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SC&A Review of the SEC-00250 Evaluation Report for the Y-12 Plant

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Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
Ac	actinium
BWXT	BWXT Y-12, LLC
CY	calendar year
DCAS	Division of Compensation Analysis and Support
dpm/d	disintegrations per minute per day
dpm/m^3	disintegrations per minute per cubic meter
ECD	Energy Citations Database
E&I	electrical and instrumentation
EE	energy employee
EI	ending inventory
ER	evaluation report
HP	health physics
ID	inventory difference (in direct quotes) or identifier
kg	kilogram
mg	milligram
MIVRML	Mobile In Vivo Radiation Monitoring Laboratory
NaI	sodium iodide
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH DCAS Claims Tracking System
NOL	normal operating loss
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
PAV	plant action value
Pb	lead
Pu	plutonium
SCPR	Subcommittee for Procedure Reviews
SEC	Special Exposure Cohort
SRDB	Site Research Database
Th	thorium

TWOPOS	time weighted one-person-one-statistic
U	uranium

Executive Summary

To date, six Special Exposure Cohort (SEC) classes have been added for the Y-12 Plant that cover the majority of the site's operational history from the start of operations in March 1943 through July 1979. This includes a portion of the period that qualified for evaluation under SEC Petition-00250 (January 1977 through December 1994). The National Institute for Occupational Safety and Health's (NIOSH's) evaluation of SEC-00250 recommended that a class be added from January 1977 through July 1979 on the basis that internal exposures to thorium could not be reconstructed with sufficient accuracy. NIOSH found that all other exposures could be reconstructed with the exception of thorium from January 1987 to December 1994, which is being held in reserve pending the receipt and evaluation of additional data from the Y-12 Plant.

SC&A was tasked with the review of NIOSH's SEC-00250 evaluation report on August 21, 2019, with the exception of the period currently held in reserve (specific to thorium). While SC&A's review would primarily focus on the reconstruction of thorium intakes, the Y-12 petitioner as well as the Advisory Board on Radiation and Worker Health (Board) expressed specific concerns about the uranium monitoring program as it applies to the "Machinist" job category. The following report is intended to address both of these aspects of SEC-00250 as well as discuss the methods currently proposed to reconstruct internal exposures to radionuclides other than uranium and thorium.

SC&A's review of available documentation related to thorium operations after July 1979 affirms that the relatively larger scale thorium operations were generally completed during the 1970s. However, it is clear that thorium work continued to occur after the recommended current cutoff date for a class to be added under SEC-00250. Unfortunately, SC&A was not able to locate documentation to definitively identify the names of workers, specific locations, and all of the unique projects involving thorium that may have occurred during the period of interest. Such information would allow for a more thorough and conclusive assessment of the available thorium data's completeness and representativeness to the unmonitored worker (observation 1).

The review and evaluation of thorium monitoring data available for dose reconstruction centered around the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) program guidance document, "Draft Criteria for the Evaluation and Use of Coworker Datasets" (NIOSH, 2015), which describes three of the main facets necessary for a viable coworker assessment: data adequacy, data completeness, and data representativeness. Although this guidance document was developed specific to coworker modeling, the core tenets to evaluate coworker feasibility are directly applicable to and encompassing of overall dose reconstruction feasibility. Therefore, SC&A used the core tenets of NIOSH (2015) as a framework for evaluating dose reconstruction feasibility in this SEC review.

Regarding data adequacy, SC&A found that the monitoring method for thorium was essentially equivalent to methods utilized at other EEOICPA sites during the SEC-00250 period. The technical methods for measuring uranium exposure have already been reviewed and accepted by the Board under the evaluation of SEC-00046 and site profile review for the Fernald site (ABRWH, 2018) (observation 2). Similar to the previous SEC evaluation, SC&A recommends a numerical adjustment be developed to account for observed negative bias in the dataset during certain years (observation 3).

Completeness of the dataset was evaluated utilizing a limited set of quarterly health physics reports that tabulate the number of thorium in vivo counts performed for a portion of the SEC-00250 period (August 1979 through September 1981). However, such summary health physics tabulations are not available for comparison for the later periods after September 1981 due to a change in reporting practices at Y-12 (finding 1). An alternate method for evaluating completeness, such as the examination of production throughput estimates of thorium, is currently unavailable for analysis and was likely redacted from the original source documentation (finding 2). Based on its research into thorium operations, SC&A identified additional thorium in vivo data during the period of interest that should be carefully discussed and evaluated to determine if they are relevant to reconstruction of thorium exposures under SEC-00250 (observation 4).

SC&A evaluated the representativeness of the thorium data by analyzing job title information available for a subset of claimants from the monitored population. Similarly, SC&A examined departmental codes in the thorium dataset to determine the frequency and magnitude of sampling among the different departments. In both cases, specific trends were difficult to discern. Therefore, SC&A determined that the dataset is likely reflective of "routine, representative" sampling as defined in NIOSH (2015) rather than targeted sampling of the highest exposed workers and/or incident driven sampling (observations 5 and 6).

