac{\text{bkg cts in 236 - Pu band}}{\text{bkg ctg time}} \end{array} \right]$$

dpm 236-Pu = activity of 236-Pu spike added to sample corrected for decay to date of count.

Corrections for sample volume to convert the result into the amount excreted in a day (24 hours) were also applied before calculating the body burden. Errors were estimated based on counting statistics and minimum detectable activity levels established and applied. Odland reported that the minimum detectable activity (MDA) as used in the program was defined as the sample activity associated with a counting error at the 95% confidence level equal to 0.95 times the sample activity (Odland 1968a). That means that any sample whose estimated error exceeded 95% of the sample activity was reported as no detectable activity (NDA).

During review of the records, assessments of the procedures indicated that the estimated errors on alpha spectrometry samples were calculated and reported at the 68% confidence level.

E.2.4. Data Preparation

E.2.4.1. Description of Changes

Adjustments to the data provided were made to fill data gaps and to overcome inconsistencies for exposure date, sample date, sample duration, and urinary excretion rate and its estimated error. Other inconsistencies observed in the data were also corrected to the extent possible.

E.2.4.1.1 Exposure Date

The exposure date was determined from the midpoint of the time an individual spent on station. Exposure date entries on the forms included all of the following: a single date, a date range, an arrival date, a month and year, a year only and a few others. Missing start dates were developed from reasonable estimates based on other recorded information, such as arrival date. Exposure end dates were derived similarly, or from recorded sample collection dates. Both of these modifications are discussed further in Appendix B.

E.2.4.1.2 Sample Date

Missing Sample Date entries for the 445 samples identified (Table E-1) were estimated with an approach that used data on sample receipt at USAF RHL and assigned laboratory sample numbers (See Appendix B). The approach recognized that receipt of samples at USAF RHL, the sample number sequence assigned, and collection date were related. Derived Sample Date information was then entered into a master data set along with the other data for each urine sample.

E.2.4.1.3 Sample Duration

Actual sample duration was documented in a very small fraction (42 samples) of the samples received. Fortunately, basic sample volume data provide the basis for making any corrections needed. As discussed above, this project elected to treat recorded sample volumes as representing 24-hour outputs unless the data forms specifically designated the samples as 12-hour samples. For those, the results were adjusted to the currently accepted nominal daily urine output (1400 mL) for Reference Man. Those adjustments were performed in the intake assessment process.

E.2.4.1.4 Other Parameters

Analytical results for daily urinary excretion and the estimated error were transcribed as entered on the hardcopy forms. However, in the case of samples reported as No Detectable Activity, the data forms were reviewed for the presence of other calculations of a numerical result and error. When found, these calculated results were used in the analysis, even when the error value exceeded the result. This procedure applied primarily when the results of multiple samples were available, as was the case for many of the High 26 Cases Group. In these cases, although the errors were large, they nevertheless provided order of magnitude information about the levels present and were useful comparisons to other values.

E.2.4.1.5 Other Inconsistencies

Other inconsistencies in the data set were also identified and corrected where possible. Although these did not affect the actual intake and dose assessments, they do affect identifying information. These reviews discovered inconsistencies in names, SSNs caused by typographical errors or keyboarding errors, errors in analysis type, inconsistent base names, and others.

E.2.5. Grouping of Cases

The majority of available records contained results from the gross alpha method on samples collected on site. Typically, one record was available for each individual and initial results indicated that intakes and doses estimated using the records would be unusually high. On the other hand, the individual records for the High 26 Cases Group generally contained several results with most from the preferred alpha spectrometry method. In between, the 115 individuals with results from alpha spectrometry follow-up analyses had more limited data. An overall approach to evaluating the cases was clearly needed.

E.2.5.1. Review of Data Available

Estimating intake from urine bioassay depends on reasonably accurate urinary excretion values that follow the expected pattern for the assumed type of exposure and Class (Type) of the contaminant. The data should be as free of artifacts as possible. The varied quality of the records cast doubt about whether reasonable estimates could be developed for all individuals. Records for the High 26 Cases Group offered the best opportunity. On the other hand, most of the records for samples collected on site raised serious questions about estimates derived from them. Some of those issues arose from initial attempts to use the High 26 records as the model for the other cases. As mentioned earlier, those studies indicated that including the results from gross alpha analyses obtained from samples collected on site produced intake estimates and doses that seemed unreasonably high. Furthermore, the pattern of results for samples collected during the resampling phase often did not follow the pattern expected for Class Y (Type S) plutonium.

Figure E-1 contains results and expected urinary excretion for one case that illustrates the difficulty. The figure shows the actual samples as data points and calculated curves for the actual CINDY fit (intake = 58,000 pCi) and reasonable “eye-ball” fits of 23,200 and 870,000 pCi. The first two samples were taken at 3 days and 59 days after the incident. This subject was one of the first responders to arrive. In addition, the last two samples, taken at 472 and 547 days after the incident were reported as NDA. They are plotted as 0.003 pCi/day for graphing purposes. The “final” fitted result was obtained by excluding the first two samples from consideration. Even for this case, the upper and lower rough estimates differ from the fitted curve by a factor of two, with associated CEDEs of approximately 10 to 270 rem (0.1 to 2.7 Sv).

The apparent difficulties with fitting urinary excretion models to the actual data required further investigation. Peer reviewers of a draft version of this report suggested that all of the data should be considered to assess whether some other form of plutonium behavior was being observed rather than the assumption of inhalation exposure to very insoluble Class Y (Type S) material. These suggestions were evaluated for this revision by considering the validity of the Class Y (Type S) assumption, by considering other routes of entry (e.g. ingestion), and by assessing the effect of the alternate approaches on all data for the High 26 group.

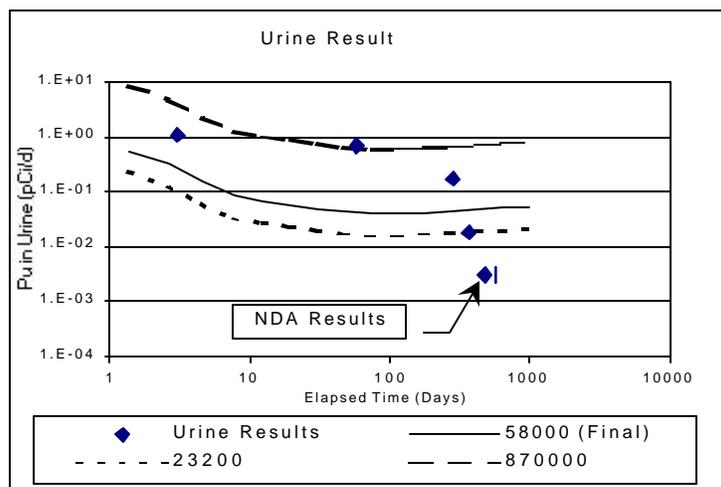


Figure E- 1. Example urinary excretion.

Regarding the conclusions about material form, numerous investigators report that plutonium produced under the conditions of the Palomares accident (i.e. explosion, and fire produce oxides of plutonium under high temperature) tend to be very insoluble (Church 2000). Furthermore, investigations at Palomares itself indicate that the material present on site consists primarily of 87% Type S (Class Y) and 13% Type M (Class W) material (Stradling 1993). Although those findings represent studies conducted at some time after the accident, it seems reasonable to expect that the solubility of plutonium would not decrease over time. Consequently, the assumption that Type S (Class Y) plutonium was the principal form present during response activities seems very reasonable.

Investigations of the behavior of the set of urine results with expected behavior involved qualitative, graphical comparisons of the dataset with the expected curve shapes for urinary excretion from inhalation of Type M (Class W) and Type S (Class Y) plutonium alone and in combination, and from ingestion of soluble and insoluble plutonium. Figure E-2 compares the urine results from the initial sampling and the re-sampling phases of the High 26 Group with the urinary excretion patterns for inhalations of Type M (Class W) plutonium, Type S (Class Y) plutonium and two combinations (one of equal amounts of Type M and Type S, and the other of 3 parts Type S and 1 part Type M). The excretion curves do not represent fits to the data. Rather they have been scaled by the amount of plutonium intake required to place them on the chart. As a matter of fact the assumed intakes are 15,000 pCi Type M, 15,000 pCi Type S, 15,000 pCi Type M plus 15,000 pCi Type S, and 5,000 pCi Type M plus 15,000 pCi Type S, respectively. The plutonium amounts are not critical for this comparison because the shapes of the curves provide the substantial observations about the behaviors.

The urine results shown in Figure E-2 seem to decrease steadily, almost monotonically, on this logarithmic presentation. However, each of the urinary excretion curves declines very rapidly at first, but then declines much more slowly. Actually, for the plutonium forms involved, there is a slight increase beginning at around 200 days that represents the continuing release of plutonium retained in the lungs combined with additional plutonium being remobilized from other organs. Most importantly, the expected excretion continues at an ever more slowly decreasing rate at times beyond 500 days after the initial rapid decrease. There are obvious differences between the data and the expected excretion.

Figure E-3, illustrates the behavior of ingested plutonium for comparison with the urine results. Again as for the inhalation case, the excretion curves differ substantially from the results. A level that seemingly predicts the excretion soon after exposure tends to over estimate excretion later. Conversely, reasonable estimates at longer times generate significant differences at the earlier times.

These discussions raise serious concerns about estimates of intake that would be derived from the data. One interpretation suggests that other, or better, models should be tried. On the other hand, the data themselves may be contribute to the difficulties; especially those from samples collected on site or soon after departing Palomares. Alternately, improvements in laboratory procedures may have contributed to the discrepancies. Conversations with USAF RHL personnel who devised and directed the urine analysis program indicated that the alpha spectrometry methods for ^{239}Pu were very much at the developmental stage for most of 1966 (Taschner 1999). Additional first-hand experience by one of this report's authors (a former director of radioanalysis at the USAF RHL from 1969 to 1976) confirms those observations as well as the difficulties in measuring such low concentrations of plutonium radioactivity (Case 2001).

Consequently methods, used in this project, excluded data from the on-site samples and attributed more significance to samples collected at later dates for the High 26 Group.

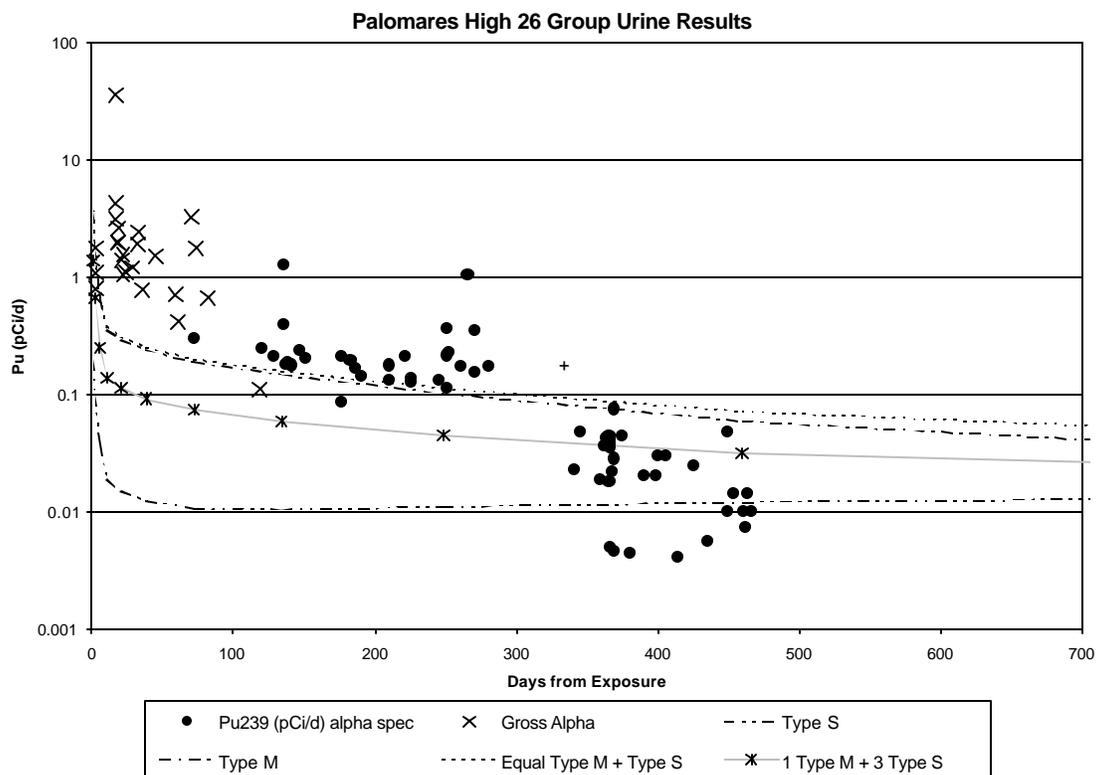


Figure E- 2. Comparison of High 26 Group urine results with excretion expected from inhalation of plutonium.

