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12/02/2021	00	New report to assess the adequacy of Los Alamos National Laboratory bioassay results for the construction of a co-exposure model. Incorporates formal internal and NIOSH review comments. Training not required. Initiated by Michael S. Kubiak and authored by Thomas R. LaBone.

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ACRONYMS AND ABBREVIATIONS

BEST	Bioassay Enrollment, Scheduling, and Tracking
C.F.R.	*Code of Federal Regulations*
DCAS	Division of Compensation Analysis and Support
DOE	U.S. Department of Energy
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESH	Environmental Safety and Health
HPC	Health Physics Checklist
JC	Johnson Controls
LANL	Los Alamos National Laboratory
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NMT	Nuclear Materials Technology
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
PAL	plutonium access list
q-q	quantile-quantile
RAS	radiometric alpha spectrometry
RWP	radiological work permit
SRDB Ref ID	Site Research Database Reference Identification (number)
TA	Technical Area
§	section or sections

1.0 INTRODUCTION

The 1999 audit of the Los Alamos National Laboratory (LANL) bioassay program listed several deficiencies in the bioassay program that were of regulatory significance [Brackett and LaBone 1999, p. 4]. Most relevant to this discussion is Finding 1: “Radiation workers are not consistently placed on the appropriate routine bioassay program.” This finding was supported by the following observations:

- Out of [redacted] individuals who signed the acknowledgment sheet for a [redacted] RWP that required [redacted] bioassay, [redacted] had not submitted a sample since 1994 and [redacted] had never submitted a sample; and

- Johnson Controls workers did not consistently submit HP Checklist forms to enroll in routine bioassay programs by admission of Johnson Controls management.

The findings of this audit prompted the Advisory Board on Radiation Worker Health (ABRWH) to ask [SC&A 2017, Board Review System 2019]:

> *Do the 1999 LANL findings regarding bioassay program deficiencies imply data inadequacy and incompleteness significant enough to impair dose reconstruction?*

This is a difficult question to answer because it is not clear how to quantify the degree to which a dose reconstruction is impaired by bioassay program deficiencies or the point at which it becomes excessive. However, we can reply “no” to the question if the bioassay data are adequate for development of a co-exposure model because the co-exposure model can be used to perform the dose reconstruction for an individual in the absence of bioassay data. Therefore, the question becomes,

> *Do the indicated bioassay program deficiencies imply data inadequacy and incompleteness significant enough to impair development of a co-exposure model?*

It is important to note that operational monitoring programs frequently have deficiencies of some sort, but the impact of these deficiencies can be difficult to quantify objectively. One might point to regulations as defining objective standards for deficiencies, but in Section 4.0 we make the argument that our ability to construct a co-exposure model is not directly related to regulatory deficiencies in the monitoring program.

In the absence of objective standards we have taken the approach of assembling data that indicates who was monitored for plutonium, when they were monitored, and what results were obtained. Then, based on decades of collective experience in constructing co-exposure models, we decide if the preponderance of evidence supports the conclusion that we can indeed construct a bounding co-exposure model. This study design is discussed in more detail in Section 3.0, and the data used are described in Section 5.0 along with their summary statistics. Details of the analysis are given in Sections 6.0 to 11.0, with final conclusions given in Section 12.0. However, before proceeding it is essential to precisely define what a co-exposure model is, how it works, and what conditions would lead us to conclude that we cannot construct the model.

2.0 CO-EXPOSURE MODELS

It will be beneficial to describe in detail how co-exposure models work using the terminology of epidemiology. The goal of a co-exposure study, as used in the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) program, is to estimate the probability distribution of external doses or internal intakes to a “target population” [Coggon et al. 2009]. In internal dose co-exposure models the target population consists of all workers exposed to a given radioactive material in a given year during the course of work (Exposed Workers in Figure 2-1). All members of the target population who were monitored are referred to as the "study population" (Monitored-Exposed in Figure 2-1). The distribution of intakes in the study population is referred to as a "co-exposure model," and it can be used to estimate the distribution of intakes in the target population. The co-exposure model is then used to estimate intakes to exposed workers who were unmonitored (Unmonitored-Exposed in Figure 2-1). In the event the entire study population is not available, the co-exposure model is constructed from the "study sample" (right flowchart in Figure 2-1). Ideally, the study sample would be selected from the study population by random sampling, but other methods can be used when random sampling is not possible.

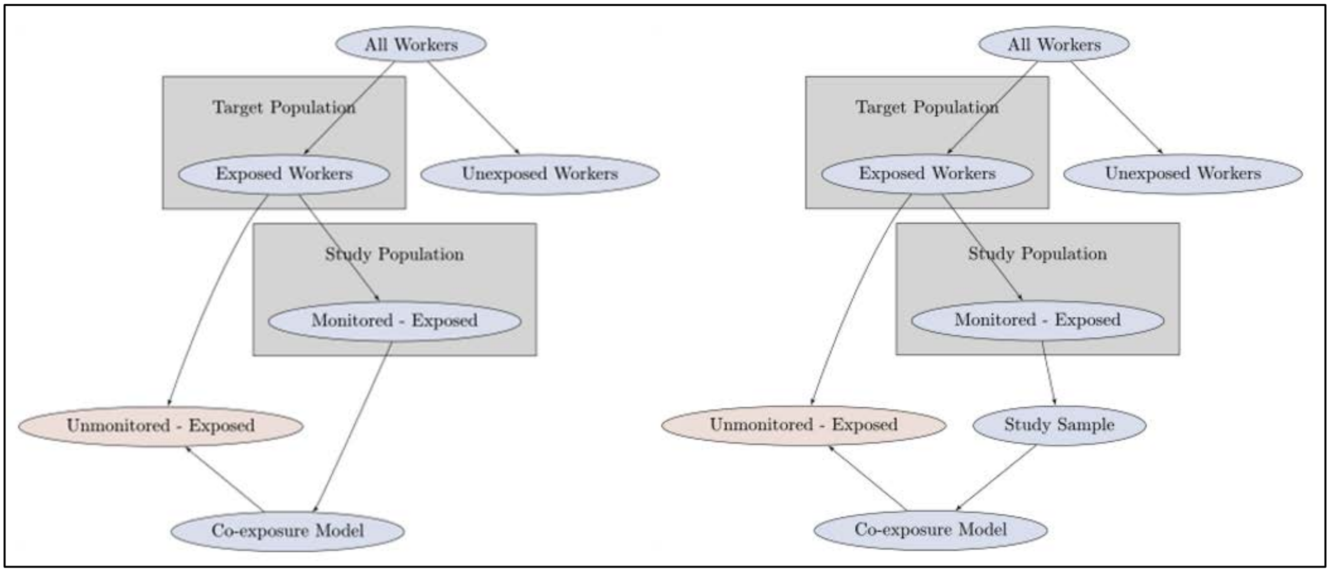

Figure 2-1. Co-exposure models where the study population is used directly (left) and where it is sampled (right).

If workers in the target population were monitored at random and the study sample (if used) was selected at random, a representative (unbiased) co-exposure model is obtained. If the monitoring of the workers in the target population was not random, a bounding (biased high) co-exposure model can still be generated if a significant portion of the most highly exposed workers in the target population were monitored. It is worth noting that monitoring programs at radiological facilities tend to focus on the most highly exposed workers, i.e., random monitoring programs are not used. Such programs inherently tend to generate bioassay data that results in biased-high co-exposure models.

Three conclusions can be drawn:

1. All of the workers in the target population do not have to be monitored to construct a co-exposure model (in fact, if all the workers were monitored there would be no need for a co-exposure model).

2. If the co-exposure model is generated from the study population, a bounding model can be generated as long as a significant portion of the most highly exposed workers in the target population are monitored. Note that <u>all</u> of those workers do not need to have been monitored, just a significant portion of them.

3. If the co-exposure model is generated from a study sample, a bounding model can be generated as long as the previous condition holds and the study sample is not missing a significant portion of the most highly exposed workers from the study population.

In summary, a representative or bounding co-exposure model can be constructed unless a significant portion of the most highly exposed workers were not monitored or do not appear in the study sample.

3.0 STUDY DESIGN

How does one demonstrate that an adequate portion of the most highly exposed workers were monitored? The program deficiency cited in the 1999 audit that appears to be the primary concern of the ABRWH [National Institute for Occupational Safety and Health (NIOSH) 2017, 2019a] is workers who were not placed on the appropriate bioassay programs as specified in LANL procedures. Bioassay programs for plutonium are specifically addressed because plutonium posed the greatest radiological hazard to workers at LANL during the study period (1996 to 2001). Therefore, a focused evaluation of the plutonium monitoring program at LANL during the study period provides the best picture of the monitoring programs LANL could implement. The ABRWH question can then be stated as:

> *Were workers who needed to be monitored for plutonium identified and placed on an appropriate bioassay program?*
>
> *Did these workers submit urine samples for analysis in a timely fashion after their work with plutonium?*

The answers to these questions are important as applied to the most highly exposed plutonium workers at LANL because the ABRWH original question can now be expressed in terms of two specific questions that can be answered by examining the records of the LANL plutonium monitoring program. The period of interest is January 1, 1996, to December 31, 2001 (the study period for this document), which runs from the beginning of the 10 *Code of Federal Regulations* (C.F.R.) Part 835 era to the implementation of electronic radiological work permits (RWPs) at LANL. 10 C.F.R. 835, 1993. During the study period, LANL had bioassay monitoring program policies, procedures, equipment, and personnel in place to determine exposure potential for workers, enroll them in the monitoring program, prepare and analyze the samples, and assess the sample results. Therefore, NIOSH presumes LANL had the wherewithal to monitor the most highly exposed plutonium workers and, therefore, data would be available from a significant proportion of the most highly exposed plutonium workers during the study period. Note that this is only one aspect of “data completeness” as discussed in *Criteria for the Evaluation and Use of Co-Exposure Datasets* [NIOSH 2020], but it is the aspect of primary relevance in this discussion.

Therefore, the next step is to analyze all available data in a search for evidence to the contrary (i.e., evidence that the plutonium bioassay data cannot be used to create a representative or bounding co-exposure model because a significant portion of the most highly exposed workers were not monitored). In short, it is not necessary to prove that the bioassay program was adequate; adequacy is presumed and evidence that it is inadequate for the construction of a co-exposure model must be sought.

Before proceeding to a more detailed discussion of the study and conclusions drawn from it, the relationship between regulatory compliance and generating co-exposure models must be discussed.

4.0 REGULATORY COMPLIANCE VERSUS CO-EXPOSURE MODELING

The 1999 audit was intended to assess whether LANL was in compliance[1] with the regulations promulgated in 10 C.F.R. Part 835. 10 C.F.R. 835, 1993. These regulations established criteria for limiting dose to workers and for acceptable design and implementation of internal dosimetry programs that were used to demonstrate compliance with these dose limits. The regulations were implemented in LANL policy statements and procedures. During audits like the one in 1999 any instance of LANL not following its procedures is of concern because it could indicate potential regulatory noncompliance. Because compliance with regulations helps to minimize and limit dose received by individuals, even one instance of noncompliance is of interest to the regulator and the site.

Dose reconstruction is concerned with making a reasonable estimate of the radiation doses received by an individual. To obtain a reasonable estimate of radiation exposure based on a co-exposure model, it need only be based on a representative (or bounding) sample of the workers performing radiological work (Section 2.0). In fact, regulatory compliance with participation in a bioassay program is neither necessary nor sufficient to construct a co-exposure model from the data from that program. To further illustrate, consider three scenarios:

1. The health physicists running the radiological protection program determine that it is unlikely under typical conditions that any workers will be exposed to radioactive materials that would deliver a dose in excess of 100 mrem committed effective dose equivalent in a year. According to 10 C.F.R. § 835.402(c)(1) no workers are placed on a bioassay program. 10 C.F.R. 835, 1993. <u>The monitoring program is in compliance with the regulations but a co-exposure model cannot be constructed because there are no bioassay data.</u>

2. Based on anticipated work, a worker is placed on an annual plutonium urine bioassay program. At the end of the year the worker had not performed any of the planned work, and in fact had never entered a regulated area. Consequently, no sample was required and none submitted. <u>The monitoring program might not be in compliance with the regulations (depending on how procedures were worded), but the delinquent sample has no effect on the ability to construct a co-exposure model because the worker was not a member of the target population and did not submit a sample.</u>

3. A worker was involved in an event with a high potential for exposure to significant levels of radioactive material. For some reason, no samples were collected from the worker. <u>According to 10 C.F.R. § 835.402(d), the monitoring program is not in compliance with the regulations. 10 C.F.R. 835, 1993. However, this noncompliance has negligible effect on the ability to construct a co-exposure model.</u> Careful study of Section 2.0 explains why this does not affect the ability to construct a co-exposure model (i.e., a significant portion of the most highly exposed workers are monitored).

Thus, compliance with the regulations in place at the time the radiological work was performed is not required in order to perform a dose reconstruction or develop a co-exposure model.[2]

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[1] In this document the word *compliance* used by itself usually means *"the act or process of complying to a desire, demand, proposal, or regimen or to coercion."* For example, if a worker did not submit a urine sample when required to do so by LANL procedures he is not in compliance with the bioassay program and the procedures that govern it. If those procedures are linked to DOE regulations so that the procedures implement a regulation, then he is not in *regulatory compliance,* or equivalently, not in compliance with the regulations.

[2] This conclusion was echoed by Dr. Ziemer at the April 15, 2021 meeting of the Advisory Board on Radiation and Worker Health [NIOSH 2021, p. 84].

5.0 DESCRIPTION OF STUDY

The approach used in this study was to assemble and analyze all the relevant available data about the plutonium monitoring program at LANL during the 1996 to 2001 study period. The question then becomes: do the data provide a "preponderance of evidence" that an unacceptably large portion of the most highly exposed workers either were not monitored or are missing from the study sample? The six datasets that are relevant to this analysis are:

- Health Physics Checklist (HPC);
- Bioassay Enrollment, Scheduling, and Tracking (BEST);
- Plutonium in vitro bioassay;
- Plutonium in vivo bioassay;
- External dose; and
- RWPs that required monitoring for plutonium and the associated acknowledgment forms.

These datasets are discussed in the following sections, which provide summary statistics for each. Detailed analyses for the HPC are in ORAUT [2021b], and those for the other five datasets are in ORAUT [2021a]. More detailed analyses of the datasets are described starting in Section 6.0.

5.1 HEALTH PHYSICS CHECKLIST DATASET

The HPC is a paper form that a worker, the manager, and a representative from Environmental Safety and Health (ESH) filled in to make changes in the worker's in vitro, in vivo, and external dose monitoring programs. HPCs are of interest because they are how workers got enrolled in bioassay programs.

HPCs from 1985 to 2002 were collected by the ORAU Team during nine targeted visits between May 20, 2019, and December 4, 2019, to LANL and Federal Records Centers in Dayton and Denver. A Site Research Database (SRDB) query for "health physics checklist" in the title and with a date retrieved between May 20, 2019, and December 4, 2019, returned 43 references. Not all 43 of these documents were entered into the HPC database because the focus of the HPC effort shifted to just the checklists from the study period (January 1, 1996 to December 31, 2001). The HPC dataset called "LANL HPC from targeted visits_2021_03_05.csv" contains 32 of the 43 SRDB documents. The dataset underwent a quality assurance test and had a transcription error rate of less than 5% (see ORAUT [2021a]).

In this discussion, HPC "adds" refers to HPC forms that requested a worker be added to a monitoring program that required an in vitro sample to be collected (e.g., an annual routine bioassay program or a termination bioassay program). Only HPC adds are of interest, not requests for a worker to be removed from a monitoring program (which does not require a sample). During the study period, 1,856 HPC adds were requested. The breakdown of HPC adds per year during the study period is shown in Figure 5-1. Of note is the relatively low number of adds in 2001, which appears to be the result of the HPC system being replaced by the electronic Dosimetry Evaluation System in that year (i.e., HPC paper forms were phased out in 2001).