Similar to the thorium analysis, SC&A evaluated the completeness of the uranium urinalysis data utilized in coworker modeling during the SEC-00250 period by comparing the amount of coworker data to the number of samples reported to have been analyzed in periodic health physics reports. The percentage of available coworker data ranged from 75 percent to 121 percent of the number of samples reported to have been analyzed by health physics. The average over this time period was 98.4 percent (observation 7). Unfortunately, the current electronic dataset does not provide information to allow for an assessment of representativeness by job classification, work area/department, or specific project/campaign (finding 3). In addition to available urinalysis data, the Y-12 Plant concurrently monitored uranium exposure via in vivo methods. Such data are not currently utilized in the coworker model but should be discussed for applicability to unmonitored workers (observation 8).

To analyze the monitoring coverage for Machinists, SC&A examined 236 individual claimants who were designated as Machinists. SC&A found that among Machinists who were monitored externally for radiation in a given year, approximately 47 percent were also monitored for uranium during that same year. In the context of the need for coworker assignment for externally monitored workers, SC&A found that approximately 51 percent of the evaluated Machinists would not require any coworker assignment, 24 percent would require coworker assignment for at least part of their SEC-00250 employment, and 25 percent would require coworker assignment for the entirety of their employment during which they were externally monitored (observation 10). Regarding the specific uranium exposure potential to Machinists at Y-12, evidence suggests that average air concentrations for workers in this production category (i.e., fabrication) were generally bounded by workers in the other two main production categories, which are defined as "metal preparation" (observation 9). Thus, monitored workers in the two metal preparation categories might be considered a bounding proxy for unmonitored Machinists in the fabrication category.

Finally, SC&A's evaluation of the remaining sources of internal exposure (i.e., fission/activation products, exotic nuclides, and other transuranic material) is primarily discussed in its 2018 review of ORAUT-RPRT-0090, "Monitoring Feasibility Evaluation for Exotic Radionuclides Produced by the Oak Ridge National Laboratory Isotopes Division" (NIOSH, 2018e). Several observations and findings from that review are currently under the purview of the Board for further discussion (observation 11). However, specific to this SEC evaluation, SC&A found that plutonium-241 has still not been addressed in the SEC-00250 evaluation report. Internal exposure to plutonium was part of the basis for SEC-00251, which extended through the end of 1976 at Y-12 (finding 4). Lastly, although the Isotopes Division ceased its isotope production operations in 1983, neither the SEC-00250 evaluation report nor NIOSH (2018e) appear to address the post-1983 time period in which residual levels of contamination associated with decontamination and decommissioning activities and/or waste management were likely to have occurred (observation 12).

1 Introduction and Background

On July 17, 2019, the National Institute for Occupational Safety and Health (NIOSH) submitted the initial issue of its evaluation report (ER) of Special Exposure Cohort (SEC) petition SEC-00250 for the Y-12 Plant (NIOSH, 2019). The evaluated class included all contractors and subcontractors of the U.S. Department of Energy and its predecessor agencies for the period from January 1, 1977, through December 31, 1994. The period immediately before 1977 is covered by SEC-00251, which concluded that internal dose reconstruction for thorium and plutonium was infeasible. It is important to note that lung counting data for thorium existed prior to January 1, 1977; however, the results cannot be interpreted for use in dose reconstruction because the monitoring is provided in milligrams (mg) of thorium rather than in the units of activity for the thorium daughters lead-212 (Pb-212) and actinium-228 (Ac-228). The practice of recording thorium lung count monitoring results in units of mg continued into 1979.

Therefore, NIOSH determined that the dose reconstruction infeasibility for thorium extended into 1979 and recommended a class be added under SEC-00250 through July 31, 1979. After July 1979, the majority of thorium-related in vivo monitoring was recorded in activity units of the thorium daughter products Pb-212 and Ac-228. However, at the time of NIOSH's evaluation, such data were only available through the end of 1986. Therefore, NIOSH held the period 1987–1994 in reserve until such data could be obtained from the Y-12 Plant and sufficiently evaluated.

NIOSH presented its findings to the Advisory Board on Radiation Worker Health (ABRWH, Board) on August 21, 2019 (ABRWH, 2019). Subsequently, the ABRWH tasked SC&A with reviewing the SEC-00250 ER conclusions, with a particular focus on the thorium operations and available data. In addition, the Y-12 petitioner and the Board expressed concern over the internal uranium monitoring coverage for certain job types. Specifically, the job title of "Machinist" was discussed as being potentially problematic in establishing dose reconstruction feasibility.

SC&A's review of the SEC-00250 ER focused on three main facets:

1. Review and characterization of available documentation in the Site Research Database (SRDB) concerning thorium operations during the period of interest (section 2).

2. Evaluation of the adequacy, completeness, and representativeness of available thorium in vivo monitoring data for use in dose reconstruction (section 3).

3. Evaluation of remaining internal exposure sources, including exotic radionuclides and uranium monitoring coverage. For the latter, SC&A specifically focused on exposure potential and monitoring coverage for Machinists (section 4).

This report presents the results of SC&A's review of the SEC-00250 ER.

2 Summary of Available Information about Thorium Operations during the Period of Interest

SC&A reviewed the SRDB to determine if there is any new information about the generation and management of thorium and the types of workers and their departments that worked with thorium. Such information can be used in characterizing the available thorium data in terms of their adequacy, completeness, and representativeness to the potentially unmonitored worker.