The remaining results generally fell into two categories: those with the results of some resampling; and those with one sample and often very high results. Urinary excretion results for the latter case ranged from 0.0 pCi/day to 237 pCi/day with corresponding committed effective dose equivalent of up to 6,000 rem (60 Sv) from an estimated intake of 20,000,000 pCi. If real, that intake would have produced a dose equivalent to the lung of almost 5,000 rem (50 Sv) and an effective dose equivalent of about 560 rem (5.6 Sv) in the first year alone. Both of those are 100 times higher than the applicable regulatory limits for non-stochastic (prompt) and stochastic (delayed) effects and would have produced deterministic (non-stochastic) effects. Clearly that case is extreme and alternative approaches to processing were needed.

E.2.5.2. Selection of Contamination Cutoff

Careful review of the group of data indicated that processing all of the cases would produce unrealistic estimates that would be based on potentially contaminated samples. Contamination of samples collected at the accident site continued to impact the evaluation as it did at the time of the accident. However, review of those data also indicated a substantial number of cases that had urinary results that were essentially below the detection limit or were quite low.

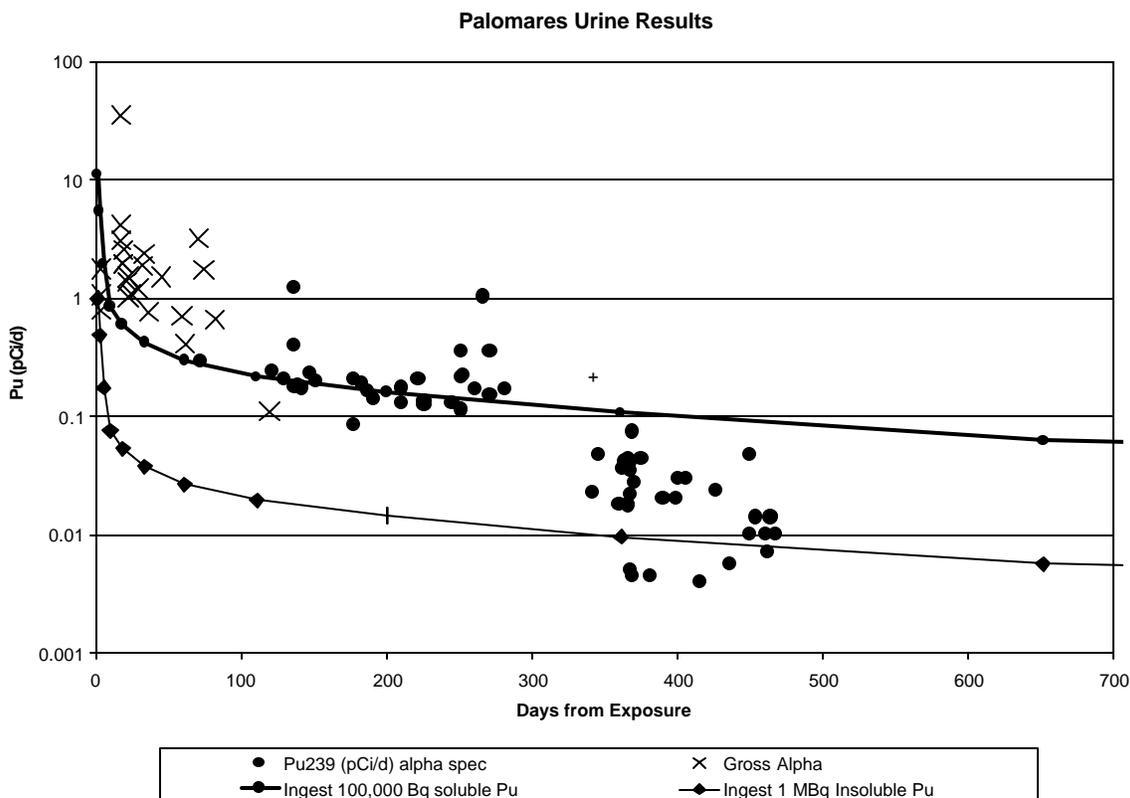


Figure E- 3. Comparison of High 26 Group Urine Results with expected excretion following ingestion.

After consultation with AFMOA, the data were reviewed again to determine whether a reasonable lower cutoff could be determined. Selection of a reasonable cutoff allows the use of professional judgement to eliminate questionable data, while at the same time, allowing reasonable estimates from apparently "uncontaminated" samples. This task was approached by evaluating selected records to calculate a Lower Limit of Detection according to current practice, and to research LLDs in use by other laboratories for similar assessments. The effort extracted sample and background counting information for 39 gross alpha samples and 3 alpha spectrometry samples. The mean and standard deviation of those were of 0.1 ± 0.1 pCi/day for gross alpha and 0.015 ± 0.003 pCi/day for alpha spectrometry. These were compared with the reported limits achieved by the combined U.S and Spanish effort to assess intakes and doses in the local population. A detection limit of 0.74 mBq/d (0.02 pCi/d) was in use from 1966 to 1985 (Iranzo 1988). That limit is essentially the same as the result obtained from Air Force data. Furthermore, the value of 0.1 pCi/day for gross alpha also seemed like a reasonable cutoff. Consequently, that value was selected as a cutoff limit. Cases with urinary excretion measurements below the level were categorized as the Contamination Cutoff Cases Group. Those with measurements above the level were categorized as the Remaining Cases Group and were not processed further in this project.

E.3 DOSE CALCULATION

E.3.1. Exposure Scenario

The type of exposure (acute or chronic; inhalation, ingestion, direct) must be known or assumed to perform a meaningful estimate of an intake of radioactive material and its associated dose equivalent. One or more of the common routes of entry (inhalation, ingestion, or direct) generally apply. Examinations of the activities that may have caused the exposure provide the clues to determining the type and route of the exposure.

As discussed above, the response to the Palomares nuclear accident involved hundreds of personnel working toward the common purpose of recovering vital materials, protecting themselves and the local populace, and restoration of the accident scene to useable and safe conditions. The accident itself released plutonium during explosions and fires that followed the impact of two of the nuclear weapons with the ground. The plutonium was released primarily as airborne dust and as residues from fire, that contaminated the ground. Since the fires essentially were out long before serious response efforts started, the main source of exposure arose from activities such as vehicle movement, handling debris during recovery, plowing fields to mix the contaminant into the soil, and vehicle movement. Persistent winds also contributed to the resuspension of contaminated soils from the ground or contaminated dusts from the surfaces of accident debris, local buildings, or agricultural crops.

Ingestion by hand to mouth transfer is a second possible route of entry. However, that route is very inefficient. Furthermore, the fraction of plutonium that enters the bloodstream from the intestines is very small (0.00001 for Type S). For reasons discussed in Sections 3.1.1.2 and 4.4.1 above, the ingestion route is not considered further.

The type of exposure was assumed to be a single acute exposure. This assumption accommodates the long time for removal of plutonium oxides from the human body. The response activity occurred from January 18, 1966 until April 3, 1966 when activities were moved from Camp Wilson to another location. Personnel on site reached a maximum in late January; tapered off during February, and then increased slightly in mid-March during the packaging of contaminated debris, soil and other wastes for disposal. Most departed the site by late March 1966. The nominal length of assignment was about two weeks. However, records indicate that some personnel stayed much longer.

E.3.2. Parameters Used in Models

Two computer methods, CINDY and LUDEP, were selected to calculate estimates of the ^{239}Pu ¹ intakes and doses. CINDY applies the system described in ICRP-30 while LUDEP uses the respiratory tract model of ICRP-66 and the organ/tissue weighting factors of ICRP-60. CINDY served as the primary method and LUDEP provided alternative estimates for comparison. Both programs require selection of input parameters that control the various factors of the intake (respiratory tract), biokinetic and excretion models used in the analysis. Table E-2 contains the parameters selected for the CINDY runs. The parameters chosen represent the default values for

¹ The isotope, ^{239}Pu , is discussed as the primary isotope of interest. Commonly, ^{240}Pu that is also present in weapons material cannot be distinguished from ^{239}Pu by the counting techniques used. However, no distinction is made for this possible presence of ^{240}Pu .

an acute inhalation exposure of Class Y ^{239}Pu obtained from ICRP-30 or other recognized appropriate sources as described in the CINDY Users Guide (PNL 1992). In addition, urine sample collection times were assumed to represent a 24-hour collection unless specifically stated otherwise.

CINDY calculated the cases in a two-step process: the intake assessment mode to estimate the intake from the urine bioassay measurements, followed by the dose assessment mode to calculate the 50-year committed dose equivalent for each organ, and the 50-year committed effective dose equivalent. For some cases, CINDY was also run in the bioassay projection mode to generate a plutonium excretion curve for plotting and further analysis. Figure E-2 above represents such a plot. In addition, CINDY was run in the calendar year dose assessment mode to calculate the annual dose equivalent to specific organs for comparison with the non-stochastic limit.

For LUDEP, a similar process was used to setup the required parameters. LUDEP bases its calculations on an estimate of the intake type and intake value. Intake is estimated for a unit intake first, using a selected excretion model such as the Jones model. Then, the derived excretion model curve is fit to the measurement data to generate an estimate of the intake. Finally, the intake is used to estimate the organ dose equivalents and the committed effective dose equivalent for the exposure type (acute, inhalation), activity parameters (worker, standard worker), and model parameters. Table E-3 contains the parameters used for estimating intakes and doses for LUDEP cases.

All cases were run with standard ICRP default values for the deposition and particle transport factors except particle density, which was set at 10 g/cm^3 , which is the density of PuO_2 rather than a density representative of dust. The compartment numbers for the clearance rate constant values and the deposition fractions in Table E-3 refer to Figure 5 of the main report. The compartment rate constants are the half-times (in days^{-1}) that material moves from the "From" compartment to the "To" compartment.

E.4 RESULTS

E.4.1. High 26 Cases Group

The High 26 Cases Group represents the collected measurement data from 26 responders who were identified for follow-up after the initial phase of sampling in 1966. The evaluation of the cases is presented with discussions of their urine bioassay measurement characteristics, the approach to performing the estimates, and a discussion of the results.

E.4.1.1. Urine Bioassay Measurement Characteristics

The High 26 Cases Group provided 127 urine samples during their on-site and resampling activities. Those 127 samples produced 25 measurements of gross alpha activity and 102 measurements of ^{239}Pu from alpha spectrometry. The 102 samples from alpha spectrometry were distributed among the 26 people as shown in Table -4. The gross alpha method reported 24 results above the minimum detectable and one result as no detectable activity.

Table E- 2. Parameters used in CINDY runs.

Parameter	Value
Subject identification	
Name	Specific to individual
ID	Set to dummy value of 1234567890
SSN	Specific to individual or 000-00-0000 if not available
Date of birth	Not available: set to dummy value of 01/01/1945
Sex:	Male (with few exceptions for obvious female names)
Intake information	
Intake exposure rate	Acute
Intake mode	Inhalation
Begin date	Specific to estimated acute exposure date for individual
Begin time	Left at default value of 00:00
Particle size (microns)	1
Facility	Palomares
Employer	U.S. Air Force
Edit/input bioassay data	
To exclude set non-blank	G or x entered if individual had a gross alpha result that was being excluded from the current model run
Bioassay type	u entered for urine
Bioassay radionuclide	Pu239
Sample end date	Sample date, specific to individual's sample
Sample end time	Left at default value of 00:00
Excretion period (hr)	24 unless dose card specifies otherwise (regardless of sample volume)
Measured value	Sample result (for units of pCi/sample) specific to individual's sample
Inverse of weighting factor	Variance of sample error (not used in methodology reported in final output)
Unit numerator	pCi
Units are per ...	[S] for sample
Sample size	Sample volume (for units of mL) specific to individual's sample
Sample size units	mL
Reference volumes	
Urine-male (mL)	1400 (not used in modeling--overridden by entries made to "excretion period" parameter)
Feces-male (g)	135 (not used in modeling--no bioassays of this type)
Intake Assessment Mode	
Radionuclides of concern	Pu239; Working units = pCi
Intake composition	Fraction inhaled = 1 ICRP-30 Class D = 0% ICRP-30 Class W = 0% ICRP-30 Class Y = 100%
Change default parameters	Radionuclide daughters: Consider? yes Select radiological units: pCi Error tolerance for integration: .0000001
Select models	Pu239: Jones excretion model

Table E- 2. Parameters used in CINDY runs.