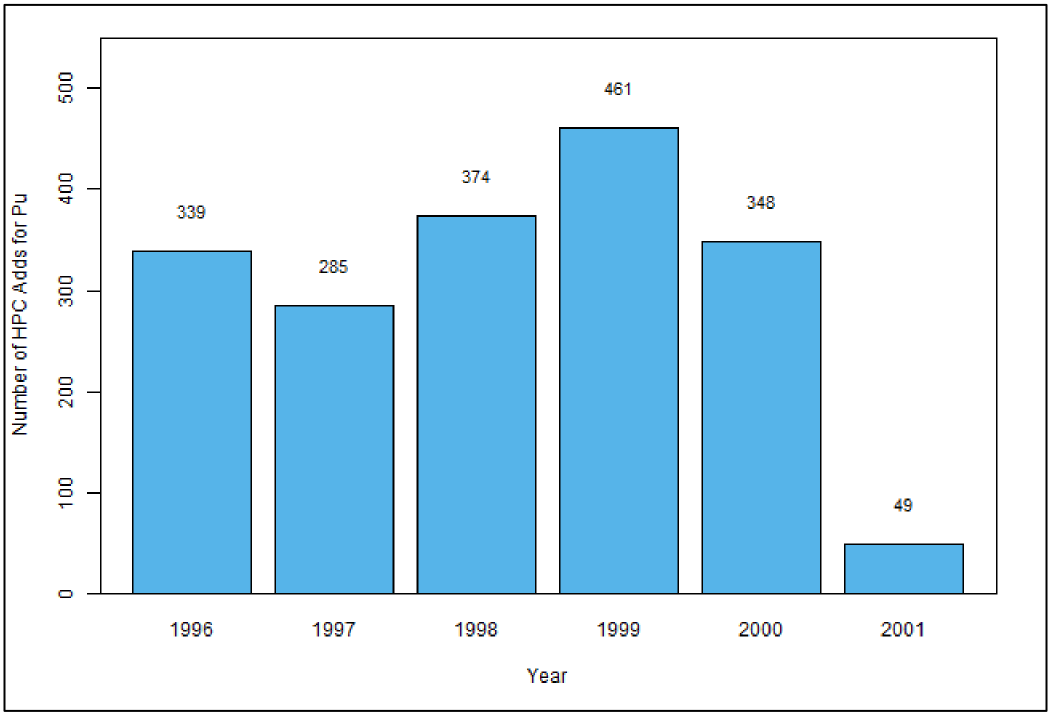

Figure 5-1. HPCs submitted per year that were adds for plutonium. See Table A-1.

5.2 BIOASSAY ENROLLMENT, SCHEDULING, AND TRACKING DATASET

BEST is a system that was used to manage bioassay program enrollments, which included adding and removing workers from routine, baseline, termination, and special monitoring programs. In this discussion enrollments that placed workers on bioassay programs are referred to as adds (which are different from adds in HPCs), which always had an associated sample request that is referred to as an Enroll Request. Sample requests not associated with adds were for routine (e.g., annual) samples, which are referred to as Non-enroll Requests. Figure 5-2 provides summaries of Enroll and Non-enroll Requests. The total number of sample requests for plutonium made through BEST in a given year is the sum of the Enroll and Non-enroll Requests in that year. For example, a total of 1,496 + 516 = 2,012 requests were made in 1996, and these sums are given in Figure 7-1. Bioassay sample kits were issued, tracked, and logged in BEST. Information extracted from the BEST database was provided electronically to the ORAU Team in 2020 [U.S. Department of Energy (DOE) 2021]. During the study period there were 13,895 requests for plutonium samples (which were for Enroll Requests and Non-enroll Requests) for 3,384 workers.

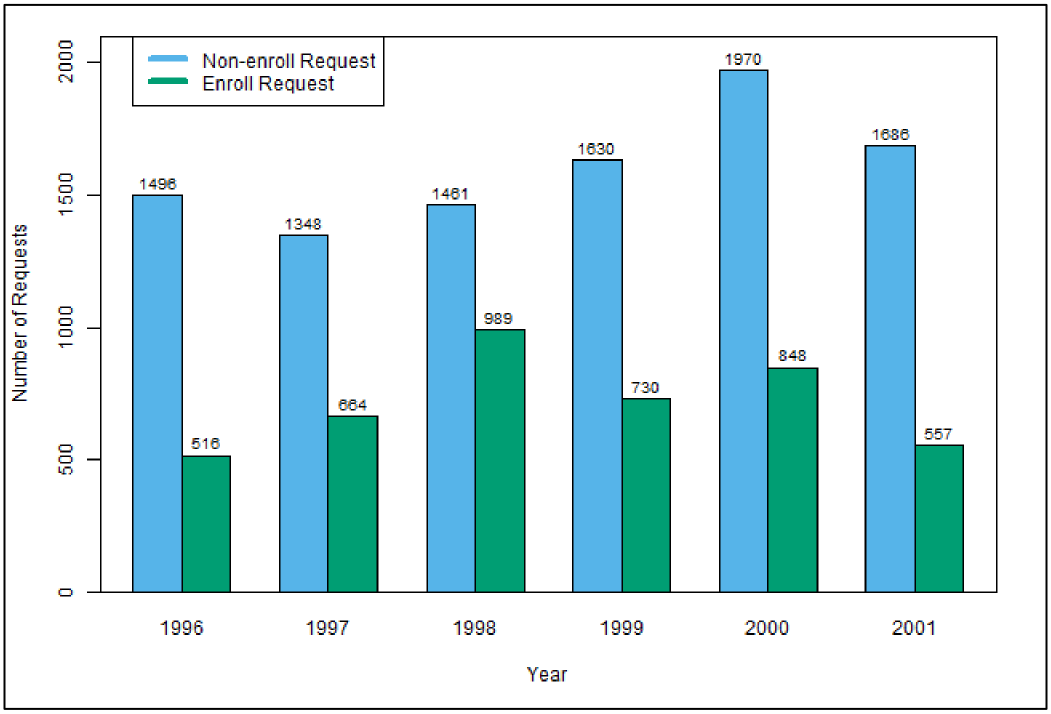

Figure 5-2. Sample requests in BEST for plutonium analysis per year. See Table A-2.

5.3 IN VITRO BIOASSAY DATASET

Creation of the in vitro bioassay dataset is detailed in ORAUT-OTIB-0063, *Los Alamos National Laboratory Bioassay Repository Database* [NIOSH 2009]. The file "LANL IN VITRO DATA FEB 2009 5-26-20.csv" was extracted from the Access database named "LANL_invitro_dataset_feb2009.mdb" located in the O:\DOE Site Images\LANL\030157133 - LANL In Vitro Dataset February 2009 folder on the ORAU Team network. There were 12,666 plutonium urine and fecal bioassay samples collected for plutonium analysis[3] from 3,219 workers during the study period. Note that these 12,666 bioassay results are the data that would be used for a co-exposure model for plutonium in urine at LANL. The year-by-year breakdown of the number of workers and samples they submitted is shown in Figure 5-3. The number of samples requested through BEST in a given year (Figure 5-2) for analysis for plutonium was greater than the number of samples received in a given year (Figure 5-3), which is discussed further in Section 7.0.

[3] By radiometric alpha spectrometry (RAS) and thermal ionization mass spectrometry.

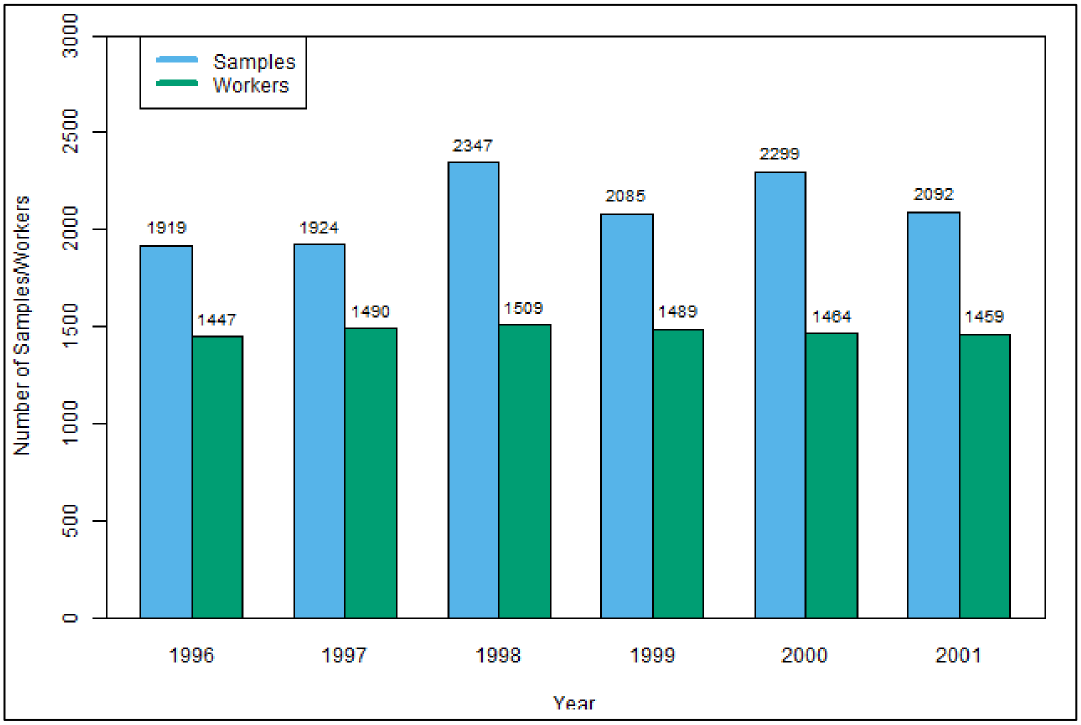

Figure 5-3. Plutonium in vitro bioassay samples submitted by workers in each year of the study. Note that these are all plutonium samples from all workers. See Table A-3.

5.4 IN VIVO BIOASSAY DATASET

Creation of the in vivo bioassay dataset is detailed in ORAUT-OTIB-0063, *Los Alamos National Laboratory Bioassay Repository Database* [NIOSH 2009]. The file "LANL in vivo TBL_NIOSH_REPORT_2005_11_09 5-26-20.csv" was extracted from the Access database named "2007_10_08-LANL_IN_VIVO_DATA-Access2003.mdb" located in the O:\DOE Site Images\LANL\030157132 - LANL In Vivo Data October 8, 2007 folder on the ORAU Team server. There are 6,817 plutonium/americium chest counts from 3,282 workers during the study period. The year-by-year breakdown of chest counts is shown in Figure 5-4. The number of workers monitored by chest counting and in vitro bioassay is essentially constant over the study period. Approximately 80% of the workers monitored for plutonium by in vitro bioassay also were monitored by chest counting.

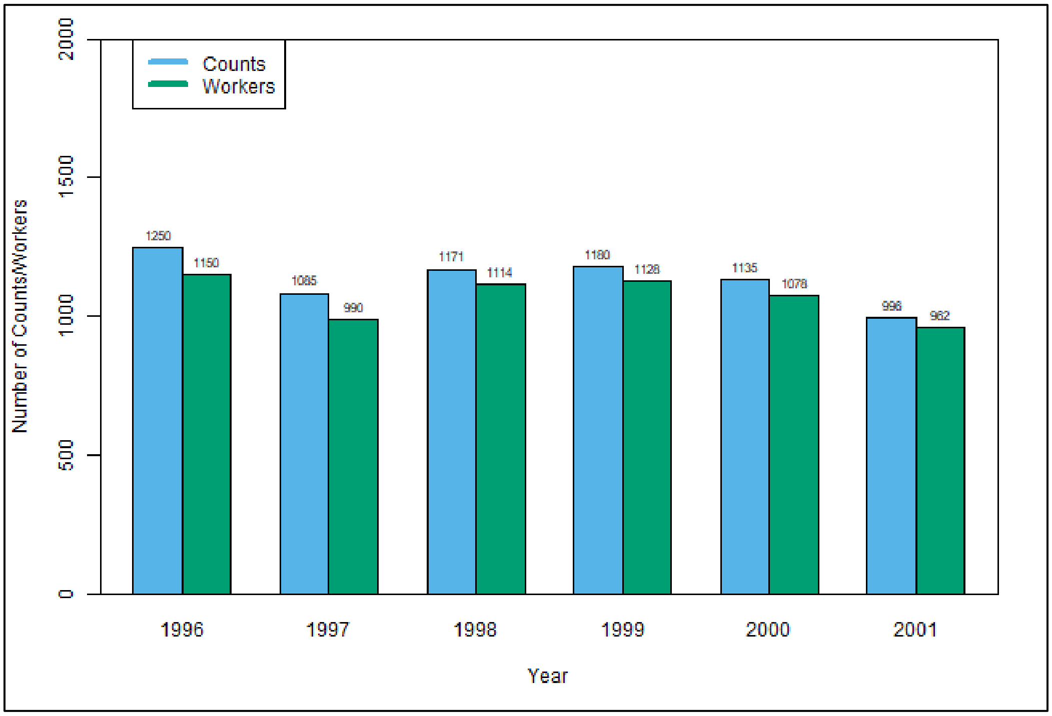

Figure 5-4. Plutonium/americium chest counts performed and the number of workers in each year of the study. See Table A-4.

5.5 EXTERNAL DOSE DATASET

The external dose records of LANL workers provide a comprehensive list of individuals (name and employee number) who performed radiological work at LANL. The external dosimetry records were used to help identify individuals who were missing employee numbers in other datasets and as an aid in the entry of those datasets. The external dose data consists of the 3.4 million records in the Access dataset located in the O:\DOE Site Images\LANL\030086614 - LANL External Whole-Body and Extremity Dosimetry Results folder.[4] There were approximately 11,000 workers at LANL who were monitored for external dose each year during the study period.

5.6 RADIOLOGICAL WORK PERMITS DATASET

RWPs and acknowledgment sheets were transcribed by the ORAU Team from the documents that were captured during the nine targeted visits (between May 20, 2019, and December 4, 2019) to LANL and Federal Records Centers in Dayton and Denver. Notable RWPs were targeted for capture, where a “notable” RWP is defined as an RWP that:

- Occurred within the study period (January 1, 1996, to December 31, 2001);
- Required urinalysis as noted on the RWP by having “Special Urinalysis” or “Pu Access List” checked or contained other equivalent terminology or notation indicating urinalysis was required; and
- Contained an associated roster (acknowledgment sheet) with names of personnel acknowledging the RWP.

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An SRDB query for “notable RWP” in the title and with a date retrieved between May 20, 2019, and December 4, 2019, returned 316 references. These documents constitute the RWP dataset called “LANL RWP from targeted visits_2021_03_11.csv.” The RWP dataset underwent a quality assurance test and had a transcription error rate of less than 5% (see ORAUT [2021a]).

RWPs were used to control work with a high potential for exposures to radiation. All other radiological work was performed according to Safe Operating Procedures. RWPs with plutonium access list (PAL) checked required that a person be on a plutonium monitoring program before performing work under the RWP. PALs were generated monthly and mailed as a memorandum to designated field contacts [Archuleta 2020]. Workers signed an acknowledgment sheet during the prejob briefing, which was required before working under the RWP. The signature on the acknowledgment sheet indicated that the worker understood the monitoring requirements of the RWP [DOE 1998]. Note that a worker could have signed an acknowledgment sheet and never performed work under that RWP; it is not a sign-in sheet. During the study period there are 19,568 records in the RWP dataset, where each record is the signature of one worker on the acknowledgment sheet of a particular RWP that had a PAL requirement. Overall, there are signatures from 1,942 workers.

