Draft White Paper

FEASIBILITY OF INTERNAL DOSE RECONSTRUCTION WITH SUFFICIENT ACCURACY AT THE NEVADA TEST SITE DURING THE UNDERGROUND TESTING PERIOD: A REVIEW OF THE NIOSH POSITION PAPER "NIOSH REVIEW OF THE SEC-00084 NEVADA TEST SITE EVALUATION REPORT: INTERNAL DOSIMETRY ISSUES ANALYSIS"

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Finding 6: The electronic database contains data that are similar to the previously analyzed data. Only the RadSafe group seems to have been consistently monitored in the monitoring types for which most data are available. Given the large number of workers whose data have now been reviewed, it is highly unlikely that further review of NTS internal dosimetry data will reveal a different sampling pattern.

Finding 7: The electronic database indicates that the RadSafe group, the only one with consistent monitoring data for four types of bioassay (plutonium, gamma, beta, and tritium), cannot be assumed to be among the job types with the highest exposure potential. On the contrary, there are indications that other (variable) job types may have had higher exposure potential, depending on the radionuclides being monitored. Hence, there is no job type with adequate data that can be used to construct a coworker model that would estimate doses with sufficient accuracy.

PURPOSE OF THE REPORT

The purpose of this report is to review the technical basis of the NIOSH SEC recommendation in its report of November 25, 2009 (NIOSH 2009), regarding SEC Petition SEC-00084. This petition asks NIOSH to include Department of Energy (DOE) and contractor and subcontractor employees at NTS during the underground testing period (starting in 1963) in the SEC. In the report under review here (NIOSH 2009), NIOSH made a recommendation that NTS workers from January 1, 1963, to December 31, 1992, be added to the SEC, based on its conclusion that it cannot reconstruct internal doses for all members of the proposed class (p. 5).

SC&A's prior analysis of available internal dosimetry data (SC&A 2008, SC&A 2009) indicated that many workers were not monitored at all or were monitored very infrequently, even in the categories where the total number of bioassay samples was large. Only the RadSafe group of workers had bioassay monitoring data for plutonium, gamma, beta [or Gross Fission Products (GFP)], and tritium in all relevant periods analyzed, while miners had tritium data. Security workers appeared to have been routinely monitored in the 1980s. SC&A also raised significant issues regarding the quality of plutonium and gamma bioassay data in various years until about 1987.

In its November 2009 report re-evaluating the feasibility of internal dose reconstruction with sufficient accuracy, as required by 42 CFR 83, which governs SEC petitions, NIOSH examined a large electronic database that had not previously been reviewed in the NTS SEC context. NIOSH concluded that it was not possible to bound internal doses with sufficient accuracy, and recommended that NTS workers between January 1, 1963, and December 31, 1992, with more than 250 days of relevant employment be added to the SEC class.

In this report, SC&A has reviewed the NIOSH November 2009 report. The aim was to review the robustness of NIOSH's conclusion and the underlying reasons for this conclusion. A necessary part of that process was to review whether the electronic database was similar to or different from the prior data reviewed by SC&A in the two reports cited above, and whether the electronic database provided any new insights as to the ability to reconstruct doses.

Finding 1 (Overall finding): Based on the analysis in this report and that presented in prior SC&A reports on internal exposure monitoring (SC&A 2008, SC&A 2009), SC&A concurs with NIOSH's overall conclusion that internal dose reconstruction for NTS workers from January 1, 1963, to December 31, 1992, with sufficient accuracy is infeasible. SC&A also examined each of the points that led NIOSH to conclude that dose reconstruction with sufficient accuracy was not feasible. That review led SC&A to conclude that NIOSH's finding is robust.

The summary of SC&A's review of NIOSH's four reasons for concluding that internal dose reconstruction with sufficient accuracy was infeasible for the SEC period is provided below.

RATIONALE OF NTS BIOASSAY SAMPLING PROGRAM (NIOSH ISSUE 1)

NIOSH found that there was insufficient documentation "to describe a consistent rationale behind the collection of personnel bioassay sampling or to indicate that sampling occurred consistently in the situations where it was required." As a result, "NIOSH cannot conclusively determine that doses to all of these potentially exposed individuals were detected by the bioassay program" (NIOSH 2009, p. 3).

SC&A's analysis shows that several groups other than RadSafe, the most intensively monitored job type, and security personnel, monitored from the 1980s onward, had significant exposure potential. There is evidence that some groups had greater exposure potential than the RadSafe group, but the data are too sparse for a definitive conclusion for all periods examined. A definitive comparison is also rendered difficult by the fact that sampling in some cases appears to have been routine, in other cases a mixture of routine and incident-driven, while in yet other cases, it seems to be mainly incident-driven. Therefore, the fact that many or most RadSafe personnel were monitored throughout the SEC period does not provide an adequate basis for constructing a coworker model for other workers with exposure potential, even for those radionuclides for which there are monitoring data in all periods. This conclusion is rendered even more robust by the fact that the sparseness of the data makes a reliable comparison between RadSafe and other groups of workers difficult or impossible in most cases.

Finding 2: The fact that many or most RadSafe personnel were monitored throughout the SEC period does not provide an adequate basis for constructing a coworker model for other workers with exposure potential, even for those radionuclides for which there are monitoring data in all periods.

DATA GAPS (NIOSH ISSUE 2)

NIOSH statement:

> *NIOSH has identified data gaps that exist in the electronically available bioassay data for certain nuclides and time periods… that impact NIOSH's ability to bound the internal dose.*

The extensive analysis done by SC&A in two prior reports (SC&A 2008, SC&A 2009), as well as the present report, confirms NIOSH's analysis regarding the scant data for radionuclides like plutonium. The large fraction of positive bioassay results in all four bioassay monitoring categories that were examined indicate significant internal exposure potential even for groups that had scant monitoring data, contrary to the assumption that the monitored workers were among those with the highest exposure potential.

The problem of the low frequency of monitoring in most cases is compounded by the lack of the information on time and context of sampling that is needed to interpret gamma and beta bioassay data. Frequent sampling and knowledge of time could make it possible to use gamma and beta bioassay data to bound fission product dose. However, these conditions are not fulfilled by the available NTS data.

Finding 3: Given that the frequency of monitoring was inadequate, and that information about timing and context of bioassay sampling is not available, it is not possible to bound fission product doses with the available NTS data.

CAMPAIGN-DRIVEN BIOASSAY PROGRAM (NIOSH ISSUE 3)

NIOSH's review of the electronic database led to their conclusion that the bioassay sampling program was "campaign driven," so that "a coworker model that is useful in reconstructing chronic intake scenarios would not necessarily be representative of the exposure patterns for the NTS workforce" (NIOSH 2009, p. 4).

SC&A's statistical analysis indicates that much of the sampling at NTS was campaign-driven or incident-driven. However, in some cases, it seems to be a mixture of incident-driven and routine monitoring, while in a couple of cases, it seems to be mainly routine monitoring. To the extent that the limited quantity of data enable an analysis, the data in most cases do not fit the usual lognormal distribution that characterizes a routine sampling protocol. SC&A also notes that, besides samples on the same day, the same workers sometimes had many or most samples in a year taken in a short period. For instance, one worker had [redacted] plutonium samples in 1964, and [redacted] of them were in a 16-day period [redacted]. To complicate interpretation, this worker also had [redacted] samples taken on exactly the same dates in the next year. In neither case do the sample collection dates correspond to test dates or the day immediately after a test.[1]

Furthermore, NTS personnel also had the potential for routine exposure. Examples include activities in contaminated areas of the test site outside the context of the activities following a specific test, waste site workers, and laboratory workers.

Finding 4: The inability to sort out monitoring done for routine exposures from that done for episodic exposures makes data interpretation very complex. Specifically, the available data do not lend themselves to creating a reliable coworker model to estimate doses with sufficient accuracy.

RADIONUCLIDE COVERAGE (NIOSH ISSUE 4)

NIOSH found that, given the variety of radionuclides and exposure patterns, it would be complicated "to definitively establish the relative mixture of the exposure source-term" for workers with no bioassay records (NIOSH 2009, p. 4).

All three datasets analyzed by SC&A (the NIOSH group of 100 in Table 7-1 of NIOSH 2007, the 120 workers in 6 job types in SC&A 2008 and SC&A 2009, and the electronic database) indicate that monitoring for plutonium for most job types and most periods was sparse. This is even more so in the case of americium and uranium data. SC&A has found no bioassay data for thorium or

[1] The data referred to for this claimant, a [redacted] group worker, can be found on the [redacted] worksheet of the plutonium data spreadsheet on the O-Drive. The list of nuclear tests and their dates can be found in DOE 2000.

radionuclide-specific fission product data other than very sparse data for Sr-90, I-131, I-133, and I-135.

Finding 5: NTS had a variety of exposure scenarios, from episodic to routine, and a large number of radionuclides to which exposure was possible. For most of these radionuclides, data are very scant to non-existent. Hence, for these unmeasured radionuclides, unmonitored workers include essentially all NTS workers.

OTHER KEY SC&A FINDINGS

SC&A compared the electronic database to the data from prior analyses of internal dosimetry data by period and job type (SC&A 2008, SC&A 2009).

Finding 6: The electronic database contains data that is similar to the previously analyzed data. Only the RadSafe group seems to have been consistently monitored in the monitoring types for which most data are available. Given the large number of workers whose data have now been reviewed, it is highly unlikely that further review of NTS internal dosimetry data will reveal a different sampling pattern.

Finding 7: The electronic database indicates that the RadSafe group, the only one with consistent monitoring data for four types of bioassay (plutonium, gamma, beta, and tritium), cannot be assumed to be among the job types with the highest exposure potential. On the contrary, there are indications that other (variable) job types may have had higher exposure potential, depending on the radionuclides being monitored. Hence, there is no job type with adequate data that can be used to construct a coworker model that would estimate doses with sufficient accuracy.

Finally, we note that this report relates only to a review of NIOSH 2009 insofar as it concerns SEC Petition SEC-00084. SC&A has not examined the period starting January 1, 1993, about which there is also a discussion in NIOSH 2009.

1.0 INTRODUCTION

The purpose of this report is to review the technical basis of the National Institute for Occupational Safety and Health (NIOSH) Special Exposure Cohort (SEC) recommendation in its report of November 25, 2009 (NIOSH 2009), regarding SEC Petition SEC-00084. This petition asks NIOSH to include Department of Energy (DOE) and contractor and subcontractor employees at Nevada Test Site (NTS) during the underground testing period (starting in 1963) in the SEC. In the report under review here (NIOSH 2009), NIOSH made a recommendation that NTS workers from January 1, 1963, to December 31, 1992, be added to the SEC, based on its conclusion that it cannot reconstruct internal doses for all members of the proposed class with sufficient accuracy (p. 5).

1.1 BACKGROUND

According to NIOSH, only about one-third of the workers at NTS have some bioassay data (NIOSH 2007, p. 15 and p. 35), necessitating a coworker model for the rest of the workers and possibly for some monitored workers who did not have data for some radionuclides for which they had exposure potential. In its report evaluating Petition SEC-00084, NIOSH stated that it had adequate data to reconstruct internal doses of unmonitored workers by constructing a coworker model based on data of 100 workers (NIOSH 2007, p. 36 and Table 7-1). The 100 workers were selected based on (1) "significant" cumulative external dose, and (2) the assumption that it was "most likely that significant internal exposure would be associated with significant external exposure" (NIOSH 2007, p. 35).

SC&A reviewed dosimetry data for the NIOSH group of 100 workers in Table 7-1 of the NIOSH Evaluation Report (NIOSH 2007), as well as data for a sample of 120 claimants, consisting of 20 workers drawn at random in each of 6 job types. SC&A's analysis was provided to the Advisory Board's Nevada Test Site Work Group in two reports (SC&A 2008, SC&A 2009). The conclusions of the two SC&A reports may be summarized as follows:

(1) Data for valid comparisons between the RadSafe group and the other workers are sparse to non-existent in most categories, such as for plutonium and gross fission products, and for most worker groups and periods (see also SC&A 2008). (Note: The periods used were 1963–1967, 1968–1970, 1971–1980, and 1981–1992.) Hence, it is not clear that RadSafe group data, the only group with data in all periods, could be used to create a coworker model. Moreover, the data indicate that miners had a higher exposure potential for tritium than the RadSafe group.

(2) The 95th percentile value of the NIOSH-100 plutonium bioassay data for the RadSafe worker group (and the whole group of 100 workers) is almost 6 times lower than the corresponding value of the SC&A RadSafe Group, indicating that the NIOSH group of 100 workers was not representative of the RadSafe workers or of NTS workers with the highest plutonium exposure potential.

(3) There are inconsistencies in plutonium and gamma bioassay data that raise questions about the quality of these data. These data quality and consistency issues are not addressed in the Evaluation Report.

(4) Cumulative external exposure of the group of 100 in Table 7-1 of NIOSH 2007 does not appear to be correlated with internal exposure potential, as reflected in the highest bioassay results or in the frequency of bioassay monitoring. Moreover, a large portion of the cumulative external exposure for this group was experienced prior to the SEC period under consideration.

(5) Table 7-1 over-represents tunnel workers compared to workers in the Flats, where most of the tests were conducted.

For the above reasons, SC&A concluded that NIOSH's selection of the 100 workers in Table 7-1 is inappropriate for the construction of an internal exposure coworker model for NTS workers. SC&A also concluded that NIOSH had not demonstrated the feasibility of a coworker model for unmonitored NTS workers (SC&A 2008, pp. 8–9).

During a Work Group meeting to discuss these findings, NIOSH agreed that the issue of internal dose needed to be revisited. NIOSH subsequently examined a large electronic database to determine whether it had sufficient data to build a reliable coworker model that would meet the requirements of 42 CFR 83, the regulation governing additions to the SEC. NIOSH's analysis and findings were reported in its November 2009 report (NIOSH 2009).

1.2 NIOSH 2009 REVIEW OF THE ELECTRONIC INTERNAL DOSIMETRY DATA

NIOSH's central conclusion was as follows:

> *As presented in this position paper, NIOSH believes that there is insufficient information to adequately support bounding internal dose (reconstructing internal dose with sufficient accuracy) for the portion of the SEC00084-NTS worker class who worked during the period of testing from 1963 through 1992.* [NIOSH 2009, p. 4]

NIOSH's conclusion regarding internal doses during the period was based on four findings:

> 1. *NIOSH has identified exposure scenarios involving varying job titles/duties and work activities, such as drill-backs, post-test work activities, and construction or other soil disturbing activities in areas that had been contaminated by previous tests. Prior to 1993, no source documentation could be located to confirm the rationale behind why bioassay samples were collected. Because of this, NIOSH cannot conclusively determine that doses to all of these potentially exposed individuals were detected by the bioassay program.*
>
>   *A review of the available data indicates a large number of radiological technicians and security personnel were routinely sampled. Other job*

titles/duties are also represented but a substantial fraction of the 'other' group of bioassay samples appears to have been collected on a more event or incident-driven basis. Although NIOSH does have access to site procedures and directives, NIOSH has not located sufficient documented evidence, other than anecdotal, to describe a consistent rationale behind the collection of personnel bioassay sampling or to indicate that sampling occurred consistently in the situations where it was required.

2. *NIOSH has identified data gaps that exist in the electronically available bioassay data for certain nuclides and time periods… that impact NIOSH's ability to bound the internal dose…*

3. *The nature of work at the NTS site and the large geographic area over which this work was conducted presents a unique challenge for bounding the internal doses at NTS. Unlike many production sites (i.e., SRS, Rocky Flats, Fernald, etc.), the NTS was primarily engaged in shorter-term campaign-driven activities that were separated by large distances, and there appears to be a direct relationship between campaigns and bioassay sampling. The concept of a campaign-driven bioassay sampling program is further supported by the fact that many of the periodic bioassay samples appear to have been collected on the same day. Because of the episodic nature of the exposures at NTS, a coworker model that is useful in reconstructing chronic intake scenarios would not necessarily be representative of the exposure patterns for the NTS workforce.*

4. *The reconstruction of internal doses at NTS is also complicated by the variety of the radionuclides to which workers may have been exposed. As indicated in the NTS site profile, the potential nuclide source-term included, but is not limited to, plutonium, americium, uranium, thorium, radium, iodine, and other fission products. For workers with no bioassay records, and who had the potential for exposure, NIOSH would have to definitively establish the relative mixture of the exposure source-term.*

NIOSH also stated that due to the end of testing in 1992, the promulgation of 10 CFR 835, and a documentable policy to adhere to it, NTS internal doses can be reconstructed from 1993 onward. Since SC&A's mandate from the Work Group in the present review extended only to matters related to the SEC petition, we have not reviewed the analysis or documentation underlying NIOSH's conclusion regarding the period starting in 1993.

1.3 FRAMEWORK FOR THIS REPORT

SC&A focused its review of NIOSH 2009 on the contents of the electronic database, which was analyzed to address the following questions:

- Was the pattern of monitoring revealed by the electronic database similar to or different from that observed by SC&A in its prior analysis referred to above (see SC&A 2008 and SC&A 2009)?
- Were there more data in the various worker categories and periods that would allow the identification of a group of workers who were at the highest exposure potential in the different categories of radionuclides for which data are necessary to estimate doses?
- Did the quality of data issues persist, or were they resolved by the new data?
- Did any new issues emerge regarding internal dose reconstruction not previously identified in the prior SC&A reports?
- Was NIOSH's overall technical analysis sustained by SC&A's prior analysis of the data and SC&A's review and analysis of the electronic database?
- Were NIOSH's conclusions regarding lack of sufficient data to reconstruct internal doses with sufficient accuracy robust?

It should be noted that SC&A worked from a set of Excel® spreadsheets prepared by NIOSH from the original database, which are in an older format. The references to the "electronic database" or "electronic data" in this report are to these Excel spreadsheets. SC&A did not attempt to verify the completeness or quality of the transcription of the original database to the multiple Excel spreadsheet format. Some observations on the issue of completeness and quality of the data in the electronic database, as reflected in the spreadsheets, are provided in this analysis.

2.0 ANALYSIS OF THE DATA

In order to analyze the monitoring practices of the six job types identified in SC&A's previous analyses (SC&A 2008, SC&A 2009), a connection had to be made between the workers contained in the new database and their job titles. Since the electronic database does not contain job classification information, only the subset of employees in the database who were claimants could be analyzed by job title. This occurs because job title data are only available in the NIOSH claimant database and not in the additional electronic bioassay database provided to and recently reviewed by NIOSH. The social security numbers (SSNs) for each worker in the database were matched to the SSNs listed for NTS claimants on NOCTS to determine which data entries represented the job titles that matched the six titles analyzed in SC&A 2008 and SC&A 2009.