Parameter	Value
Dose Assessment Mode (specified period)	
Radionuclides of concern	Pu239
Intake estimate	Working units = pCi Quantity inhaled: in pCi, specific to individual based on results of intake assessment mode run ICRP-30 Class D = 0% ICRP-30 Class W = 0% ICRP-30 Class Y = 100%
Change default parameters	Dose reporting times = 1 report time Report time in years = 50 Select radiological units: pCi Error tolerance for integration: .0000001
Select models	Pu239: Jones excretion model
Jones Excretion Model Parameters	
Compartment	Fractional Rates (1/d) Transfer rate constant (1/d)
1	4.75 × 10 ⁻³ 0.558
2	2.39 × 10 ⁻⁴ 4.42 × 10 ⁻²
3	8.55 × 10 ⁻⁵ 3.60 × 10 ⁻³
4	1.42 × 10 ⁻⁵ 2.84 × 10 ⁻⁵
Systemic Model – Pu	
Bone	Fraction from transfer compartment: 0.45 Transfer compartment clearance half-time (d) : 0.25 Organ clearance half-time (d): 18,200 Fraction reaching urine: 0.5 Fraction Reaching feces: 0.5
Liver	Fraction from transfer compartment: 0.45 Transfer compartment clearance half-time (d): 0.25 Organ clearance half-time (d): 7,300 Fraction reaching urine: 0.5 Fraction Reaching feces: 0.5
Testes	Fraction from transfer compartment: 0.00035 Transfer compartment clearance half-time (d): 0.25 Organ clearance half-time (d): 3,650,000 Fraction reaching urine: 0.5 Fraction Reaching feces: 0.5
Pu f₁ values	
Inhalation	Class D: 0.001 Class W: 0.001 Class Y: 0.00001
Ingestion	Soluble: 0.001 Insoluble: 0.00001

Table E- 3. LUDEP Input Parameters.

Input parameters		
Intake regime	Exposure Subject Intake	Occupational Standard worker Acute, inhalation, 1 Bq (used to generate excretion curve)
Time	50 years	
Deposition	Exposure Subject AMAD (:m) Advanced mode	Occupational Standard worker 1 All defaults except density = 10 g/cc <u>ICRP Defaults</u> 1. SUBJECT: Adult Male 2. ACTIVITY: Light Exercise 3. TYPE: Nose Breather 4. DISPERSION: polydisperse <u>Physiological Parameters</u> a) Functional Residual Capacity: 3301 cc b) Extra-thoracic Dead Space: 50 cc c) Bronchial Dead Space: 49 cc d) Bronchiolar Dead Space: 47 cc e) Height: 176 cm f) Tracheal Diameter: 1.650 cm g) First Bronchiolar Diameter: 0.165 cm <u>Activity Related Parameters</u> h) Ventilation Rate: 1.50 cu.m/h i) Respiratory Frequency: 20.0 /min j) Tidal Volume: 1250 cc k) Volumetric Flow Rate: 833 cc/s l) Fraction breathed through nose: 1.000 <u>Aerosol Size Parameters</u> m) AMAD: 1.0000 μm (changed from default of 4) n) AMTD: 0.3407 μm o) Φ_g : 2.43 p) Den: 10.00 g/cc (changed from default of 3) w) SF: 1.50 <u>Deposition</u> q. ET1 17.54 % r. ET2 22.59 % s. BB 1.38 %* t. bb 2.22 %* u. AI 13.04 % Total = 56.78% v. F_s^* (BB%) = 49.76, (bb%) = 49.98%

Table E- 3. LUDEP Input Parameters.

Particle transport (See Figure 5)		
	Compartment From – To	Rate Constant (1/d)
	1 to 4	0.02
	2 to 4	0.001
	3 to 4	0.0001
	3 to 10	0.000020
	4 to 7	2.0
	5 to 7	0.03
	6 to 10	0.01
	7 to 11	10.0
	8 to 11	0.03
	9 to 10	0.01
	11 to GI	100.0
	12 to 13	0.001
	14 Out	1.0
	Compartment	Deposition Fraction
	ET_{seq}/ET_2	0.00050
	BB_{seq}/BB	0.00700
	BB_2/BB	=Fs1
	Bb_{seq}/bb	0.00700
	Bb_2/bb	=Fs2
	AI_2/AI	0.6000
	AI_3/AI	0.1000
Absorption	Selected S for default values	
Radio-nuclides	ICRP-38 database	Pu239
Biokinetic model	ICRP-30	Part 4: Pu(Y)M.mod (for Pu, class Y, male) Organs = liver, whole skeleton, testes (default for Pu239) Bone type = surface seeker (default for Pu239) Blood half life = 0.25 d (default for Pu23)
Calculations		
Excretion/Retention (the results of this run are then entered as the bioassay function in the intake estimate mode)	Quantity to calculate Select ICRP-54 function Enter own function Period of integration Time Number of points Intervals	urinary excretion rate Pu/Am (J) (this is the Jones Plutonium Excretion Model) Used defaults as follows: A(1) = 4.75E-03 $t_{1/2}$ 1.24E+00 d A(2) = 2.39E-04 $t_{1/2}$ 1.57E+01 d A(3) = 8.55E-05 $t_{1/2}$ 1.82E+02 d A(4) = 1.42E-05 $t_{1/2}$ 2.44E+04 d A(5) = 0.00E+00 $t_{1/2}$ 0.00E+00 d A(6) to A(10) are zero Retention $t_{1/2}$ in blood: 1.000E-07 1 day 1 day to 730 days 730 Linear

Table E- 3. LUDEP Input Parameters.

Intake estimation	Data filename	*.dat file for individual, showing days elapsed from exposure to sample, sample result in Bq/d, and sample error in Bq/d, as in the following example for an individual with three samples 10 0.005 0.0005 43 0.004 0.0014 78 0.001 0.001
	Assumed errors	errors included in data set
	Modify for DTPA?	no modification
	Bioassay function filename	File from excretion/retention mode run
	Estimate intake	command line, estimated intake appears on screen

Review of the procedures for calculating the radioactivity results and their errors revealed that the reported errors for gross alpha measurements represented the 95% confidence level while the reported errors for alpha spectrometry measurements represented the 68% confidence level. Since the criterion for reporting a result as no detectable activity was based on the 95% confidence limit, alpha spectrometry results may not have followed that convention. Therefore, some alpha spectrometry results may have been reported as positive when the estimated errors did not support that conclusion. Nevertheless, the approach was more likely to report a numerical result, which is preferable to the NDA report. Unfortunately, the numerical values for the laboratory's NDA were not discussed in any of the reports of the sampling and analysis effort reviewed for this project.

Table E- 4. Breakdown of alpha spectrometry samples.

Number of Samples	Number of Submitters
3	5
4	2
5	14
6	3
7	2

The measurement results from alpha spectrometry revealed that actual numerical values and the associated counting errors were calculated even when the sample was reported as NDA. Those results were used in developing these estimates when recorded on the individual data cards. The alpha spectrometry results contained 63 reported values while the remainder were reported as NDA or were not reported, apparently because of a laboratory error. Of the 63 results, 15 were less than their error at the 68% confidence level and 33 results were greater than the 68% level but less than the 95% confidence level. Only 15 results were above the 95% confidence level. This means that for 48 of the 63 reported results, zero was included in the range of possible results.

Reproducibility of the laboratory measurements was also evaluated using samples that were reprocessed. Although limited, five samples were reprocessed primarily to correct low chemical recovery. One of those was processed three times, reporting two numerical results that were less than the 68% confidence level error, and one result as NDA. Of the other four samples, three

showed differences in reported radioactivity of two to three times. The remaining sample was a valid NDA report.

In considering the impact of these apparent analytical difficulties, the levels of radioactivity of these samples (less than 0.1 pCi/d) may produce only a few detectable events during counting periods of 100 to 400 minutes recorded. For those techniques, background counting levels are also very low, usually on the order of one count in thousands of minutes. Although these levels are quite low, they can represent plutonium intakes that require evaluation.

Figure E-4 illustrates the urine results obtained from the High 26 Cases Group. Those results show the variability in measured plutonium values. The expected behavior of urinary excretion from inhalation of Class Y (Type S) ²³⁹Pu and an equal mixture of Class W (Type M) and Class Y (Type S) ²³⁹Pu are also shown. The results do not correspond to the expected pattern very well at all as was previously discussed in Section 4 of the main report. Consequently, attempts to fit the urinary excretion model to the measurements were expected to be difficult.

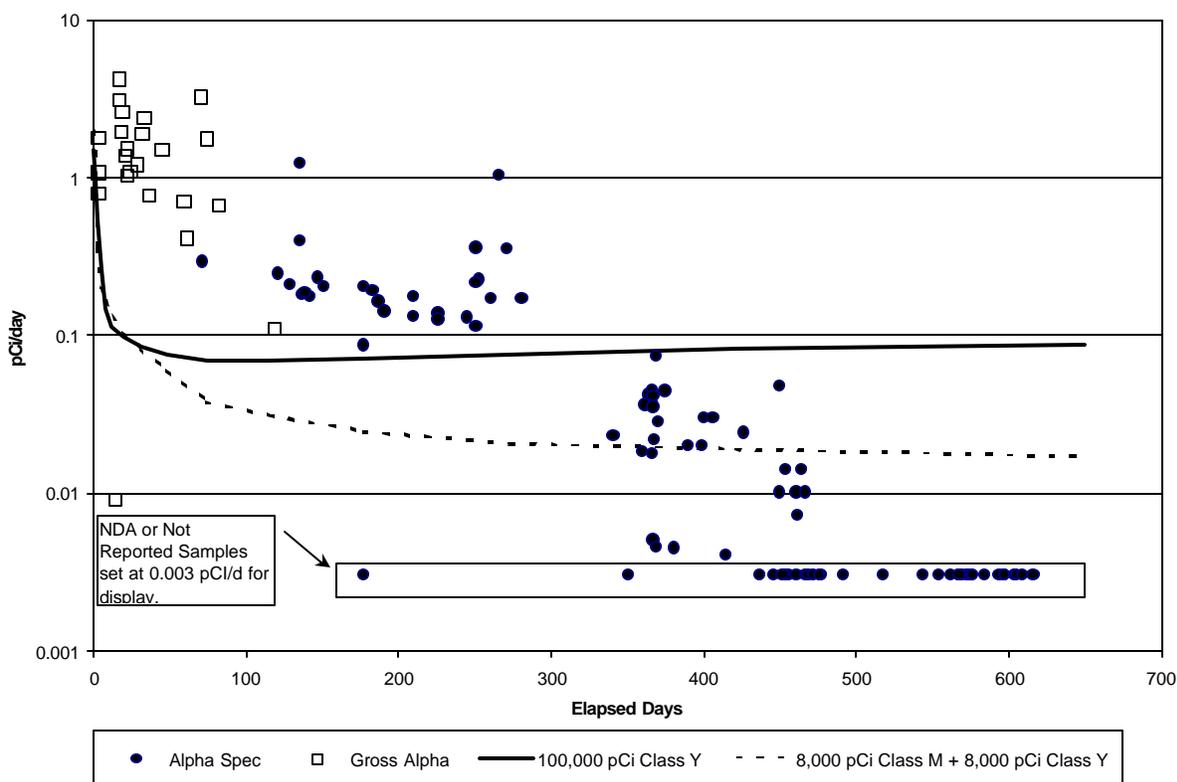


Figure E- 4. High 26 Cases Group urine results.

E.4.1.2. Approach to Estimates

The urine analysis results for the High 26 Cases Group indicated that those cases with several measurements for samples collected over the entire initial and resampling efforts could provide the best data for testing. To do this, several variations on use of the data and setup for the CINDY and LUDEP programs were used. For samples, assumptions were developed for the date

of exposure, the use of gross alpha results and the use of NDA results. For the programs, the main adjustment involved the method for weighting results during intake assessment using CINDY and LUDEP.

E.4.1.2.1 Date of Exposure

The entire High 26 Cases Group arrived during the early phases of the response effort. Some arrived the day following the accident while others arrived somewhat later. All arrived in January 1966. Some remained on site for only a few days or weeks while others remained for the entire deployment. Rather than use the midpoint of the assumed on-site period as the date of exposure for this group, their arrival date at Palomares was selected. This assumption was judged conservative since it would estimate slightly higher intakes because more days would elapse between the assumed exposure and sampling. The effect would be minimal as shown by tests of both CINDY and LUDEP (Section 3.3.1).

E.4.1.2.2 Use of Gross Alpha Measurements

Twenty-two of the 25 gross alpha results (one of the group had no gross alpha results) were from samples collected on dates that represent on-site activities. The gross alpha activity of these samples ranged from NDA to 35 pCi/d. That former result represents a very high urinary level. Tests were run that included and excluded the gross alpha results, including those collected on and off site as separate cases. The results indicated that both CINDY and LUDEP tended to produce better fits for samples with lower values and taken at longer time following the exposure.

E.4.1.2.3 Use of NDA Results

Samples reported as no detectable activity do not produce a numerical result. However, these samples indicate that their radioactivity content is near or below the level that can be measured with confidence. That is, at those levels, the analysis indicates that the radioactivity may, or may not, be present. Since many of the results obtained during the resample period were reported as NDA (see Figure E-4 above), a method was needed to make them available to CINDY and LUDEP. The available choices included careful review of the data records for entries representing a calculation of a numerical quantity for the sample that was reported as NDA. Figure B-3, Appendix B illustrates such a case. Those were used whenever possible. For the remaining samples, options included recalculation from the recorded counting data, arbitrarily setting the value to zero, or arbitrarily setting the value to the lower limit of detection (0.003 pCi/day) for alpha spectrometry samples. All of those approaches were used.

E.4.1.2.4 Weighting Factors for Urine Measurements

Section 3.2.1.1 discusses the selection of weighting factors for estimating intakes from bioassay measurements and Section 3.2.2 summarizes some performance tests. Those were confirmed for the High 26 Cases Group data. Selection of the “ratio-of-the-means” method in CINDY and the “errors included in data set” method for LUDEP provided conservative estimates of intake. That

is, the selected methods provided estimates that were balanced between being unreasonably high and artificially low.