5.6.1 Summary of Radiological Work Permits by Technical Area

The breakdown by year and Technical Area (TA) of RWPs with PAL requirements is given in Table 5-1. Areas mentioned in these RWPs [ORAUT 2004] are:

- TA-3 Core Area (a.k.a. South Mesa Site): ^{238}Pu, ^{239}Pu, ^{235}U, ^{238}U, depleted uranium (DU), natural uranium, ^{210}Po.
- TA-18 Pajarito Laboratory: ^{235}U, ^{239}Pu, ^{240}Pu, ^{233}U, mixed fission products, ^{131}I, polonium.
- TA-21 DP Site (a.k.a. DP Mesa): ^{239}Pu, ^{238}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{235}U, ^{238}U, ^{210}Po, ^{227}Ac, ^{3}H.
- TA-35 Ten Site: ^{3}H, ^{90}Sr, ^{140}Ba, ^{140}La, ^{235}U, DU, ^{237}Np, plutonium, polonium, cobalt, volatile fission products.
- TA-48 Radiochemistry Site: uranium, transuranic, mixed activation products, mixed fission products.
- TA-49 Frijoles Mesa Site: ^{3}H, plutonium, uranium.
- TA-50 Waste Management Site: all radionuclides.
- TA-54 Waste Disposal Site: all radionuclides.
- TA-55 Plutonium Facility Site: ^{239}Pu, ^{3}H.

Note that all RWPs with PAL checked that have any date (signed, effective, or expired) in the study period are included in this table. Year is the year in which the RWP expired. This table shows that a reasonable number of RWPs were obtained for the primary plutonium facilities at LANL.

Table 5-1. RWPs issued by TA and the year in which the RWP expired.

TA	1996	1997	1998	1999	2000	2001	2002	Totals
3	172	139	151	189	36	66	6	**759**
18	0	0	0	0	1	0	0	**1**
21	1	4	3	1	1	1	0	**11**
35	1	0	0	0	0	0	0	**1**
48	0	0	2	2	0	0	0	**4**
49	0	0	5	0	0	0	0	**5**
50	2	42	26	34	27	20	0	**151**
54	3	32	42	4	0	0	3	**84**
55	218	230	20	239	238	287	4	**1,236**
Totals	**397**	**447**	**249**	**469**	**303**	**374**	**13**	**2,252**

6.0 ANALYSIS OF DATA

The LANL datasets are interrelated as shown in Figure 6-1. Analysis of the HPC -> BEST -> IN-VITRO branch should indicate if a worker placed on a plutonium bioassay program submitted samples for analysis. The following questions can be asked and answers offered based on the information in those three datasets:

- If a sample was requested through BEST was it received and analyzed?
  - Compare sample requests in BEST to results reported in the in vitro bioassay database.
- Were samples in the in vitro bioassay dataset requested through BEST?
  - Compare results in the in vitro database to BEST to see if they were requested through BEST.
- Was a worker entered into BEST if requested to do so via an HPC?
  - Compare transactions initiated by HPCs to information that was uploaded into BEST.

Ideally, that analysis would answer most of the questions about whether a plutonium co-exposure model could be generated from the plutonium bioassay data. However, there is a known problem of HPCs not being submitted consistently. Analysis of the HPC -> BEST -> IN-VITRO branch cannot indicate anything if the HPC was never submitted. To address this issue, the ORAU Team analyzed the RWP -> ACKNOWLEDGMENT SHEET -> IN-VITRO/IN-VIVO branch, which can show if a worker who did work with potential for exposure to plutonium was monitored for plutonium. Note that this analysis is independent of whether a worker submitted an HPC. In other words, if an individual performed radiological work that required monitoring for plutonium and was properly monitored, the HPC paperwork is irrelevant. The questions are:

- Were workers who signed an RWP acknowledgment sheet with a PAL requirement monitored in a timely fashion?
  - Identify workers who signed an acknowledgment sheet that were monitored during an RWP-approved work period or after that RWP period (see Section 10.0 for details).
  - Identify workers who were eventually monitored after the end of the post-RWP monitoring window (see Section 10.0 for details).
- What fraction of workers who signed the acknowledgment sheet for a given RWP was monitored?

   – Examine the fraction of workers in a workgroup (all workers who signed a given acknowledgment form) who were monitored.

- What were the relative exposures of different groups to plutonium?

   – Compare ^{238}Pu and ^{239}Pu excretion rates for the different groups.

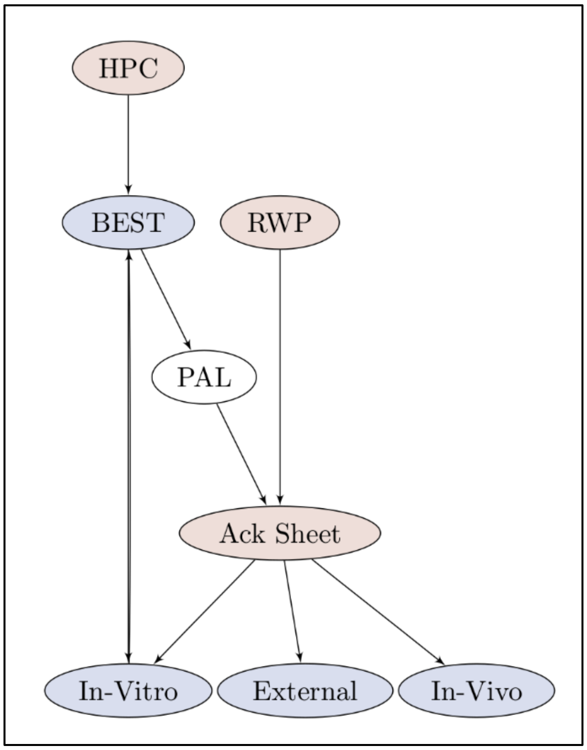

Figure 6-1. Relationship between datasets analyzed in this report. It is believed that the plutonium access list (PAL) was generated from BEST and was used to verify workers signing the acknowledgment sheet (Ack Sheet) were on a Pu bioassay program.

7.0 COMPARISON OF BIOASSAY ENROLLMENT, SCHEDULING, AND TRACKING AND THE IN VITRO DATASET

Overall, out of 13,895 requests made through BEST for samples to be analyzed for plutonium, 11,914 (85.7%) were fulfilled. All requests from BEST were tracked and most were accounted for with reasons being given for why sample requests were not fulfilled (Table 7-1). Of the 1,981 samples not received, 1,613 have legitimate reasons for not being received. Note that INACTIVATED FOR MIGRATION refers to sample requests that were canceled to migrate BEST to a new database, and that NO CHARGE means that no charge code was provided to pay for the analysis.

Table 7-1. Reasons for sample kits requested through BEST not being submitted.

Reason	Number
Travel	1
Vacation	1
Label/seal problems	4
Holiday break	5
Change of station	6
Sick leave	10
None given	17
Extended leave of absence	25
Lost kit	37
No charge	79
Miscellaneous	94
No longer in area	115
Monitoring no longer required	175
Terminated	203
No sample submitted	351
Inactivated for migration	858
Total	1,981

The number of requests through BEST and the number of samples received from all workers by year is given in Figure 7-1. The company an individual works for is identified in BEST for every request, and a breakdown of the number of requests by company for the nine companies with more than 100 requests (which is 90% of the requests from all 181 companies identified) is shown in Table 7-2.

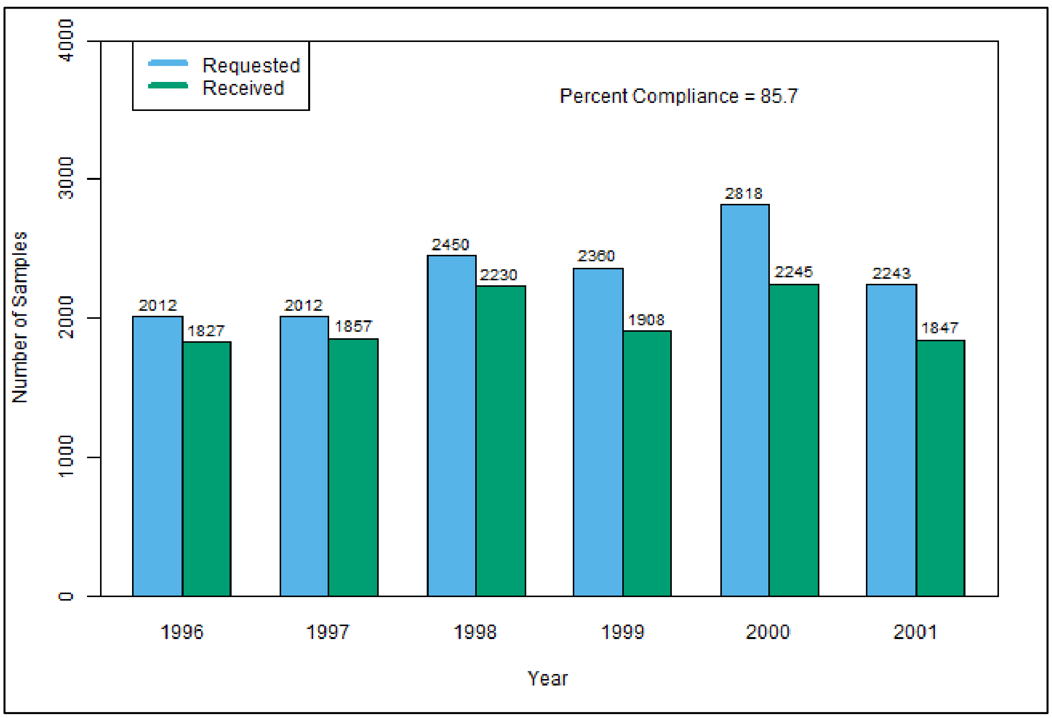

Figure 7-1. Plutonium samples requested through BEST and received for all workers. See Table A-5.

Table 7-2. Requests for in vitro samples for plutonium analysis by company (9 companies with more than 100 requests).

Company	Number
The Plus Group	133
Kleen-Tech Building Services	155
Butler Services	156
Protection Technology Los Alamo	240
Weirich and Associates	241
Comforce Technical Services	263
JC[a] Northern NM	454
KSL Services	1,365
LANL	9,632

a. JC = Johnson Controls.

To provide more detail, the number of requests and samples by year is given for each of the top three companies (Johnson Controls [JC], KSL Services [KSL], and LANL) in Figures 7-2 to 7-4. With the percentage of requests that resulted in samples being received ranging from 72% for JC to 89% for KSL, Figures 7-2 through 7-4 show that if a sample was requested it was usually received (or LANL was aware that it was not received). The observed decrease in the number of requests made to and samples received from JC workers in 1999 to 2001 (see Figure 7-2) can be attributed to a planned reduction in the number of these workers being monitored [NIOSH 2019b].

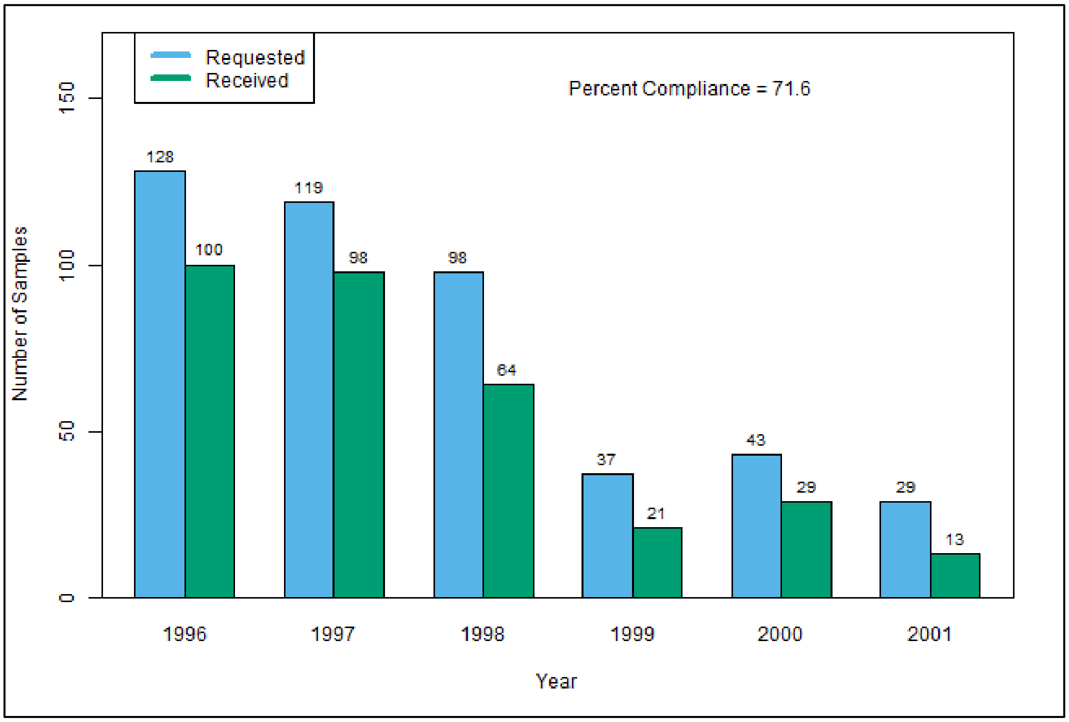

Figure 7-2. Samples requested from JC workers through BEST that were received and analyzed for plutonium. See Table A-6.

The reverse question, how many samples were requested through BEST, is also of interest because we want to confirm that BEST was the primary mechanism for requesting plutonium samples. Of the 12,666 in vitro samples submitted for plutonium analysis, 11,852 were requested through BEST (93.6%). Indications are that samples lost in process due to problems like low recovery were reported and the kit number was removed from BEST. This could explain some of the instances where a plutonium result in the in vitro dataset could not be traced back to BEST. The data discussed in this section show that a comprehensive program was in place at LANL to request and track plutonium samples.

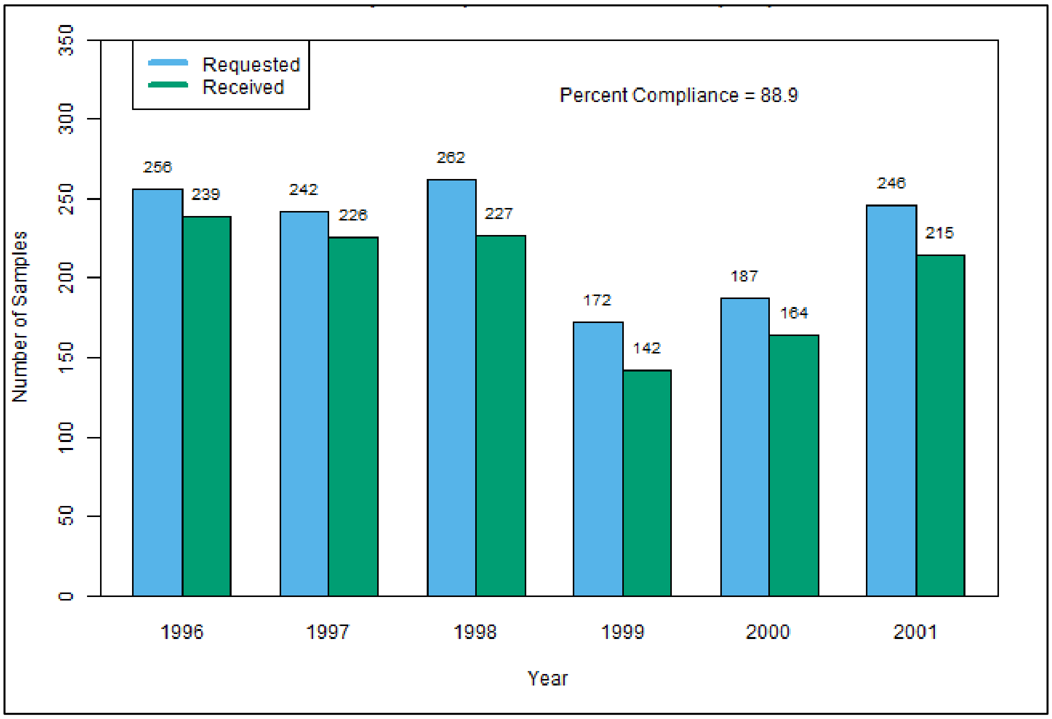

Figure 7-3. Samples requested from KSL workers through BEST that were received and analyzed for plutonium. See Table A-7.