The Y-12 site profile site description (NIOSH, 2007) summarizes the buildings where thorium was processed. However, SC&A found additional information in other documents that shows that work with thorium occurred in other buildings as well. The following list summarizes the buildings and the activities performed in each, based on the currently available references for the Y-12 Plant.

- Building 9205-1: pellet/scrap preparation, arc melting, crop and trim machining, and sawing (NIOSH, 2007)
- Building 9204-4: mold press sintering, ingot forging, canning and annealing after first cold roll, and final inspection/assembly (NIOSH, 2007)
- Building 9201-1: ingot canning before first cold roll (NIOSH, 2007; Case, Hibbs, & Whitson, 1960, PDF p. 3)
- Building 9201-5: pellet/scrap preparation, arc melting, crop and trim machining, and sawing (NIOSH, 2019, p. 23; Hibbs, 1961, PDF p. 3; BWXT Y-12, LLC (BWXT), 2001, PDF p. 11)
- Building 9201-5N (Alpha 5N): plating, machining, and W-71 thorium work (NIOSH, 2018b, p. 2)
- Building 9204-4: mold press sintering, ingot forming, annealing, and assembly (NIOSH, 2019, p. 23; BWXT, 2001, PDF p. 11)
- Building 9212: based on a worker interview, possibly rolling, shaping, and machining (BWXT, 2005, PDF p. 56)
- Building 9215: cold and hot rolling (NIOSH, 2007) and hydroforming (NIOSH, 2019; Case et al., 1960, PDF p. 3; Hibbs, 1961, PDF p. 7)
- Building 9206: cleaning and final plating (NIOSH, 2007)
- Building 9766: machining (NIOSH, 2007)
- Building 9202: development activities (NIOSH, 2007), arc melting, double hammer forging, machining, and annealing (NIOSH, 2019, p. 23; Case et al., 1960, PDF pp. 3–4; Hibbs, 1961, PDF p. 7; BWXT, 2001, PDF p. 11)
- Building 9902: storage (NIOSH, 2019, p. 23)
- Building 9995: storage (NIOSH, 2019, p. 23)
- Beta 2E: W071 thorium work, development activities (NIOSH, 2018b, p. 3)

While the first work with thorium began in 1947, extensive processing of thorium at Y-12 did not occur until 1952 (Owings, 1995, PDF p. 63). Work with thorium continued through 1975 based on worker interviews (NIOSH, 2019, p. 25). Based on a table of thorium discards to the burial ground, activities related to processing or handling thorium continued until about 1976. Activities associated with thorium resumed in about 1980 and sporadically continued until at least 1988 (there were no thorium discards from 1989 through 1994) (Owings, 1995, PDF pp. 64–65). In 1983, a significant amount of thorium was discarded (64,397 kilograms (kg)), but no evidence was found as to the source of this discarded material. Based on a worker interview (NIOSH, 2018a, PDF p. 4), arc melting for refurbished parts stopped in about 1987 to 1989; machining ceasing in this same timeframe. From 1952 to 1986, Y-12 sent 13,534 kg thorium oxide, 25,992 kg thorium metal, 1,016 kg thorium fluorides, and 53,886 kg miscellaneous thorium materials to the Feed Materials Production Center (FMPC) ("Major Thorium Campaigns," n.d., PDF p. 15). Note that it is not clear how much of this thorium was sent by Y-12 after 1980, if any. Actual thorium processing at Fernald appears to have ended sometime in 1979. However, stewardship activities continued beyond this date as Fernald served as the central thorium repository for the United States beginning in 1972 and extending until remediation was complete in 2006 (NIOSH, 2017).

The type of work conducted with thorium at Y-12 after 1989 is not well defined, based on the available documentation. By 1995, all arc melting of thorium was shut down due to a sodium potassium accident (NIOSH, 2018a, PDF p. 4). All special projects involving thorium ceased after December 8, 1999, after a catastrophic event involving depleted uranium operations with a Y-12 furnace (NIOSH, 2019, p. 25), although a worker interview (NIOSH, 2018b, p. 3) stated that "thorium is processed even today – in Beta 2E. Current thorium work is in development – no machining or grinding."

In reviewing documentation in the SRDB, SC&A noted a number of different labor categories associated with process areas that, at times, were used for thorium operations. Table 1 summarizes the labor categories and the buildings in which these types of workers were identified, if the reference provided this information.

Table 1. Labor categories associated with thorium process areas

Labor category	Building or process area	Reference
Rad Engineer	9206, 9212	NIOSH, 2018b, PDF p. 7
Process Quality Control	Alpha 4N, Beta 2E	NIOSH, 2018c, PDF p. 7
Procedure Coordinator	Assembly organization	NIOSH, 2018c, PDF p. 7
System Engineer Supervisor	Alpha 5, Beta 2E, 9201-5	NIOSH, 2018a, PDF p. 4
Process Engineer	Process area not identified	NIOSH, 2018a, PDF p. 4
Boilermaker	9212, 9206, Alpha 4, Beta 4	BWXT, 2005, p. 48
Plant Maintenance	9206, 9212, 9995	BWXT, 2005, pp. 48, 50
Chem Recovery	9212, E Wing casting	BWXT, 2005, p. 48
Machinist	9212, 9215, Beta 2	BWXT, 2005, pp. 48, 50
Laborer/Janitor	9206, 9212	BWXT, 2005, p. 50
Material Handler	9212	BWXT, 2005, p. 56

Finally, SC&A searched the SRDB for information on department numbers to assist with identifying thorium exposures by department. Table 2 provides the information found. These departments may having worked with thorium or been in areas where thorium was present, but these areas also contained other radioactive materials, including natural, enriched, and depleted uranium.