The electronic database provided monitoring results for seven different radionuclides—americium, beta/gross fission products, gamma, plutonium, strontium, tritium, and uranium. Three of these radionuclides (americium, strontium, and uranium) had very sparse data and therefore could not provide substantial insight into the monitoring practices associated with these contaminants. Therefore, these three radionuclides could not be analyzed in the same depth as the other four; however, they are discussed briefly in Section 3.6.

The vast majority of data entries were urinalysis samples given in the units of microcurie per cc (MI/cc); however, other bioassay types and units were also occasionally listed. For example, several data entries were listed as whole-body scans that did not have an associated result included. In addition, many urinalysis samples were given in units other than MI/cc, such as total microcurie, disintegrations per minute, millicurie/cc. In order to analyze the magnitude of the bioassay entries for various categories of workers, the data had to be normalized to a consistent set of units and bioassay types. Furthermore, while whole-body counts are listed in the electronic database as having been performed, it does not contain any actual measurements. Therefore, all non-urinalysis samples were removed for the purposes of characterizing the magnitude of the intakes experienced by the workers and comparing them to previously compiled data.[2] Urinalysis samples that could not be converted to MI/cc, or reasonably assumed to be in these units, were removed. Any data entries designated as 'Less than' or 'Not Detectable' were assumed to be zero. Blank entries with no indication that the sample was 'not detectable' or 'less than' were removed, because there was insufficient evidence that the sample was ever analyzed. It is important to note that the removal of samples was only for the purposes of analyzing the 'concentration in urine,' and does not apply when characterizing the total number of samples, number of workers sampled, and frequency of monitoring for the designated worker categories and time periods. It also should be noted that only a small proportion of the data, less than 9% for the 4 major radionuclides, had to be removed in this way. The largest percentage of samples removed occurred for plutonium (15.35%), which is a result of the large number of whole-body scans included in this dataset (accounting for roughly 12.5% of the data entries). The 3 remaining radionuclides had approximately 5%, 8%, and 10% of their samples

[2] The number of whole-body counts listed in the electronic database is noted in this analysis to provide an idea of the relative magnitude of urine bioassay data used to whole-body counting data that could not be used, since no measurements were available in the electronic database for these counts.

removed for beta, tritium, and gamma, respectively. So the analysis provided here is based on the vast majority of monitoring data in the electronic database.

The data for claimants as compiled by SC&A from the electronic database and NIOSH's NOCTS database for claimants are available in spreadsheets on the O-Drive for NIOSH and the Board. The original spreadsheets compiled by NIOSH are also available on the O-Drive. All these data contain names and SSNs of workers and are protected by the Privacy Act.

3.0 RESULTS

The following subsections present the bioassay data for the claimants in the electronic database, sorted by job category for the four main monitoring categories:

- Plutonium
- Gamma
- Beta (Gross Fission Products)
- Tritium

Each subsection contains a set of tables that show an overview of the data (how many samples, how many workers sampled, etc.); data characteristics (number of positive, negative, zero, less than, blank, and non-detectable results); number of samples by designated period; and the number of samples per worker given as a rank order at the 50^{th}, 75^{th}, and 95^{th} percentiles. In addition to the tables, three chart types are presented that show the number of workers monitored in any given year; the rank ordered concentration in urine for all workers in the database, as well as the identified job types, with data from all timeframes group together; and finally the rank ordered 50^{th} percentile concentration in urine for all workers as a function of year.

These tables and charts are designed to enable a comparison with previously analyzed data in these four bioassay and six job categories. For instance, the samples by period show that the RadSafe group was the most consistently monitored, and the security group was also monitored in the 1980s and early 1990s. Furthermore, the cumulative distribution functions for each bioassay group in charts labeled "Rank-Ordered [Bioassay type] Concentration in Urine," are designed to provide an overview of the relative magnitudes of the bioassay measurements for the various groups of workers. These charts are discussed in terms of their implications for a coworker model in Section 4. In reviewing them, it must be kept in mind that these charts of rank-ordered bioassay measurements contain no separation of values by period. A parsing by period is important. The last figure in each set shows that, for the most part, bioassay results in the early part of the SEC period (roughly the decade starting in 1963) are generally higher than those in later periods.

However, in most cases, the data are too sparse to construct cumulative distribution functions by period that would allow comparison of bioassay results by job type. Hence, the rank-ordered charts by job type show all data for each job type without regard to period. These charts allow one to determine the probability that the bioassay measurement will be less than a particular amount for a given type of bioassay. For instance, the rank ordering of gamma bioassay by job type shows that there is a 60% probability that the bioassay value for the RadSafe job type will be less than about 1.2×10^{-7} MI/cc, while that for laborers is considerably higher at about 1×10^{-6} MI/cc. This would usually indicate a greater exposure potential for laborers relative to RadSafe workers. However, as we will see below, the interpretation of much of the NTS bioassay data is rendered complex by the presence in many situations of a large number of short-lived radionuclides, and by the apparent incident-driven nature of much of the sampling.

3.1 PLUTONIUM

Table 3-1: Overview of Plutonium Data

Plutonium Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Pu	
Data Overview								
Total Samples	468	18	[redacted]	[redacted]	25	227	952	9,273
# Individuals	40	[redacted]	[redacted]	[redacted]	15	29	144	2,518
Urine Samples	430 (91.88%)	14 (77.78%)	[redacted] (100.00%)	–	19 (76.00%)	178 (78.41%)	826 (86.76%)	8,116 (87.52%)
Whole-Body Counts	38 (8.12%)	[redacted] (22.22%)	–	[redacted] (100.00%)	[redacted] (24.00%)	49 (21.59%)	126 (13.24%)	1,157 (12.48%)
Pu-239	467 (99.79%)	18 (100.00%)	[redacted] (71.43%)	[redacted] (100.00%)	24 (96.00%)	220 (96.92%)	933 (98.00%)	Not Counted
Pu-238	[redacted] (0.21%)	–	[redacted] (28.57%)	–	[redacted] (4.00%)	[redacted] (3.08%)	19 (2.00%)	Not Counted
Data Characteristics								
Number of Positive Results	361 (77.14%)	12 (66.67%)	[redacted] (57.14%)	–	13 (52.00%)	160 (70.48%)	694 (72.90%)	6,598 (71.15%)
Number of Results Listed as 'Less than'[3]	38 (8.12%)	–	–	–	[redacted] (16.00%)	–	60 (6.30%)	509 (5.49%)
Number of Negative Results	26 (5.56%)	[redacted] (11.11%)	[redacted] (42.86%)	–	[redacted] (8.00%)	13 (5.73%)	60 (6.30%)	831 (8.96%)
Number of Zero Results	[redacted] (1.07%)	–	–	–	–	[redacted] (2.20%)	12 (1.26%)	167 (1.80%)
Number of Results listed as 'No Detectable'	–	–	–	–	–	–	–	[redacted]
Number of Blank Results	38 (8.12%)	[redacted] (22.22%)	–	[redacted] (100.00%)	[redacted] (24.00%)	49 (21.59%)	126 (13.24%)	1,167 (12.58%)
# of Samples by Period								
Total Samples	468	18	[redacted]	[redacted]	25	227	952	9,273
1963–1967	10 (2.14%)	–	–	–	–	–	10 (1.05%)	133 (1.43%)
1968–1970	44 (9.40%)	–	[redacted] (28.57%)	–	[redacted] (32.00%)	[redacted] (1.76%)	92 (9.66%)	741 (7.99%)
1971–1980	226 (48.29%)	[redacted] (16.67%)	–	–	[redacted] (32.00%)	25 (11.01%)	354 (37.18%)	2,756 (29.72%)
1981–1992	188 (40.17%)	15 (83.33%)	[redacted] (71.43%)	[redacted] (100.00%)	[redacted] (36.00%)	198 (87.22%)	496 (52.10%)	5,643 (60.85%)

[3] These data entries appear with an 'LT' in the detection column and either a zero or a blank entry in the analyze amount column. This applies to all four radionuclide types except where noted for gamma.

Table 3-1: Overview of Plutonium Data

Plutonium Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Pu	
Rank Ordered Percentile of Samples per Claimant/Worker								
# Individuals	40	[redacted]	[redacted]	[redacted]	15	29	144	2,518
50th Percentile # Samples	10	[redacted]	[redacted]	–	[redacted]	7.5	[redacted]	[redacted]
75th Percentile # Samples	17	[redacted]	[redacted]	–	[redacted]	11	[redacted]	[redacted]
95th Percentile # Samples	29	[redacted]	[redacted]	–	[redacted]	14.1	23.6	13
Maximum # Samples	30	[redacted]	[redacted]	[redacted]	[redacted]	16	30	31

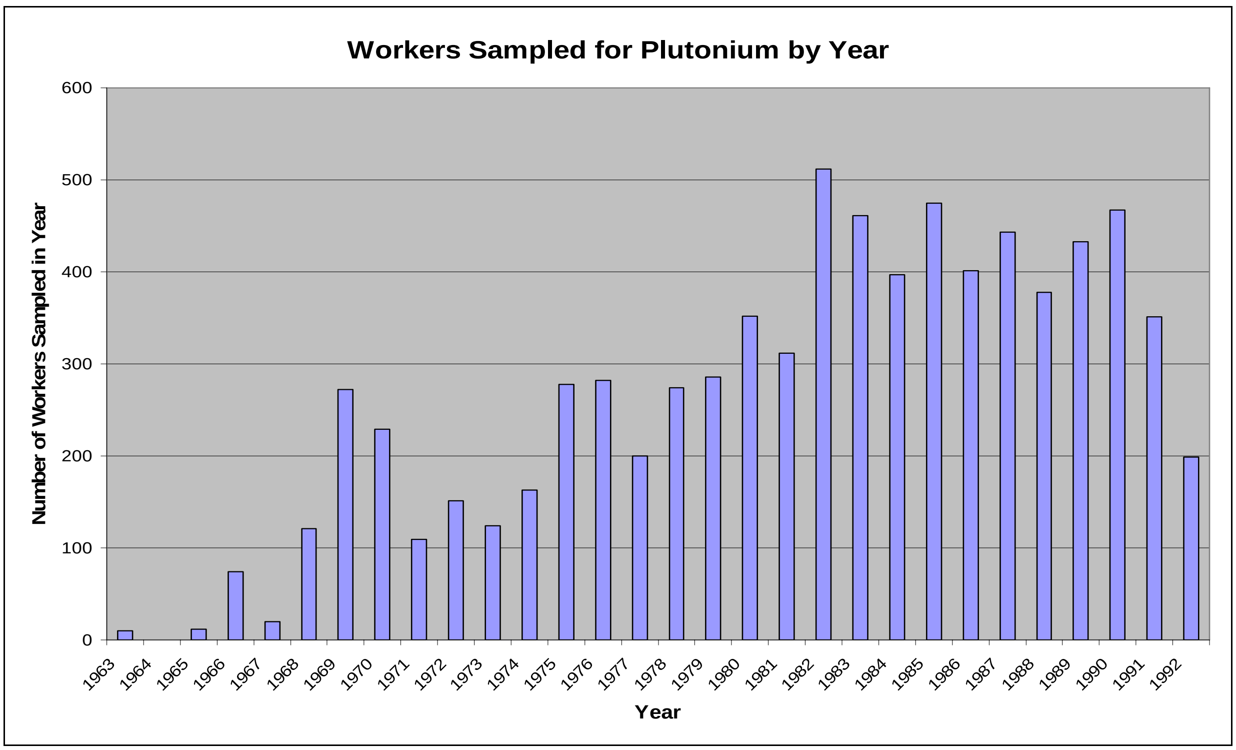

Figure 3-1: Workers Sampled for Plutonium by Year

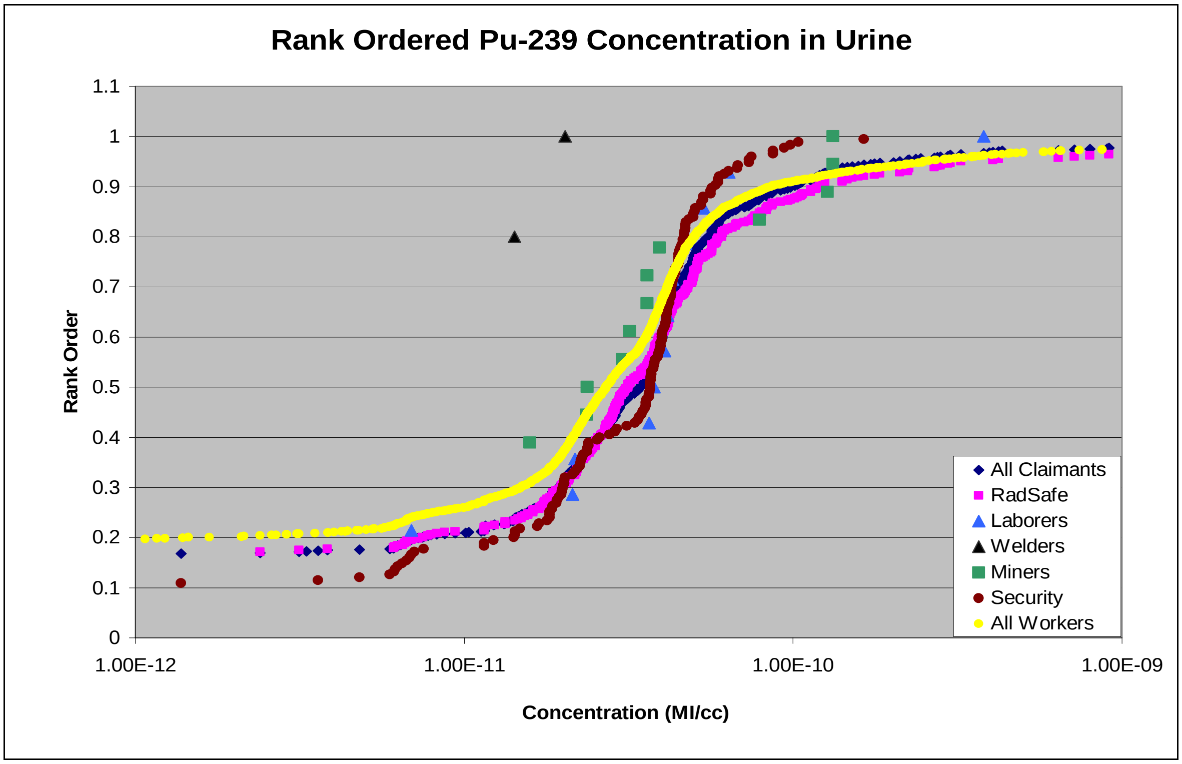

Figure 3-2: Rank-Ordered Plutonium-239 Concentration in Urine

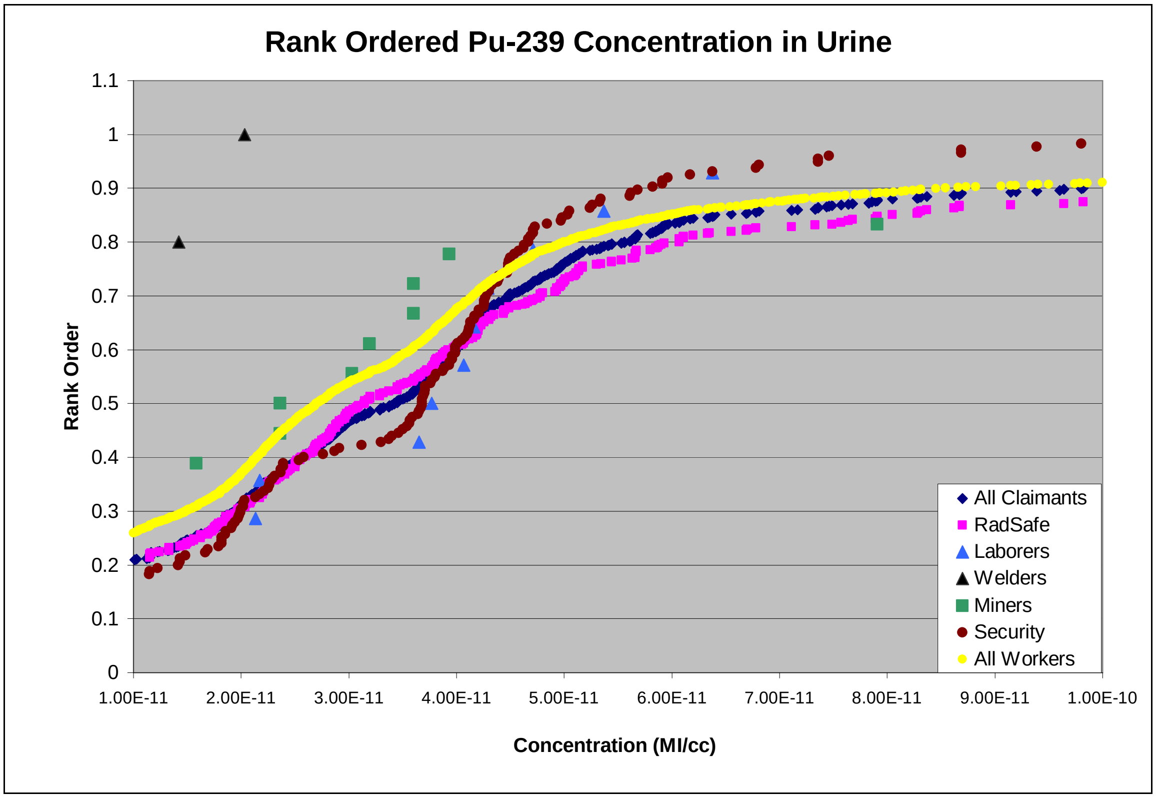

Figure 3-3: Rank-Ordered Pu-239 Concentration in Urine – Expanded Horizontal Axis