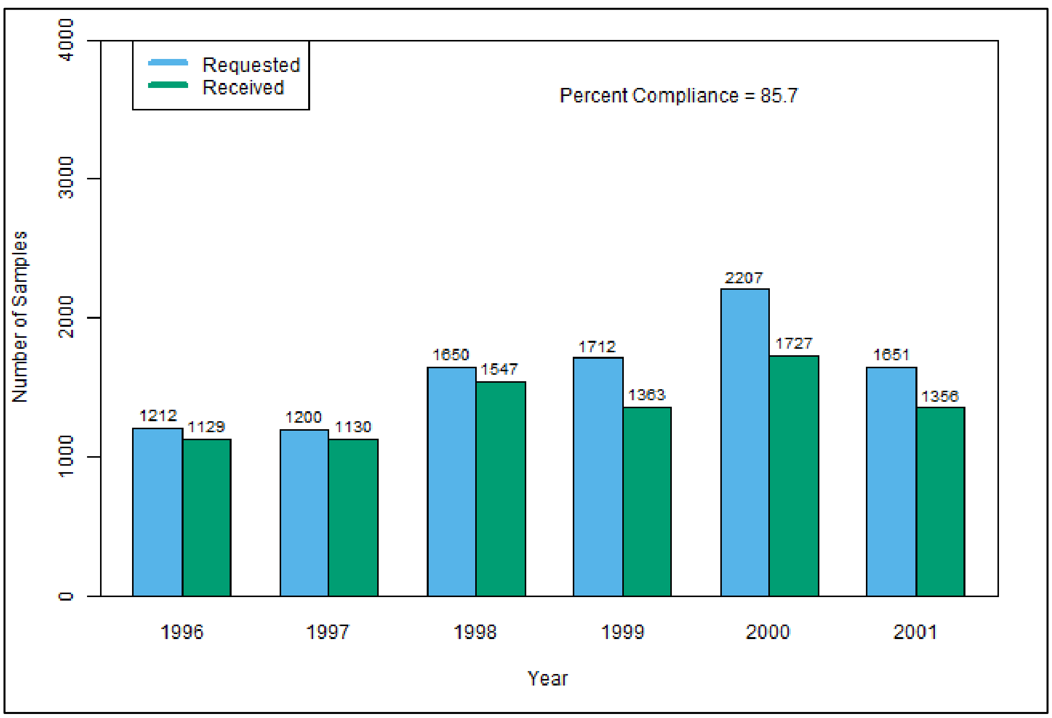

Figure 7-4. Samples requested from LANL workers through BEST that were received and analyzed for plutonium. See Table A-8.

8.0 DEFINITION OF GROUPS

Analyzing the HPC and RWP datasets requires statistics describing the entire populations of workers who filled out an HPC or signed an RWP acknowledgment form. Statistics describing certain subgroups of the population are necessary as well. Specifically, four subgroups of interest were defined:

- JC,
- LANL ESH,
- LANL Nuclear Materials Technology (NMT), and
- All others (Other).

ESH, NMT, and JC were selected because workers in those groups had the most signatures on RWP acknowledgment sheets: 17,860 out of 19,568 signatures or 91.3% were from individuals in one of these three groups. In addition, ESH is considered to represent radiological control personnel, NMT is considered to represent operators, and JC was considered to represent maintenance workers. JC is also of interest because it was specifically mentioned in the 1999 audit. The basic strategy used to assign workers to groups was:

- Assign each person who signed the acknowledgment form to the group written on the form next to the signature. If the group on the acknowledgment form contained the letters “ESH” the person was assigned to the ESH group for that record, and likewise for “NMT” and “JC”.
- Repeat the procedure for any record not assigned to a group using the group information in BEST.
- Any record not assigned at this point is assigned to Other.

Note that these groupings are not the same as the BEST company groupings used in Section 7.0.

9.0 COMPARISON OF HEALTH PHYSICS CHECKLIST AND BIOASSAY ENROLLMENT, SCHEDULING, AND TRACKING

There are 1,856 adds via HPCs during the study period for plutonium. The breakdown of adds by year and group is shown in Figure 9-1. Of note is that workers in Other made up most of the adds. This is not unexpected considering that:

- Adds in the HPCs are for workers coming on bioassay programs, and
- Subcontractors like those found in Other would be expected to have a higher turnover rate than LANL workers.

The low number of HPC adds for JC could be due to (1) HPC adds not being submitted consistently for JC workers added to bioassay monitoring, which is consistent with the findings in the 1999 audit of the internal dosimetry program, or (2) low turnover of workers or work, meaning no adds or changes to current bioassay monitoring, which would contribute to the low number of HPC adds.

Ideally, each of the HPC adds would be associated with an enrollment in BEST that would request a sample for plutonium analysis. A detailed comparison of the HPC with BEST [ORAUT 2021b] showed that:

- 1,802 out of 1,856 = 97.09% of the plutonium adds in HPCs matched BEST (when only considering BEST), and
- 1,848 out of 1,856 = 99.57% matched when also considering samples in the in vitro dataset that did not have a request in BEST.

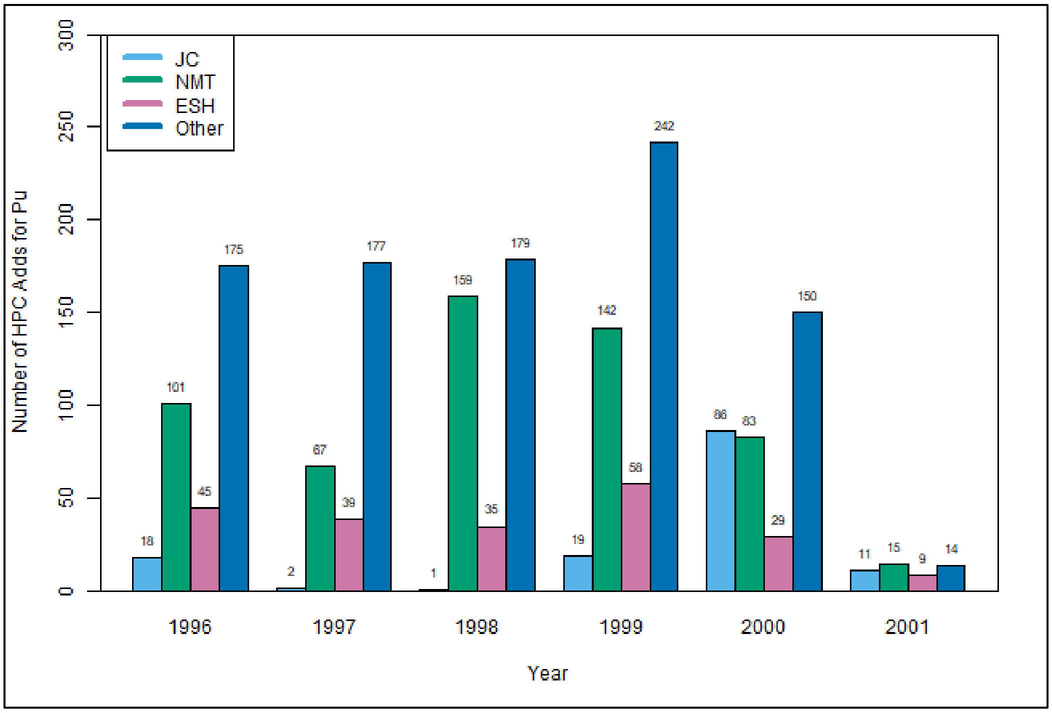

Figure 9-1. HPC adds per group. See Table A-9.

Therefore, workers who submitted HPC add forms almost certainly were entered in the BEST system where samples were requested with a high probability of being received. This is quite good, but again, this result reveals nothing about the HPCs that were not submitted or forms that were not captured by the ORAU Team. These concerns will be addressed when comparing bioassay requirements of the RWP with the in vitro dataset.

10.0 COMPLIANCE WITH RADIOLOGICAL WORK PERMIT MONITORING REQUIREMENTS

A key part of this study is to quantify the extent to which the LANL workforce complied with the bioassay requirements for work involving plutonium. In particular, the focus is on work regulated by RWPs with a PAL requirement, which indicates that the worker needed to be on a plutonium bioassay program before doing work under the RWP. Workers were required to sign the RWP acknowledgment sheet for an RWP to indicate they understood the monitoring and personal protection equipment requirements of that RWP. Note that their signatures did not denote that they actually performed any work, only that they understood the requirements to work under that RWP.

A summary of the number of workers, RWPs, and submitted plutonium in vitro samples is given in Figure 10-1. The Year of an RWP is defined to be the year in which the RWP expired. This plot gives an idea of how many workers were doing radiological work in each year and how many samples they submitted, and it indicates that there is a considerable amount of data available to analyze.

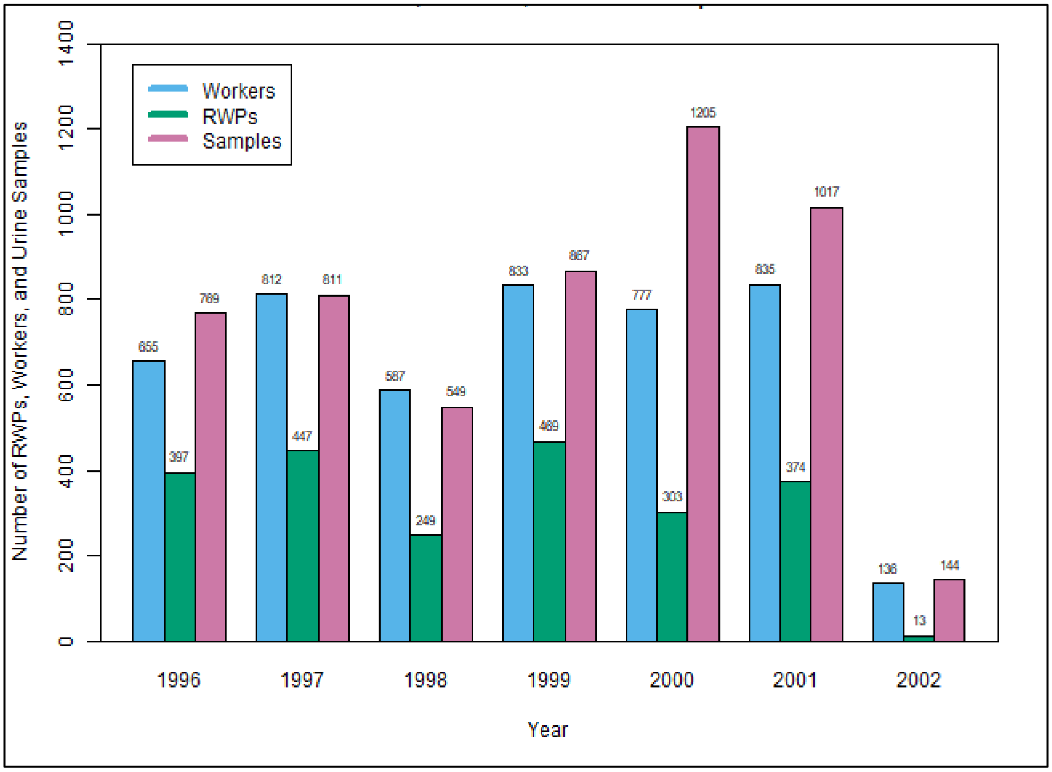

Figure 10-1. Plutonium samples from workers who signed an acknowledgment sheet on an RWP that had a PAL requirement. See Table A-10.

The number of workers from each group who signed an acknowledgment form in each year is given in Figure 10-2 and the number of RWPs acknowledgments signed by workers in each group by year is given in Figure 10-3. These plots show that ESH had fewer workers than NMT and JC, but their workers signed in on a proportionally larger number of RWPs. For example, in 1996 the average ESH worker signed in on 9.4 RWPs whereas the average JC and NMT worker signed in on 4.6 and 3.0 RWP, respectively. This is consistent with ESH workers moving from work location to work location performing radiological control functions, and it is the basis for quantifying compliance with bioassay programs using *worker* and *work* as metrics.

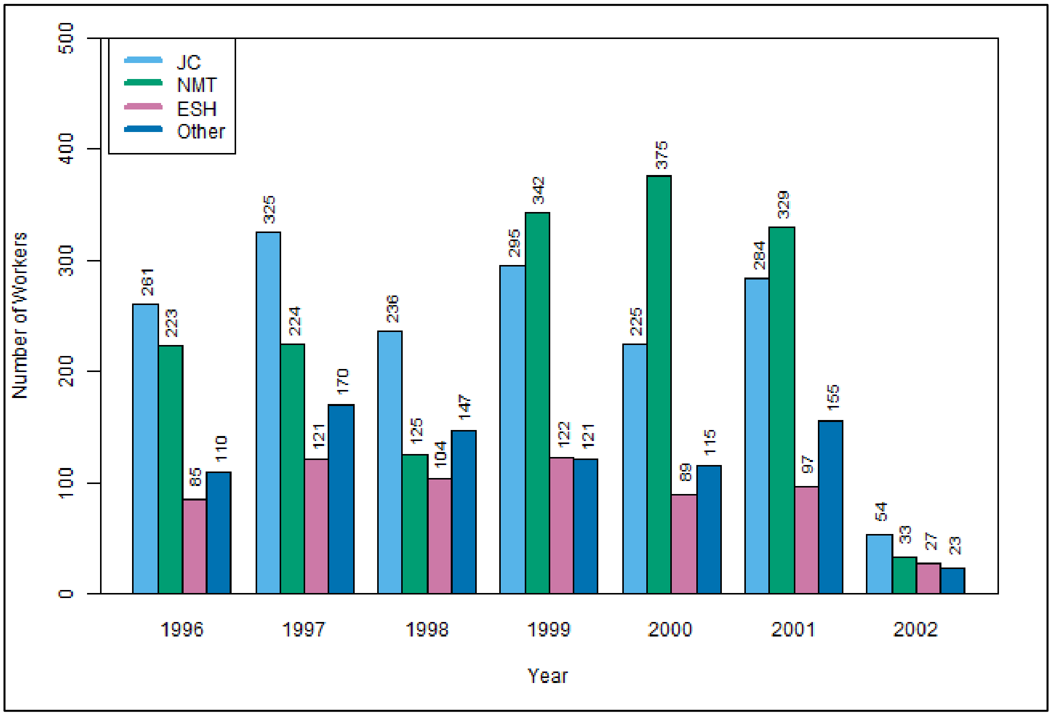

Figure 10-2. Workers in each of the groups who signed RWP acknowledgment forms in each year. See Table A-11.

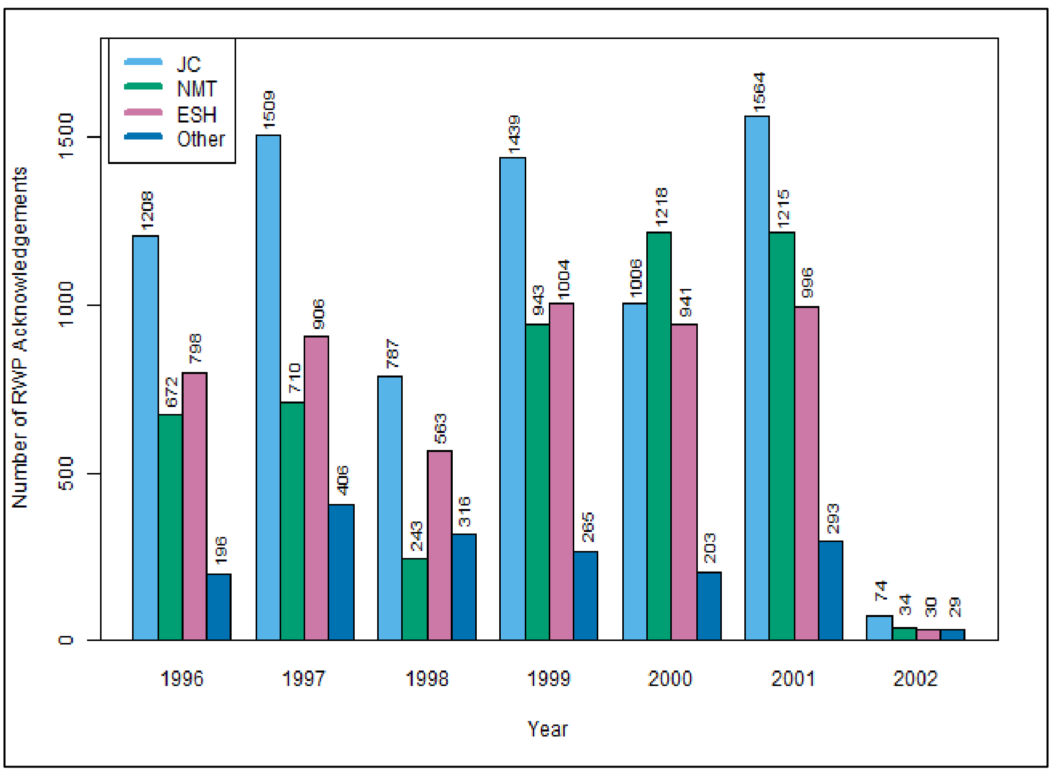

Figure 10-3. RWP acknowledgments signed by workers in each group by year. See Table A-12.