Table 2. Potential department numbers associated with thorium processing, with corresponding department or process area name

Department number	Department or process area name	Reference
2637-54	9204-4 Forming	Martin Marietta, 1989, p. 27
2637-55	9201-5 Melting	Martin Marietta, 1989, p. 27
2624-23	9201-5 West Machine Shop	Martin Marietta, 1989, p. 27
2624-24	9201-5 North Machine Shop	Martin Marietta, 1989, p. 27
2624	9201-5N	"Magnesium," 1994, PDF pp. 4-–6
2235	9201-5N	"Magnesium," 1994, PDF pp. 4–36
2366	9201-5N	"Magnesium," 1994, PDF pp. 4–36
0110	9201-5N	"Magnesium," 1994, PDF pp. 4–36
5001	Maintenance division – janitorial	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5002	Maintenance division – process maint. and equip. change	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5004	MTM (control)	Davis, 1985b, PDF pp. 11–13
5005	Maintenance division – material control	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5008	Maintenance division	Davis, 1985a, PDF p. 7
5021	Maintenance division – plant services	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5022	Maintenance division – machine shop	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5024	Maintenance division – valve and pump shop	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5048	Maintenance division – fabrication shop	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5060	Plant Engineering (control)	Davis, 1985b, PDF pp. 11–13
5075	Maintenance division – instrument maint.	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5077	Maintenance division – electrical	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5004	Personnel division	Davis, 1985a, PDF p. 7
5041	Personnel division	Davis, 1985a, PDF p. 7
5088	Personnel division	Davis, 1985a, PDF p. 7
5108	Personnel division	Davis, 1985a, PDF p. 7
5268	Technical services division	Davis, 1985a, PDF p. 7
5270	Technical services division – development & PTP coord.	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5096	Operations division – laundry	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5730	Operations division – cascade ops.	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5784	Operations division – scrap metal preparation	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5785	Operations division – chemical processing	Davis, 1985a, PDF p. 7 Davis, 1985b, PDF pp. 11–13
5044	Plant engineering division	Davis, 1985a, PDF p. 7

Department number	Department or process area name	Reference
5090	Medical	Davis, 1985b, PDF pp. 11–13
5269	Technology lab	Davis, 1985b, PDF pp. 11–13

Observation 1: Although SC&A uncovered additional information concerning process departments and areas associated with thorium work, no definitive list was identified to aid in assessing the scope of thorium monitoring at the Y-12 plant. Sought-after documentation might have included those workers actually classified as thorium workers in addition to department and work area designations. Such information would have aided in evaluating the monitoring program's effectiveness and representativeness.

3 Evaluation of Thorium Data

The main focus of the SEC-00250 ER was the assessment of dose reconstruction feasibility for thorium and its associated progeny. The three primary areas of evaluation in an SEC context are discussed in the EEOICPA guidance document, "Draft Criteria for the Evaluation and Use of Coworker Datasets" (NIOSH, 2015). Although this guidance document was developed specific to coworker modeling, the core tenets to evaluate coworker feasibility are directly applicable and encompassing of overall dose reconstruction feasibility. Therefore, the evaluation criteria are used interchangeably in this SEC review and can summarized as:

- Data adequacy (section 3.1)
- Data completeness (section 3.2)
- Data representativeness (section 3.3)

Each of these areas is discussed in detail in the following subsections.

3.1 Data adequacy

In general, data adequacy refers to the technical ability of the monitoring method to accurately reflect the exposure it is intended to quantify. The NIOSH "Draft Criteria for the Evaluation and Use of Coworker Datasets" (NIOSH, 2015) specifies the following concerning in vivo monitoring adequacy:

> When *in vivo* measurements are used, the overall measurement program must be carefully reviewed to ensure that the data accurately represent the quantity of the radionuclide in the organ of interest. [NIOSH, 2015, p. 4]

Considerations in evaluating data adequacy should include: adequacy of the phantoms used, correction for self-absorption of low-energy photons, parent/progeny equilibrium, appropriate ratio development (as needed), and measurement bias. Section 3.1.1 describes the in vivo monitoring system in use at Y-12. Most of the technical adequacy issues relevant to Y-12 have already been discussed by the Board via the SEC-00046 evaluation for the Fernald site (section 3.1.2). Section 3.1.3 provides an analysis of the potential for bias in the available data for Y-12; such an analysis is also consistent with the evaluation of thorium in vivo data utilized at Fernald.

3.1.1 Description of in vivo methods

The fixed in vivo monitoring facility at Y-12 was originally developed in the 1950s, with routine use beginning in the early 1960s. The system used two thallium-activated 9-inch (diameter) by 4-inch sodium iodide (NaI) detectors placed above and below the chest cavity of the individual. By 1965, an additional two 5-inch NaI detectors were added and situated on the side and underneath the arms of the energy employee (EE). These additional detectors helped to differentiate internal exposure versus external contamination of the EE.