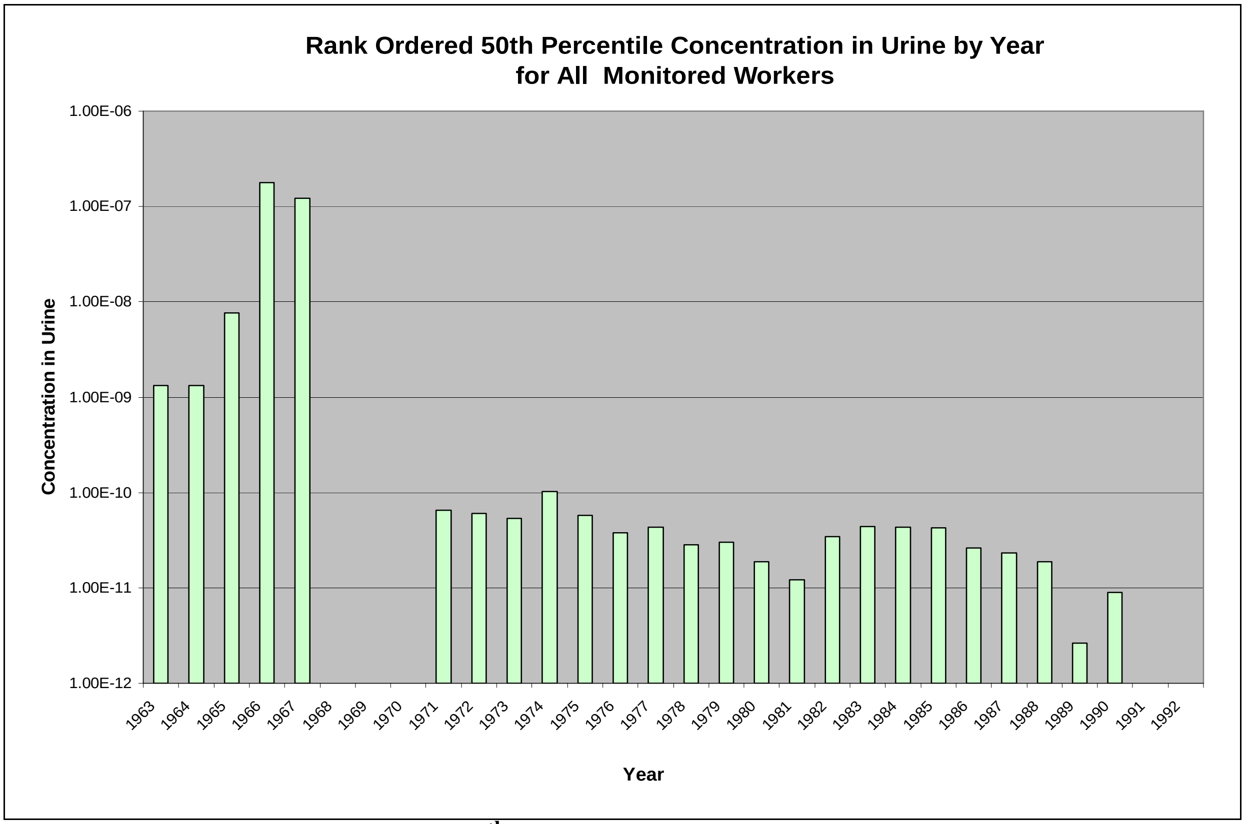

Figure 3-4: Rank-Ordered 50th Percentile Concentration in Urine by Year for All Monitored Workers

3.2 GAMMA

Table 3-2: Overview of Gamma Data

Gamma Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Gamma	
Data Overview								
Total Samples	2658	153	47	15	407	875	5343	46,767
# Individuals	46	24	12	10	47	35	280	5,093
Urine Samples	2627 (98.83%)	139 (90.85%)	46 (97.87%)	14 (93.33%)	384 (94.35%)	834 (95.31%)	5209 (97.49%)	45,404 (97.09%)
Whole-Body Counts	31 (1.17%)	14 (9.15%)	[redacted] (2.13%)	[redacted] (6.67%)	23 (5.65%)	41 (4.69%)	134 (2.51%)	1,363 (2.91%)

Table 3-2: Overview of Gamma Data

Gamma Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Gamma	
Data Characteristics								
Number of Positive Results	1928 (72.54%)	94 (61.44%)	41 (87.23%)	11 (73.33%)	322 (79.12%)	286 (32.69%)	3561 (66.65%)	30,629 (65.49%)
Number of Results Listed as 'Less than'*	70 (2.63%)	–	–	–	[redacted] (1.47%)	–	100 (1.87%)	786 (1.68%)
Number of Negative Results	–	–	–	–	–	–	–	–
Number of Zero Results	219 (8.24%)	11 (7.19%)	[redacted] (6.38%)	–	18 (4.42%)	150 (17.14%)	476 (8.91%)	5,037 (10.77%)
Number of Results listed as 'No Detectable'	410 (15.43%)	34 (22.22%)	[redacted] (4.26%)	[redacted] (20.00%)	36 (8.85%)	398 (45.49%)	1070 (20.03%)	8,932 (19.10%)
Number of Blank Results	31 (1.17%)	14 (9.15%)	[redacted] (2.13%)	[redacted] (6.67%)	25 (6.14%)	41 (4.69%)	136 (2.55%)	1,383 (2.96%)
# of Samples by Period								
Total Samples	2,658	153	47	15	407	875	5,343	46,767
1963–1967	204 (7.67%)	31 (20.26%)	11 (23.40%)	[redacted] (13.33%)	72 (17.69%)	[redacted] (0.46%)	489 (9.15%)	4,916 (10.51%)
1968–1970	306 (11.51%)	12 (7.84%)	[redacted] (4.26%)	–	36 (8.85%)	[redacted] (0.23%)	502 (9.40%)	3,503 (7.49%)
1971–1980	1,065 (40.07%)	41 (26.80%)	[redacted] (10.64%)	[redacted] (40.00%)	149 (36.61%)	32 (3.66%)	1,740 (32.57%)	10,200 (21.81%)
1981–1992	1,083 (40.74%)	69 (45.10%)	29 (61.70%)	[redacted] (46.67%)	150 (36.86%)	837 (95.66%)	2,612 (48.89%)	28,148 (60.19%)
Rank Ordered Percentile of Samples per Claimant/Worker								
# Individuals	46	24	12	10	47	35	280	5,093
50th Percentile # Samples	34	[redacted]	[redacted]	[redacted]	[redacted]	24.5	[redacted]	[redacted]
75th Percentile # Samples	85	[redacted]	[redacted]	[redacted]	10.25	37.25	22	[redacted]
95th Percentile # Samples	180.9	20	12.2	[redacted]	27.3	45.75	85	39
Maximum # Samples	234	36	17	[redacted]	38	52	234	234

* One entry had internally inconsistent information. It was listed as 'LT' in the "detection" column and as a positive result in the "analyze amount" column. We chose to count this entry towards the positive results and not the 'less than' result totals. This was the only instance of a positive result associated with a 'less than' tag for any of the four major radionuclides.

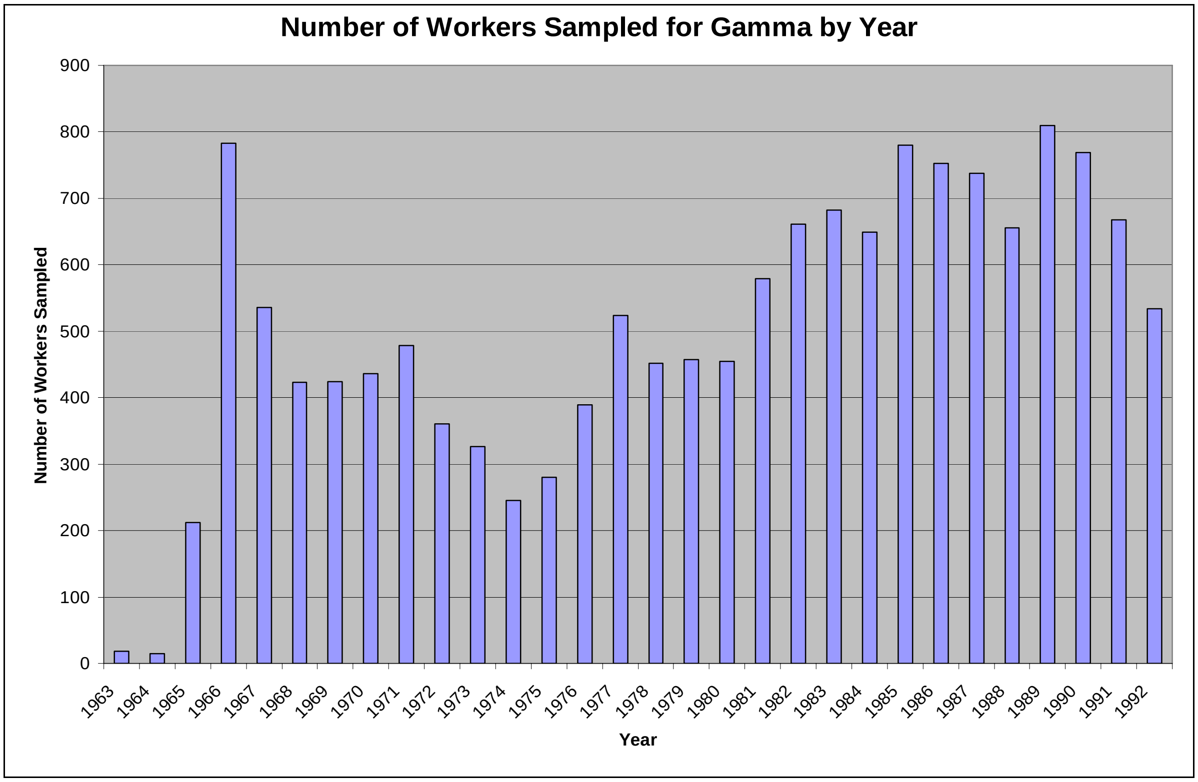

Figure 3-5: Number of Workers Sampled for Gamma by Year

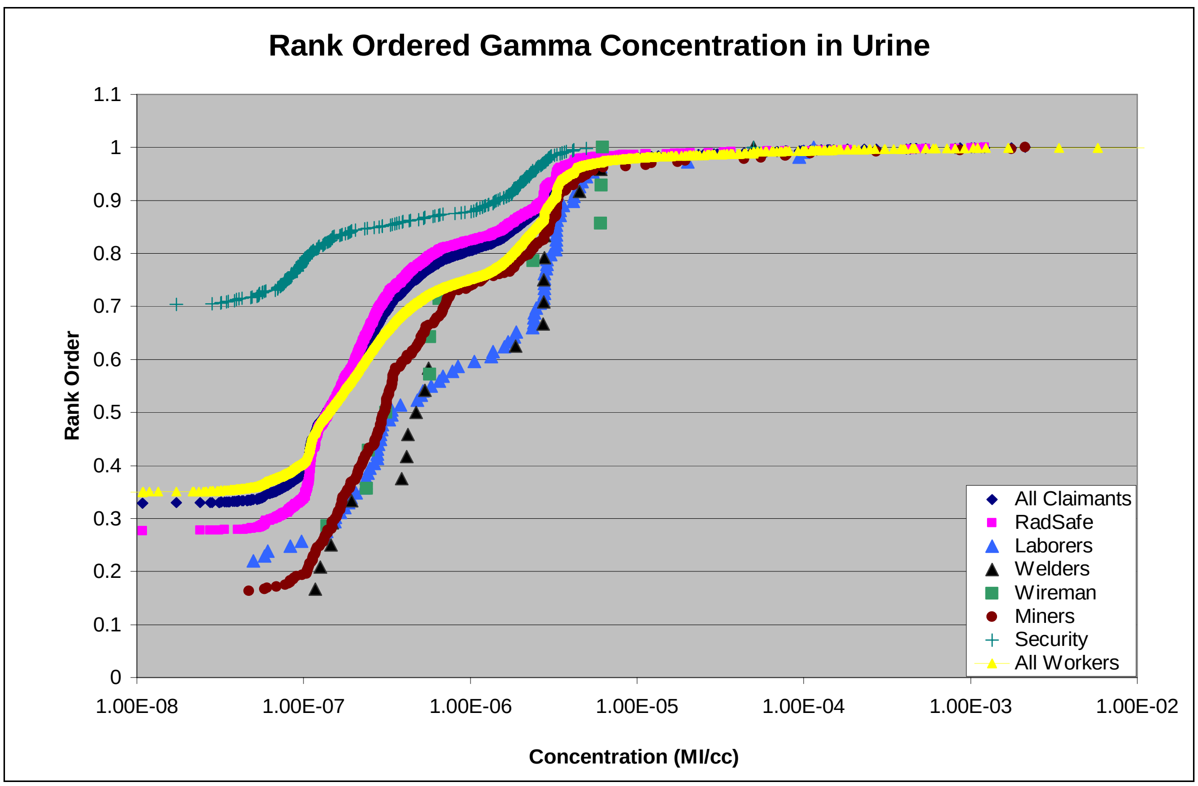

Figure 3-6: Rank-Ordered Gamma Concentration in Urine

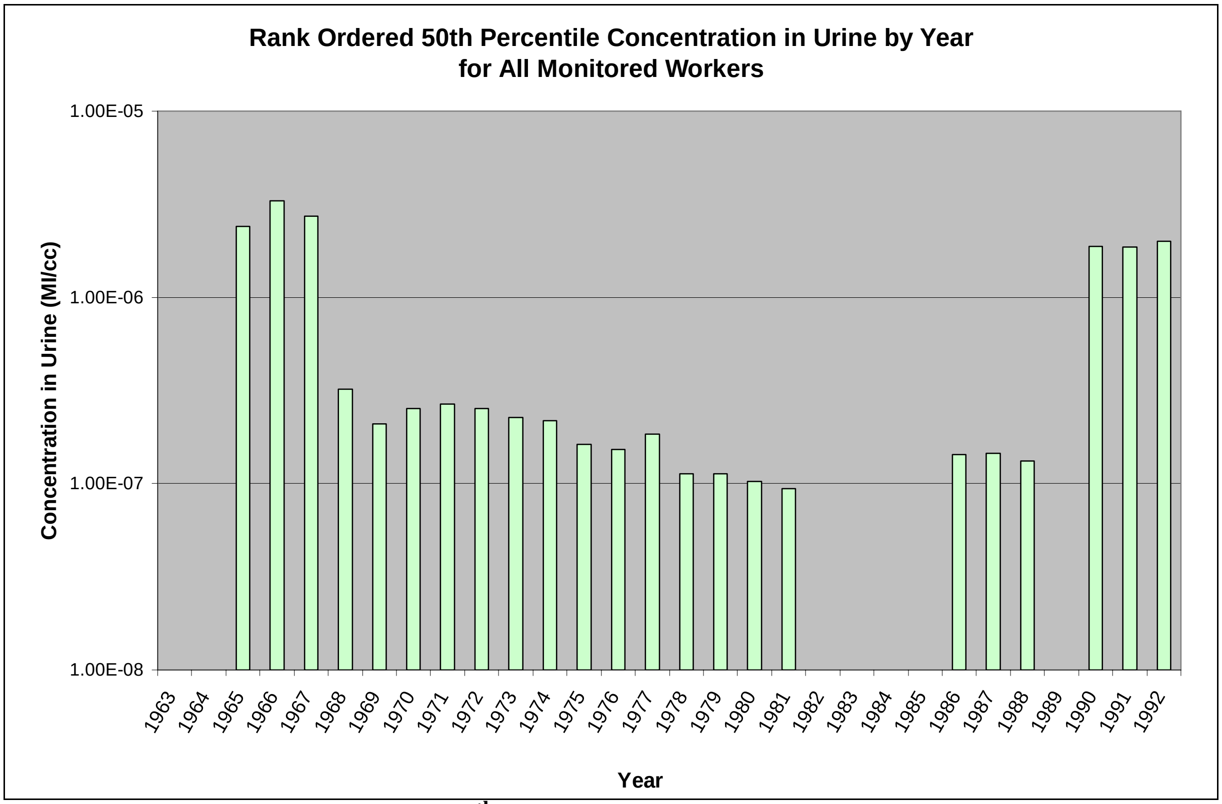

Figure 3-7: Rank-Ordered 50th Percentile Concentration in Urine by Year for All Monitored Workers

3.3 BETA

Table 3-3: Overview of Beta Data

Beta Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Beta	
Data Overview								
Total Samples	1,173	44	12	[redacted]	42	597	2,362	22,308
# Individuals	40	[redacted]	[redacted]	[redacted]	14	29	138	2,671
Urine Samples	1,157 (98.64%)	44 (100.00%)	11 (91.67%)	[redacted] (50.00%)	39 (92.86%)	591 (98.99%)	2,327 (98.52%)	21,949 (98.39%)[4]
Whole-Body Counts	16 (1.36%)	–	[redacted] (8.33%)	[redacted] (50.00%)	[redacted] (7.14%)	[redacted] (1.01%)	35 (1.48%)	358 (1.60%)

[4] There was also one wound swab included in the database for beta.