Measuring compliance by *work* implies that if a worker signs 10 RWPs in a year (for example) and complies with the monitoring requirements for all of them, there are 10 instances of compliance. When calculating compliance with the monitoring program, using this measure puts more weight on workers who sign multiple RWPs in a year. To determine if workers submitted samples in a timely fashion, a time window for submission of the in vitro samples needs to be established. If a sample was collected within the window, the worker was deemed to be in compliance with the monitoring requirements of that RWP. Work is defined to be the combination of a specific worker and a specific RWP the worker acknowledged. Each record in the RWP dataset represents one instance of work. If a worker submitted a sample:

- Between the effective date and the expiration date of the RWP (the active dates of the RWP), or
- By the end of the year after the year in which the RWP expired[5] (the post-RWP sampling window),

the worker was considered to have complied with the monitoring requirements for that work.

It is also important to examine if the worker was in compliance with the monitoring requirements for that year with no consideration of the number of acknowledged RWPs. There is no unique way to define this measure. In this report, measuring compliance by a worker is determined by checking compliance with any of the acknowledged RWPs that year. For example, if a worker signed 10 RWPs and was in compliance (in terms of work) with nine of them, then the worker was in compliance for the year. Using this measure puts equal weight on each worker when calculating compliance with the monitoring program. Other definitions of compliance can be used (e.g., using only the post-RWP window and requiring a worker to be in compliance with all instances of work rather than just one). Use of these alternative definitions does not change the conclusions of this report on the development of a co-exposure model for plutonium.

Another sampling window of interest considers monitoring for plutonium at any time after the post-RWP window. This open window is relevant for plutonium because doses from intakes of plutonium can be bound by samples taken at any time after the intake.[6] Sampling results in the open window can be used to address the concern that the most highly exposed workers were not monitored during the active dates of the RWP or in the post-RWP window. An overall summary of compliance with the RWP monitoring requirements is given in Table 10-1, and more detailed information is given in Attachment B. The overall compliance with the plutonium bioassay programs (when 100% compliance with such programs was problematic) was quite good for a large facility like LANL.

Table 10-1. Summary of statistics for monitoring of RWP work.[a]

Group	Number of workers	Number of RWPs	Work	Worker	Work(O)	Worker(O)
JC	703	1,396	81.0	65.1	92.6	83.5
ESH	227	2,128	96.5	84.1	98.1	87.8
NMT	660	1,393	97.1	95.3	99.0	98.2
Other	556	579	70.6	63.3	81.4	74.5

a. Work and Worker columns refer to the percentage of work and workers, respectively, who were properly monitored as determined using the active RWP period and post-RWP window. Work(O) and Worker(O) columns refer to the percentage of work and workers, respectively, who were properly monitored as determined using the active RWP period, post-RWP window, and open window.

Because the acknowledgment sheets were not RWP sign-in sheets, this does not mean that all the workers who signed the acknowledgment sheet for a given RWP were in one place at one time. Nevertheless, they can be considered to constitute a workgroup. As shown in Figure 10-4, for 96.8%

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5 For example, if the RWP expired anytime in 1996, the post-RWP window goes to December 31, 1997.

6 Thermal ionization mass spec (TIMS) that was routinely used at LANL during the study period could easily bound the dose from weapons grade plutonium to less than 100 mrem at any time after the intake.

of the 2,252 RWPs, at least half of the workers who signed a given RWP were monitored (in the active RWP period or post-RWP window). This implies that it is highly likely that workers who were exposed to plutonium and not monitored had potentially exposed coworkers who were monitored.

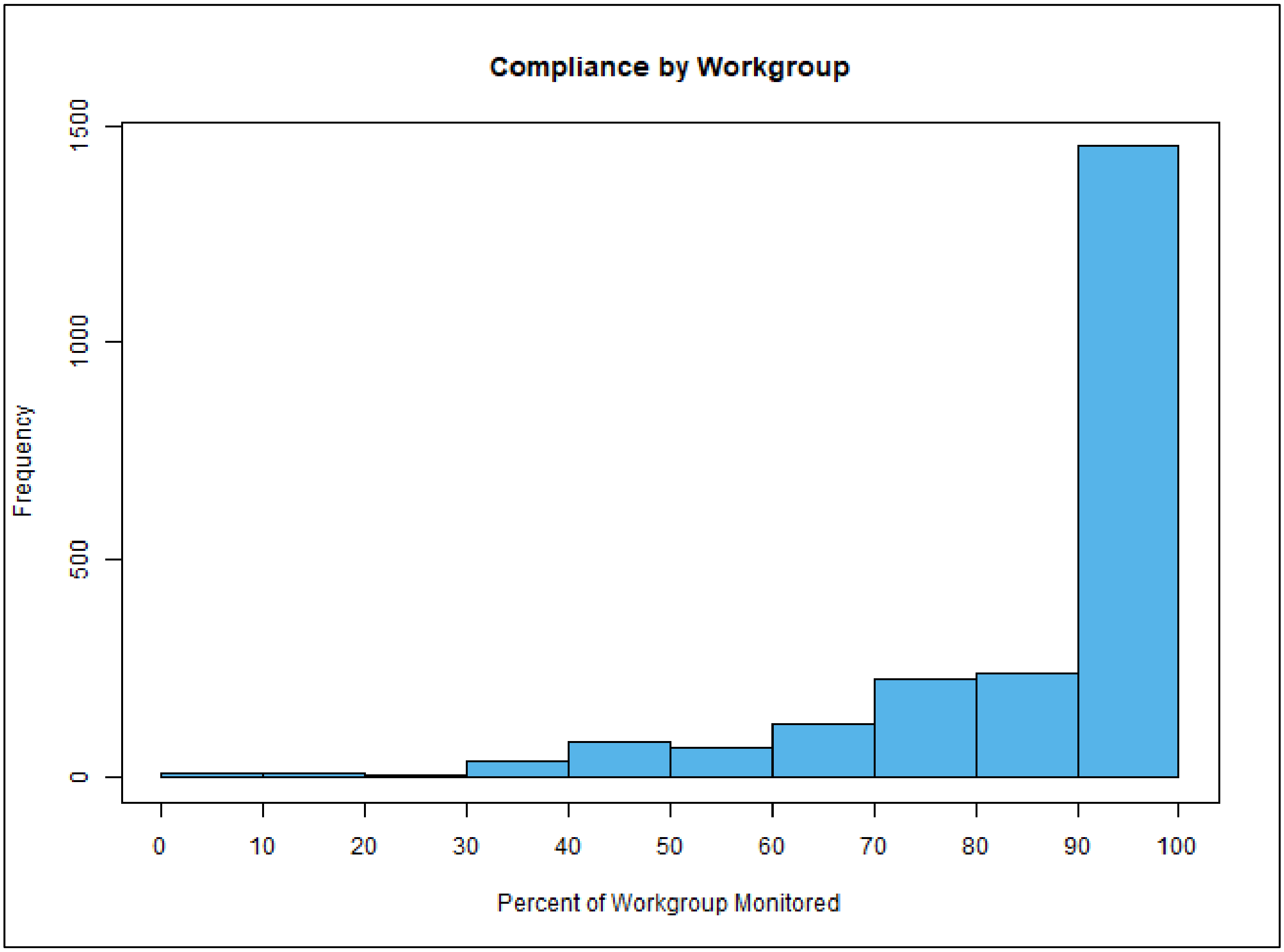

Figure 10-4. Histogram of the frequencies of workgroup monitoring percentages for 2,252 RWPs. See Table A-13.

11.0 PLUTONIUM RESULTS FOR JOHNSON CONTROLS, ENVIRONMENTAL SAFETY AND HEALTH, NUCLEAR MATERIALS TECHNOLOGY, AND OTHER

In previous sections we have established that while there is a considerable amount of data available on which to base a co-exposure model for plutonium at LANL, some groups have more than others. Therefore it is of interest to compare some measure of relative exposures of the groups to see if the groups with less data are more highly exposed. An approximate measure of the exposures to each of the four groups is the plutonium in urine analytical results for the groups. Figure 11-1 is a lognormal quantile-quantile (q-q) plot of the ^{238}Pu (radiometric alpha spectrometry [RAS] only) results for the four groups. The data for the four groups are clearly different with NMT and ESH, the most completely monitored groups (see Table 10-1), being the highest.

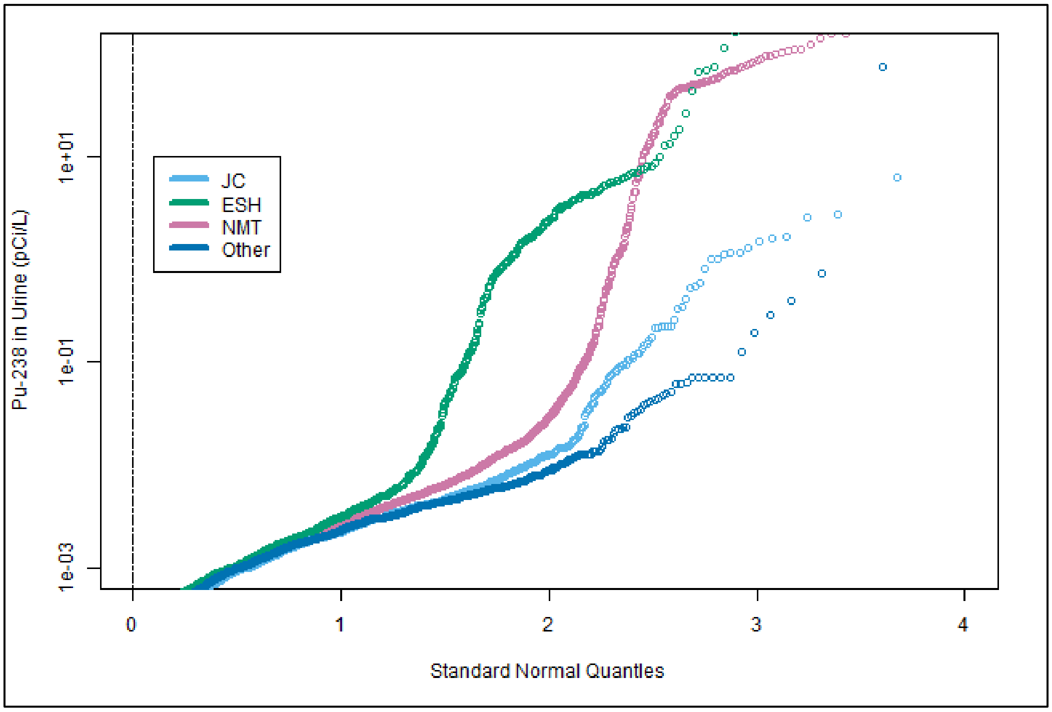

Figure 11-1. Comparison of ^{238}Pu in the urine of JC, ESH, and NMT workers who submitted samples in the study period.

Figure 11-2 is a lognormal q-q plot for the combined ^{239}Pu (RAS only) results for the four groups. The data for the four groups are fairly similar, with NMT and ESH being slightly higher. The relatively high results for JC are the result of [redacted] JC workers who had relatively high levels of ^{239}Pu in their urine from what appears to have been a single event.

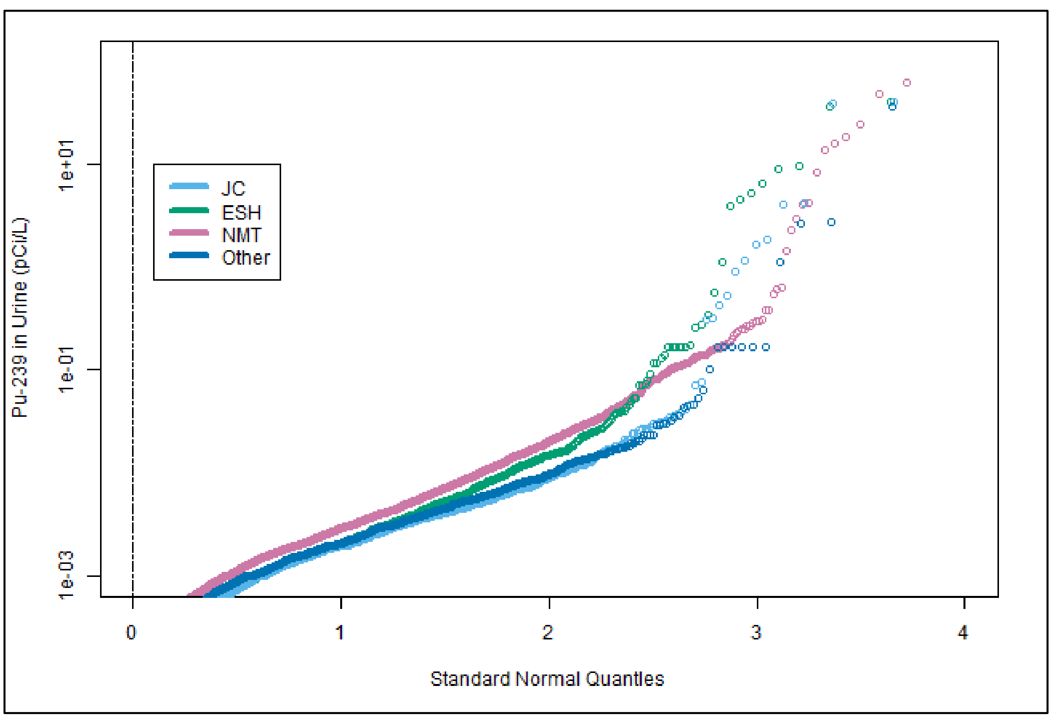

Figure 11-2. Comparison of ^{239}Pu in the urine of JC, ESH, and NMT workers who submitted samples.

12.0 SUMMARY AND CONCLUSIONS

This discussion began with the question,

> *Did the regulatory deficiencies pointed out in the 1999 audit of the LANL internal dosimetry program imply that the data generated by that program in the 1996 to 2001 period are unsuitable for use in generating a co-exposure model for plutonium for use in the EEOICPA compensation program?*

The fundamental philosophy of co-exposure models was reviewed, and it was concluded that a bounding co-exposure model can be constructed as long as a significant portion of the most highly exposed workers were monitored and present in the study sample. The fact that regulatory deficiencies have no direct relationship with the ability to construct co-exposure models was noted. The premise of the study designed to answer the question was to presume that LANL had the desire and wherewithal to properly monitor workers who had a significant potential for exposure to plutonium and to look at the available data for indications that this did not occur. The following are the main findings from this study:

- The HPC was a paper form used to remove or add workers to monitoring programs in the BEST database. BEST was used to request samples and track when the sample was received. HPC adds were compared to the BEST dataset, and it was concluded that workers were put on the requested plutonium bioassay program nearly 100% of the time.