In 1984, an additional room was built attached to Building 9711-1 to house coaxial hyperpure germanium detectors. An abstract of the technical report, “Coaxial Germanium Detectors in the Y-12 In Vivo Monitor,” stated:

> In comparison studies with the existing NaI(TI) detection system, the germanium system performed with higher resolution, better low-energy efficiency (facilitating the distinction between internal and external contamination), reduced sensitivity to background radiation, and higher stability with respect to temperature fluctuations and the passage of time. [ECD, 1984, PDF p. 2]

Early calibration phantoms at Y-12 (circa 1960s) used tiers of untempered masonite, with sources placed at different locations among the different tiers. By the 1970s, Y-12 switched to using the radiation-equivalent-manikin absorption phantom, which consisted of a compartmentalized plastic shell that contained organic material to approximate typical human tissue as well as sponge material to simulate lung tissue. By at least 1983, the site was using realistic phantom torsos that were developed under the direction of Lawrence Livermore National Laboratory in the late 1970s (King & Barclay, 1983).

3.1.2 Precedent with prior EEOICPA SEC evaluations

In addition to the stationary whole-body count facility, Y-12 also operated the Mobile In Vivo Radiation Monitoring Laboratory (MIVRML), which traveled to various offsite facilities to provide periodic onsite monitoring.

The MIVRML was designed to provide nearly identical counting and analysis capabilities as the stationary whole-body count facility at Y-12. A 1969 article, “Design and Development of a Mobile In Vivo Radiation Monitoring Laboratory’ from the American Industrial Hygiene Association Journal stated the following:

> Although the background in the mobile laboratory is higher, the sensitivity compared favorably with the Y-12 counter.
>
> . . . .
>
> The Y-12 Plant has designed and built a completely self-contained mobile in vivo radiation monitoring laboratory. Sensitivity of the laboratory compares favorably with fixed facilities. [Scott, Abele, Bryant, Cromwell, & West, 1969, pp. 168, 169]

In addition, a documented communication with a former worker at Y-12 who was involved in the design and development of the MIVRML stated the following:

> As far as the analytical techniques used in the development of the MIVRML counter, it copied and followed the Y-12 counter techniques and methods. They used a differential counting method in processing the spectra that was identical to the analytical technique used at Y-12. [NIOSH, 2012b, p. 3]

Facilities that used the MIVRML in addition to Y-12 during the period of interest included Fernald, Portsmouth Gaseous Diffusion Plant, Goodyear Atomic Corporation, Oak Ridge Gaseous Diffusion Plant, and Reactive Metals Inc. The use of the MIVRML at Fernald is of particular importance because the reconstruction of thorium exposures using in vivo data has already been taken up by the Board at this site under SEC-00046. Under that evaluation, the Board found that dose reconstruction was feasible using the MIVRML thorium data that were provided in units of activity for the daughter products Pb-212 and Ac-228, which began in 1979. Similar to SEC-00250, the Board found that dose reconstruction was infeasible for periods in which the thorium lung burdens were reported in units of mass (mg).

Because the evaluation of internal exposure to thorium and its progeny is based on the measurement of Pb-212 and Ac-228, it is necessary to establish an appropriate equilibrium relationship between these isotopes and the primary radiologically significant isotopes thorium-232 (Th-232), Th-228, and radium-228. For Y-12, NIOSH has adopted the assumption of triple chemical separation in analyzing the available in vivo data. This assumption was also used, and accepted by the Board, during the evaluation of SEC-00046 at Fernald.

Observation 2: The in vivo monitoring program using the stationary count facilities at the Y-12 Plant employed essentially identical methods and equipment as the Mobile In Vivo Radiation Monitoring Laboratory (MIVRML), which was likewise developed at Y-12. The Board has previously evaluated the adequacy of the MIVRML system at the Fernald site and found it to be a reasonable and scientifically accurate monitoring methodology for use in EEOICPA.

Finally, evaluation of the Pb-212 and Ac-228 data measured by the MIVRML at Fernald under SEC-00046 identified a potential negative bias in the results that required correction prior to use in either individual dose reconstruction or coworker modeling. The evaluation of bias for the Fernald thorium data was presented in attachment D of the Fernald occupational internal dose technical basis document (NIOSH, 2017). A similar analysis is presented in section 3.1.3 of this report for the Y-12 thorium dataset.

3.1.3 Evaluation of potential negative bias

Negative bias refers to the calculational characteristic in which measurements are consistently biased away from their likely true value (whether biased low or alternately biased high). Based on the evaluation of SEC-00046 at Fernald, such a bias can be accounted for by evaluating the raw dataset (including all negative results) to establish if any bias exists. If such a bias is observed, a correction factor can be developed for each applicable period to account for this measurement characteristic.

The evaluation for a potential bias in the data relies on the assumption that the available exposure data are based on a combination of normal analytical background (with a mean of zero) and the actual monitoring results reflecting real internal radiation exposures, which are assumed to be lognormally distributed. By fitting a line through the observed negative results on a normal probability plot and evaluating the intercept, one can determine whether a bias exists. If the intercept of the fitted line is zero, no bias likely exists. If the intercept is negative (or positive), then a bias likely exists equivalent to the magnitude of the intercept. Table 3 summarizes the results of SC&A's bias assessment. As shown in the table, a negative bias appears to exist for both Pb-212 and Ac-228 for several evaluated years.