Table 3-3: Overview of Beta Data

Beta Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Beta	
Data Characteristics								
Number of Positive Results	1,137 (96.93%)	43 (97.73%)	11 (91.67%)	[redacted] (50.00%)	36 (85.71%)	585 (97.99%)	2,292 (97.04%)	20,946 (93.89%)
Number of Results Listed as 'Less than'	17 (1.45%)	–	–	–	–	–	21 (0.89%)	135 (0.61%)
Number of Negative Results	[redacted] (0.26%)	[redacted] (2.27%)	–	–	[redacted] (2.38%)	[redacted] (0.84%)	10 (0.42%)	180 (0.81%)
Number of Zero Results	–	–	–	–	–	–	–	–
Number of Results listed as 'No Detectable'	–	–	–	–	–	[redacted] (0.17%)	[redacted] (0.04%)	[redacted]
Number of Blank Results	16 (1.36%)	–	[redacted] (8.33%)	[redacted] (50.00%)	[redacted] (11.90%)	[redacted] (1.01%)	38 (1.61%)	1,041 (4.67%)
# of Samples by Period								
Total Samples	1,173	44	12	[redacted]	42	597	2,362	22,308
1963–1967	37 (3.15%)	[redacted] (6.82%)	–	–	[redacted] (7.14%)	–	59 (2.50%)	1,148 (5.15%)
1968–1970	112 (9.55%)	–	–	–	[redacted] (9.52%)	–	169 (7.15%)	1,120 (5.02%)
1971–1980	497 (42.37%)	–	–	[redacted] (50.00%)	18 (42.86%)	[redacted] (0.67%)	685 (29.00%)	4,614 (20.68%)
1981–1992	527 (44.93%)	41 (93.18%)	12 (100.00%)	[redacted] (50.00%)	17 (40.48%)	593 (99.33%)	1,449 (61.35%)	15,426 (69.15%)
Rank Ordered Percentile of Samples per Worker								
# Individuals	40	[redacted]	[redacted]	[redacted]	14	29	138	2,671
50th Percentile # Samples	22	[redacted]	[redacted]	[redacted]	[redacted]	21.5	10	[redacted]
75th Percentile # Samples	50	10.75	[redacted]	[redacted]	[redacted]	27.75	26	10
95th Percentile # Samples	69	17.75	10	[redacted]	[redacted]	35.75	58.1	32
Maximum # Samples	77	20	11	[redacted]	10	45	77	88

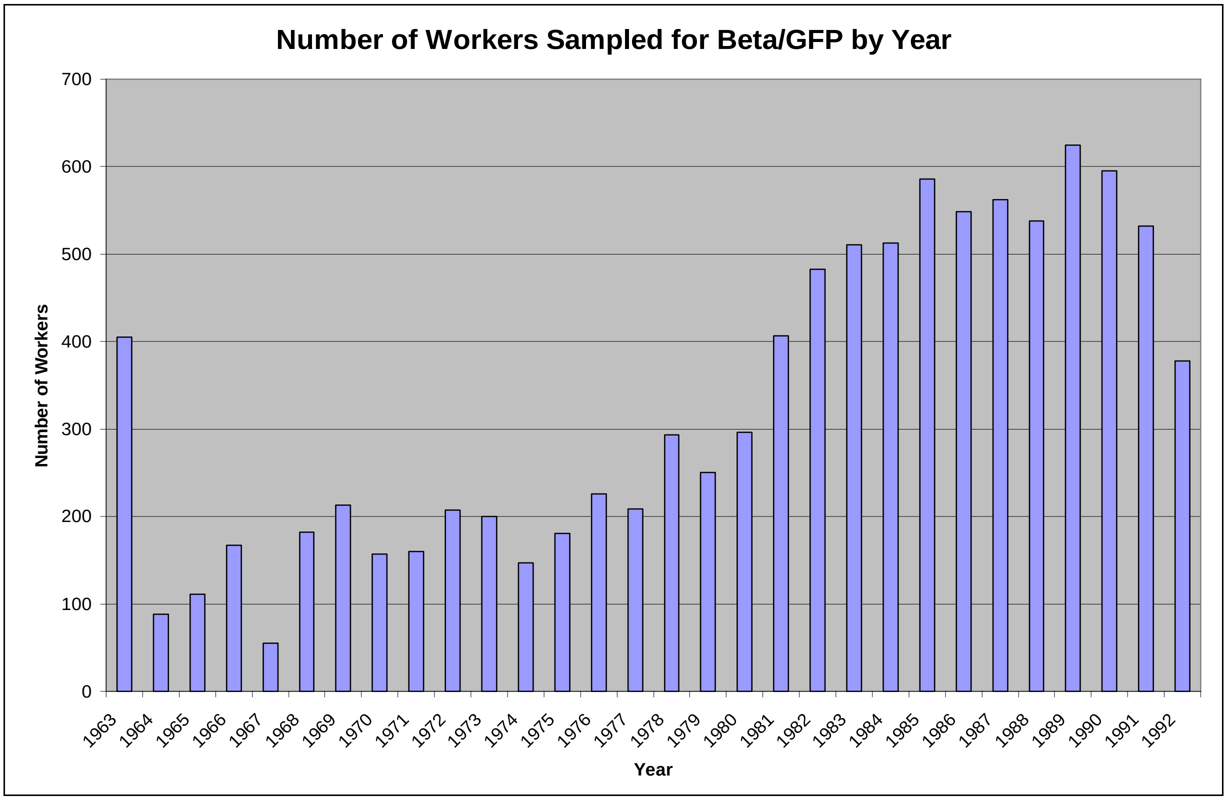

Figure 3-8: Number of Workers Sampled for Beta/GFP by Year

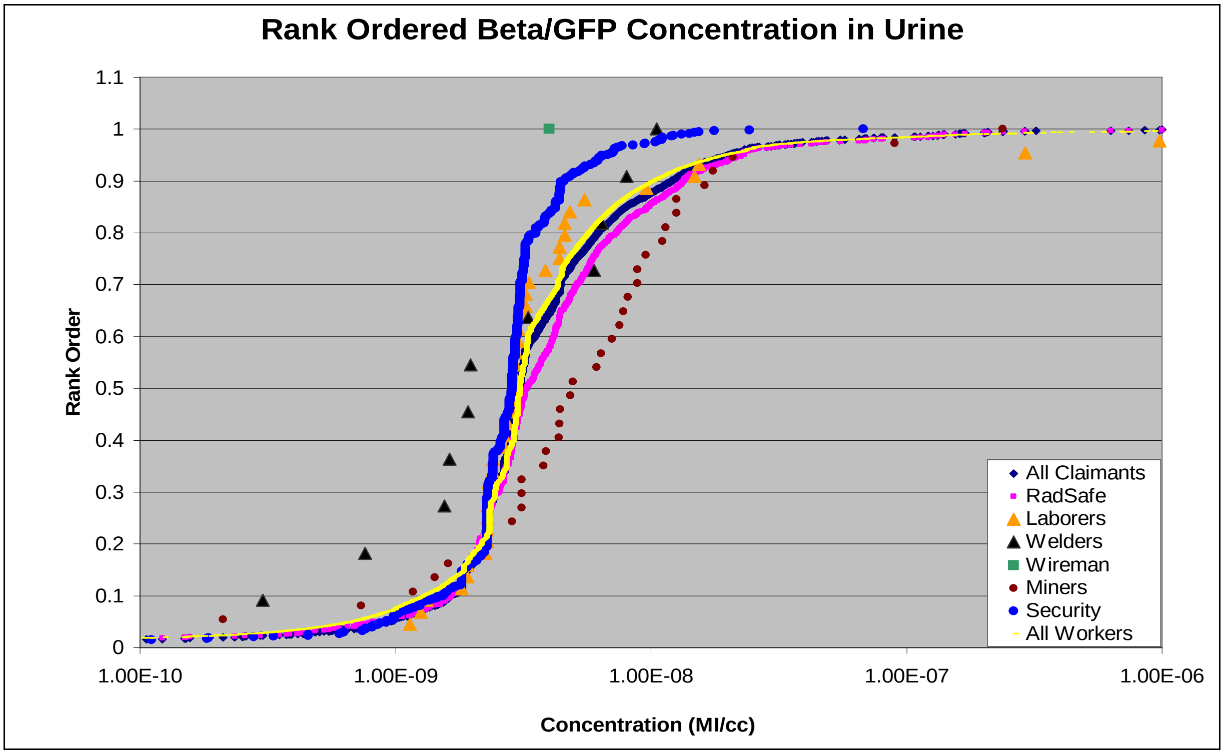

Figure 3-9: Rank-Ordered Beta/GFP Concentration in Urine

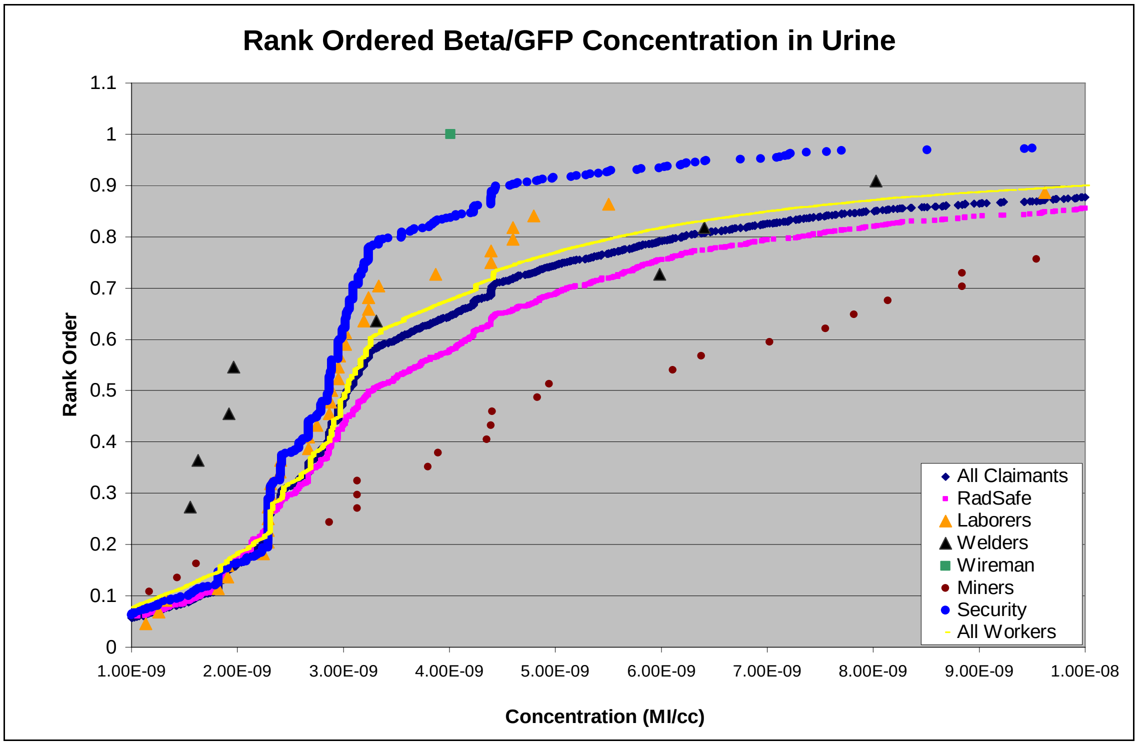

Figure 3-10: Rank-Ordered Beta/GFP Concentration in Urine – Expanded Horizontal Axis

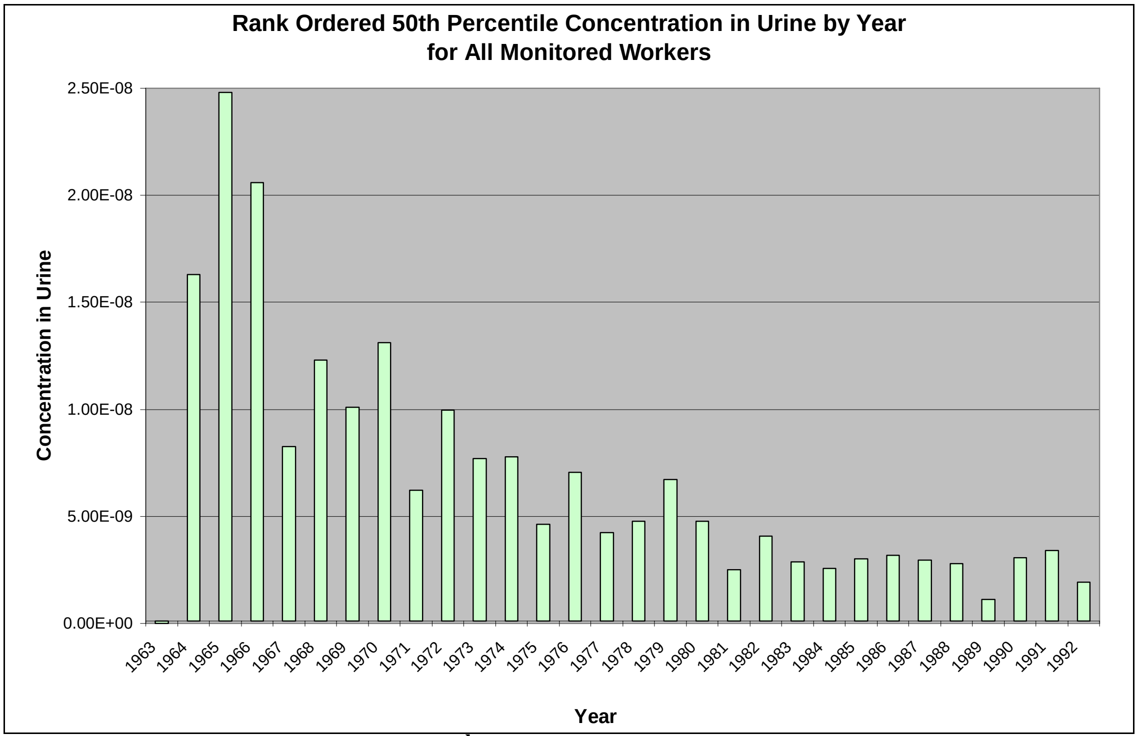

Figure 3-11: Rank-Ordered 50th Percentile Concentration in Urine by Year for All Monitored Workers

3.4 TRITIUM

Table 3-4: Overview of Tritium Data

Tritium Data	Claims							All Workers in Database
	RadSafe	Laborers	Welders	Wireman	Miners	Security	All Claimant Pu	
Data Overview								
Total Samples	1,985	221	39	37	822	826	4,977	42,748
# Individuals	13	17	[redacted]	13	50	34	244	4,724
Urine Samples	1,900 (95.72%)	207 (93.67%)	35 (89.74%)	31 (83.78%)	762 (92.70%)	764 (92.49%)	4,673 (93.89%)	40,253 (94.16%)
Whole-Body Counts	85 (4.28%)	14 (6.33%)	[redacted] (10.26%)	[redacted] (16.22%)	60 (7.30%)	62 (7.51%)	304 (6.11%)	2,495 (5.84%)
Data Characteristics								
Number of Positive Results	1,718 (86.55%)	202 (91.40%)	29 (74.36%)	28 (75.68%)	722 (87.83%)	755 (91.40%)	4,320 (86.80%)	36,199 (84.68%)
Number of Results Listed as 'Less than'	148 (7.46%)	[redacted] (1.36%)	[redacted] (5.13%)	[redacted] (5.41%)	23 (2.80%)	[redacted] (0.36%)	276 (5.55%)	2,448 (5.73%)
Number of Negative Results	21 (1.06%)	[redacted] (0.45%)	[redacted] (10.26%)	–	[redacted] (0.12%)	[redacted] (0.73%)	41 (0.82%)	602 (1.41%)
Number of Zero Results	13 (0.65%)	–	–	–	[redacted] (0.24%)	–	19 (0.38%)	135 (0.32%)
Number of Results listed as 'No Detectable'	–	–	–	–	–	–	–	[redacted]
Number of Blank Results	85 (4.28%)	15 (6.79%)	[redacted] (10.26%)	[redacted] (18.92%)	74 (9.00%)	62 (7.51%)	321 (6.45%)	3,361 (7.86%)
# of Samples by Period								
Total Samples	1,985	221	39	37	822	826	4,977	42,748
1963–1967	42 (2.12%)	[redacted] (2.71%)	[redacted] (5.13%)	[redacted] (8.11%)	57 (6.93%)	[redacted] (0.36%)	179 (3.60%)	2,753 (6.44%)
1968–1970	167 (8.41%)	[redacted] (3.62%)	–	–	48 (5.88%)	[redacted] (0.12%)	322 (6.47%)	2,616 (6.12%)
1971–1980	923 (46.50%)	69 (31.22%)	[redacted] (15.38%)	28 (75.68%)	393 (47.81%)	35 (4.24%)	1,929 (38.76%)	11,108 (25.98%)
1981–1992	853 (42.97%)	138 (62.44%)	31 (79.49%)	[redacted] (16.22%)	324 (39.42%)	787 (95.28%)	2,547 (51.18%)	26,271 (61.46%)
Rank Ordered Percentile of Samples per Worker								
# Individuals	13	17	[redacted]	13	50	34	244	4,724
50^{th} Percentile # Samples	18	[redacted]	[redacted]	[redacted]	[redacted]	22	[redacted]	[redacted]
75^{th} Percentile # Samples	28.5	10.25	5.25	[redacted]	15	38.5	26	[redacted]
95^{th} Percentile # Samples	118.7	40.5	12.3	7.7	84.5	43	83.8	40
Maximum # Samples	120	100	15	[redacted]	110	48	138	162