- The in vitro bioassay database contained all the plutonium analytical results reported by LANL. In vitro bioassay sample requests in BEST were compared to the in vitro bioassay database. It was concluded that the requests were fulfilled an average of about 86% of the time. Compliance by major companies ranged from around 72% for JC to about 89% for LANL employees. All samples that were not received were tracked, and most had an explanation of why the sample was not submitted.

- The plutonium samples in the in vitro bioassay dataset were compared to BEST and it was concluded that about 94% of the samples were requested through BEST.

- Workers who signed acknowledgment sheets for RWPs that required plutonium monitoring (as indicated by the PAL checkbox on the RWP) were compared to the in vitro and in vivo bioassay datasets to determine if they were in compliance with the monitoring requirements. Compliance was defined in a number of different ways (see Table 10-1 and the plots in Attachment B), but in all cases it was found that a significant portion of the most highly exposed workers are available for inclusion in the co-exposure model and that no workers from major organizations were inadequately represented in the bioassay datasets.

- The workers who signed the acknowledgment form for a given RWP were considered to constitute a workgroup. Approximately 97% of the 2,252 RWP had 50% or more of the workers monitored.

The preponderance of evidence supports the conclusion that the plutonium bioassay data reported by LANL in the 1996 to 2001 study period include a significant portion of the most highly exposed workers and are therefore adequate to construct a co-exposure model for plutonium.

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ATTACHMENT A
DATA FOR BAR CHARTS

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Table A-1. Data for Figure 5-1, HPCs submitted per year that were adds for plutonium during the study period.

1996	1997	1998	1999	2000	2001
339	285	374	461	348	49

Table A-2. Data for Figure 5-2, Sample requests in BEST for plutonium analysis per year.

Type	1996	1997	1998	1999	2000	2001
Enroll	516	664	989	730	848	557
Non-enroll	1,496	1,348	1,461	1,630	1,970	1,686

Table A-3. Data for Figure 5-3, Plutonium in vitro bioassay samples submitted by workers in each year of the study. Note that these are all plutonium samples from all workers.

Type	1996	1997	1998	1999	2000	2001
Samples	1,919	1,924	2,347	2,085	2,299	2,092
Workers	1,447	1,490	1,509	1,489	1,464	1,459

Table A-4. Data for Figure 5-4, Plutonium/americium chest counts performed and workers in each year of the study.

Type	1996	1997	1998	1999	2000	2001
Counts	1,250	1,085	1,171	1,180	1,135	996
Workers	1,150	990	1,114	1,128	1,078	962

Table A-5. Data for Figure 7-1, Plutonium samples requested through BEST and received for all workers.

Type	1996	1997	1998	1999	2000	2001
Requested	2,012	2,012	2,450	2,360	2,818	2,243
Received	1,827	1,857	2,230	1908	2,245	1,847

Table A-6. Data for Figure 7-2, Samples requested from JC workers through BEST that were received and analyzed for plutonium.

Type	1996	1997	1998	1999	2000	2001
Requested	128	119	98	37	43	29
Received	100	98	64	21	29	13

Table A-7. Data for Figure 7-3, Samples requested from KSL workers through BEST that were received and analyzed for plutonium.

Type	1996	1997	1998	1999	2000	2001
Requested	256	242	262	172	187	246
Received	239	226	227	142	164	215

Table A-8. Data for Figure 7-4, Samples requested from LANL workers through BEST that were received and analyzed for plutonium.

Type	1996	1997	1998	1999	2000	2001
Requested	1,212	1,200	1,650	1,712	2,207	1,651
Received	1,129	1,130	1,547	1,363	1,727	1,356

Table A-9. Data for Figure 9-1, HPC adds per group.

Type	1996	1997	1998	1999	2000	2001
JC	18	2	1	19	86	11
NMT	101	67	159	142	83	15
ESH	45	39	35	58	29	9
Other	175	177	179	242	150	14

Table A-10. Data for Figure 10-1, Plutonium samples from workers who signed an acknowledgment sheet on an RWP that had a PAL requirement.

Type	1996	1997	1998	1999	2000	2001	2002
Workers	655	812	587	833	777	835	136
RWPs	397	447	249	469	303	374	13
Samples	769	811	549	867	1,205	1,017	144

Table A-11. Data for Figure 10-2, Workers in each of the groups who signed RWP acknowledgment forms in each year.

Type	1996	1997	1998	1999	2000	2001	2002
JC	261	325	236	295	225	284	54
NMT	223	224	125	342	375	329	33
ESH	85	121	104	122	89	97	27
Other	110	170	147	121	115	155	23

Table A-12. Data for Figure 10-3, RWP acknowledgments signed by workers in each group by year.

Type	1996	1997	1998	1999	2000	2001	2002
JC	1,208	1,509	787	1,439	1,006	1,564	74
NMT	672	710	243	943	1,218	1,215	34
ESH	798	906	563	1004	941	1,215	30
Other	196	406	316	265	203	293	29

Table A-13. Data for Figure 10-4, Histogram of the frequencies of workgroup monitoring percentages for 2,252 RWPs.

Bin	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Number	9	8	5	37	83	68	122	228	241	1451

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS

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ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

B.1 ACTIVE RWP DATES AND POST-RWP WINDOW

Table 10-1 in Section 10.0 gave a broad overview of the compliance with RWP plutonium monitoring programs. This section provides a more detailed breakdown of that information:

- Compliance by group (JC, ESH, NMT, and Other) by year for work and worker using the active RWP period and post-RWP window (Section B.1, Figures B-1 to B-8 and Tables B-1 to B-8).
- Compliance by group (JC, ESH, NMT, and Other) by year for work and worker using the active RWP period, post-RWP window, and open window (Section B.2, Figures B-9 to B-16 and Tables B-9 to B-16).

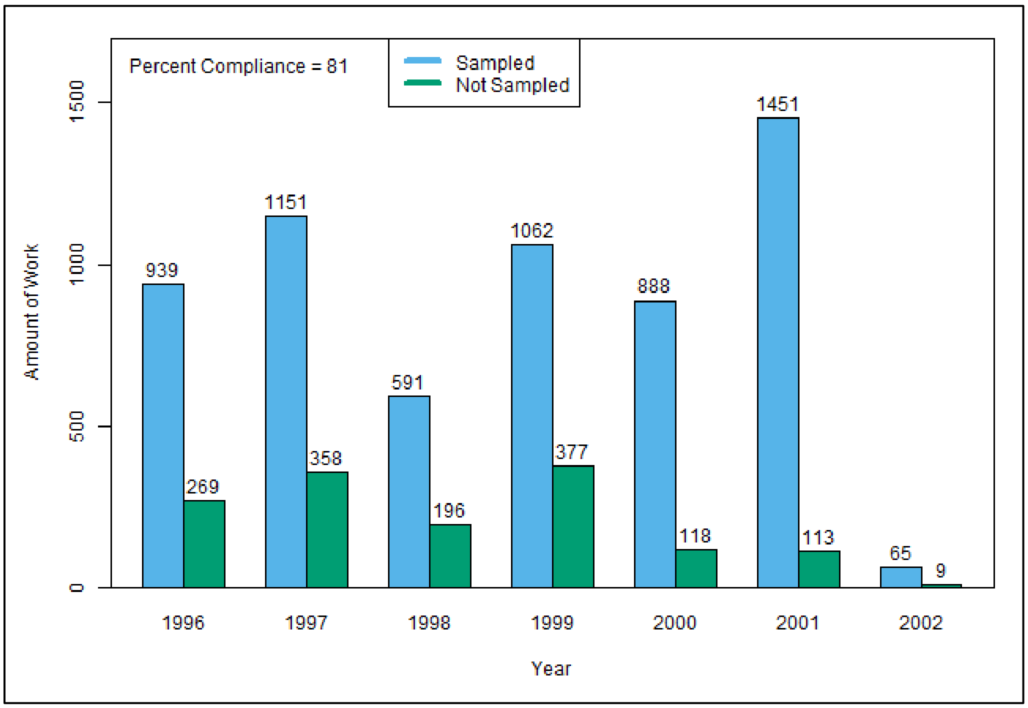

Figure B-1. Work performed by JC that was properly monitored (Sampled).

Table B-1. Data for Figure B-1, Work performed by JC that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	939	1,151	591	1,062	888	1,451	65
Not sampled	269	358	196	377	118	113	9

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

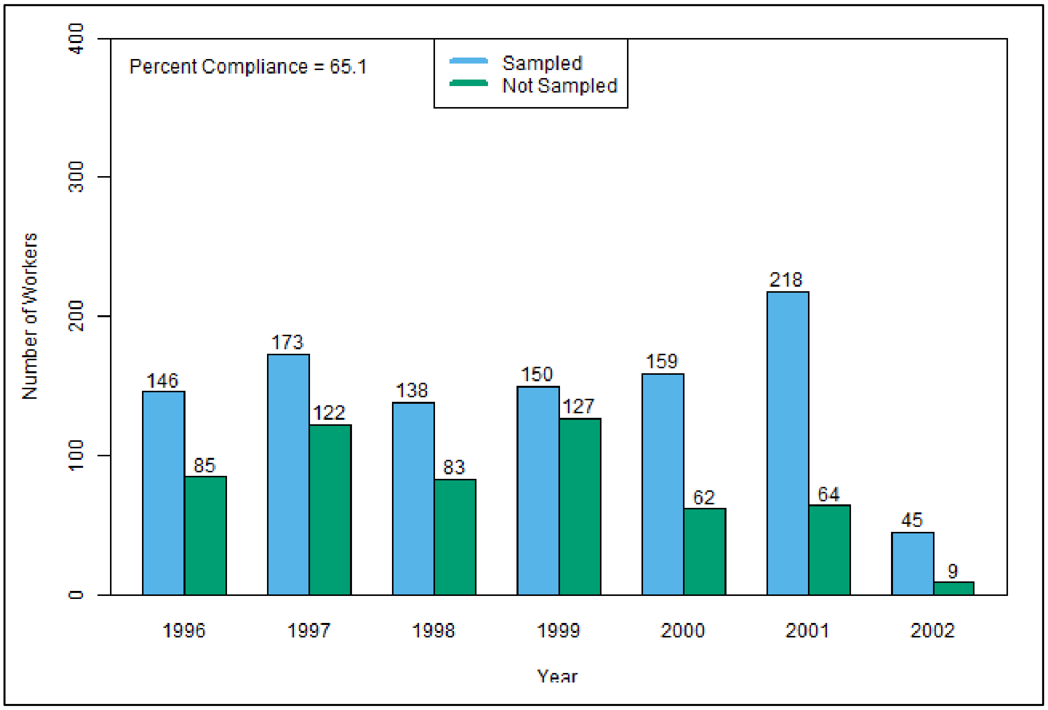

Figure B-2. JC workers who were properly monitored (Sampled).

Table B-2. Data for Figure B-2, JC workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	146	173	138	150	159	218	45
Not sampled	85	122	83	127	62	64	9

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

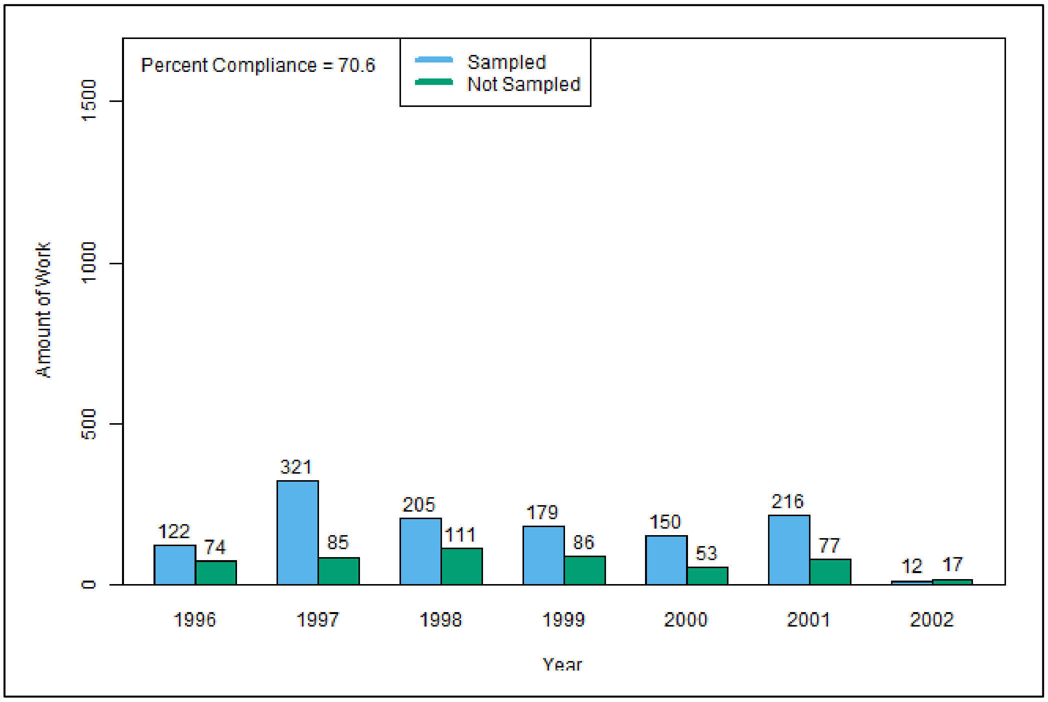

Figure B-3. Work performed by Other that was properly monitored (Sampled).

Table B-3. Data for Figure B-3, Work performed by Other that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	122	321	205	179	150	216	12
Not sampled	74	85	111	86	53	77	17

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

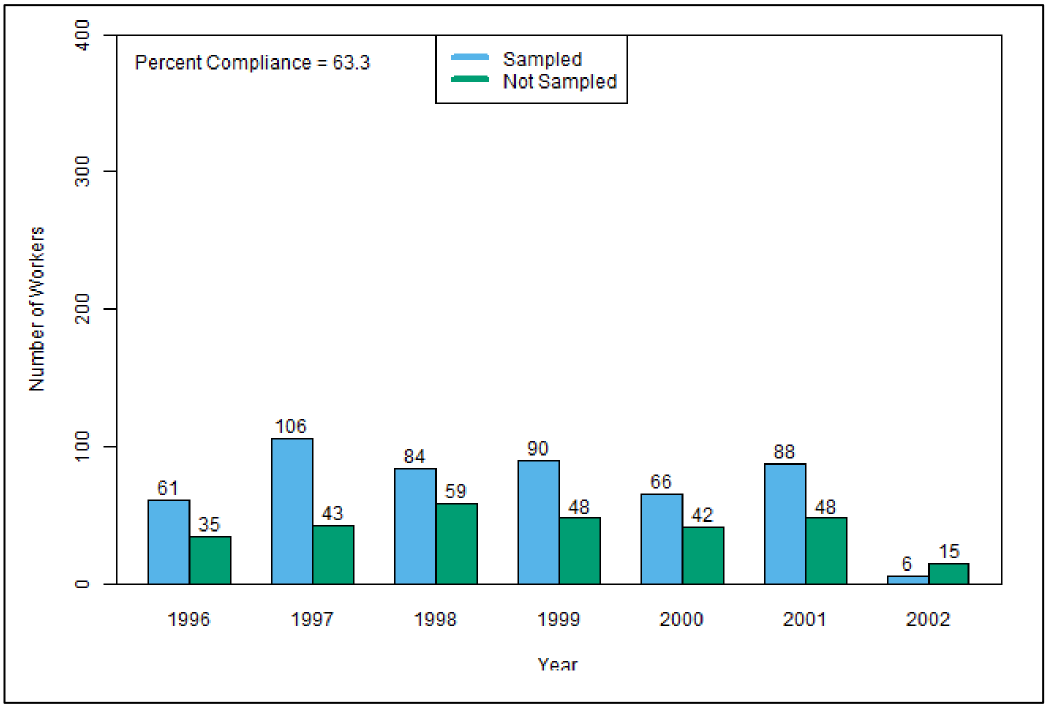

Figure B-4. Other workers who were properly monitored (Sampled).