Table 3. Results of negative bias analysis of Ac-228 and Pb-212 chest counts

Year	Ac-228 bias (nCi)	Pb-212 Bias (nCi)
1979 (partial year)	No negative results	No negative results
1980	No negative results	0.58
1981	−0.08	−0.04
1982	−0.04	−0.04
1983	−0.08	−0.02
1984	−0.07	−0.03
1985	−0.06	0.01
1986	−0.03	0.05

Observation 3: SC&A's evaluation of the potential for bias in the data identified a negative bias in the Ac-228 data for the years 1981–1986 and Pb-212 for 1981–1984. NIOSH should consider developing adjustment factors to assure any negative bias in the reported results is correctly accounted for in a claimant-favorable manner.

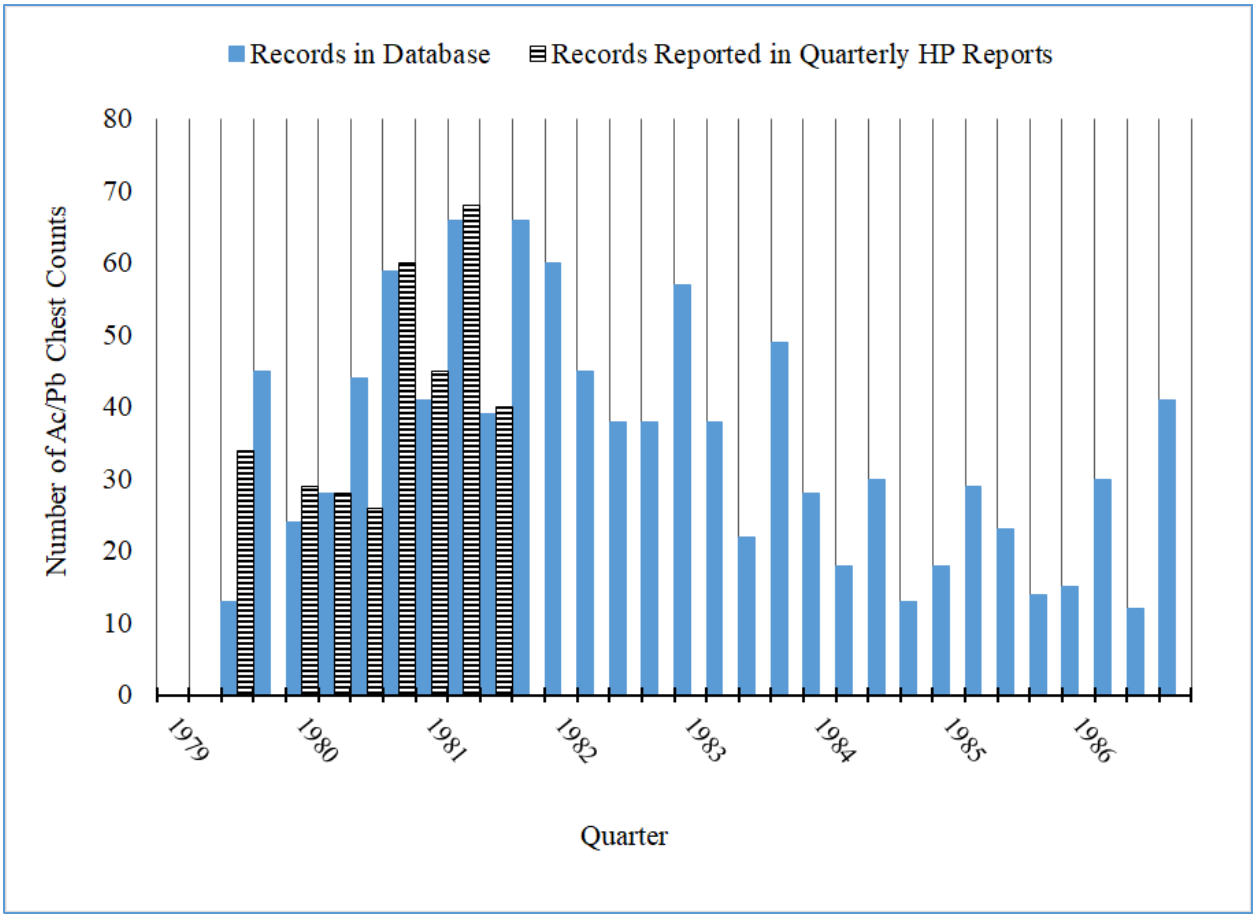
3.2 Data completeness

The completeness of a dataset generally refers to whether the data available for analysis for a given site, timeframe, and radionuclide reflect the totality of monitoring results taken at the site. In most cases, data completeness is evaluated by a comparison of the quantity of monitoring results available for analysis against summary documents that tabulate the number of samples taken during a given period. For Y-12, these data are typically found in the quarterly health physics summary reports. However, the number of in vivo monitoring results by quarter for thorium is only reported through the third quarter of 1981. After this timeframe, the quarterly health physics reports only report the number of uranium monitoring results in a given period.

A secondary consideration when evaluating completeness is whether significant temporal gaps appear to exist in the monitoring results. The number of thorium lung counts available for analysis is plotted in figure 1, along with the number reported in quarterly health physics reports (where available).