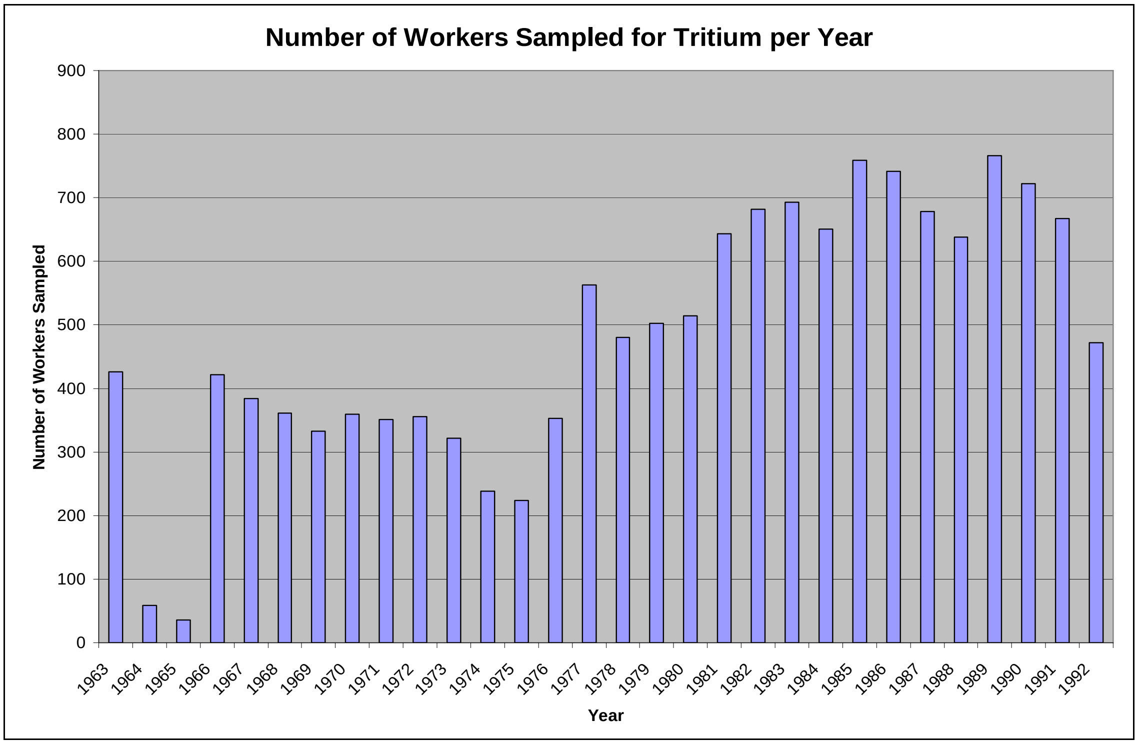

Figure 3-12: Number of Workers Sampled for Tritium by Year

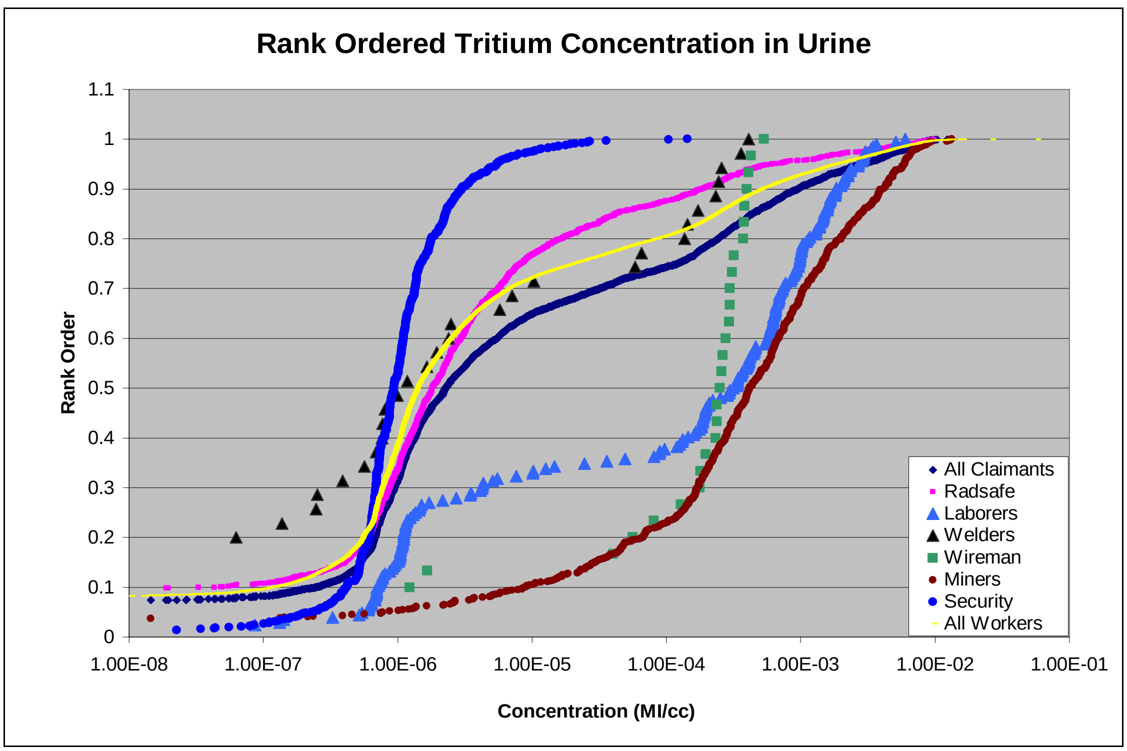

Figure 3-13: Rank-Ordered Tritium Concentration in Urine

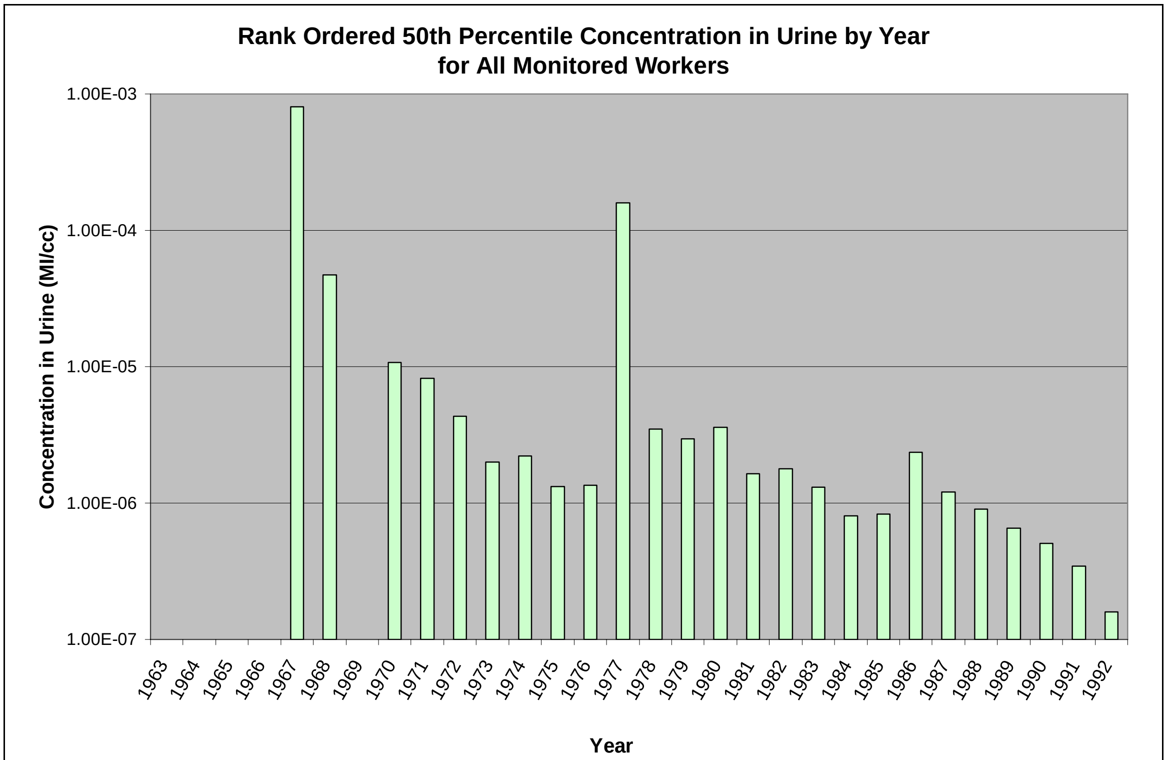

Figure 3-14: Rank-Ordered 50th Percentile Concentration in Urine by Year for All Monitored Workers

3.5 STATISTICAL ANALYSIS REGARDING MONITORING PATTERN

Figure 3-15 contains a plot of the plutonium-239 biosamples in the electronic database that were matched to a claimant and hence, to a job type. Only Pu-239 samples are included in this plot.[5] The plot shows samples for five groups of claimants; RadSafe workers, security workers, miners, laborers and welders.[6] The number of samples in each job category is shown in the key in parentheses. While the samples from the RadSafe worker claimants span the entire period, the samples from security worker claimants are almost all in the period after 1980. The small number of samples from miners and laborers are scattered throughout the time period. The [[redacted]] in this dataset had samples only in the late 1980s and early 1990s.

The samples for the five job categories are displayed in a percentile plot in Figure 3-16. A similar plot using the normal score of each sample value on the horizontal axis is shown in Figure 3-17. NIOSH typically has used the normal score plot to estimate the parameters of a lognormal distribution for use in a coworker model. If the plutonium-239 sample values came

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[5] Plutonium-239 records were identified by the analyte description code values of 06 and 11, as documented in Table A-1 of ORAUT 2008b. Many of these records had contradictory comments in the database fields titled Comment 1 and Comment 2, indicating Pu-239 in the Comment 1 field and Pu-238 in the Comment 2 field. In these cases, information in the Comment 2 field was ignored.

[6] The sixth category, "wiremen," could not be included in the analysis in this section, since there was only [[redacted]] in this category in the electronic database with just one plutonium bioassay sample.

from a lognormal distribution, the plots in Figure 3-17 would appear as approximately straight lines. Although the plot for security workers appears to be approximately linear in the upper half of the plot, the plot for the RadSafe workers has a highly non-linear shape, with an extremely high upper tail extending to over a factor of 100 times higher than the remainder of the distribution. The high tail values may indicate that the plutonium-239 data in the electronic database includes incident-related samples, combined with the results from a more routine sampling program.

Normal score plots for gross gamma concentration in urine for claimants in five job categories are displayed in Figure 3-18. The plots for all job types except welders have a non-linear shape, with upper tails extending much higher than the remainder of the distribution. The high tail values may indicate that the gross gamma data in the electronic database have incident-related samples included with routine sampling results. Only one matched claimant was identified as a [redacted], with samples in a single time period from the late 1980s to the early 1990s.

Normal score plots for gross beta concentrations in urine are shown in Figure 3-19. Again, the plots for all categories of workers except welders have a non-linear shape, with upper tails extending much higher than the remainder of the distribution. These high tail values may indicate that the gross beta data in the electronic database also include incident-related samples, combined with routine sampling results.

Figure 3-20 contains plots of tritium concentrations in urine for the five categories of workers. Although the tritium plots have non-linear shapes, there are no unusual values in the upper tails. The tritium data in the electronic database appear to be mainly part of a routine monitoring program during the period under consideration.

The number of Pu-239 biosamples was sufficient to construct plots for the RadSafe and security worker claimants by decade. A percentile plot for the RadSafe claimant samples in the electronic database by decade from the 1960s to the 1990s is shown in Figure 3-21. Note that the plot for the 1960s begins at a percentile value of approximately 80%, since approximately 80% of the samples' values were below the minimum detection limit (MDL). Data points below the MDL are not shown in this type of graph, but these data points do affect the position in the plot of the first sample value that is above the MDL.

Figure 3-22 contains a normal score plot for the RadSafe claimant samples for the four decades. All four decades have nonlinear plots. These distributions do not appear to be lognormal. In the 1960s, 80% of the samples are below the MDL, while the remaining samples are among the highest in the database. In each decade after the 1960s, the upper tails contain high outliers. These patterns are indicative of biosamples collected from RadSafe workers involved in high-exposure incidents at the site that are combined with samples from a more routine, ongoing sampling program. It is also important to note that apart from some samples in the early 1980s, possibly incident-driven, the highest bioassay concentrations of plutonium-239 for RadSafe workers are in the 1960s, despite the fact that this period had the smallest rate of sampling for this group of workers.

A percentile plot is shown in Figure 3-23 for the security worker claimants. The security worker biosamples cover only the 1981–1992 period. The normal score plot for security workers in Figure 3-24 is non-linear in the 1980s, although the upper tail is well behaved with no extreme outliers. The security worker biosamples appear to be the results of a regular sampling program, with no evidence of unusual incidents. The plot for the much smaller number of security worker samples in the 1990s begins at over 60%, indicating that well over half of the samples were below the MDL. The early 1990s samples may have an approximately lognormal-shaped distribution in the upper tail. This indicates that security personnel sampling for plutonium for the early 1990s may also have been of the routine variety. This contrasts with indications of mixed incident-driven and routine sampling for the RadSafe group. Most other data, except tritium, for the rest of the job types indicate either incident-driven sampling or mixed incident-driven and routine sampling.

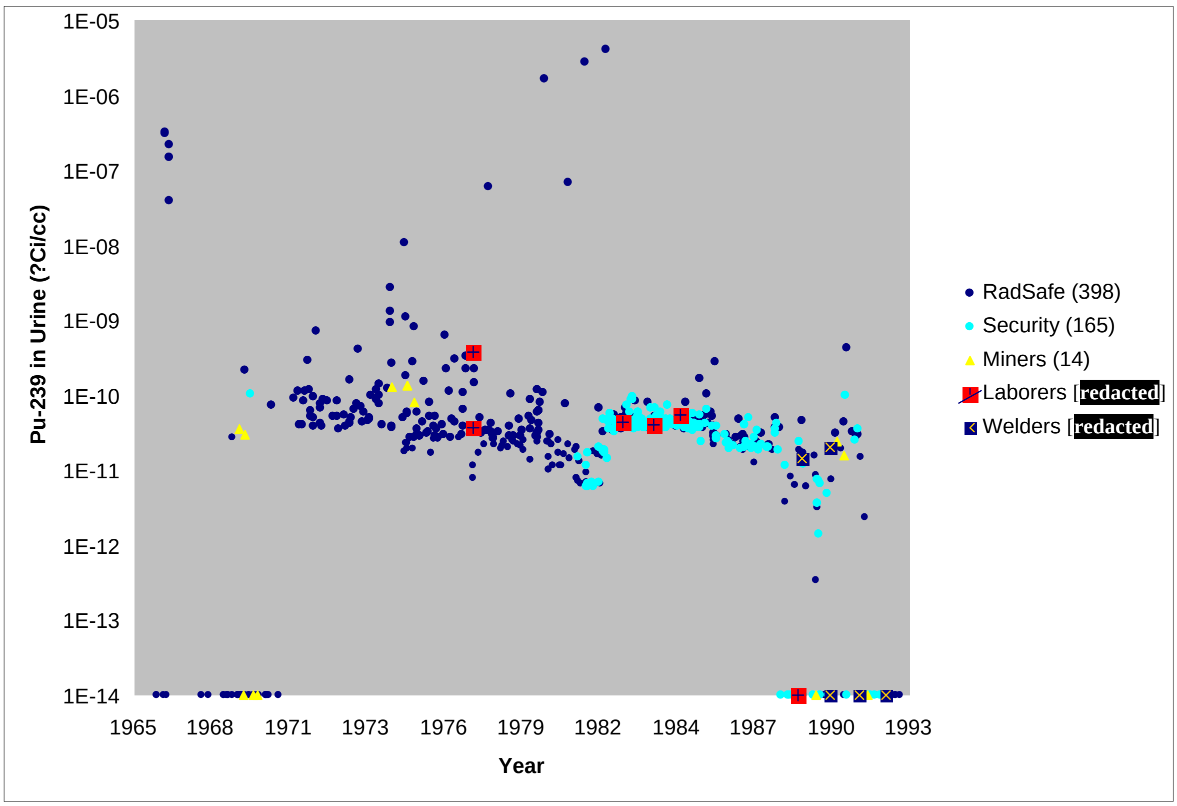

Figure 3-15: Pu-239 Biosamples by Claimant Job Type
(Number of Samples Shown in Parentheses)