E.4.1.3. Results

The methods applied to estimating intakes and doses described above were applied to the 26 individual cases. Some adjustments were necessary to accommodate the specific data qualities for each case. Although intake and committed dose equivalent dose to organs, and committed effective dose equivalent were estimated, they are not adopted as official estimates for any individual because of the difficulties discussed earlier in the report. This section summarizes the overall results and discusses approaches for developing estimates that are more reasonable.

The urine results for the 26 individuals in this group exhibited two common traits that could have substantially affected the intake estimates and doses. These traits were 1) an unexpectedly rapid decrease in urine concentration for follow-up program samples, and significant variation in replicate analyses of individual samples. Figure D-5 illustrates these two traits.

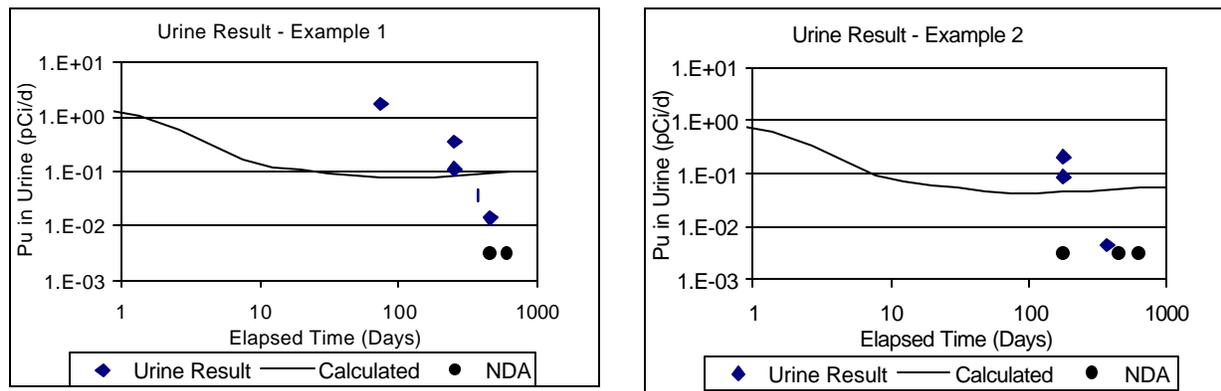


Figure E- 5. Examples of urine result characteristics.

Interestingly, most samples in this group show decreasing urinary excretion, usually reaching the non-detectable level for later samples. Of course, if those latter values are correct, then the estimated intakes and corresponding doses would be much lower than reported in this study. Alternately, the rapid decrease in value could be related to improved laboratory capability.

The variability of replicate measurements was only reported for a few samples. However, if those reported are typical of the analytical performance, then similar variability would be expected for the other samples. Unfortunately, there are no data to support this possibility.

E.4.1.3.1 Intakes and Doses from Urinalysis

For the 26 cases, the preliminary intake estimates varied from 34,000 pCi to 570,00 pCi from CINDY and 19,000 pCi to 2,600,000 pCi from LUDEP with the gross alpha results excluded in all the cases. Estimates of committed effective dose equivalent ranged from 10 rem to 170 rem (0.1 to 1.7 Sv) from CINDY and 1.3 to 180 rem (0.013 to 1.8 Sv) from LUDEP. LUDEP ranged from -83% to +150% of CINDY results. The range of differences between LUDEP results and CINDY results seems reasonable considering the variation in the data and the complexities of the

assessment. In addition to the intakes and CEDE estimates, 50-year committed dose equivalents were calculated for organs using CINDY. Those results are listed in Table E-5 to illustrate the range of estimated values. However, when compared with independent estimates from environmental data and with the results of other exposure cases, these estimates seem unreasonably high.

Table E- 5. High 26 Preliminary Intake, Committed Dose Equivalent and Committed Effective Dose Equivalent Estimates.

Subject	Intake (pCi)	CEDE	Testes	Breast	R Marrow	Lung	Thyroid	Bone Sur	Liver	Other	LL Int.	UL Int.	S Int.
Data Masked	6.8E+04	21	3.0	0.0	16.3	76.9	0.0	212.9	38.4	3.5	0.0	0.0	0.0
Data Masked	8.6E+04	26	3.7	0.0	20.6	97.2	0.0	269.2	48.6	4.5	0.0	0.0	0.0
Data Masked	6.2E+04	19	2.7	0.0	14.8	70.1	0.0	194.1	35.0	3.2	0.0	0.0	0.0
Data Masked	6.3E+04	19	2.7	0.0	15.1	71.2	0.0	197.2	35.6	3.3	0.0	0.0	0.0
Data Masked	5.60E+05	170	24.3	0.0	133.9	633.0	0.0	1753.0	316.5	29.2	0.1	0.0	0.0
Data Masked	6.5E+04	20	2.8	0.0	15.5	73.5	0.0	203.5	36.7	3.4	0.0	0.0	0.0
Data Masked	1.6E+05	49	7.0	0.0	38.3	180.9	0.0	500.9	90.4	8.3	0.0	0.0	0.0
Data Masked	1.1E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	4.2E+04	13	1.8	0.0	10.0	47.5	0.0	131.5	23.7	2.2	0.0	0.0	0.0
Data Masked	6.4E+04	20	2.8	0.0	15.3	72.3	0.0	200.3	36.2	3.3	0.0	0.0	0.0
Data Masked	5.5E+04	17	2.4	0.0	13.2	62.2	0.0	172.2	31.1	2.9	0.0	0.0	0.0
Data Masked	4.4E+04	14	1.9	0.0	10.5	49.7	0.0	137.7	24.9	2.3	0.0	0.0	0.0
Data Masked	7.6E+04	23	3.3	0.0	18.2	85.9	0.0	237.9	43.0	4.0	0.0	0.0	0.0
Data Masked	7.2E+04	22	3.1	0.0	17.2	81.4	0.0	225.4	40.7	3.8	0.0	0.0	0.0
Data Masked	1.8E+05	55	7.8	0.0	43.0	203.5	0.0	563.5	101.7	9.4	0.0	0.0	0.0
Data Masked	2.1E+05	65	9.1	0.0	50.2	237.4	0.0	657.4	118.7	11.0	0.0	0.0	0.0
Data Masked	6.6E+04	20	2.9	0.0	15.8	74.6	0.0	206.6	37.3	3.4	0.0	0.0	0.0
Data Masked	6.8E+04	21	3.0	0.0	16.3	76.9	0.0	212.9	38.4	3.5	0.0	0.0	0.0
Data Masked	6.9E+04	21	3.0	0.0	16.5	78.0	0.0	216.0	39.0	3.6	0.0	0.0	0.0
Data Masked	3.4E+04	10	1.5	0.0	8.1	38.4	0.0	106.4	19.2	1.8	0.0	0.0	0.0
Data Masked	1.00E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	7.1E+04	22	3.1	0.0	17.0	80.3	0.0	222.3	40.1	3.7	0.0	0.0	0.0
Data Masked	4.4E+04	14	1.9	0.0	10.5	49.7	0.0	137.7	24.9	2.3	0.0	0.0	0.0
Data Masked	5.8E+04	18	2.5	0.0	13.9	65.6	0.0	181.6	32.8	3.0	0.0	0.0	0.0
Data Masked	6.4E+04	20	2.8	0.0	15.3	72.3	0.0	200.3	36.2	3.3	0.0	0.0	0.0
Data Masked	9.9E+04	30	4.3	0.0	23.7	111.9	0.0	309.9	56.0	5.2	0.0	0.0	0.0

Annual dose equivalents to the organs and effective dose equivalent per year are shown in Figure E-6 for an intake of 34,000 pCi; the lowest intake estimated by CINDY. These curves represent the accumulation of dose to the specified organ in each year following exposure. Readers should note that the lung dose dominates for the first few years. According to this estimate, the bone dose then predominates thereafter, reaching a maximum at around 13 years following exposure and then slowly declining. These curves illustrate the need to consider both the delivery of the dose and the 50-year cumulative total when assessing the potential for health effects.

E.4.2. Repeat Analysis Cases Group

Palomares responders were placed in the Repeat Analysis Cases Group if they met one or both of the following conditions:

- They submitted an initial urine sample while on site that was analyzed for gross alpha radioactivity and then reanalyzed by alpha spectrometry for ^{239}Pu ; or
- They submitted an initial sample while on site that was analyzed by gross alpha counting and then submitted one or more follow-up samples after returning to their base of assignment for analysis by alpha spectrometry.

In general, the urine measurements for this group were not as robust as those for the High 26 Cases Group and follow-up did not extend beyond an initial resampling attempt. The following sections discuss the urine measurements available for this group, the process of estimating the intakes and dose equivalents, and the results.

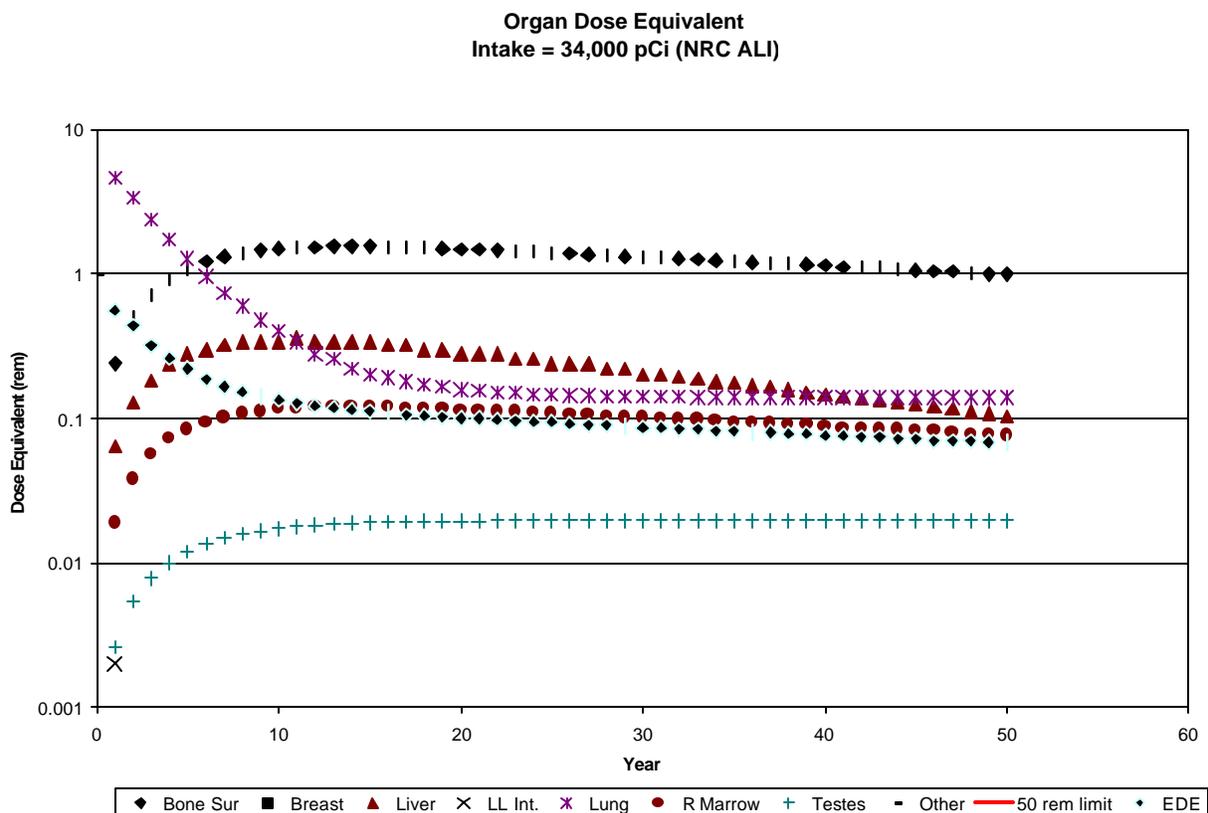


Figure E- 6. Annual organ dose equivalent for 34,000 pCi intake of ²³⁹Pu.

E.4.2.1. Urine Bioassay Measurement Characteristics

The Repeat Analysis Cases Group provided 82 urine samples that produced usable results. Other samples submitted did not produce usable results for several reasons. These reasons included laboratory errors during processing and chemical recoveries that were unreported, too low to be measured or below 40%. This project established a minimum requirement for chemical recovery at 40% for alpha spectrometry samples as a reasonable lower limit for credible results. The 82 samples were collected from 54 individuals during January 17, 1966 to June 22, 1966. Figure E-7 illustrates the distribution of sample results obtained for this group. Most of the samples (88) were collected on dates (before April 3, 1966) that represent on-site activity, while 66 samples were collected after that time. The results indicate that the gross alpha and alpha spectrometry measurements are primarily greater than 0.1 pCi/d and that the two types of measurements are interspersed among one another. Gross alpha results, however, tended to have higher values than the alpha spectrometry measurements.