As shown in figure 1, the number of thorium in vivo results available for dose reconstruction agrees reasonably well with the number reported in the periodic health physics reports. One notable exception occurs in the third quarter of 1979, when only 13 of the 34 in vivo measurements reported to have been performed appear in the database. Conversely, in the third quarter of 1980, the available dataset includes 44 total measurements while the quarterly health physics report only indicates that 26 such analyses were performed. Overall, for quarters where comparisons can be made, they show a completeness percentage of approximately 95 percent (314 measurements in the available dataset with 330 reported in the health physics periodic summaries over those same quarters).

Figure 1. Comparison of thorium data available for coworker analysis to number of thorium in vivo measurements reported in quarterly health physics reports



It should be noted that figure 1 does not show any appreciable gaps in available thorium monitoring; however, there are significant fluctuations in the number of thorium samples from quarter to quarter. Without knowledge of the number of monitoring results performed during the latter evaluated period, it is not possible to know if such fluctuations are to be expected. However, similar types of fluctuations also appear to have occurred during the earlier period in which completeness comparisons can be made.

Finding 1: Available documentation only reports the number of quarterly thorium in vivo measurements up through the third quarter of 1981. For this limited time period, the completeness of in vivo thorium data available for dose reconstruction was approximately 95 percent. Direct evaluation of the completeness and availability of thorium in vivo records after this time is not currently possible.

Although periodic reporting of the number of thorium analyses is not always available, another potential comparison that can be used to evaluate the completeness of available records is to compare the sampling frequency to the production throughput of the radioisotope of interest in the Y-12 facility processes. SC&A was only able to locate one reference that purported to provide this information, 'Historical Review of Accountable Nuclear Materials at the Y-12 Plant' which states:

> The annual thorium throughput is shown in Table XXXII for the period CY 1947 through FY 1994. Table XXXIII shows annual totals for shipments, NOLs [normal operating losses], adjustments, EI [ending inventory], and ID [inventory difference] for the same period as throughput. Table XXXIV lists ID by year and cumulative for the period CY 1947 through FY 1994. Table XXXV through Table XXXVII show discards to the burial ground, sanitary and storm sewer, and S-3 Pond. [Owings, 1995, PDF p. 63]

However, the noted tables containing the throughput and accountability data have been omitted from the available SRDB reference, with the exception of the discards to the burial ground, the sanitary and storm sewer, and the S-3 Pond.

Finding 2: Information on the annual processing and throughput of thorium materials at the Y-12 plant is currently unavailable to supplement the thorium monitoring completeness evaluation. Evidence suggests that such throughput information was once tabulated in existing documentation. However, it is likely the information was redacted from the original source documentation and thus is not available for analysis at this time.

Finally, another facet of completeness can be assessed based on comparison of captured hardcopy[1] records to the electronic database of in vivo records available for analysis. For example, if a comparison found that monitoring records contained in hardcopy documents were not correctly included in the available electronic dataset, this would represent a potential completeness concern. However, if hardcopy records consistently appeared in the electronic dataset, this would indicate the relative completeness of the electronic records.

SC&A located two such documents in the SRDB, one for 1979 and the other for January 1983. For the 1979 records, SC&A found 60 total records in the logbook file, only 3 of which were not located in the database. These three records all indicated a department that was likely associated with the K-25 site rather than Y-12.

For January 1983, 265 total records were identified as containing Pb-212/Ac-228 in vivo records, with only 33 (~12 percent) appearing in the available database. Closer examination of the records indicate that the omitted records were labelled as "Type 1" or "Type 4," while the included records were labelled as "Type 6" or "Type 7." Instructions on interpreting Y-12 dosimetry records that were provided to NIOSH in 2003 indicate the "Type" designations are defined as follows (Souleyrette, 2003):

- Type 1: uranium-235 (U-235)

[1] In the context of this report, "hardcopy" refers to PDFs of original source documents rather than an electronic database such as a Microsoft Excel file in which data have been transcribed.

- Type 4: U-238 and U-235
- Type 6: thorium and U-235 (first thorium count)
- Type 7: U-235 and thorium (second thorium count)

Although the definitions of Type 1 and Type 4 in vivo records do not specifically indicate thorium monitoring, clearly those in vivo samples were also used to evaluate thorium lung burdens at least in January 1983. It is possible that the "Type 6 and 7" designation is actually used to distinguish those workers who actually handled thorium, and thus were targeted for thorium monitoring, from those workers who only had incidental thorium measurements taken to along with the uranium analysis. Table 4 presents a simple quantitative analysis showing the arithmetic average and rank-ordered 95th percentile of the omitted records for 1983 versus the database records. As shown in the far-right column of the table, the omitted data from January 1983 bounds the available database values, with the exception of the rank-ordered 95th percentile for Pb-212. In that case, the omitted records compare favorably to the annual database value but are nearly double the database value for January 1983 alone.

Table 4. Quantitative comparison of database thorium logbook results to omitted logbook thorium results

In vivo result (nCi) *	1983 database (all months)	1983 database (January only)	1983 data omitted from database (January only)
Ac-228 average	-0.04	-0.04	***-0.02***
Ac-228 average (corrected)	0.02	0.02	***0.03***
Pb average	-0.01	-0.04	***0.09***
Pb average (corrected)	0.05	0.02	***0.15***
Ac-228 rank-ordered 95th percentile	0.10	0.10	***0.13***
Pb-212 rank-ordered 95th percentile	0.20	0.10	0.19

* Corrected values assume all negative values are set to zero.