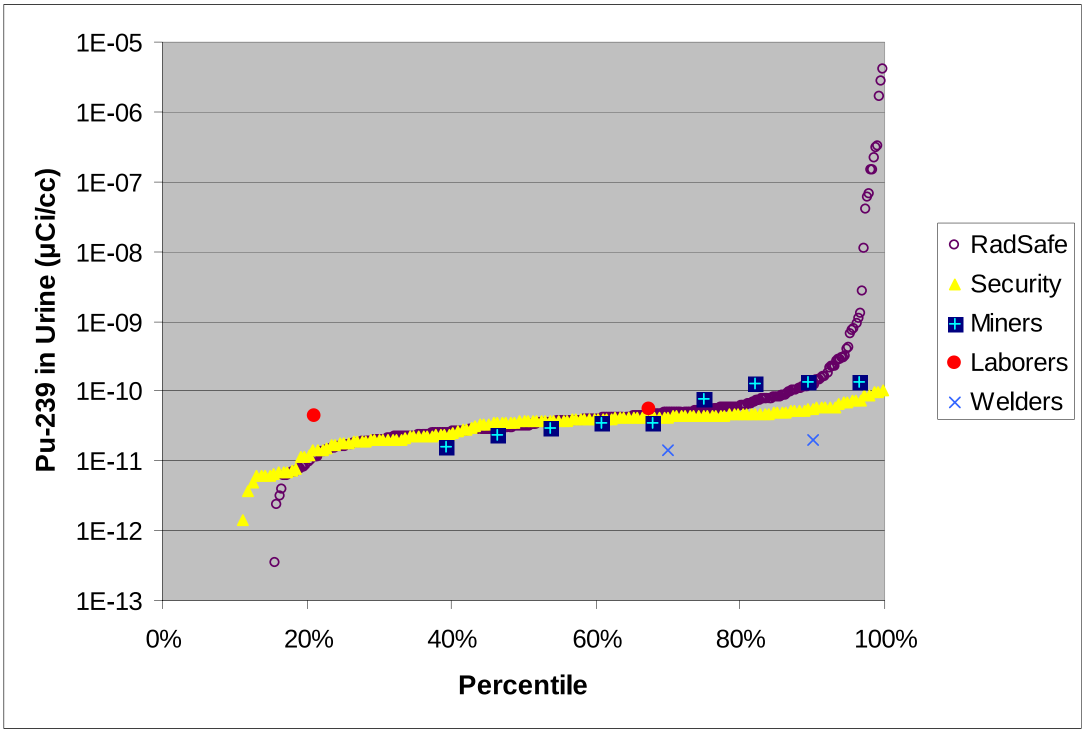

Figure 3-16: Percentile Plot of Pu-239 Biosamples by Claimant Job Type

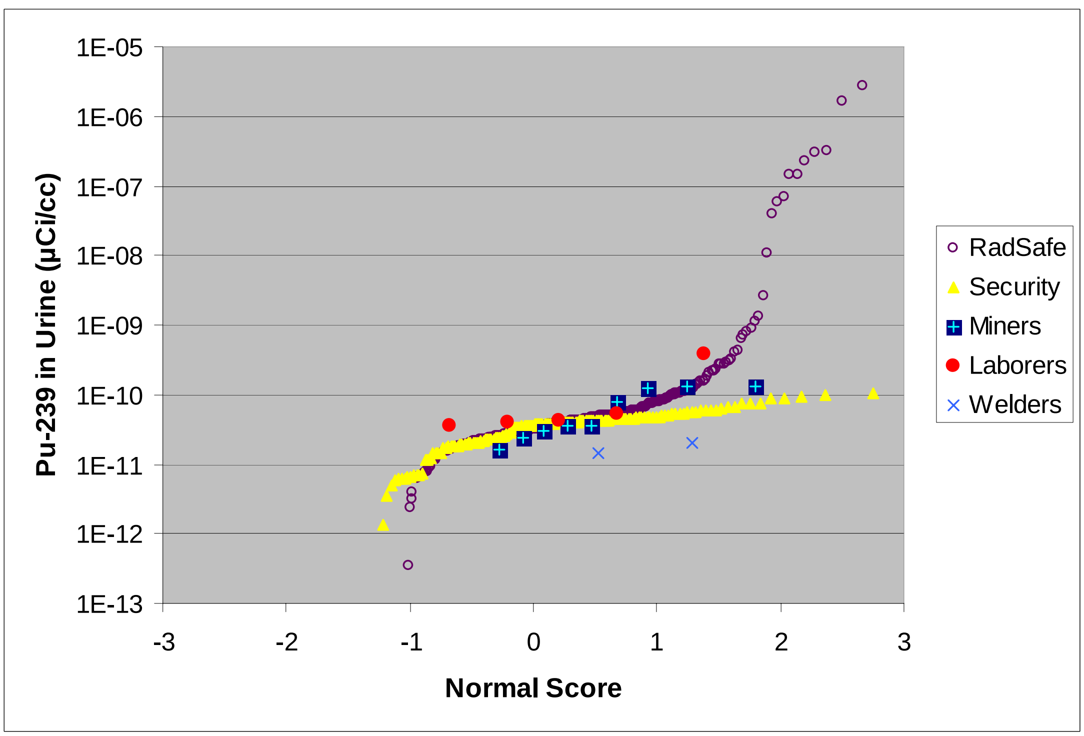

Figure 3-17: Normal Score Plot of Pu-239 Biosamples by Claimant Job Type

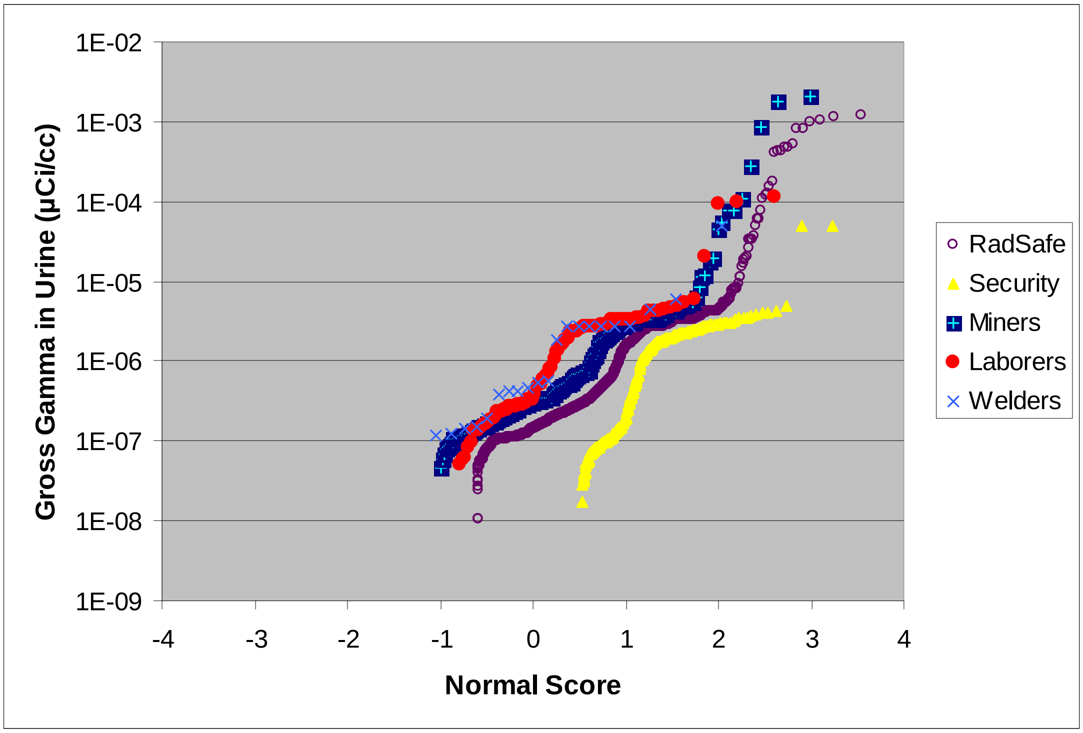

Figure 3-18: Normal Score Plot of Gross Gamma Biosamples by Claimant Job Type

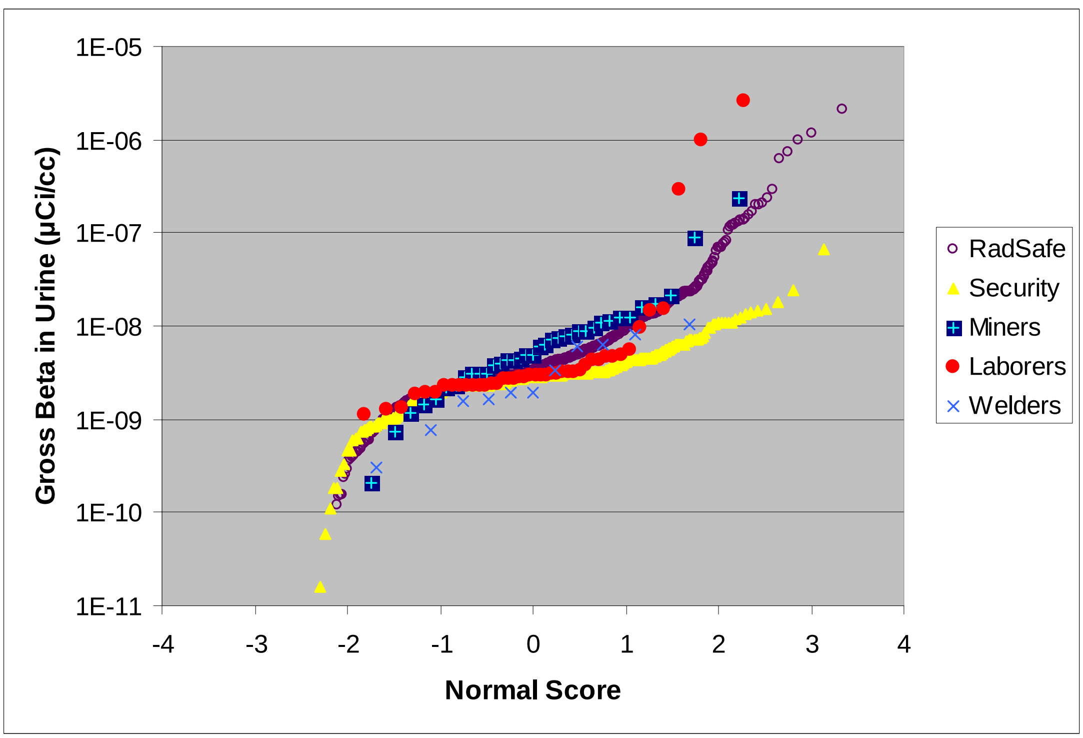

Figure 3-19: Normal Score Plot of Gross Beta Biosamples by Claimant Job Type

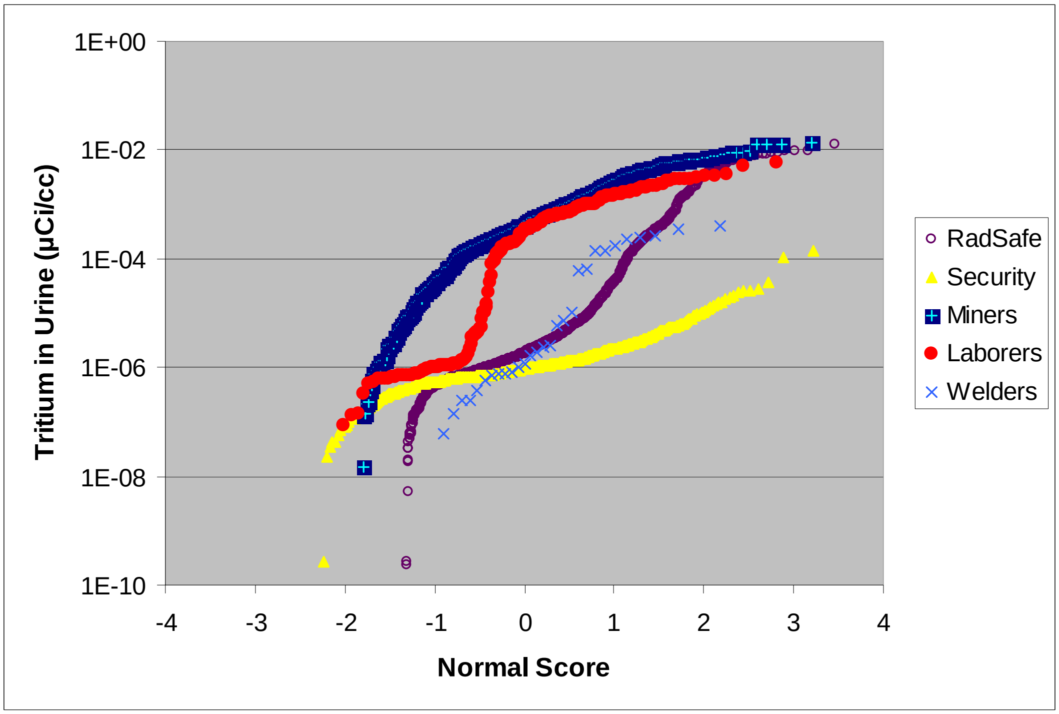

Figure 3-20: Normal Score Plot of Tritium Biosamples by Claimant Job Type

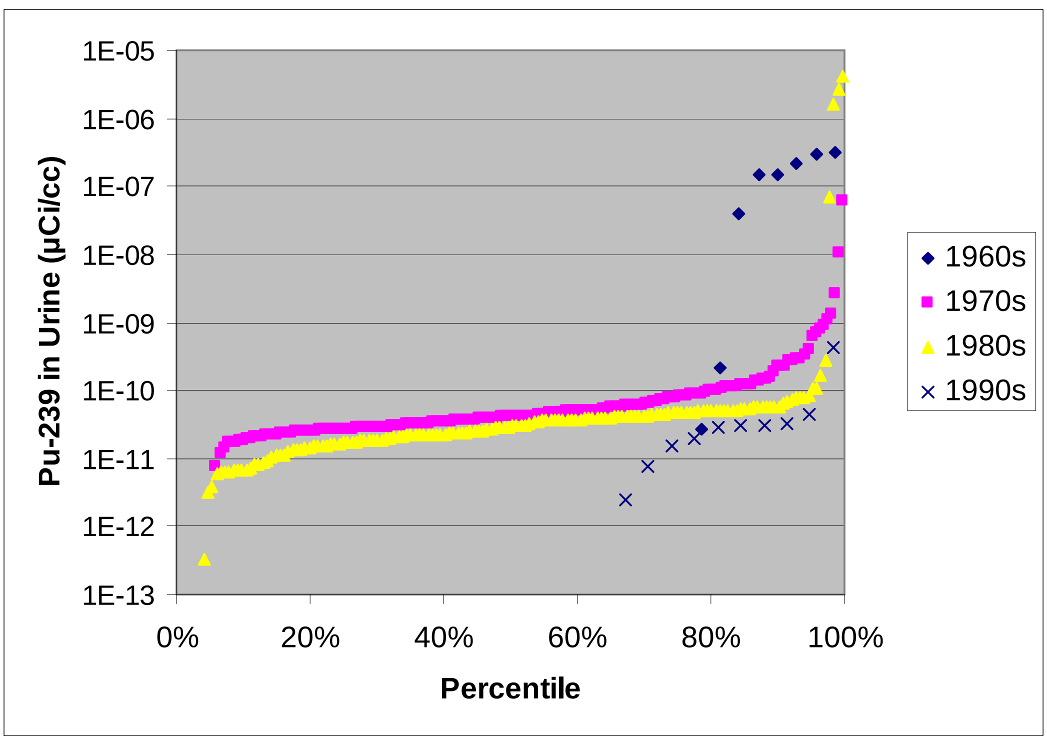

Figure 3-21: Percentile Plot of Pu-239 Biosamples for RadSafe Claimants by Decade

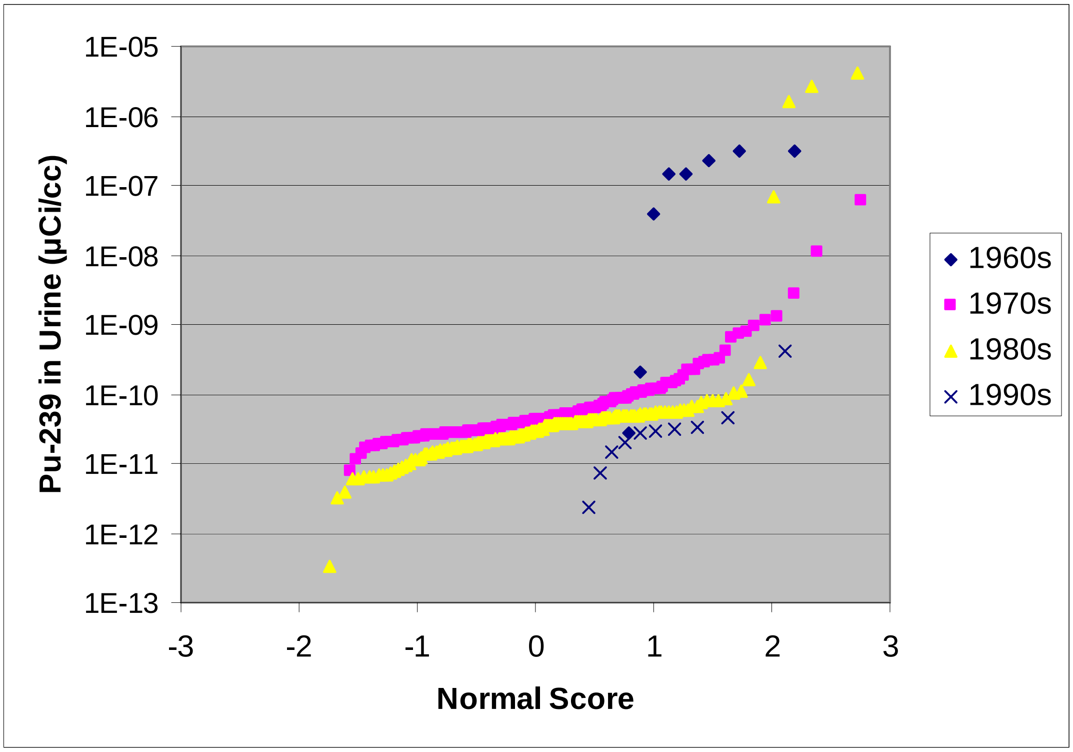

Figure 3-22: Normal Score Plot of Pu-239 Biosamples for RadSafe Claimants by Decade

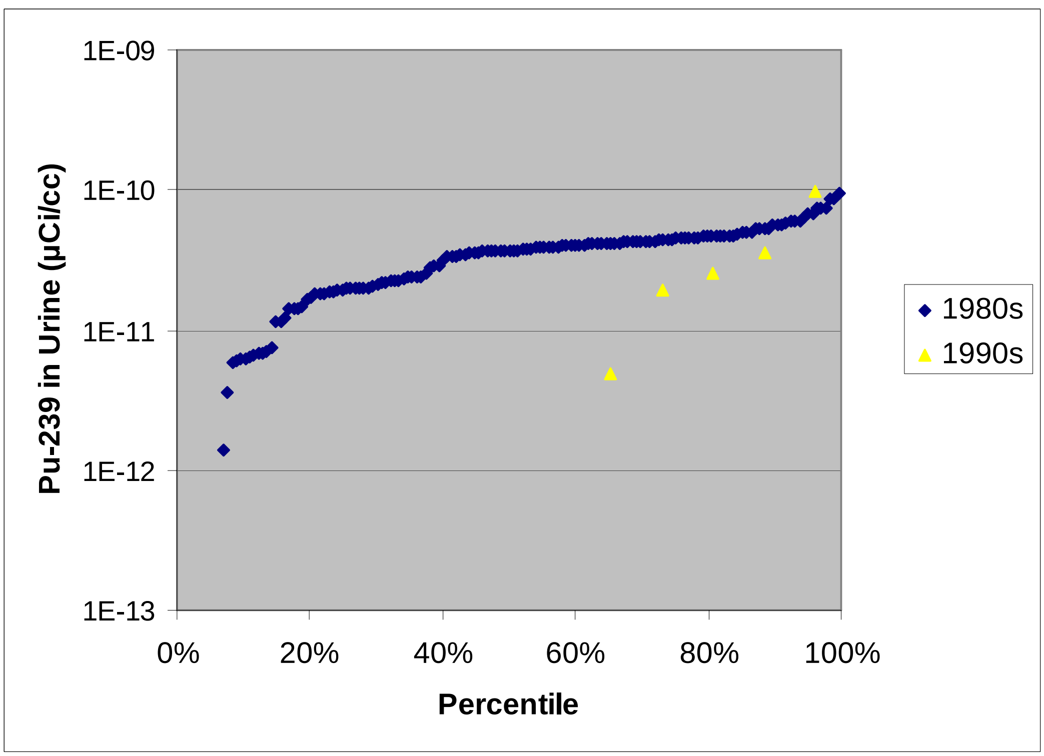

Figure 3-23: Percentile Plot of Pu-239 Biosamples for Security Claimants by Decade

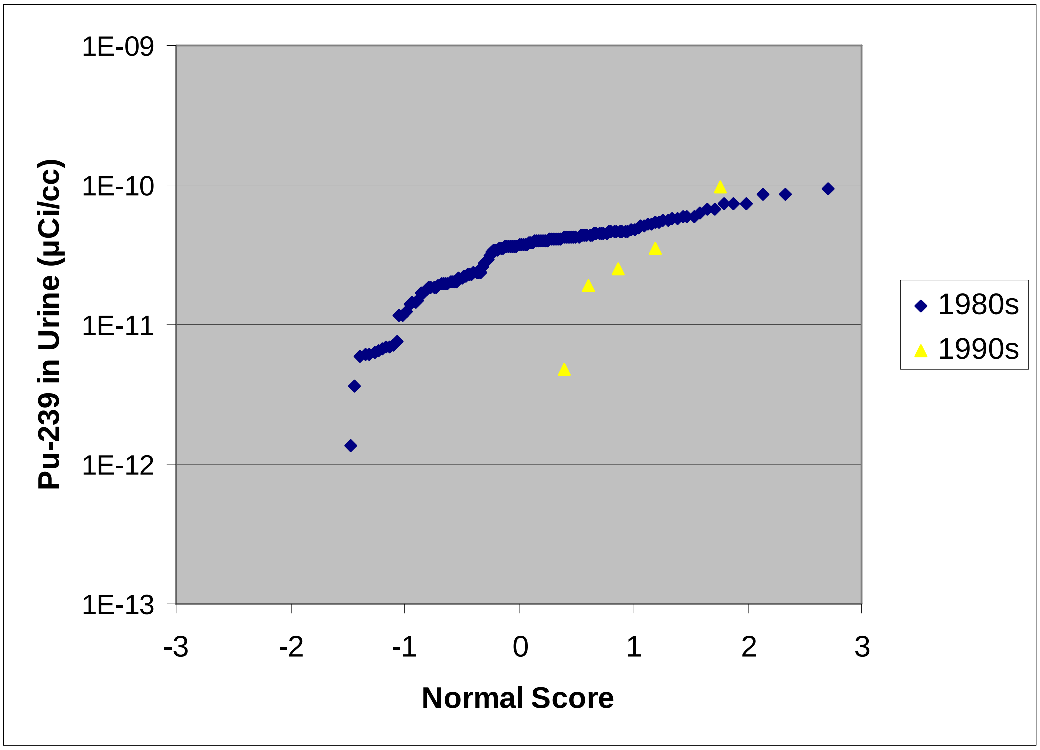

Figure 3-24: Normal Score Plot of Pu-239 Biosamples for Security Claimants by Decade

3.6 OTHER RADIONUCLIDES

The four kinds of bioassay data analyzed for adequacy of quantity of data and for certain aspects of quality in SC&A 2008 and SC&A 2009 were plutonium, tritium, gamma, and beta. (Comments regarding the interpretation of gamma and beta monitoring are provided below.) But there were other radionuclides present at NTS for which there are scant or no internal dosimetry data.