A more detailed review of the data indicated that the samples and analyses were distributed as shown in Table E-6. This distribution seemed to imply that most of the samples were characterized by a gross alpha measurement followed by reanalysis by alpha spectrometry in an attempt to identify the radionuclide responsible for the gross alpha result. In most cases, the alpha spectrometry result was lower than the gross alpha measurement. Twenty-three individuals were characterized by this situation. Unfortunately, resampling was not accomplished for those in this group of 23.

Results for Repeat Analysis Group

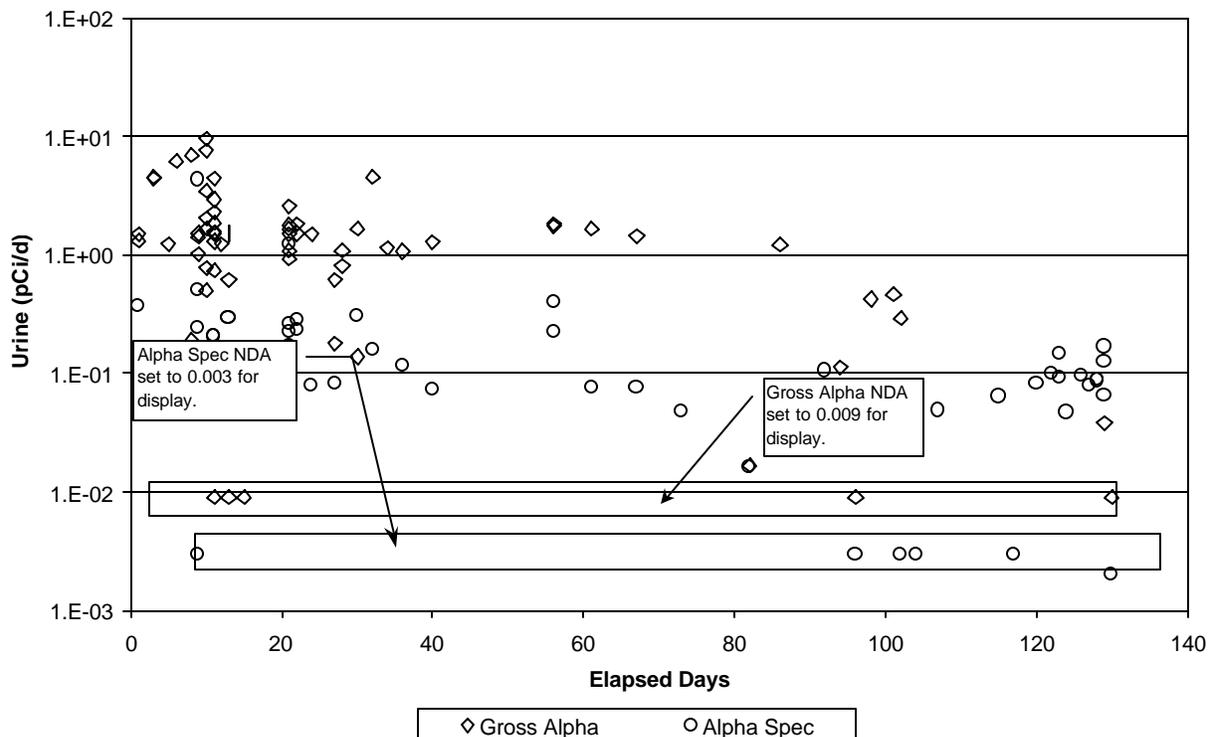


Figure E- 7. Results for Repeat Analysis Cases Group.

The remaining 31 individuals had records characterized by at least two samples with gross alpha measurements on the initial sample and gross alpha or alpha spectrometry or both on the resample. Alpha spectrometry measurements were performed on several initial samples.

Table E- 6. Distribution of Samples for the Repeat Analysis Cases Group.

Number of Samples	Number of Submitters
1	23
2	25
3	3
4	1
5	2

E.4.2.1.1 Date of Exposure

The Repeat Analysis Cases Group had exposure dates that extended over a broader range of dates than the High 26 Cases Group. However, many were among the initial responders who arrived in January 1966. Many stayed on site for one to two weeks, with some up to a month. A few may have remained until the very end of operations. Just as for the High 26 Cases Group, some sample dates were not available in their records and were assigned. Since the time on site seemed shorter and better recorded for this group, the exposure date was assumed as the midpoint of the time at Camp Wilson.

E.4.2.1.2 Use of Measurements

Many gross alpha results for resamples were not reported at all. Therefore, the approach to calculating the estimated intake assumed the following.

- Gross alpha results for samples collected on site were excluded from the analysis.
- Gross alpha results reported as NDA were included with an assumed value of 0.009 pCi/d.
- Alpha spectrometry results reported as NDA were reviewed and numerical values included if found on data cards.
- Some alpha spectrometry results that did not fit the expected urinary excretion pattern were excluded even if the sample was not collected on site.

E.4.2.1.3 Weighting Factors for Urine Measurements

Section 3.2.1.1 discusses the selection of weighting factors for estimating intakes from bioassay measurements and Section 3.2.2 summarizes some performance tests. Those were confirmed for the High 26 Cases Group data and applied to the Repeat Analysis Cases Group.

E.4.2.2. Results

The methods used for estimating intakes and doses for the High 26 Cases Group were applied to the Repeat Analysis Cases Group. Some adjustments were necessary to accommodate the specific data qualities for each case. The results are anonymously listed in Table E-7. This section summarizes the overall results and discusses approaches for developing estimates that are more reasonable.

E.4.2.2.1 Intakes and Doses

For the 54 cases, the estimated intakes varied from 2,900 pCi to 1,300,000 pCi from CINDY and 11,900 pCi to 5,240,000 pCi from LUDEP with the gross alpha results excluded in all the cases. Estimates of committed effective dose equivalent ranged from 0.9 rem to 400 rem (0.009 to 4.0 Sv) from CINDY and 0.8 to 367 rem (0.008 to 3.67 Sv) from LUDEP. LUDEP results ranged from -238% to +94% of CINDY results. In addition to the intakes and CEDE estimates, annual dose equivalents and committed dose equivalents were calculated for organs using both CINDY and LUDEP.

Table E- 7. Repeat Analysis Group Preliminary Intake, Committed Dose Equivalent, and Committed Effective Dose Equivalent Estimates.

Name	Intake (pCi)	CEDE	Testes	Breast	R Marrow	Lung	Thyroid	Bone Sur	Liver	Other	LL Int.	UL Int.	S Int.
Data Masked	1.00E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	1.70E+05	54	7.4	0.0	40.7	192.2	0.0	532.2	96.1	8.9	0.0	0.0	0.0
Data Masked	4.40E+03	1.4	0.2	0.0	1.1	5.0	0.0	13.8	2.5	0.2	0.0	0.0	0.0
Data Masked	6.90E+04	21	3.0	0.0	16.5	78.0	0.0	216.0	39.0	3.6	0.0	0.0	0.0
Data Masked	2.30E+04	7.1	1.0	0.0	5.5	26.0	0.0	72.0	13.0	1.2	0.0	0.0	0.0
Data Masked	1.40E+05	43	6.1	0.0	33.5	158.3	0.0	438.3	79.1	7.3	0.0	0.0	0.0
Data Masked	9.40E+05	290	40.9	0.0	224.8	1062.6	0.0	2942.6	531.3	49.0	0.1	0.0	0.0
Data Masked	1.90E+05	58	8.3	0.0	45.4	214.8	0.0	594.8	107.4	9.9	0.0	0.0	0.0
Data Masked	1.10E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	4.30E+03	1.3	0.2	0.0	1.0	4.9	0.0	13.5	2.4	0.2	0.0	0.0	0.0
Data Masked	3.10E+05	95	13.5	0.0	74.1	350.4	0.0	970.4	175.2	16.2	0.0	0.0	0.0
Data Masked	2.00E+05	61	8.7	0.0	47.8	226.1	0.0	626.1	113.0	10.4	0.0	0.0	0.0
Data Masked	1.50E+05	46	6.5	0.0	35.9	169.6	0.0	469.6	84.8	7.8	0.0	0.0	0.0
Data Masked	3.90E+05	120	17.0	0.0	93.3	440.9	0.0	1220.9	220.4	20.3	0.0	0.0	0.0
Data Masked	3.60E+05	110	15.7	0.0	86.1	407.0	0.0	1127.0	203.5	18.8	0.0	0.0	0.0
Data Masked	2.60E+04	8	1.1	0.0	6.2	29.4	0.0	81.4	14.7	1.4	0.0	0.0	0.0
Data Masked	4.40E+03	1.4	0.2	0.0	1.1	5.0	0.0	13.8	2.5	0.2	0.0	0.0	0.0
Data Masked	1.90E+05	58	8.3	0.0	45.4	214.8	0.0	594.8	107.4	9.9	0.0	0.0	0.0
Data Masked	5.50E+05	170	23.9	0.0	131.5	621.7	0.0	1721.7	310.9	28.7	0.1	0.0	0.0
Data Masked	2.90E+03	0.89	0.1	0.0	0.7	3.3	0.0	9.1	1.6	0.2	0.0	0.0	0.0
Data Masked	1.20E+05	37	5.2	0.0	28.7	135.7	0.0	375.7	67.8	6.3	0.0	0.0	0.0
Data Masked	4.40E+03	1.4	0.2	0.0	1.1	5.0	0.0	13.8	2.5	0.2	0.0	0.0	0.0
Data Masked	1.30E+06	400	56.5	0.0	310.9	1469.6	0.0	4069.6	734.8	67.8	0.1	0.0	0.0
Data Masked	9.40E+04	29	4.1	0.0	22.5	106.3	0.0	294.3	53.1	4.9	0.0	0.0	0.0
Data Masked	4.70E+03	1.4	0.2	0.0	1.1	5.3	0.0	14.7	2.7	0.2	0.0	0.0	0.0
Data Masked	1.80E+05	55	7.8	0.0	43.0	203.5	0.0	563.5	101.7	9.4	0.0	0.0	0.0
Data Masked	4.00E+05	120	17.4	0.0	95.7	452.2	0.0	1252.2	226.1	20.9	0.0	0.0	0.0
Data Masked	4.90E+04	15	2.1	0.0	11.7	55.4	0.0	153.4	27.7	2.6	0.0	0.0	0.0
Data Masked	3.20E+04	9.8	1.4	0.0	7.7	36.2	0.0	100.2	18.1	1.7	0.0	0.0	0.0
Data Masked	9.20E+04	28	4.0	0.0	22.0	104.0	0.0	288.0	52.0	4.8	0.0	0.0	0.0
Data Masked	2.50E+05	77	10.9	0.0	59.8	282.6	0.0	782.6	141.3	13.0	0.0	0.0	0.0
Data Masked	9.30E+04	29	4.0	0.0	22.2	105.1	0.0	291.1	52.6	4.9	0.0	0.0	0.0
Data Masked	1.80E+05	55	7.8	0.0	43.0	203.5	0.0	563.5	101.7	9.4	0.0	0.0	0.0
Data Masked	1.40E+05	43	6.1	0.0	33.5	158.3	0.0	438.3	79.1	7.3	0.0	0.0	0.0
Data Masked	1.30E+05	40	5.7	0.0	31.1	147.0	0.0	407.0	73.5	6.8	0.0	0.0	0.0
Data Masked	2.70E+05	83	11.7	0.0	64.6	305.2	0.0	845.2	152.6	14.1	0.0	0.0	0.0
Data Masked	6.80E+04	21	3.0	0.0	16.3	76.9	0.0	212.9	38.4	3.5	0.0	0.0	0.0
Data Masked	2.10E+05	65	9.1	0.0	50.2	237.4	0.0	657.4	118.7	11.0	0.0	0.0	0.0
Data Masked	7.70E+03	2.4	0.3	0.0	1.8	8.7	0.0	24.1	4.4	0.4	0.0	0.0	0.0
Data Masked	2.40E+05	74	10.4	0.0	57.4	271.3	0.0	751.3	135.7	12.5	0.0	0.0	0.0
Data Masked	2.70E+05	83	11.7	0.0	64.6	305.2	0.0	845.2	152.6	14.1	0.0	0.0	0.0
Data Masked	1.40E+05	43	6.1	0.0	33.5	158.3	0.0	438.3	79.1	7.3	0.0	0.0	0.0
Data Masked	1.10E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	2.80E+04	8.6	1.2	0.0	6.7	31.7	0.0	87.7	15.8	1.5	0.0	0.0	0.0
Data Masked	9.50E+04	29	4.1	0.0	22.7	107.4	0.0	297.4	53.7	5.0	0.0	0.0	0.0
Data Masked	3.10E+05	95	13.5	0.0	74.1	350.4	0.0	970.4	175.2	16.2	0.0	0.0	0.0
Data Masked	1.10E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	1.90E+05	58	8.3	0.0	45.4	214.8	0.0	594.8	107.4	9.9	0.0	0.0	0.0
Data Masked	1.40E+05	43	6.1	0.0	33.5	158.3	0.0	438.3	79.1	7.3	0.0	0.0	0.0
Data Masked	1.40E+05	43	6.1	0.0	33.5	158.3	0.0	438.3	79.1	7.3	0.0	0.0	0.0
Data Masked	1.20E+05	37	5.2	0.0	28.7	135.7	0.0	375.7	67.8	6.3	0.0	0.0	0.0
Data Masked	1.85E+05	55	8.0	0.0	44.2	209.1	0.0	579.1	104.6	9.7	0.0	0.0	0.0
Data Masked	4.40E+03	1.4	0.2	0.0	1.1	5.0	0.0	13.8	2.5	0.2	0.0	0.0	0.0
Data Masked	4.00E+05	120	17.4	0.0	95.7	452.2	0.0	1252.2	226.1	20.9	0.0	0.0	0.0

E.4.3. Contamination Cutoff Cases Group

The Contamination Cutoff Cases Group of analyses was created to calculate estimated intake and dose equivalent for those whose urine measurement results indicated potentially contaminated samples collected at the accident site but were below a reasonable minimum level that did not represent unusually high exposures. While the data for this group were not found especially robust, this approach allows additional cases to be evaluated. As discussed in Section 4.4.2, a level of 0.1 pCi/d was adopted as reasonable maximum level for cases included in the Contamination Cutoff Cases Group.