Table B-4. Data for Figure B-4, Other workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	61	106	84	90	66	88	6
Not sampled	35	43	59	48	42	48	15

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

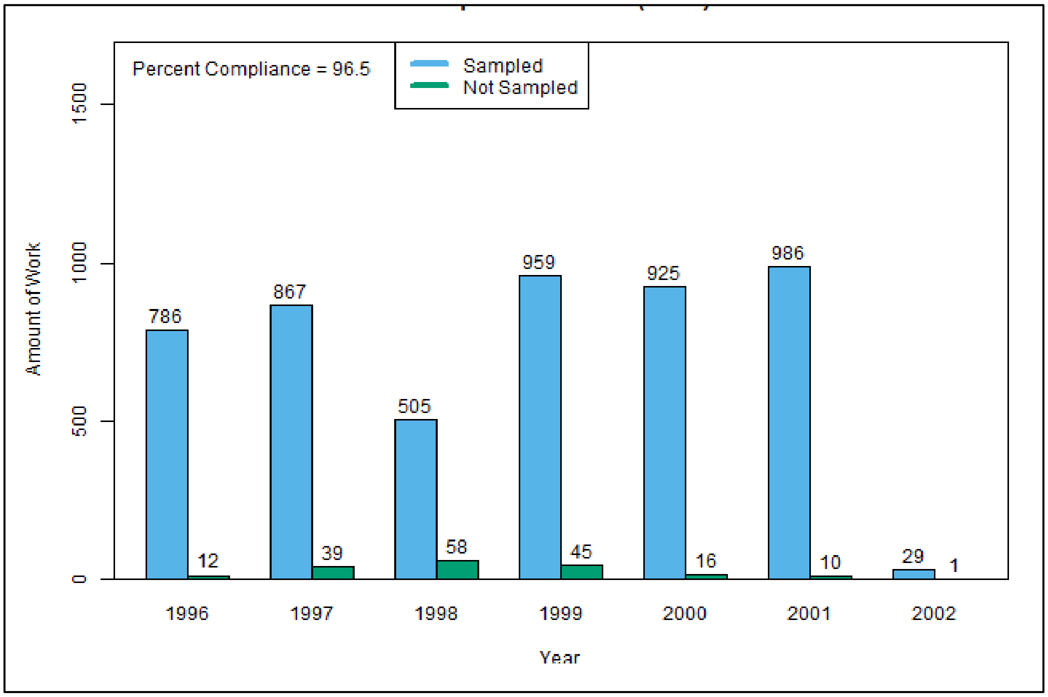

Figure B-5. Work performed by ESH that was properly monitored (Sampled).

Table B-5. Data for Figure B-5, Work performed by ESH that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	786	867	505	959	925	986	29
Not sampled	12	39	58	45	16	10	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

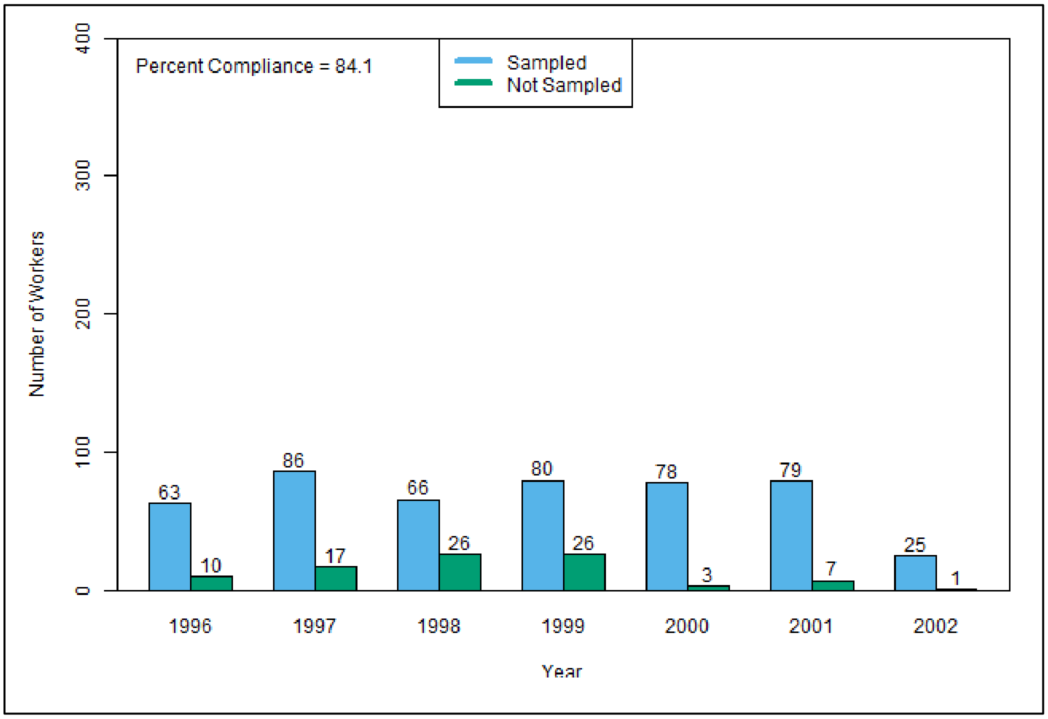

Figure B-6. ESH workers who were properly monitored (Sampled).

Table B-6. Data for Figure B-6, ESH workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	63	86	66	80	78	79	25
Not sampled	10	17	26	26	3	7	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

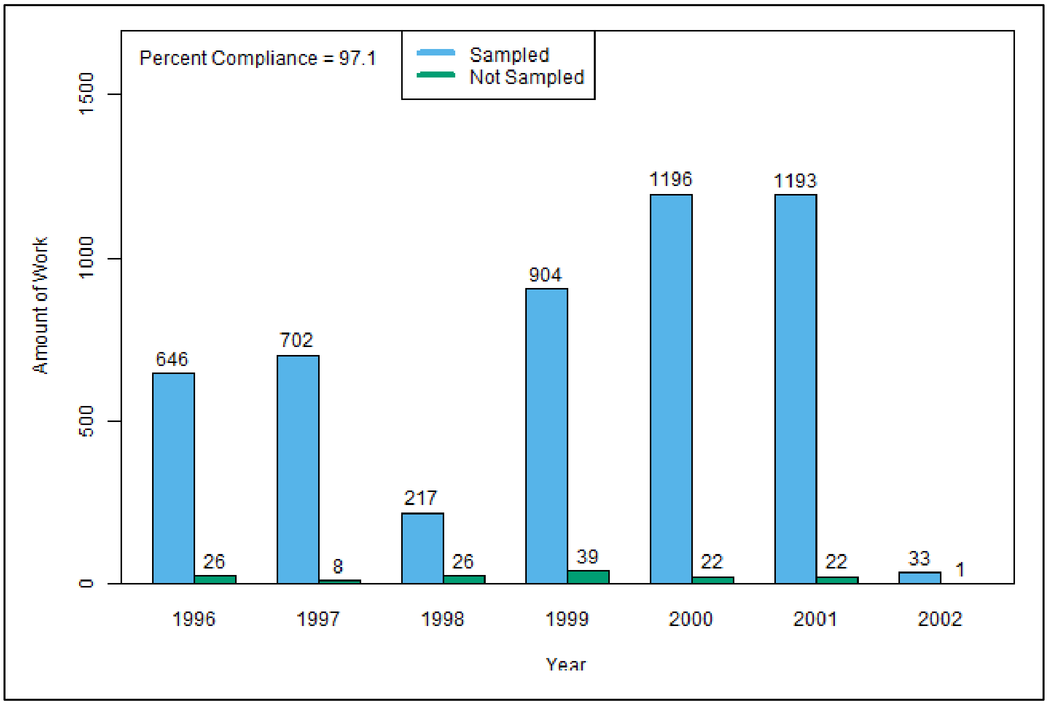

Figure B-7. Work performed by NMT that was properly monitored (Sampled).

Table B-7. Data for Figure B-7, Work performed by NMT that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	646	702	217	904	1,196	1,193	33
Not sampled	26	8	26	39	22	22	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

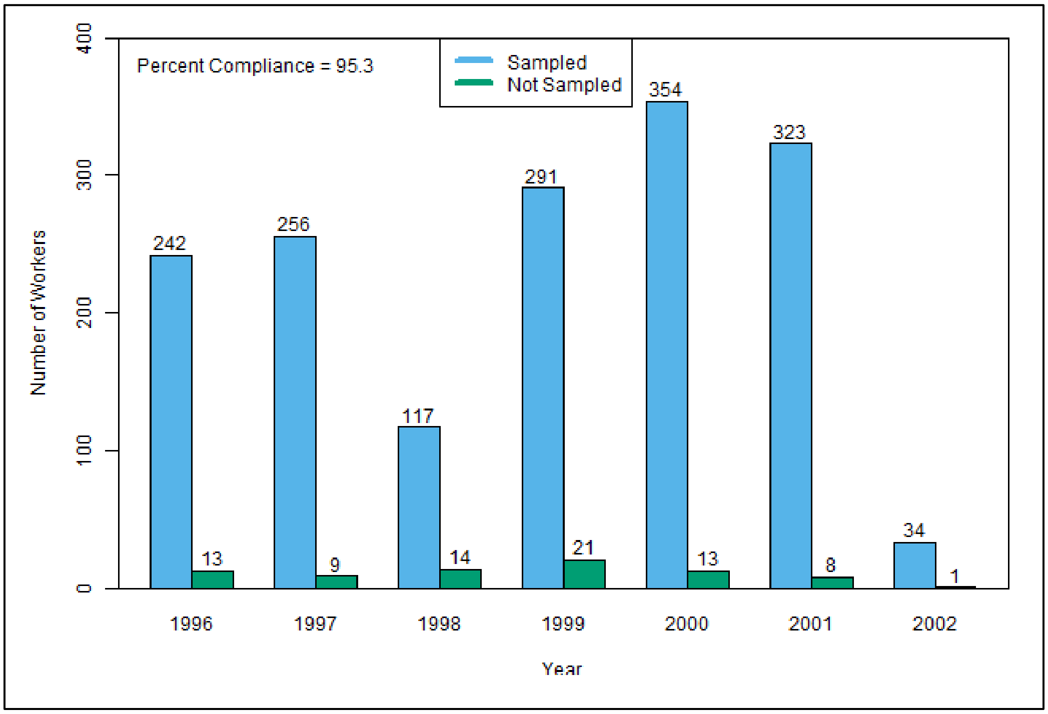

Figure B-8. NMT workers who were properly monitored (Sampled).

Table B-8. Data for Figure B-8, NMT workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	242	256	117	291	354	323	34
Not sampled	13	9	14	21	13	8	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

B.2 ACTIVE RWP DATES, POST-RWP WINDOW, AND OPEN WINDOW

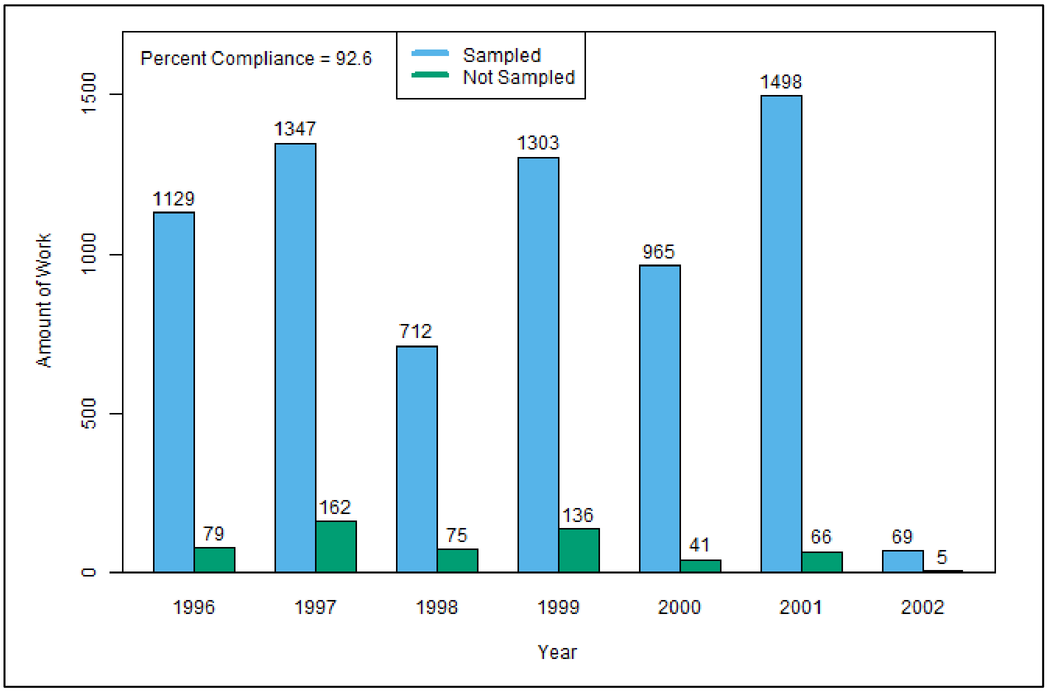

Figure B-9. Work performed by JC that was properly monitored (Sampled).

Table B-9. Data for Figure B-9, Work performed by JC that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	1,129	1,347	712	1,303	965	1,498	69
Not sampled	79	162	75	136	41	66	5

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

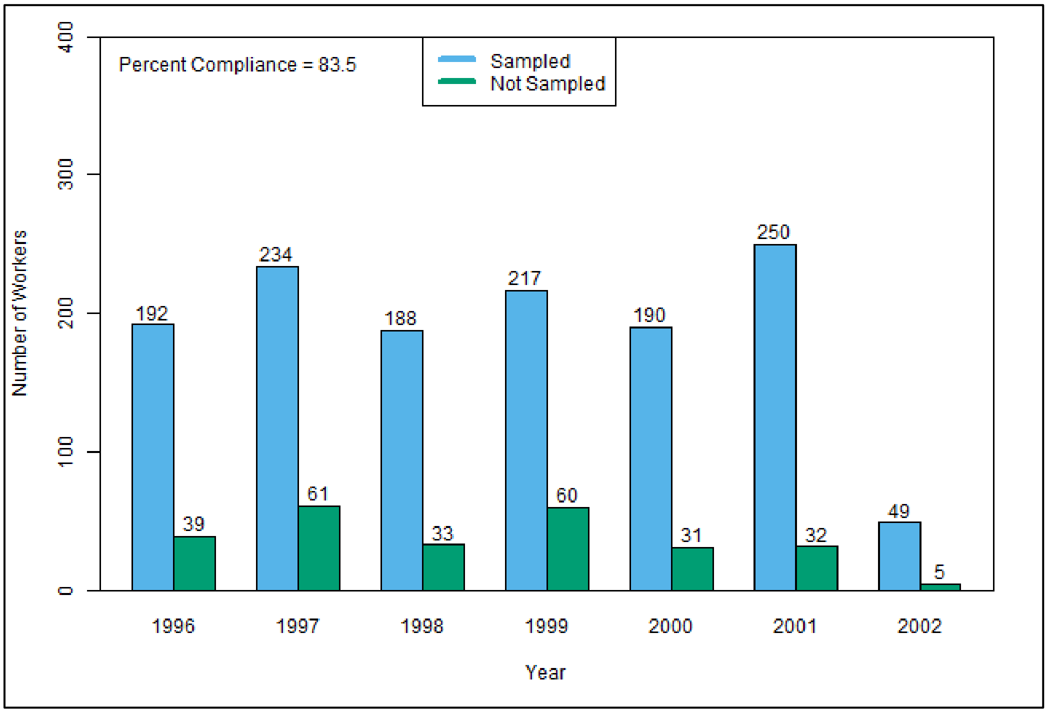

Figure B-10. JC workers who were properly monitored (Sampled).