NIOSH 2009 also provides some examples of other radionuclides of concern at NTS during the SEC period, including "americium, uranium, thorium, radium, iodine, and other fission products" (p. 4). The electronic database indicates that data for these radionuclides are very sparse to non-existent for all categories of workers during the SEC period. For instance, SC&A found 173 uranium entries during the SEC period in the uranium spreadsheet on the O-Drive, with 21 of them being labeled as whole-body scans with no associated data.[7] There are even fewer entries in the americium spreadsheet (116 entries, of which 20 are "whole-body" entries

[7] The fact that there are no whole-body counting data in the electronic database may not mean that there are none in the raw DOE records. It appears that the whole-body counting data were not transcribed into the electronic database. NIOSH 2009 states that there are "300 bioassay records for uranium up to the year 1992" (p. 3). SC&A has not attempted to track down the source of the difference, since both figures would appear to be insufficient, especially in light of the fact that Area 3 and Area 5 waste site workers also had potential for exposure to uranium. A list of radionuclides to which NTS workers had exposure potential, by period and Area, can be found in ORAUT 2008a, Table 2-2, pp. 30–32.

with no associated data. The smallest number of entries is in the strontium-90 spreadsheet; 30 urine samples, with two blank entries and no whole-body count entries.

SC&A did not locate any data for radioiodines or thorium isotopes in the electronic database, though iodine was occasionally noted in the 'Comment 2' column of the gamma database. As noted below, SC&A did locate a very small number of data points for I-131, I-133, and I-135 in its earlier analysis of NTS data. We have not located other fission product-specific monitoring data in the electronic database spreadsheets on the O-Drive.

In its 2008 revision of the NTS Site Profile, NIOSH provided a list of radionuclides to which NTS workers had exposure potential by period and area and, in some cases, types of operations in particular periods (ORAUT 2008a, Table 2-2, pp. 30–32). The table also lists whether the potential was for internal exposure, external exposure, or both. For instance, drill-back operations and mine-back operations during the underground testing period created exposure potential for I-131, I-133, and I-135, among a host of others. Waste site Areas 3 and 5 had exposure potential to a variety of radionuclides, including uranium and thorium isotopes.

In summary, data for most of the radionuclides during the SEC period, other than the four categories described above in Sections 3.1 through 3.4, appear to be scant, if they exist at all.

3.7 QUALITY OF DATA

We reviewed the electronic database for any new quality issues that might be indicated, in addition to the ones discussed in Attachment B of SC&A 2008. Some observations are set forth below:

- Many data points are accompanied by large error estimates ranging to more than 500%.
- The plutonium data indicate codes for the Pu-239 isotope (codes 6 or 11, ORAUT 2008b, Table A-1, p. 68), and the "Comment 1" column affirms that the analyte is Pu-239. However, a large number of the "Comment 2" entries are "Pu-238," while others are "Pu-239." We could not identify a reason for the difference. We have assumed these samples to be Pu-239 based on the analysis code.
- Another new issue is that SC&A could not identify the significance of the notation "Hddr_error" in the comment column of the electronic database where the radionuclide is normally listed. SC&A raised this issue at the Work Group meeting on December 15, 2009. However, NIOSH also could not identify its meaning. We have ignored it in this analysis.

It is also clear that the electronic database is incomplete. SC&A pulled out all the claimants in the prior datasets analyzed—100 from the group in the NIOSH Evaluation Report (Table 7-1, NIOSH 2007) and 120 from the group that SC&A analyzed in addition (SC&A 2008, SC&A 2009). Overlap between these two datasets was eliminated.

Since each of the spreadsheets in the electronic database only contain those workers who had at least one internal monitoring data point for that type of monitoring, we chose all those workers from the prior datasets who had any internal monitoring data for that type of analysis to check whether their names and/or SSNs were in the electronic database. A complete or near complete match of the lists of workers would indicate that the electronic database was likely to include almost all workers with some internal dosimetry data. However, as the table below shows, many of the workers in the prior SC&A analysis are not in the electronic database:

Table 3-5: Monitored Claimants Analyzed in SC&A 2008 Found in the Electronic Database

	Number of Claimants from NIOSH 100 + SC&A 120 Monitored	Number (Percentage) Also Identified in Electronic Database
Tritium	87	80 (91.95%)
Pu	52	44 (84.62%)
GFP Beta	72	48 (66.67%)
Gamma	115	89 (77.39%)

For example, during our previous data compilation, we identified 87 claimants from the SC&A 120 and NIOSH 100 (no overlapping) who had records for tritium monitoring. Of these, 80 (or 91.95%) also appeared in the spreadsheet for tritium in the electronic database during the SEC period. This means that about 8% of the 87 claimants we studied who had tritium monitoring in their hardcopy records are not in the electronic database. Other categories have a lower ratio of matches. Fully one-third of the 72 workers studied by SC&A in prior reports with GFP/beta monitoring data are not in the electronic database. This demonstrates that the electronic database does not include a significant number of workers who were monitored. There is no information on the basis of the choice for those who were not included in the available documentation provided by NIOSH. SC&A has not attempted to make a detailed analysis of this issue, since our conclusion that further analysis of more data is highly likely to show the same patterns and problems in the data. However, a comment and an example are provided in Section 4.

4.0 COMPARISON WITH PRIOR SC&A RESULTS

4.1 DATA ADEQUACY – QUANTITY

The electronic database has about 122,187 bioassay data entries during the SEC period proposed by NIOSH, that is, from January 1, 1963 to December 31, 1992. Of these, 121,404 are in the SEC period requested in the petition, which ends on September 30, 1992. Almost all of these entries fall into the same four categories of data that SC&A had evaluated in its prior reports on internal monitoring (SC&A 2008, SC&A 2009); plutonium, gamma, beta (or gross fission products), and tritium. As described above, SC&A analyzed the electronic data by job type by matching SSNs with NOCTS. The same six job types were selected, in order to make possible a comparison of the contents of the electronic database with the earlier data compiled from raw DOE records provided to NIOSH.

The analysis in Sections 3.1 through 3.4 for these four categories of bioassay shows that these data closely follow the pattern found in SC&A 2008 and SC&A 2009. For example:

- RadSafe workers had monitoring data for all periods examined (1963–1967, 1968–1970, 1971–1980, and 1981–September 30, 1992), though there are fewer data per year in the 1960s than in the later periods.
- Security workers had the next largest amount of monitoring data, but it was almost all in the 1981–1992 period.
- The other four job categories had little to no plutonium monitoring data in most of the periods.
- Miners had tritium monitoring data in all periods. The data indicate that miners had the greatest exposure potential to tritium compared to the other job types analyzed, including the RadSafe category.

In comparing frequency of monitoring, it must be borne in mind that only workers with some monitoring data are found in the electronic database. In contrast, SC&A selected 20 workers at random from among claimants. Like the majority of NTS workers, many of them in the laborer, welder, and wireman categories, had no bioassay monitoring data. With that caveat in mind, SC&A finds that the frequency of monitoring for the six job types and four monitoring types analyzed is generally comparable between the electronic database and the earlier SC&A analysis. For instance, in the SC&A set of 120, only RadSafe workers averaged more than one plutonium sample per worker, except in the first period (1963–1967). Security guards had the vast majority of samples in the 1981–1992 period, when they had more than one sample per worker, and few to none in the other periods. All four other categories had either zero plutonium bioassay samples or much less than one sample per worker in each of the four periods. A similar pattern is observed in the electronic database.

One new feature does emerge from the electronic database due to the much larger amount of data in it. An examination of the cumulative distribution functions shown in Section 3 for tritium, gamma, and beta bioassay shows that RadSafe worker bioassay readings were generally less than at least one other group of workers. In the case of gamma bioassay data, which are much more plentiful than plutonium data, the RadSafe group of workers had lower bioassay readings than that of all claimants in the electronic database, and also of welders, wiremen, and miners. Plutonium data are far too sparse for a reliable comparison across job types. However, even in this case, the few data points prior to 1980s that are available for laborers indicate the potential that this group may have had higher exposures than the RadSafe group.

In these comparisons of cumulative distribution functions shown in Section 3, some limitations of the cumulative distribution functions should be kept in mind:

- The bioassay results generally indicate higher exposures in the 1960s and possibly the 1970s than in the 1980s and early 1990s. However, a definitive interpretation of relative exposures is not possible, since the context of the bioassay (routine monitoring versus incident-driven monitoring) is not known. Comparing a higher result derived from an incident with one that was a routine sample could be misleading.
- The cumulative distribution functions of bioassay readings in Sections 3.1 through 3.4 are constructed without regard to the periods in which the samples were taken. Comparisons of relative exposures are complicated by this fact, and by the tendency of higher bioassay results in the early part of the period studied here. In principle, one could construct cumulative distribution functions by period. But in the case of NTS bioassay data, there are simply not enough data points for most periods and worker types to construct meaningful data comparisons that would yield definitive results.

But even with these caveats in mind, it is clear that a conclusion that the RadSafe group had the highest exposure potential is not supported by the data. One cannot even make a less rigorous assertion that the RadSafe group was among those with the highest exposure potential. Indeed, the cumulative distribution functions, as well as the detailed individual data points, indicate that there may not have been a single group that was most exposed to the variety of radionuclides present at the NTS. Different groups of workers may have had higher exposures to different radionuclides in different periods. The exception may be miners, who may have been the most exposed to tritium, assuming that samples were mainly taken on a routine basis, as is indicated by the analysis in Section 3.5. Again, a definitive conclusion would require more information about whether the samples were routine or incident driven.

SC&A's overall conclusions of this comparative analysis regarding data adequacy are as follows:

(1) **All three data sets are similar:** All three datasets examined in detail by SC&A—the NIOSH group of 100 in Table 7-1 of the Evaluation Report (NIOSH 2007), the 120 claimants in six job categories analyzed in SC&A 2008, and the more than 170 claimants present in the electronic database in the six job categories already studied—exhibit the same general characteristics. The sample size is very large, and this conclusion is robust. Further study of the data is unwarranted, since it is highly likely to lead to the same general results.

(2) **The RadSafe worker group was the only one with a significant quantity of internal monitoring data throughout the SEC period.** The available data point to a definitive conclusion that, among the groups with exposure potential analyzed here, only the RadSafe group had significant monitoring data in all periods for plutonium, gamma, beta, and tritium (except possibly 1963–1967 for plutonium). But data for several other radionuclides are either not available or very scant, even for the RadSafe group.

(3) **There is no suitable reference group with a demonstrated high relative exposure potential to construct a coworker model.** Bioassay monitoring data of the RadSafe group, which is the only group with data in all periods for plutonium, gamma, beta, and tritium, cannot be used to reliably construct a coworker model that could yield bounding doses for unmonitored NTS workers. In other words, they cannot be used to reconstruct internal dose with sufficient accuracy, as required by 42 CFR 83. There are two reasons for this. First, the data for other groups of workers with exposure potential are too scant for most groups of workers and most periods to enable a reliable comparison to be made of exposure potential of various groups with the RadSafe group. It is essential to have adequate data in the various periods, since exposure potential varied by period.[8] Second, the data in the electronic database analyzed by job type in this report indicate that the RadSafe group of workers may not have been among those with the highest exposure potential. Indeed, the data indicate that other groups had higher exposure potential, at least some of the time. The data also indicate that there may have been no single group of workers that had high exposure potential to the various radionuclides at NTS. Exposure potential appears to have been a function of job type, period, radionuclide (or radionuclide group), and possibly, on a finer grid, individual tests or test series. (This last variable has not been examined by SC&A, since data are already too scant in most categories on a much coarser grid.) Finally, there is no other group of workers with an adequate quantity of data to construct a coworker model that would meet the criterion of estimating internal dose with sufficient accuracy.

The above conclusions point to the central overall conclusion that NTS internal dosimetry data are inadequate in quantity to support the construction of a coworker model that would allow estimation of internal dose for unmonitored workers with sufficient accuracy for the SEC period.

4.2 QUALITY OF DATA

It is very difficult to evaluate which results can be considered positive valid bioassay results, in relation to the capacity of measurement in each time period. The citations below are only examples; they are not a summary of all findings from a complete analysis for all years in the electronic database. SC&A did not consider this necessary, since the electronic database presents similar issues to those of interpretation and quality as those described in SC&A 2008, Attachment B.

[8] The choice of starting and ending dates for the various periods is a matter of judgment based on the number of tests, venting incidents, and frequency of monitoring. This is discussed in SC&A 2008, p. 6.

- **Uncertainty regarding the minimum detectable amount (MDA) of plutonium:** The Pu MDA from the Occupational Internal Dosimetry TBD (ORAUT 2008b) from 1961 to 1976 was 0.005 dpm/sample (2.25 E-6 µCi/sample), while activities in the electronic database are given in µCi/cc. Since the sample size is not always available, converting a dpm/sample value to µCi/cc is associated with some uncertainty.
- **Positive results below MDA:** The MDA for Pu-239 for 1977–1987 is listed as 5E-11µCi/mL. In 1969, for example, there are 343 results, 281 of them listed as LT (below detection). From the 61 reported positive results, 23 are below the MDA for 1977–1987. It is unclear how such positive results below the MDA are to be interpreted.
- **Anomalies in reported errors:** The reported errors on those 23 results are very high (range of 80% to 98.8%). From the 39 results above 5E-11 µCi/mL, 11 had reported errors on the range 80% to 98.8%, and 15 had reported errors above 70%. In 1971, all reported errors are listed as zeros. In 1972, there were 171 results and only 3 reported errors listed as different from zero. Fifty-two results are below the MDA for 1977–1987. There are similar issues in plutonium results in 1980.
- **No reported gamma bioassay MDA before 1977:** For gamma emitters, the MDA is not defined in the Occupational Internal Dosimetry TBD for the years before 1977 (ORAUT 2008b).
- **Potentially inconsistent gamma MDAs up to 1977:** In 1965 the samples that showed a reported result had concentrations mostly in the range 2–3 E-6 MI/cc. In 1966, the number of samples increased to about 3,000. There were 3 samples with results of the order of E-9, one of the order of E-8, 2 of the order of E-7 and about 2,500 in the range of 1–5 E-6 MI/cc. Should 1.0 E-6 be considered an MDA for the period? In 1970, there are a significant number of positive results on the order E-8 MI/cc. Did the MDA change? The validity of the gamma results is questionable because of the uncertainties on the MDA values.

Furthermore, as discussed above, the electronic database is incomplete; it may omit some of the most intensively monitored workers. For instance, one of the workers most intensively monitored for plutonium in 1965 with 13 bioassay samples is not in the electronic database.

In its November paper, NIOSH raised a further issue regarding the quality of data as it pertains to the beta/GFP dataset:

> *…[T]he bioassay data available to assess fission product exposures are more generally listed as gross beta analyses. Given that fission products were the most likely source of potential exposure and the makeup of the fission products source term was project and time-dependent, this brings into question the ability to reconstruct a representative distribution of NTS fission product exposures during this time period.* [NIOSH 2009, p. 3]

The same problem would apply to gamma bioassay data. The paucity of urine data for specific fission products is problematic (of course it would be best to have radionuclide-specific data), but this problem could be largely overcome with regard to bounding doses if there were timely measurements of mixed fission products. For example, the dose reconstructor could assign all activity labeled as "mixed fission products" or "gross fission products" to the fission product (among those likely to present) that would yield the highest dose to the organ of interest. Furthermore, given the variety of activities and exposure scenarios at NTS, it is important to know the context of the monitoring in relation to the nuclear tests, rocket tests, or other work, such as waste handling and disposal. This kind of data is also generally unavailable. Indeed, as noted above, some of the monitoring appears to have been incident-driven, while some of it was not. Sorting out the data would be very complex, if it is possible at all.

Since this issue is of some importance in the specific circumstances of NTS and the NIOSH recommendation, SC&A examined it in more detail using examples of venting releases.

4.3 POTENTIAL EXPOSURES TO ABOVE-GROUND RELEASES OF FISSION AND ACTIVATION PRODUCTS

Hundreds of underground tests conducted at the NTS resulted in varying degrees of above-ground contamination with fission and activation products. Some of the releases included large quantities of short-lived radionuclides representing potentially high radiation doses from intakes during the early hours or days after individual tests, and smaller quantities of radionuclides with intermediate or long half-lives representing intake hazards for weeks, months, or years after the tests. Releases of activity resulted from containment failure or post-test operations, such as drillback activities, purging of gases, or sampling of underground activity. These above-ground releases may have been the greatest source of doses to NTS workers as a whole during the period 1963–1992, but there is a paucity of bioassay data with which to reconstruct doses from intakes of the released fission and activation products.

Releases from underground tests typically included noble gases, particularly Xe-133, Xe-133m, Xe-135, Kr-87, and Kr-88, as well as other "volatile" fission products, such as isotopes of iodine and ruthenium (DOE 1996). For example, the primary radionuclides identified in releases from the tunnel test Door Mist (August 31, 1967) included Ru-103, Ru-106, I-131, I-133, I-135, and Xe-135 (DOE 1996). Releases occurred as expected at the tunnel portal and during drillback, but there was also unexpected seepage through cables to a cable-splice building. Total releases exceeded 10^6 Ci.

A number of underground tests resulted in substantial releases of a variety of fission or activation products other than the noble gases, iodines, and rutheniums. For example, identified radionuclides in releases from the shaft test TEE (May 7, 1965) included Na-24, Sr-91, Sb-122, Sb-124, Te-132, Cs-138, Ba-139, and Ba-140, in addition to I-131, I-132, I-133, I-135, and isotopes of Kr and Xe. Rapid releases occurred from a line-of-site pipe at surface ground zero. Releases lasting over 4 days occurred from the surface ground zero area (DOE 1996).

A few surface or near-surface "cratering" tests spread large quantities of many different radionuclides over a wide area. Following the Plowshare cratering event Palanquin (April 14, 1965), the measured concentration of gross beta activity in air at an offsite location was

87,000 pCi/m^3. Reported concentrations of I-131, I-133, and I-135 in air at an offsite location following the test were 12,000 pCi/m^3, 65,000 pCi/m^3, and 160,000 pCi/m^3, respectively (DOE 1996).