E.4.3.1. Urine Bioassay Measurement Characteristics

The Contamination Cutoff Cases Group contained 313 individuals who provided 344 samples. Of the 344 samples, 30 samples were collected on site, had high results and were subsequently reanalyzed. The 314 resamples produced results that were substantially below the values of the initial group of 30 samples. Of the 314 repeat samples, 13 results were produced by alpha spectrometry. Figure E-8 illustrates the distribution of the results with sample collection date. The figure also shows that the majority of samples were collected during the period of on-site activity and were susceptible to sample contamination.

E.4.3.2. Approach to Estimates

The procedures for analysis of the High 26 Cases Group were applied to the Contamination Cutoff Cases Group, except that the intakes and dose equivalents were calculated using only the CINDY program. LUDEP was not used. NDA reports were not encountered in this group.

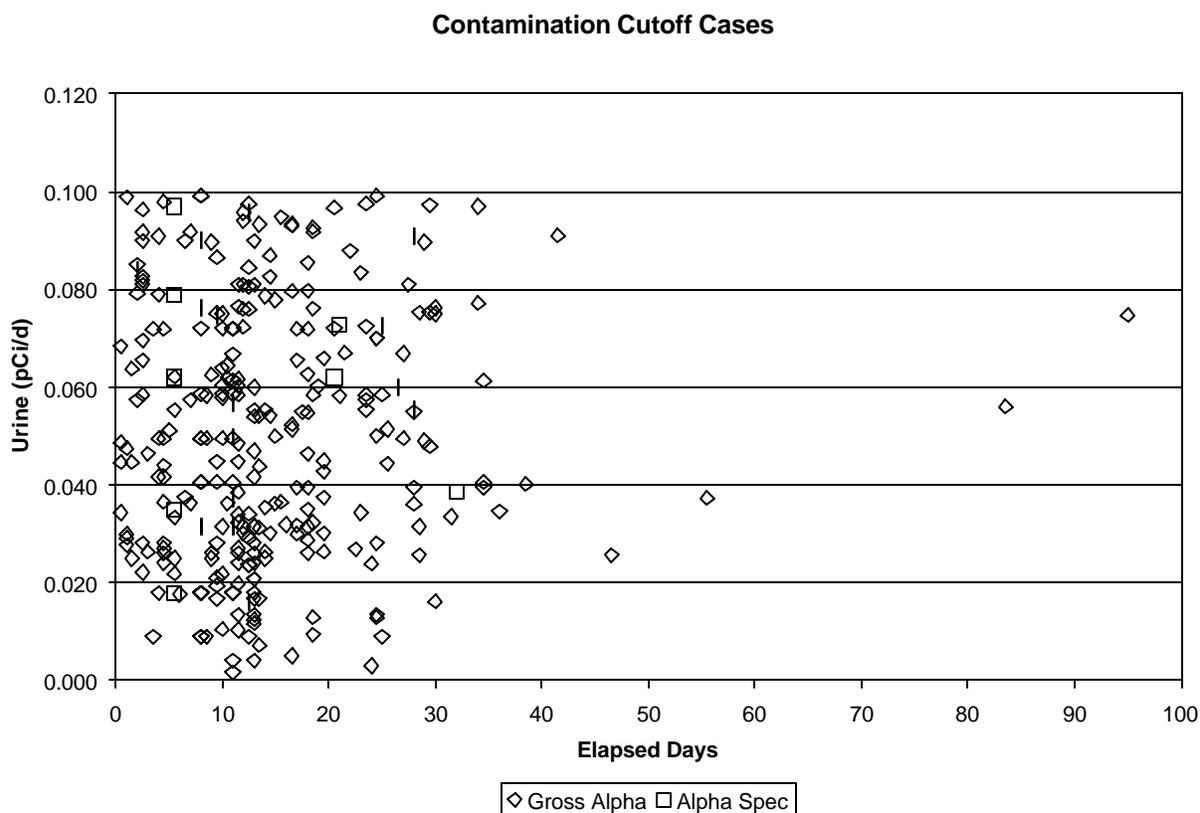


Figure E- 8. Urine results for the Contamination Cutoff Cases Group.

E.4.3.2.1 Date of Exposure

The Contamination Cutoff Cases Group had exposure dates that began over a similar range of dates to the Repeat Analysis Cases Group. Many of this group stayed on site for one to two weeks, with some up to a month. A few appeared to remain until the very end of operations. As

for the High 26 Cases Group, some sample dates were assigned. Since the time on site seem shorter and better recorded for this group, the exposure date was assumed as the midpoint of the time at Camp Wilson.

E.4.3.2 Use of Measurements

As mentioned in Section D-4.3.1, 30 individuals submitted more than one sample. The lowest results for any individual were used regardless of whether the analysis was performed using gross alpha counting or alpha spectrometry.

E.4.3.2.3 Weighting Factors for Urine Measurements

Each individual case contained only one measurement. Consequently, weighting factors were not a consideration for this group of assessments.

E.4.3.3. Results

The methods used for estimating intakes and doses for the High 26 Cases Group were applied to the Repeat Analysis Cases Group. Some adjustments were necessary to accommodate the specific data qualities for each case. The results for each individual are listed anonymously with the pertinent data used for calculating the estimated intake and dose equivalent in Table E-8. This section summarizes the overall results and discusses approaches for developing estimates that are more reasonable.

E.4.3.3.1 Intakes and Doses

For the 313 individuals in the Contamination Cutoff Cases Group, the estimated intakes varied from 1,500 pCi to 110,000 pCi. Estimates of committed effective dose equivalent ranged from 0.46 rem to 34 rem (0.0046 to 0.34 Sv). The higher intake and dose estimate were produced by a urine sample, taken at 25 days after the assumed exposure date, which produced a result of 0.099 pCi/d of gross alpha activity. According to the excretion function derived, the urinary content on day 25 represents approximately 9×10^{-7} of the inhalation intake. This case illustrates how urine concentrations that are even slightly above detectability can lead to sizeable estimated intakes and dose equivalents.

E.4.3.4. Remaining Cases Group

The individual cases that were not evaluated in one of the previous three groups were placed in the Remaining Cases Group. These samples included those from individuals who submitted only one sample, or from cases where some follow-up was attempted but results were inadequate because of low or no chemical recovery or laboratory error. This group contains sample measurements on 1,063 individuals for 1,219 samples. Figure E-9 illustrates the distribution of the results with positive values. The remaining results were zero, NDA, or not reported.

Table E- 8. Contamination Cutoff Group Preliminary intake, committed dose equivalent, and committed effective dose equivalent estimates.

Name	Intake (pCi)	CEDE	Testes	Breast	R Marrow	Lung	Thyroid	Bone Sur	Liver	Other	LL Int.	UL Int.	S Int.
Data Masked	1.5E+03	0.46	0.1	0.0	0.4	1.7	0.0	4.7	0.8	0.1	0.0	0.0	0.0
Data Masked	2.4E+03	0.74	0.1	0.0	0.6	2.7	0.0	7.5	1.4	0.1	0.0	0.0	0.0
Data Masked	2.5E+03	0.77	0.1	0.0	0.6	2.8	0.0	7.8	1.4	0.1	0.0	0.0	0.0
Data Masked	2.6E+03	0.8	0.1	0.0	0.6	2.9	0.0	8.1	1.5	0.1	0.0	0.0	0.0
Data Masked	2.8E+03	0.86	0.1	0.0	0.7	3.2	0.0	8.8	1.6	0.1	0.0	0.0	0.0
Data Masked	2.9E+03	0.89	0.1	0.0	0.7	3.3	0.0	9.1	1.6	0.2	0.0	0.0	0.0
Data Masked	3.2E+03	0.98	0.1	0.0	0.8	3.6	0.0	10.0	1.8	0.2	0.0	0.0	0.0
Data Masked	3.3E+03	1	0.1	0.0	0.8	3.7	0.0	10.3	1.9	0.2	0.0	0.0	0.0
Data Masked	3.4E+03	1	0.1	0.0	0.8	3.8	0.0	10.6	1.9	0.2	0.0	0.0	0.0
Data Masked	3.6E+03	1.1	0.2	0.0	0.9	4.1	0.0	11.3	2.0	0.2	0.0	0.0	0.0
Data Masked	3.8E+03	1.2	0.2	0.0	0.9	4.3	0.0	11.9	2.1	0.2	0.0	0.0	0.0
Data Masked	3.8E+03	1.2	0.2	0.0	0.9	4.3	0.0	11.9	2.1	0.2	0.0	0.0	0.0
Data Masked	4.0E+03	1.2	0.2	0.0	1.0	4.5	0.0	12.5	2.3	0.2	0.0	0.0	0.0
Data Masked	4.1E+03	1.3	0.2	0.0	1.0	4.6	0.0	12.8	2.3	0.2	0.0	0.0	0.0
Data Masked	4.7E+03	1.4	0.2	0.0	1.1	5.3	0.0	14.7	2.7	0.2	0.0	0.0	0.0
Data Masked	4.7E+03	1.4	0.2	0.0	1.1	5.3	0.0	14.7	2.7	0.2	0.0	0.0	0.0
Data Masked	5.0E+03	1.5	0.2	0.0	1.2	5.7	0.0	15.7	2.8	0.3	0.0	0.0	0.0
Data Masked	5.5E+03	1.7	0.2	0.0	1.3	6.2	0.0	17.2	3.1	0.3	0.0	0.0	0.0
Data Masked	5.8E+03	1.8	0.3	0.0	1.4	6.6	0.0	18.2	3.3	0.3	0.0	0.0	0.0
Data Masked	6.0E+03	1.8	0.3	0.0	1.4	6.8	0.0	18.8	3.4	0.3	0.0	0.0	0.0
Data Masked	6.1E+03	1.9	0.3	0.0	1.5	6.9	0.0	19.1	3.4	0.3	0.0	0.0	0.0
Data Masked	6.4E+03	2	0.3	0.0	1.5	7.2	0.0	20.0	3.6	0.3	0.0	0.0	0.0
Data Masked	6.4E+03	2	0.3	0.0	1.5	7.2	0.0	20.0	3.6	0.3	0.0	0.0	0.0
Data Masked	6.8E+03	2.1	0.3	0.0	1.6	7.7	0.0	21.3	3.8	0.4	0.0	0.0	0.0
Data Masked	6.8E+03	2.1	0.3	0.0	1.6	7.7	0.0	21.3	3.8	0.4	0.0	0.0	0.0
Data Masked	7.0E+03	2.2	0.3	0.0	1.7	7.9	0.0	21.9	4.0	0.4	0.0	0.0	0.0
Data Masked	7.9E+03	2.4	0.3	0.0	1.9	8.9	0.0	24.7	4.5	0.4	0.0	0.0	0.0
Data Masked	8.0E+03	2.5	0.3	0.0	1.9	9.0	0.0	25.0	4.5	0.4	0.0	0.0	0.0
Data Masked	8.4E+03	2.6	0.4	0.0	2.0	9.5	0.0	26.3	4.7	0.4	0.0	0.0	0.0
Data Masked	8.6E+03	2.6	0.4	0.0	2.1	9.7	0.0	26.9	4.9	0.4	0.0	0.0	0.0
Data Masked	8.7E+03	2.7	0.4	0.0	2.1	9.8	0.0	27.2	4.9	0.5	0.0	0.0	0.0
Data Masked	9.2E+03	2.8	0.4	0.0	2.2	10.4	0.0	28.8	5.2	0.5	0.0	0.0	0.0
Data Masked	9.4E+03	2.9	0.4	0.0	2.2	10.6	0.0	29.4	5.3	0.5	0.0	0.0	0.0
Data Masked	9.5E+03	2.9	0.4	0.0	2.3	10.7	0.0	29.7	5.4	0.5	0.0	0.0	0.0
Data Masked	9.8E+03	3	0.4	0.0	2.3	11.1	0.0	30.7	5.5	0.5	0.0	0.0	0.0
Data Masked	1.0E+04	3.1	0.4	0.0	2.4	11.3	0.0	31.3	5.7	0.5	0.0	0.0	0.0
Data Masked	1.0E+04	3.1	0.4	0.0	2.4	11.3	0.0	31.3	5.7	0.5	0.0	0.0	0.0
Data Masked	1.1E+04	3.4	0.5	0.0	2.6	12.4	0.0	34.4	6.2	0.6	0.0	0.0	0.0
Data Masked	1.1E+04	3.4	0.5	0.0	2.6	12.4	0.0	34.4	6.2	0.6	0.0	0.0	0.0
Data Masked	1.1E+04	3.4	0.5	0.0	2.6	12.4	0.0	34.4	6.2	0.6	0.0	0.0	0.0
Data Masked	1.1E+04	3.4	0.5	0.0	2.6	12.4	0.0	34.4	6.2	0.6	0.0	0.0	0.0
Data Masked	1.1E+04	3.4	0.5	0.0	2.6	12.4	0.0	34.4	6.2	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.2E+04	3.7	0.5	0.0	2.9	13.6	0.0	37.6	6.8	0.6	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.3E+04	4	0.6	0.0	3.1	14.7	0.0	40.7	7.3	0.7	0.0	0.0	0.0
Data Masked	1.4E+04	4.3	0.6	0.0	3.3	15.8	0.0	43.8	7.9	0.7	0.0	0.0	0.0
Data Masked	1.4E+04	4.3	0.6	0.0	3.3	15.8	0.0	43.8	7.9	0.7	0.0	0.0	0.0
Data Masked	1.4E+04	4.3	0.6	0.0	3.3	15.8	0.0	43.8	7.9	0.7	0.0	0.0	0.0
Data Masked	1.5E+04	4.6	0.7	0.0	3.6	17.0	0.0	47.0	8.5	0.8	0.0	0.0	0.0
Data Masked	1.5E+04	4.6	0.7	0.0	3.6	17.0	0.0	47.0	8.5	0.8	0.0	0.0	0.0
Data Masked	1.5E+04	4.6	0.7	0.0	3.6	17.0	0.0	47.0	8.5	0.8	0.0	0.0	0.0
Data Masked	1.5E+04	4.6	0.7	0.0	3.6	17.0	0.0	47.0	8.5	0.8	0.0	0.0	0.0
Data Masked	1.5E+04	4.6	0.7	0.0	3.6	17.0	0.0	47.0	8.5	0.8	0.0	0.0	0.0
Data Masked	1.6E+04	4.9	0.7	0.0	3.8	18.1	0.0	50.1	9.0	0.8	0.0	0.0	0.0
Data Masked	1.6E+04	4.9	0.7	0.0	3.8	18.1	0.0	50.1	9.0	0.8	0.0	0.0	0.0
Data Masked	1.6E+04	4.9	0.7	0.0	3.8	18.1	0.0	50.1	9.0	0.8	0.0	0.0	0.0
Data Masked	1.7E+04	5.2	0.7	0.0	4.1	19.2	0.0	53.2	9.6	0.9	0.0	0.0	0.0
Data Masked	1.7E+04	5.2	0.7	0.0	4.1	19.2	0.0	53.2	9.6	0.9	0.0	0.0	0.0
Data Masked	1.7E+04	5.2	0.7	0.0	4.1	19.2	0.0	53.2	9.6	0.9	0.0	0.0	0.0
Data Masked	1.7E+04	5.2	0.7	0.0	4.1	19.2	0.0	53.2	9.6	0.9	0.0	0.0	0.0