Table B-10. Data for Figure B-10, JC workers who were properly monitored during the study period (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	192	234	188	217	190	250	49
Not sampled	39	61	33	60	31	32	5

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

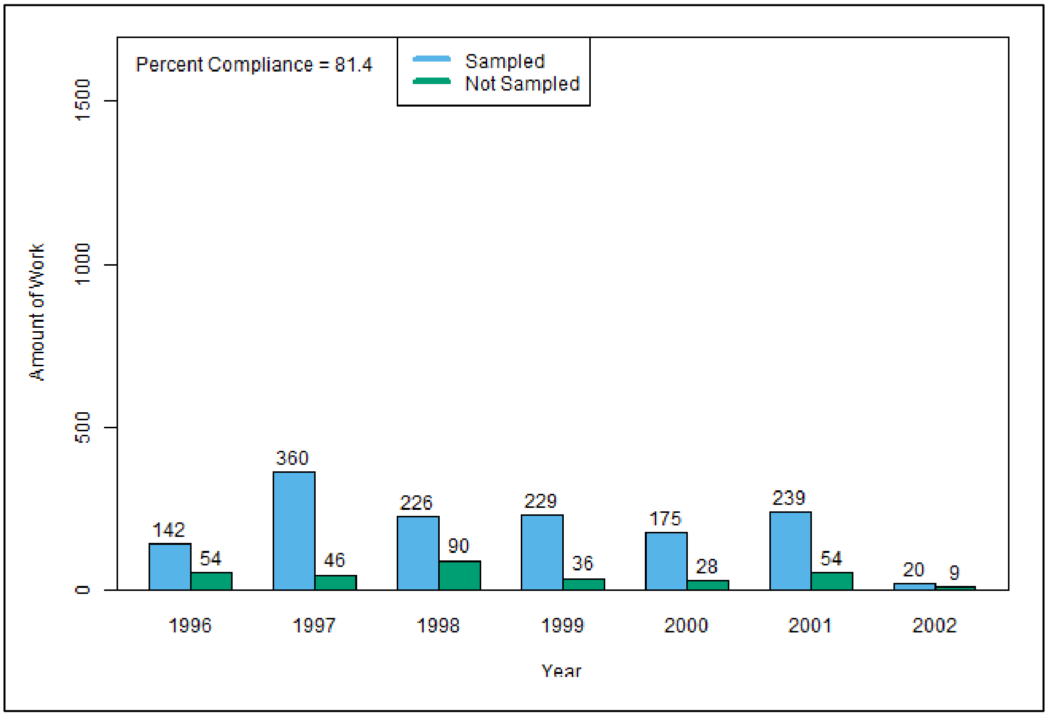

Figure B-11. Work performed by Other that was properly monitored (Sampled).

Table B-11. Data for Figure B-11, Work performed by Other that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	142	360	226	229	175	239	20
Not sampled	54	46	90	36	28	54	9

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

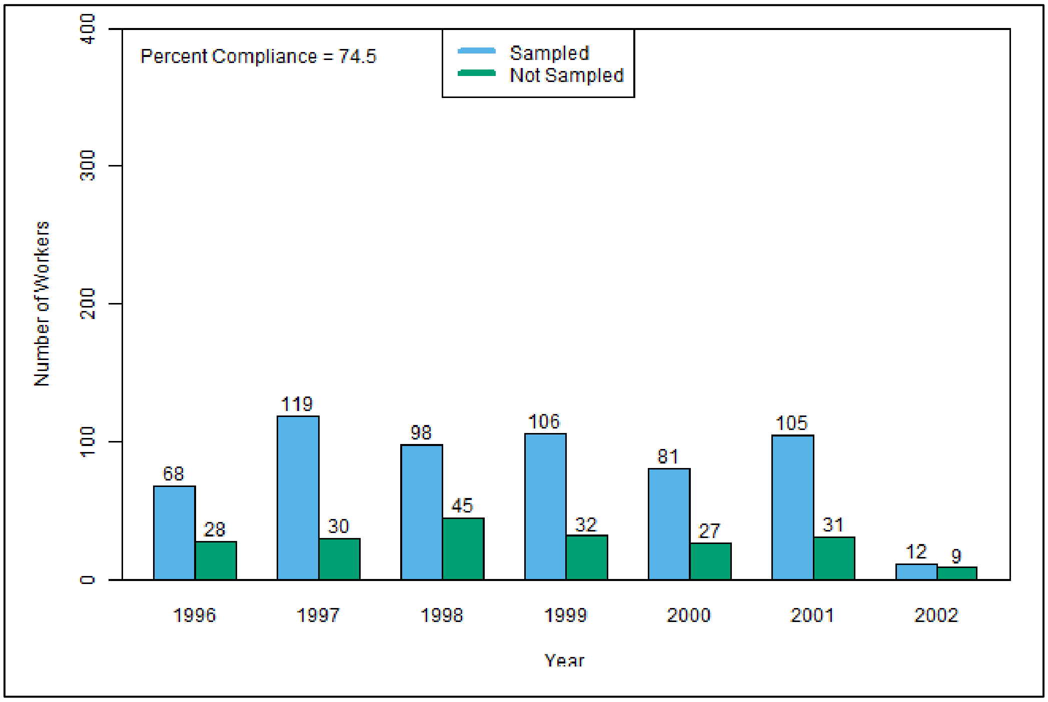

Figure B-12. Other workers who were properly monitored (Sampled).

Table B-12. Data for Figure B-12, Other workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	68	119	98	106	81	105	12
Not sampled	28	30	45	32	27	31	9

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

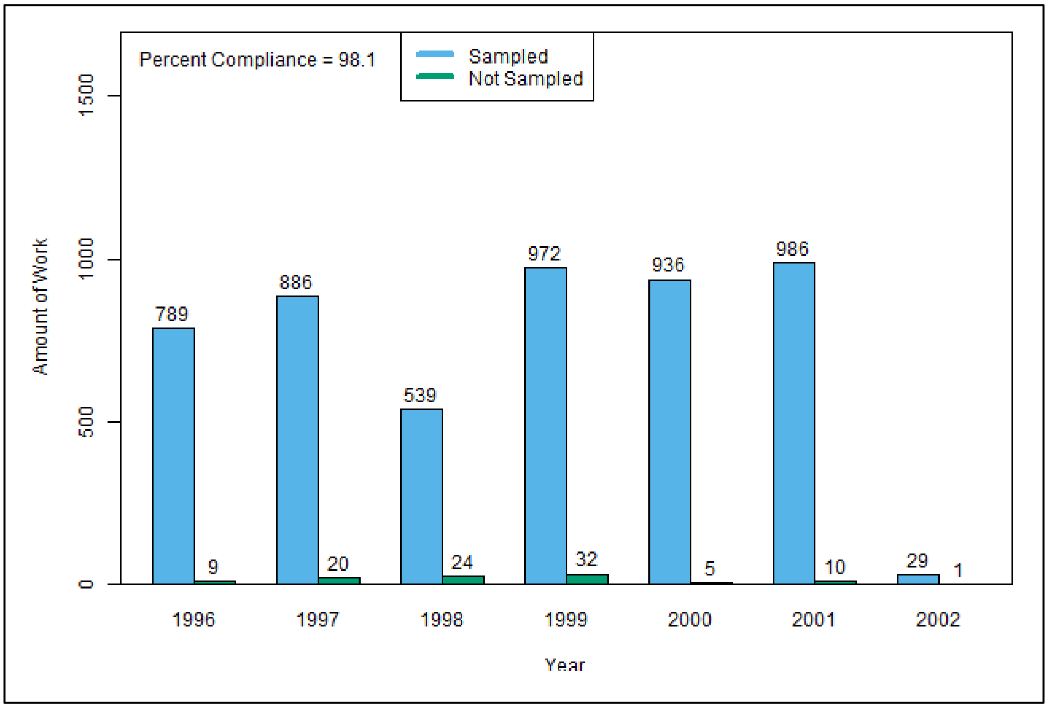

Figure B-13. Work performed by ESH that was properly monitored (Sampled).

Table B-13. Data for Figure B-13, Work performed by ESH that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	789	886	539	972	936	986	29
Not sampled	9	20	24	32	5	10	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

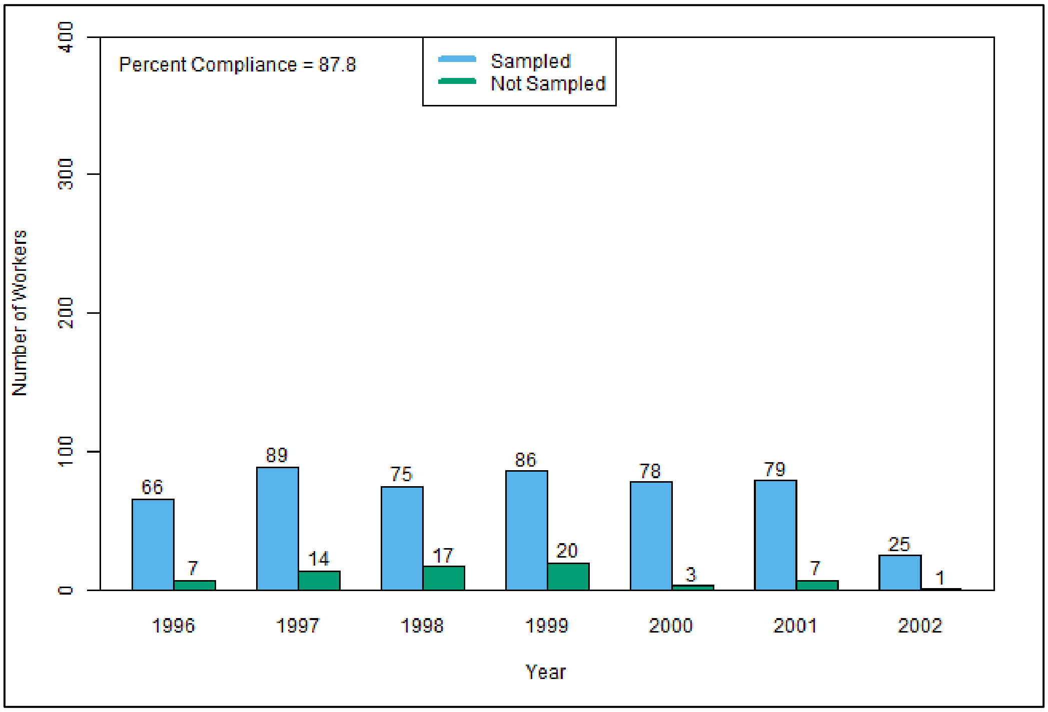

Figure B-14. ESH workers who were properly monitored (Sampled).

Table B-14. Data for Figure B-14, ESH workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	66	89	75	86	78	79	25
Not sampled	7	14	17	20	3	7	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

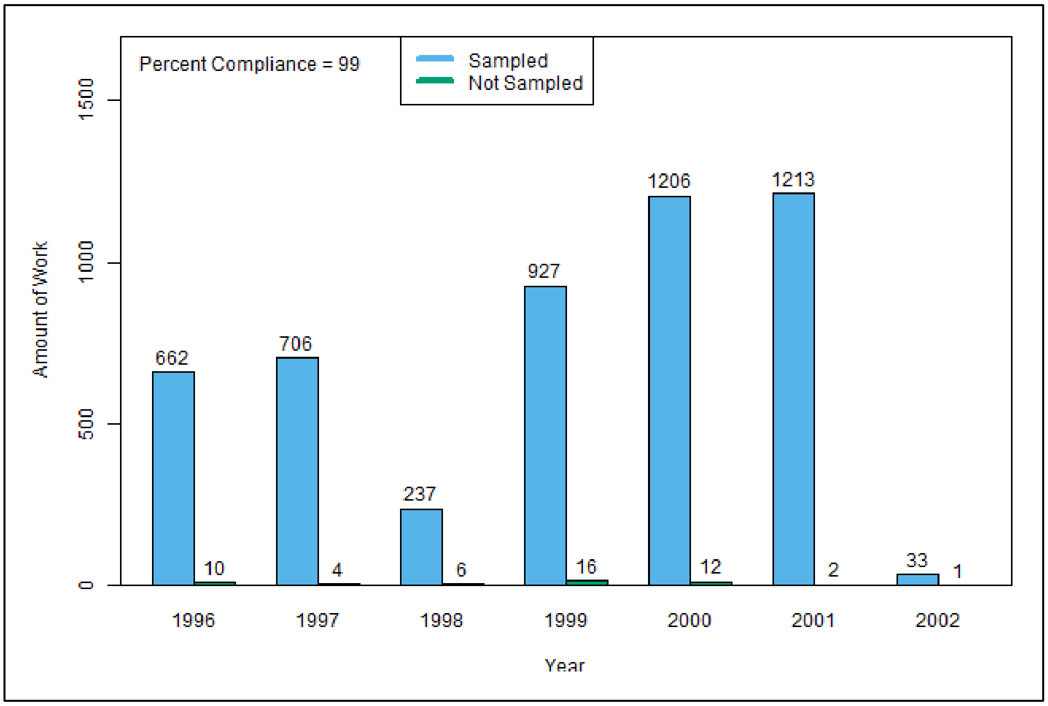

Figure B-15. Work performed by NMT that was properly monitored (Sampled).

Table B-15. Data for Figure B-15, Work performed by NMT that was properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	662	706	237	927	1,206	1,213	33
Not sampled	10	4	6	16	12	2	1

ATTACHMENT B
GROUP-SPECIFIC COMPLIANCE WITH RADIOLOGICAL WORK PERMITS (continued)

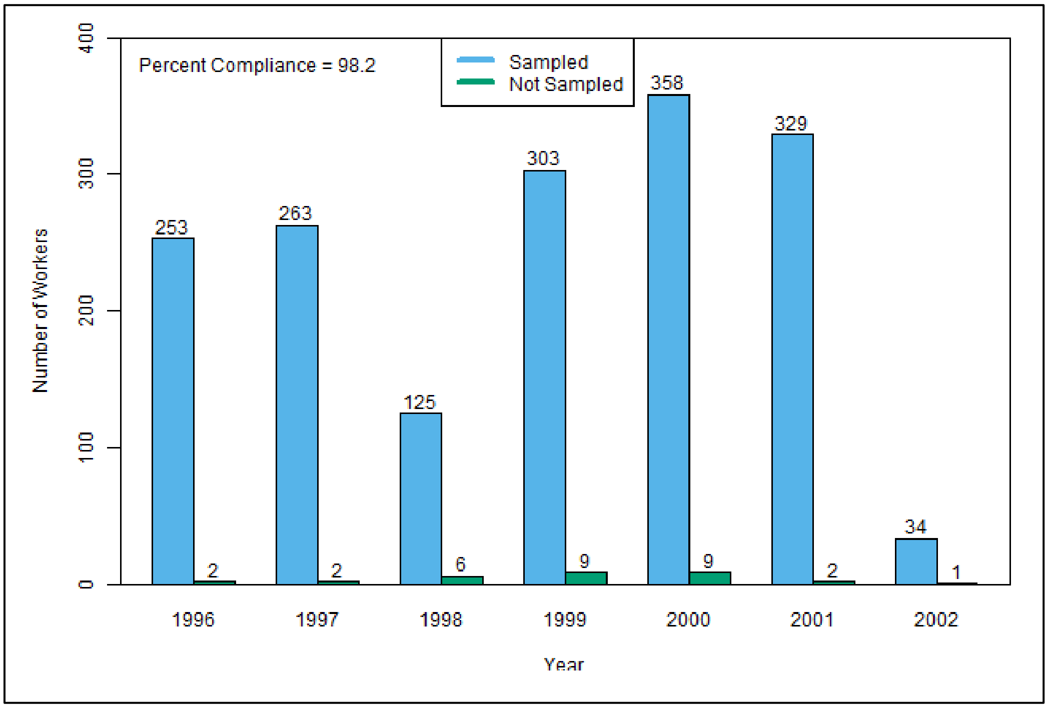

Figure B-16. NMT workers who were properly monitored (Sampled).

Table B-16. Data for Figure B-16, NMT workers who were properly monitored (Sampled).

Type	1996	1997	1998	1999	2000	2001	2002
Sampled	253	263	125	303	358	329	34
Not sampled	2	2	6	9	9	2	1