Chertok and Lake (1971a and 1971b) studied internal deposition of radionuclides in pigs exposed to radioactive fallout from the Plowshare cratering event Schooner (December 8, 1968). The pigs were kept in cages in the expected path of the plume, so that they would inhale debris and eat food contaminated by the fallout. Radionuclides found in tissues of pigs exposed for 3 days included W-188/Re-188, Te-132, Au-196, I-131, Ru-103, and As-74. The same investigators studied the bioavailability of radionuclides produced by the Plowshare cratering events Cabriolet (January 26, 1968) and Buggy (March 12, 1968) by measuring activity in excreta of dogs or pigs administered fallout debris in a single oral dose (Chertok and Lake 1970 and 1971c). The radionuclides detected in excreta included W-187, Au-198, Te-132, I-131, Ru-103, Ce-141, Mo-99, Sb-122, and Ba-140/La-140. Radionuclides found to be absorbed into blood to a significant extent from the Cabriolet or Buggy fallout were I-131, W-187, Te-132, Mo-99, Ru-103, and Sb-122.

Some unexpected releases of radionuclides, or unexpectedly large quantities of released activity, created the potential for dosimetrically significant intake of short-lived radionuclides that are usually ignored in dose reconstructions for internally deposited fission products. For example, the shaft test Parrot (December 16, 1964) included an initially rapid burst, followed by a continuous long-term leakage at a slower rate, with total releases exceeding 2×10^5 Ci (DOE 1996). Uncontrolled releases resulted from a crack in a pipe below the surface. The released activity was approximately 45% Cs-138 ($T_{1/2}$ = 32.2 min), 45% Kr-85m (4.5 h), and 10% I-135 (6.6 hr), along with traces of other iodines. Cesium-138 is a fission product, and is also produced by decay of the fission product Xe-138 ($T_{1/2}$ = 14.2 min). Due to the high mobility of Xe-138, its progeny Cs-138 may be found in significant quantities at relatively far distances from a nuclear event.

Table 4-1 lists a number of fission or activation products of potential dosimetric importance that were released in large quantities from one or more shaft, tunnel, or cratering tests from late 1963 (start of the Limited Test Ban Treaty) through 1992 (DOE 1996). These radionuclides, which are all beta/gamma emitters, are listed in order of increasing radiological half-life. Only a few of these radionuclides were addressed in the NTS bioassay program (e.g., selected radioiodines and Sr-90), and reported measurements of those radionuclides are sparse. Some urinary excretion data are reported as gross beta or gross fission products, but these measurements were not sufficiently frequent or timely to allow estimation of bounding doses for the range of fission products to which workers may have been exposed.

A long delay between collection and analysis of urine samples for gross fission products in some cases suggests that monitoring was focused on relatively long-lived fission products, with the main exception that short-lived radioiodines, such as I-133 (20.8 hr) and I-135 (6.6 hr), were occasionally measured in urine. For example, a urine sample collected from an NTS worker ("Worker A") on January 15, 1965, was analyzed for "gross beta" about 2.5 months after the collection date (data from NIOSH's Excel file for 100 workers). A urine sample collected from another worker ("Worker B") on February 19, 1965, was analyzed for gross beta about 1.5 months after the collection date. In both cases, the gross beta measurements would not have reflected intakes of radionuclides with half-lives up to several days.

Table 4-1: Some Radionuclides Other Than Noble Gases Identified in Releases from Shaft, Tunnel, or Crater Tests at NTS after August 5, 1963[a]

Radionuclide	Half-life	Radionuclide	Half-life
Cs-139	9.27 min	Sb-122	2.70 d
Rb-89	15.2 min	Mo-99	2.75 d
Rb-88	17.8 min	Au-198	2.77 d
Cs-138	32.2 min	Te-132	3.25 d
I-134	52.6 min	I-131	8.04 d
Nb-97	1.20 hr	Nd-147	11.0 d
Ba-139	1.38 hr	Ba-140	12.7 d
As-78	1.51 hr	As-74	17.8 d
La-142	1.54 hr	Ce-141	32.5 d
I-132	2.30 hr	Nb-95	35.2 d
Mn-56	2.58 hr	Ru-103	39.3 d
Sr-92	2.71 hr	Sr-89	50.5 d
Ru-105	4.44 hr	Y-91	58.5 d
I-135	6.61 hr	Sb-124	60.2 d
Sr-91	9.50 hr	Zr-95	64.0 d
Na-24	15.0 hr	W-188	69.4 d
Zr-97	16.9 hr	Mn-54	313 d
I-133	20.8 hr	Ru-106	368 d
W-187	23.9 hr	Sr-90	29.1 yr
Ce-143	1.38 d	Cs-137	30.0 yr
La-140	1.68 d		

[a]Data collected from summaries of individual tests at the NTS (DOE 1996)

Urinary radioiodine data for "Worker B" can be used to illustrate that short-lived fission products (say, half-lives less than 1 day) may be important and sometimes the dominant internal emitters in persons exposed to fresh fission products. Bioassay data for Worker B (addressed above) during the period 1963–1965 are reported only for three brief intervals: June 12–13, 1963; October 17–23, 1963; and February 19–20, 1965. Comparison of these dates with dates of nuclear tests at the NTS suggests that the purpose of the bioassay measurements during these three periods was to assess intake of activity released after underground tests. Measurements of I-131 ($T_{1/2}$ = 8.04 d), I-133 (20.8 hr), and I-135 (6.6 hr) in urine samples collected from Worker B on February 19–20 reveal sizable intake of all three radionuclides. The time of exposure is not indicated, but there were known releases of radioiodine from shaft tests conducted on February 18 and 19, 1965, and releases of unspecified radionuclides from a shaft test conducted on February 16, 1965 (DOE 1996). Concentrations of I-133 and I-135 in urine were far greater than the concentration of I-131, indicating much higher intakes of the shorter-lived isotopes. The estimated intakes of I-133 and I-135 and the resulting thyroid doses depend strongly on the time of collection of the urine sample after intake, due to their short half-lives and the rapid decline in urinary iodine following intake. Regardless of the time between intake and sample collection, however, the data for Worker B indicate that the dose to the thyroid from I-133 was at least an order of magnitude greater than the dose from I-131, which is generally assumed to be the most important iodine isotope in the early period following a nuclear event. This example shows that it is important to assess the doses to workers from intake of short-lived, as well as longer-lived, beta-gamma emitters released by the tests.

Worker B addressed above is one of the more extensively monitored workers addressed in the NIOSH Excel file for 100 workers. Nearly 300 bioassay measurements for this worker were made during the period 1963–1990. In addition to limitations in these measurements indicated above, the problem arises that there were often long periods (many months) between measurements and no apparent systematic monitoring scheme for detecting chronic intake of radionuclides or unexpected elevated intakes between nuclear tests. The same problem exists for most other workers addressed in the file. This is an important issue for the dose reconstructions because of the widespread releases of radionuclides with intermediate or long half-lives over the site. Due to such limitations in the database, **it is questionable whether reasonable bounding doses can be derived, even for many of the most extensively monitored NTS workers. On the other hand, the database would allow the derivation of partial, lower-bound doses for many workers.**

Of course, even if interpretation of gamma and beta data to reconstruct bounding doses for fission products were possible, this would still not solve the problem of insufficiency of data for other radionuclides. Finally, as noted in Section 3, the most plentiful data are for a group, RadSafe, whose results do not indicate relatively high exposure potential for gamma and beta, compared to other groups. For gamma data, the cumulative distribution function for the RadSafe group indicates lower bioassay results than those for all workers for the most part (Section 3.2).

5.0 CONCLUSIONS REGARDING INTERNAL DOSE RECONSTRUCTION FEASIBILITY

Based on the above analysis and that presented in prior SC&A reports on internal exposure monitoring (SC&A 2008, SC&A 2009), SC&A concurs with NIOSH's overall conclusion that, "there is insufficient information to adequately support bounding internal dose (reconstructing internal dose with sufficient accuracy) for the portion of the SEC00084-NTS worker class who worked during the period of testing from 1963 through 1992" (NIOSH 2009, p. 4).

SC&A also examined each of the four points that led NIOSH to conclude that dose reconstruction with sufficient accuracy was not feasible. They are discussed below.

5.1 RATIONALE OF NTS BIOASSAY SAMPLING PROGRAM

NIOSH statement:

> 1. *NIOSH has identified exposure scenarios involving varying job titles/duties and work activities, such as drill-backs, post-test work activities, and construction or other soil disturbing activities in areas that had been contaminated by previous tests. Prior to 1993, no source documentation could be located to confirm the rationale behind why bioassay samples were collected. Because of this, NIOSH cannot conclusively determine that doses to all of these potentially exposed individuals were detected by the bioassay program.*
>
> *A review of the available data indicates a large number of radiological technicians and security personnel were routinely sampled. Other job titles/duties are also represented but a substantial fraction of the 'other' group of bioassay samples appears to have been collected on a more event or incident-driven basis. Although NIOSH does have access to site procedures and directives, NIOSH has not located sufficient documented evidence, other than anecdotal, to describe a consistent rationale behind the collection of personnel bioassay sampling or to indicate that sampling occurred consistently in the situations where it was required.*
> [NIOSH 2009, p. 3]

SC&A's analysis presented above shows conclusively that there were several job types with exposure potential; however, most groups examined had little or no data for most periods for plutonium and several other radionuclides. Much of the monitoring appears to have been incident-driven, as indicated by a lack of lognormal fit in several cases, described above in Section 3.5. Furthermore, the bioassay data for several groups of workers indicate that they may have had higher exposure potential than RadSafe workers, though given the lack of information about monitoring timing and context, it is not possible to definitively establish this. In this kind of situation, the fact that many or most RadSafe personnel were monitored does not provide an adequate basis for constructing a coworker model for other workers with exposure potential, even for those radionuclides for which there are monitoring data in all periods. This conclusion is rendered even more robust by the fact that the sparseness of the data makes a robust comparison between RadSafe and other groups of workers difficult or impossible in most cases, with some exceptions, such as plutonium monitoring comparisons between security and RadSafe personnel in the 1980s, or tritium monitoring comparisons between RadSafe and miner job types. To the extent that a comparison is possible, the RadSafe group is not indicated as suitable for estimating internal doses with sufficient accuracy under 42 CFR 83.

5.2 DATA GAPS

NIOSH statement:

> 2. *NIOSH has identified data gaps that exist in the electronically available bioassay data for certain nuclides and time periods… that impact NIOSH's ability to bound the internal dose.*
>
> - *Specific radionuclide analyses for fission products are not available to NIOSH. Rather, the bioassay data available to assess fission product exposures are more generally listed as gross beta analyses. Given that fission products were the most likely source of potential exposure and the makeup of the fission products source term was project and time-dependent, this brings into question the ability to reconstruct a representative distribution of NTS fission product exposures during this time period.*
> - *NIOSH identified only 300 bioassay records for uranium up to the year 1992. While it may be that there was a limited potential for exposure to uranium, and 300 bioassay results could be an appropriate number, NIOSH has not located sufficient documentation to support or refute that possibility. As is the case with uranium, NIOSH has indentified that the number of workers monitored for plutonium appears to be small (e.g., fewer than 200 from many years), considering the size of the NTS workforce. While it can be argued that few people were monitored because of the low potential for exposure, the evidence in the database (i.e., a large number of positive Pu results) confirms that there was clearly a source-term for plutonium that was capable of producing measurable intakes.* [NIOSH 2009, pp. 2–3]

The extensive analysis done by SC&A in two prior reports (SC&A 2008, SC&A 2009), as well as the present report, confirms NIOSH's analysis regarding the scant data for radionuclides like plutonium with exposure potential. The large fraction of positive bioassay results in all four bioassay monitoring categories that were examined indicate significant internal exposure potential, contrary to the prior belief that such exposure potential was not significant for most groups of workers, or at least that the monitored workers were among those with the highest exposure potential. While such a belief may have been the reason for a lack of internal exposure monitoring in most periods, it is not sustained by the available data. SC&A also found that the notion that external dose would be an indicator of internal exposure potential was not borne out by the data for the 100 workers selected for NIOSH's coworker model in its Evaluation Report (NIOSH 2007).

In regards to estimating dose from fission products, we have already noted above in Section 4.3, that interpretation of beta and gamma bioassay data is problematic and complex, due to the lack of data regarding the time and context of the these measurements.

5.3 CHRONIC AND EPISODIC EXPOSURE

NIOSH statement:

> 3. *The nature of work at the NTS site and the large geographic area over which this work was conducted presents a unique challenge for bounding the internal doses at NTS. Unlike many production sites (i.e., SRS, Rocky Flats, Fernald, etc.), the NTS was primarily engaged in shorter-term campaign driven activities that were separated by large distances, and there appears to be a direct relationship between campaigns and bioassay sampling. The concept of a campaign driven bioassay sampling program is further supported by the fact that many of the periodic bioassay samples appear to have been collected on the same day. Because of the episodic nature of the exposures at NTS, a coworker model that is useful in reconstructing chronic intake scenarios would not necessarily be representative of the exposure patterns for the NTS workforce.* [NIOSH 2009, p. 4]

SC&A's statistical analysis indicates that much of the sampling at NTS was campaign-driven or incident-driven. However, in some cases, it seems to be a mixture of incident-driven and routine monitoring, while in a couple of cases, it seems to be mainly routine monitoring. To the extent that the limited quantity of data enable an analysis, the data in most cases do not fit the usual lognormal distribution that characterizes a routine sampling protocol. SC&A also notes that besides samples on the same day, the same workers sometimes had many or most samples in a year taken in a short period. For instance, one worker had [redacted] plutonium samples in 1964, and [redacted] of them were in a 16-day period in [redacted]. To complicate interpretation, this worker also had [redacted] samples taken on exactly the same dates in the next year. In neither case do the sample collection dates correspond to test dates or the day immediately after a test.[9]

Furthermore, NTS personnel also had potential for routine exposure. Examples include activities in contaminated areas of the test site outside of the context of the aftermath of a specific test, waste site workers, and laboratory workers. The inability to sort out monitoring done for routine exposures from that done for episodic exposures makes data interpretation very complex.

[9] The data referred to for this claimant, a [redacted] group worker, can be found on the [redacted] worksheet of the plutonium data spreadsheet on the O-Drive. The list of nuclear tests and their dates can be found in DOE 2000.

5.4 RADIONUCLIDE COVERAGE

NIOSH statement:

> 4. *The reconstruction of internal doses at NTS is also complicated by the variety of the radionuclides to which workers may have been exposed. As indicated in the NTS site profile, the potential nuclide source-term included, but is not limited to, plutonium, americium, uranium, thorium, radium, iodine, and other fission products. For workers with no bioassay records, and who had the potential for exposure, NIOSH would have to definitively establish the relative mixture of the exposure source-term.* [NIOSH 2009, p. 4]

All three datasets analyzed by SC&A (the NIOSH group of 100 in Table 7-1 of NIOSH 2007, the 120 workers in 6 job types in SC&A 2008 and SC&A 2009, and the electronic database) indicate that monitoring for plutonium for most job types and most periods was sparse. There was even less monitoring of americium and uranium. SC&A has found no bioassay data for thorium. Data for specific fission products are very sparse and appear to be limited to a small number of samples for Sr-90, I-131, I-132, I-133, and I-135. A compilation of I-131, I-133, and I-135 data for workers in the SC&A 120 set can be found in SC&A 2008, Attachment A, starting on page 46). For instance, among 120 workers over a period of about 30 years, there were only 30 I-131 samples in all, of which 12 were for the RadSafe Group and 15 were for the Miners group, leaving the other 4 groups essentially unmonitored throughout the SEC period, including during the several serious ventings of tests that occurred between 1963 and the end of 1970. Moreover, all but one of the miner samples were in the 1980s, while all but two of the RadSafe samples were between 1963 and 1970 (SC&A 2008, Table 16, p. 47).

5.5 PERIOD OF THIS ANALYSIS AND PERIOD OF THE RECOMMENDED SEC

In the above analysis, SC&A has examined data from January 1, 1963, to September 30, 1992, which is the period in SEC Petition SEC-00084 (see NIOSH 2007 and NTS SEC Petition 2007). This corresponds to the same period for which an addition to the SEC class is requested in the petition (SEC-00084). The period for the above analysis was chosen to maintain comparability with the earlier analysis.

NIOSH has recommended an addition of NTS workers to the SEC class that is slightly broader than the SEC period in the petition—from January 1, 1963, to December 31, 1993. The last nuclear test at NTS was on September 23, 1992 (DOE 2000, pp. 88–89). Since post-test activities would extend for some time after the test, this appears to be a reasonable short extension of the SEC period. SC&A did a brief check of the data from October 1, 1992, to December 31, 1992, and found it to be consistent with that from the earlier testing period in 1992. For instance, the frequency of plutonium monitoring between the last 3 months of 1992 (12 per month in all) was slightly lower than during January 1, 1992, and September 30, 1992 (nearly 15 per month), when testing was taking place. The gamma bioassay frequency also dropped somewhat in the immediate post-test period (86 per month from October to December 1992, inclusive, compared to 127 per month for the January–September 1992 period). For americium, there were no data at all after August 1983, even though the NTS site profile lists exposure potential for this radionuclide as extending to the time of writing (2008) (see Table 2-2 in ORAUT 2008a, p. 30).

SC&A has not investigated the period from January 1, 1993 onward, since that is well outside the SEC period and outside of the work authorized so far by the Work Group. It should be noted here that during the course of the review of the Site Profile and SEC Evaluation Report, NIOSH revised its site profile. Most relevant to the present discussion is the fact that NIOSH revised its site description (where the radionuclide list and exposure potential in various periods are noted), its environmental dose section (relevant for internal dose) and its occupational internal dose section in 2008.

5.6 PARTIAL INTERNAL DOSE ESTIMATION

Should NTS workers in the underground testing period be added to the SEC class, the issue of partial dose reconstructions for cancers not included in the SEC compensation list would remain.

Much of the NTS bioassay data can be used for estimating partial internal doses for those workers who were monitored. For instance, SC&A found no systemic quality issues associated with tritium data. There are quality issues associated with plutonium data for up to about 1987 (SC&A 2008, Attachment B); however, these data could be used for partial dose reconstruction for the workers who provided the bioassay samples, provided appropriate caution is observed when interpreting results marked "less than" and their relation to the minimum detectable amounts specified in the NTS Site Profile.

For workers who have gamma and mixed fission product monitoring data, a partial dose might be estimated on the basis of a likely mixture of the radionuclides present, provided there is a specific test or group of tests that is considered to be the likely source of the exposure and the urine samples were taken at known times after release of radionuclides to the environment.

A dose to the thyroid may be estimated in cases where iodine isotopes were measured at known times after a test considered the likely source of the radioiodine.

6.0 REFERENCES

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