Table E- 8. Contamination Cutoff Group Preliminary intake, committed dose equivalent, and committed effective dose equivalent estimates.

Data Masked	4.1E+04	13	1.8	0.0	9.8	46.3	0.0	128.3	23.2	2.1	0.0	0.0	0.0
Data Masked	4.1E+04	13	1.8	0.0	9.8	46.3	0.0	128.3	23.2	2.1	0.0	0.0	0.0
Data Masked	4.1E+04	13	1.8	0.0	9.8	46.3	0.0	128.3	23.2	2.1	0.0	0.0	0.0
Data Masked	4.2E+04	13	1.8	0.0	10.0	47.5	0.0	131.5	23.7	2.2	0.0	0.0	0.0
Data Masked	4.2E+04	13	1.8	0.0	10.0	47.5	0.0	131.5	23.7	2.2	0.0	0.0	0.0
Data Masked	4.2E+04	13	1.8	0.0	10.0	47.5	0.0	131.5	23.7	2.2	0.0	0.0	0.0
Data Masked	4.3E+04	13	1.9	0.0	10.3	48.6	0.0	134.6	24.3	2.2	0.0	0.0	0.0
Data Masked	4.3E+04	13	1.9	0.0	10.3	48.6	0.0	134.6	24.3	2.2	0.0	0.0	0.0
Data Masked	4.3E+04	13	1.9	0.0	10.3	48.6	0.0	134.6	24.3	2.2	0.0	0.0	0.0
Data Masked	4.4E+04	14	1.9	0.0	10.5	49.7	0.0	137.7	24.9	2.3	0.0	0.0	0.0
Data Masked	4.5E+04	14	2.0	0.0	10.8	50.9	0.0	140.9	25.4	2.3	0.0	0.0	0.0
Data Masked	4.5E+04	14	2.0	0.0	10.8	50.9	0.0	140.9	25.4	2.3	0.0	0.0	0.0
Data Masked	4.6E+04	14	2.0	0.0	11.0	52.0	0.0	144.0	26.0	2.4	0.0	0.0	0.0
Data Masked	4.6E+04	14	2.0	0.0	11.0	52.0	0.0	144.0	26.0	2.4	0.0	0.0	0.0
Data Masked	4.7E+04	14	2.0	0.0	11.2	53.1	0.0	147.1	26.6	2.5	0.0	0.0	0.0
Data Masked	4.7E+04	14	2.0	0.0	11.2	53.1	0.0	147.1	26.6	2.5	0.0	0.0	0.0
Data Masked	4.7E+04	14	2.0	0.0	11.2	53.1	0.0	147.1	26.6	2.5	0.0	0.0	0.0
Data Masked	4.8E+04	15	2.1	0.0	11.5	54.3	0.0	150.3	27.1	2.5	0.0	0.0	0.0
Data Masked	4.9E+04	15	2.1	0.0	11.7	55.4	0.0	153.4	27.7	2.6	0.0	0.0	0.0
Data Masked	4.9E+04	15	2.1	0.0	11.7	55.4	0.0	153.4	27.7	2.6	0.0	0.0	0.0
Data Masked	4.9E+04	15	2.1	0.0	11.7	55.4	0.0	153.4	27.7	2.6	0.0	0.0	0.0
Data Masked	5.0E+04	15	2.2	0.0	12.0	56.5	0.0	156.5	28.3	2.6	0.0	0.0	0.0
Data Masked	5.0E+04	15	2.2	0.0	12.0	56.5	0.0	156.5	28.3	2.6	0.0	0.0	0.0
Data Masked	5.0E+04	15	2.2	0.0	12.0	56.5	0.0	156.5	28.3	2.6	0.0	0.0	0.0
Data Masked	5.0E+04	15	2.2	0.0	12.0	56.5	0.0	156.5	28.3	2.6	0.0	0.0	0.0
Data Masked	5.0E+04	15	2.2	0.0	12.0	56.5	0.0	156.5	28.3	2.6	0.0	0.0	0.0
Data Masked	5.1E+04	16	2.2	0.0	12.2	57.7	0.0	159.7	28.8	2.7	0.0	0.0	0.0
Data Masked	5.1E+04	16	2.2	0.0	12.2	57.7	0.0	159.7	28.8	2.7	0.0	0.0	0.0
Data Masked	5.1E+04	16	2.2	0.0	12.2	57.7	0.0	159.7	28.8	2.7	0.0	0.0	0.0
Data Masked	5.1E+04	16	2.2	0.0	12.2	57.7	0.0	159.7	28.8	2.7	0.0	0.0	0.0
Data Masked	5.2E+04	16	2.3	0.0	12.4	58.8	0.0	162.8	29.4	2.7	0.0	0.0	0.0
Data Masked	5.2E+04	16	2.3	0.0	12.4	58.8	0.0	162.8	29.4	2.7	0.0	0.0	0.0
Data Masked	5.2E+04	16	2.3	0.0	12.4	58.8	0.0	162.8	29.4	2.7	0.0	0.0	0.0
Data Masked	5.2E+04	16	2.3	0.0	12.4	58.8	0.0	162.8	29.4	2.7	0.0	0.0	0.0
Data Masked	5.2E+04	16	2.3	0.0	12.4	58.8	0.0	162.8	29.4	2.7	0.0	0.0	0.0
Data Masked	5.3E+04	16	2.3	0.0	12.7	59.9	0.0	165.9	30.0	2.8	0.0	0.0	0.0
Data Masked	5.3E+04	16	2.3	0.0	12.7	59.9	0.0	165.9	30.0	2.8	0.0	0.0	0.0
Data Masked	5.3E+04	16	2.3	0.0	12.7	59.9	0.0	165.9	30.0	2.8	0.0	0.0	0.0
Data Masked	5.4E+04	17	2.3	0.0	12.9	61.0	0.0	169.0	30.5	2.8	0.0	0.0	0.0
Data Masked	5.4E+04	17	2.3	0.0	12.9	61.0	0.0	169.0	30.5	2.8	0.0	0.0	0.0
Data Masked	5.4E+04	17	2.3	0.0	12.9	61.0	0.0	169.0	30.5	2.8	0.0	0.0	0.0
Data Masked	5.5E+04	17	2.4	0.0	13.2	62.2	0.0	172.2	31.1	2.9	0.0	0.0	0.0
Data Masked	5.5E+04	17	2.4	0.0	13.2	62.2	0.0	172.2	31.1	2.9	0.0	0.0	0.0
Data Masked	5.5E+04	17	2.4	0.0	13.2	62.2	0.0	172.2	31.1	2.9	0.0	0.0	0.0
Data Masked	5.5E+04	17	2.4	0.0	13.2	62.2	0.0	172.2	31.1	2.9	0.0	0.0	0.0
Data Masked	5.5E+04	17	2.4	0.0	13.2	62.2	0.0	172.2	31.1	2.9	0.0	0.0	0.0
Data Masked	5.6E+04	17	2.4	0.0	13.4	63.3	0.0	175.3	31.7	2.9	0.0	0.0	0.0
Data Masked	5.6E+04	17	2.4	0.0	13.4	63.3	0.0	175.3	31.7	2.9	0.0	0.0	0.0
Data Masked	5.7E+04	18	2.5	0.0	13.6	64.4	0.0	178.4	32.2	3.0	0.0	0.0	0.0
Data Masked	5.7E+04	18	2.5	0.0	13.6	64.4	0.0	178.4	32.2	3.0	0.0	0.0	0.0
Data Masked	5.7E+04	18	2.5	0.0	13.6	64.4	0.0	178.4	32.2	3.0	0.0	0.0	0.0
Data Masked	5.8E+04	18	2.5	0.0	13.9	65.6	0.0	181.6	32.8	3.0	0.0	0.0	0.0
Data Masked	5.9E+04	18	2.6	0.0	14.1	66.7	0.0	184.7	33.3	3.1	0.0	0.0	0.0
Data Masked	6.0E+04	18	2.6	0.0	14.3	67.8	0.0	187.8	33.9	3.1	0.0	0.0	0.0
Data Masked	6.1E+04	19	2.7	0.0	14.6	69.0	0.0	191.0	34.5	3.2	0.0	0.0	0.0
Data Masked	6.1E+04	19	2.7	0.0	14.6	69.0	0.0	191.0	34.5	3.2	0.0	0.0	0.0
Data Masked	6.1E+04	19	2.7	0.0	14.6	69.0	0.0	191.0	34.5	3.2	0.0	0.0	0.0
Data Masked	6.2E+04	19	2.7	0.0	14.8	70.1	0.0	194.1	35.0	3.2	0.0	0.0	0.0
Data Masked	6.2E+04	19	2.7	0.0	14.8	70.1	0.0	194.1	35.0	3.2	0.0	0.0	0.0
Data Masked	6.2E+04	19	2.7	0.0	14.8	70.1	0.0	194.1	35.0	3.2	0.0	0.0	0.0
Data Masked	6.3E+04	19	2.7	0.0	15.1	71.2	0.0	197.2	35.6	3.3	0.0	0.0	0.0
Data Masked	6.3E+04	19	2.7	0.0	15.1	71.2	0.0	197.2	35.6	3.3	0.0	0.0	0.0
Data Masked	6.3E+04	19	2.7	0.0	15.1	71.2	0.0	197.2	35.6	3.3	0.0	0.0	0.0
Data Masked	6.4E+04	20	2.8	0.0	15.3	72.3	0.0	200.3	36.2	3.3	0.0	0.0	0.0
Data Masked	6.4E+04	20	2.8	0.0	15.3	72.3	0.0	200.3	36.2	3.3	0.0	0.0	0.0
Data Masked	6.4E+04	20	2.8	0.0	15.3	72.3	0.0	200.3	36.2	3.3	0.0	0.0	0.0
Data Masked	6.4E+04	20	2.8	0.0	15.3	72.3	0.0	200.3	36.2	3.3	0.0	0.0	0.0
Data Masked	6.5E+04	20	2.8	0.0	15.5	73.5	0.0	203.5	36.7	3.4	0.0	0.0	0.0
Data Masked	6.5E+04	20	2.8	0.0	15.5	73.5	0.0	203.5	36.7	3.4	0.0	0.0	0.0
Data Masked	6.5E+04	20	2.8	0.0	15.5	73.5	0.0	203.5	36.7	3.4	0.0	0.0	0.0
Data Masked	6.6E+04	20	2.9	0.0	15.8	74.6	0.0	206.6	37.3	3.4	0.0	0.0	0.0

Table E- 8. Contamination Cutoff Group Preliminary intake, committed dose equivalent, and committed effective dose equivalent estimates.

Data Masked	7.2E+04	22	3.1	0.0	17.2	81.4	0.0	225.4	40.7	3.8	0.0	0.0	0.0
Data Masked	7.2E+04	22	3.1	0.0	17.2	81.4	0.0	225.4	40.7	3.8	0.0	0.0	0.0
Data Masked	7.3E+04	22	3.2	0.0	17.5	82.5	0.0	228.5	41.3	3.8	0.0	0.0	0.0
Data Masked	7.3E+04	22	3.2	0.0	17.5	82.5	0.0	228.5	41.3	3.8	0.0	0.0	0.0
Data Masked	7.4E+04	23	3.2	0.0	17.7	83.7	0.0	231.7	41.8	3.9	0.0	0.0	0.0
Data Masked	7.4E+04	23	3.2	0.0	17.7	83.7	0.0	231.7	41.8	3.9	0.0	0.0	0.0
Data Masked	7.5E+04	23	3.3	0.0	17.9	84.8	0.0	234.8	42.4	3.9	0.0	0.0	0.0
Data Masked	7.6E+04	23	3.3	0.0	18.2	85.9	0.0	237.9	43.0	4.0	0.0	0.0	0.0
Data Masked	7.6E+04	23	3.3	0.0	18.2	85.9	0.0	237.9	43.0	4.0	0.0	0.0	0.0
Data Masked	7.7E+04	24	3.3	0.0	18.4	87.0	0.0	241.0	43.5	4.0	0.0	0.0	0.0
Data Masked	7.7E+04	24	3.3	0.0	18.4	87.0	0.0	241.0	43.5	4.0	0.0	0.0	0.0
Data Masked	7.7E+04	24	3.3	0.0	18.4	87.0	0.0	241.0	43.5	4.0	0.0	0.0	0.0
Data Masked	7.8E+04	24	3.4	0.0	18.7	88.2	0.0	244.2	44.1	4.1	0.0	0.0	0.0
Data Masked	7.8E+04	24	3.4	0.0	18.7	88.2	0.0	244.2	44.1	4.1	0.0	0.0	0.0
Data Masked	7.9E+04	24	3.4	0.0	18.9	89.3	0.0	247.3	44.7	4.1	0.0	0.0	0.0
Data Masked	8.0E+04	25	3.5	0.0	19.1	90.4	0.0	250.4	45.2	4.2	0.0	0.0	0.0
Data Masked	8.0E+04	25	3.5	0.0	19.1	90.4	0.0	250.4	45.2	4.2	0.0	0.0	0.0
Data Masked	8.0E+04	25	3.5	0.0	19.1	90.4	0.0	250.4	45.2	4.2	0.0	0.0	0.0
Data Masked	8.1E+04	25	3.5	0.0	19.4	91.6	0.0	253.6	45.8	4.2	0.0	0.0	0.0
Data Masked	8.2E+04	25	3.6	0.0	19.6	92.7	0.0	256.7	46.3	4.3	0.0	0.0	0.0
Data Masked	8.3E+04	25	3.6	0.0	19.8	93.8	0.0	259.8	46.9	4.3	0.0	0.0	0.0
Data Masked	8.3E+04	25	3.6	0.0	19.8	93.8	0.0	259.8	46.9	4.3	0.0	0.0	0.0
Data Masked	8.3E+04	25	3.6	0.0	19.8	93.8	0.0	259.8	46.9	4.3	0.0	0.0	0.0
Data Masked	8.5E+04	26	3.7	0.0	20.3	96.1	0.0	266.1	48.0	4.4	0.0	0.0	0.0
Data Masked	8.5E+04	26	3.7	0.0	20.3	96.1	0.0	266.1	48.0	4.4	0.0	0.0	0.0
Data Masked	8.5E+04	26	3.7	0.0	20.3	96.1	0.0	266.1	48.0	4.4	0.0	0.0	0.0
Data Masked	8.6E+04	26	3.7	0.0	20.6	97.2	0.0	269.2	48.6	4.5	0.0	0.0	0.0
Data Masked	8.7E+04	27	3.8	0.0	20.8	98.3	0.0	272.3	49.2	4.5	0.0	0.0	0.0
Data Masked	8.7E+04	27	3.8	0.0	20.8	98.3	0.0	272.3	49.2	4.5	0.0	0.0	0.0
Data Masked	8.7E+04	27	3.8	0.0	20.8	98.3	0.0	272.3	49.2	4.5	0.0	0.0	0.0
Data Masked	8.8E+04	27	3.8	0.0	21.0	99.5	0.0	275.5	49.7	4.6	0.0	0.0	0.0
Data Masked	8.8E+04	27	3.8	0.0	21.0	99.5	0.0	275.5	49.7	4.6	0.0	0.0	0.0
Data Masked	8.9E+04	27	3.9	0.0	21.3	100.6	0.0	278.6	50.3	4.6	0.0	0.0	0.0
Data Masked	8.9E+04	27	3.9	0.0	21.3	100.6	0.0	278.6	50.3	4.6	0.0	0.0	0.0
Data Masked	9.0E+04	28	3.9	0.0	21.5	101.7	0.0	281.7	50.9	4.7	0.0	0.0	0.0
Data Masked	9.1E+04	28	4.0	0.0	21.8	102.9	0.0	284.9	51.4	4.7	0.0	0.0	0.0
Data Masked	9.2E+04	28	4.0	0.0	22.0	104.0	0.0	288.0	52.0	4.8	0.0	0.0	0.0
Data Masked	9.2E+04	28	4.0	0.0	22.0	104.0	0.0	288.0	52.0	4.8	0.0	0.0	0.0
Data Masked	9.3E+04	29	4.0	0.0	22.2	105.1	0.0	291.1	52.6	4.9	0.0	0.0	0.0
Data Masked	9.3E+04	29	4.0	0.0	22.2	105.1	0.0	291.1	52.6	4.9	0.0	0.0	0.0
Data Masked	9.3E+04	29	4.0	0.0	22.2	105.1	0.0	291.1	52.6	4.9	0.0	0.0	0.0
Data Masked	9.4E+04	29	4.1	0.0	22.5	106.3	0.0	294.3	53.1	4.9	0.0	0.0	0.0
Data Masked	9.4E+04	29	4.1	0.0	22.5	106.3	0.0	294.3	53.1	4.9	0.0	0.0	0.0
Data Masked	9.6E+04	29	4.2	0.0	23.0	108.5	0.0	300.5	54.3	5.0	0.0	0.0	0.0
Data Masked	9.7E+04	30	4.2	0.0	23.2	109.7	0.0	303.7	54.8	5.1	0.0	0.0	0.0
Data Masked	1.0E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	1.0E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	1.0E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	1.0E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	1.0E+05	31	4.3	0.0	23.9	113.0	0.0	313.0	56.5	5.2	0.0	0.0	0.0
Data Masked	1.1E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	1.1E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	1.1E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	1.1E+05	34	4.8	0.0	26.3	124.3	0.0	344.3	62.2	5.7	0.0	0.0	0.0
Data Masked	1.2E+05	37	5.2	0.0	28.7	135.7	0.0	375.7	67.8	6.3	0.0	0.0	0.0
Data Masked	1.2E+05	37	5.2	0.0	28.7	135.7	0.0	375.7	67.8	6.3	0.0	0.0	0.0
Data Masked	1.2E+05	37	5.2	0.0	28.7	135.7	0.0	375.7	67.8	6.3	0.0	0.0	0.0
Data Masked	1.2E+05	37	5.2	0.0	28.7	135.7	0.0	375.7	67.8	6.3	0.0	0.0	0.0
Data Masked	1.5E+05	46	6.5	0.0	35.9	169.6	0.0	469.6	84.8	7.8	0.0	0.0	0.0
Data Masked	1.5E+05	46	6.5	0.0	35.9	169.6	0.0	469.6	84.8	7.8	0.0	0.0	0.0

E.4.3.5. Approach to Estimates

Intake and dose were not estimated for individuals in the Remaining Cases Group because sample contamination from on-site collection was suspected and because the sample data contained uncertainties about exposure dates and recorded sample collection dates. However, the lowest and the highest urine results of 0 and 237.9 pCi/d of gross alpha radioactivity were input to CINDY, and produced estimated intakes of 75,000 pCi to 20,000,000 pCi corresponding

to CEDEs of about 23 rem to 6,000 rem (0.23 to 60 Sv). Results of this magnitude are clearly unrealistic, not supported by the air concentrations observed at Palomares and require careful evaluation.

E.4.3.6. Results

A range of estimates for the Remaining Cases Group showed that the intakes could range from 75,000 pCi to 20,000,000 pCi with CEDEs of 23 rem to 6,000 rem (0.23 to 60 Sv). The upper end of the range represents very substantial exposures that should not be attributed to any individual without follow-up sampling to provide confirmation of the results. Additional efforts could be made to determine more details about the specific dates of assignment and duties of the individuals. These estimates indicate the possible difficulties that may be encountered when samples, contaminated from collected on site, are analyzed. Unfortunately, the possibility of contamination prevents useful evaluation of these data, especially without the benefit of follow-up samples.

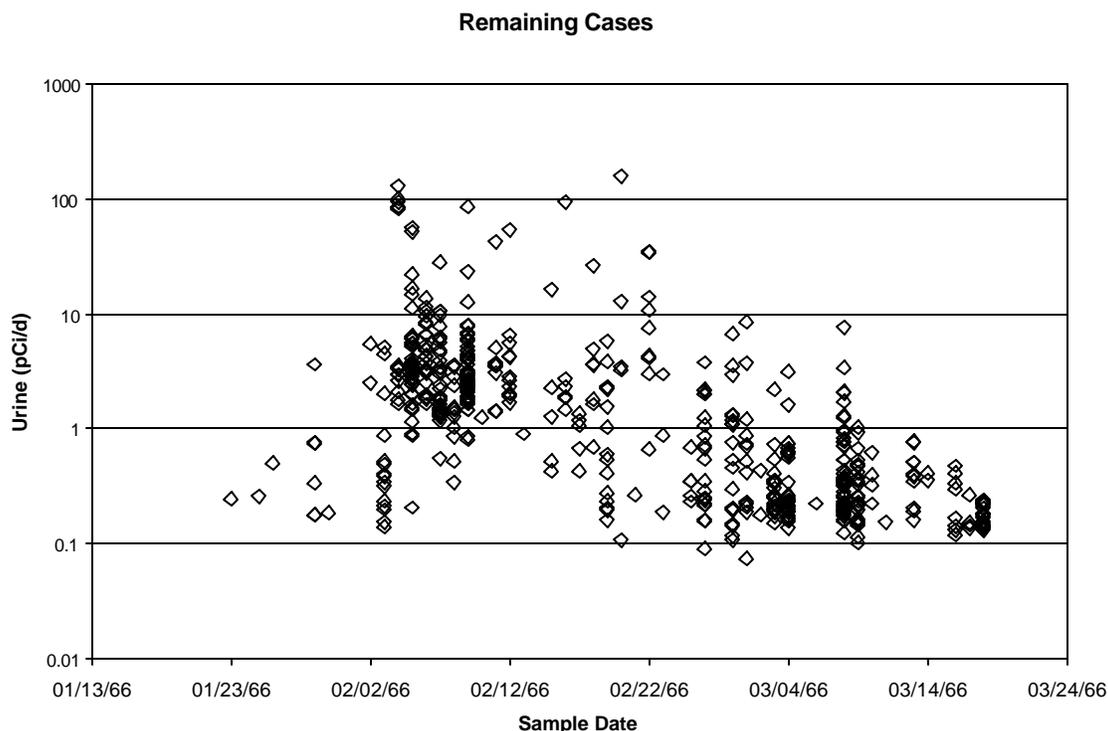


Figure E- 9. Urine results for the Remaining Cases Group.

As a final note, Figure E-9 shows a decreasing trend for the sample results. If resampling had been extended beyond the end of March 1966 as for some other groups, there is ample reason to expect that urinary excretion for this group would have followed similar patterns. Consequently, there are no more reasons to believe that this group received unusual exposures than the other groups. However, the data are simply not available to confirm the status of the individuals in this group. Therefore, follow-up sampling now for selected members of this group could provide information for re-evaluation of the possible exposures.