Observation 4: Evidence suggests additional Pb/Ac in vivo data may be available that were not considered in the SEC-00250 ER due to their in vivo "type" designation. Limited analysis of omitted data discovered for January 1983 suggests the data are comparable to, or in some cases greater than, the current database values under consideration. NIOSH should consider capturing and analyzing any additional data unless sufficient justification exists for omitting such monitoring results.

3.3 Data representativeness

Data representativeness reflects the ability of a monitoring program to correctly identify the important job types, areas, and, by extension, exposure potential of the monitored workforce. Per the NIOSH coworker implementation guidelines, the representativeness of a monitored population can be described as follows:

> In general, three types of monitoring programs have been employed at sites covered under EEOICPA. These programs, listed in hierarchical order of preference for use in coworker modeling are: 1) routine, representative sampling of the workers; 2) routine measurement of workers with the highest exposure

> potential; and 3) the collection of samples after the identification of an incident. . . .
>
> For routine monitoring programs, a review of the program should be conducted to determine the basis for the selection of program participants. It must be established who was monitored and why they were monitored. [NIOSH, 2015, p. 8]

The available dataset of in vivo lung counting does not specifically provide a job designation or work area. However, a subset of the monitored population can be identified with EEOICPA claimants, from which a job title evaluation can be conducted. Section 3.3.1 describes this job-specific evaluation for the claimant subset of the monitored population. Furthermore, while work location is not specifically provided, the available dataset does provide a "Department Code" associated with each monitoring result. Thus, a quantitative analysis of the magnitude of results from different departments can be made, presented in section 3.3.2.

3.3.1 Evaluation by job title

As stated in the previous section, job title is not specifically identified for each monitored worker in the thorium in vivo dataset. However, a subset of claimants can be identified among the monitored population for a which a reasonable job categorization can be made. The claimant subset made up approximately 30 percent of the samples in the available dataset (309 of 1,044 total results). This claimant subpopulation consisted of approximately 114 unique job titles in the NIOSH DCAS Claims Tracking System (NOCTS). Therefore, it was necessary for SC&A to categorize the claimant subpopulation into more manageable job classifications. The framework for job classification developed by SC&A is summarized in the following list, with a general description of each of the 11 classifications.

1. **Administrative/Inventory:** This job classification includes inventory clerks, shipping clerks, secretaries, estimators, planners, and other managerial job duties that would occasionally require entrance into radiological areas or other close proximity to radiological materials where internal exposure to thorium was feasible but less likely than other hands-on job categories.

2. **E&I, Maintenance:** Workers in this classification would enter and perform duties in radiological areas on a routine or semiroutine basis. However, the exposure potential was likely more consistent with off-normal radiological conditions. Examples of typical jobs might include electrical and equipment repairs/modification, pipefitting or other installation work, troubleshooting, and/or regular filter/dust bag replacement.

3. **Health Physics:** Health physicists and other industrial hygiene and safety personnel would be in charge of regular surveys of uranium/thorium work areas, setup/removal/analysis of air sampling systems, and other radiation monitoring duties. The performance of such tasks was consistently described as bringing the EEs "all over the plant," including production areas, recycling areas, research laboratories, and waste disposal areas such as the burial grounds.

4. **Janitor:** The exposure potential to janitors could be related to both routine and nonroutine cleaning duties. Nonroutine duties likely included clean up of spills, decontamination of production machinery and associated parts, and any other encounters with contamination requiring cleaning.

5. **Laboratory Testing:** Job duties were expected to include inspection of assembly components and other analytical chemistry-based laboratory tests on radioactive material. In addition, it is expected that laboratory workers would be involved in experimental work with both standard and exotic radiological sources.

6. **Operator, Assembly:** Workers associated with this job category often referred to themselves as an "assembly person" or "weapons assembler." This would often include workers whose job title was given as "Machinist," and routine duties would be described as assembly, disassembly, degreasing, machining, bonding, welding, grinding, and ultimately sampling of the material. However, this job classification also includes the chemical processing of uranium and other materials using column leachers, evaporators, denitrators, fluid bed conversion equipment, and material reduction (e.g., the typical duties of a chemical operator).

7. **Other Construction Trades:** Similar to E&I/Maintenance, this job category would typically involve exposure potential in off-normal radiological conditions. However, it would also include nonradiological jobs in clean areas, such as hanging doors, installation of office shelving, painting in noncontaminated areas, and refrigeration repair.

8. **Radiography and Inspection:** This job category generally involved the latter stages of production. The EEs would be involved in the inspection and x-raying of welds, leak detection, thermal expansion, conductivity tests, and other radiography activities. Such work would be expected to occur on both radioactive and nonradioactive weapons components as required.

9. **Science and Engineering:** This category would be expected to involve only intermittent exposure potential, as the EEs were involved in evaluating the overall scientific aspects of the program, including metallurgy, nuclear engineering, process equipment design, and development of standard production procedures. However, the job duties might also include occasional field review of existing procedures and production methods to facilitate improvement of the radiological process.

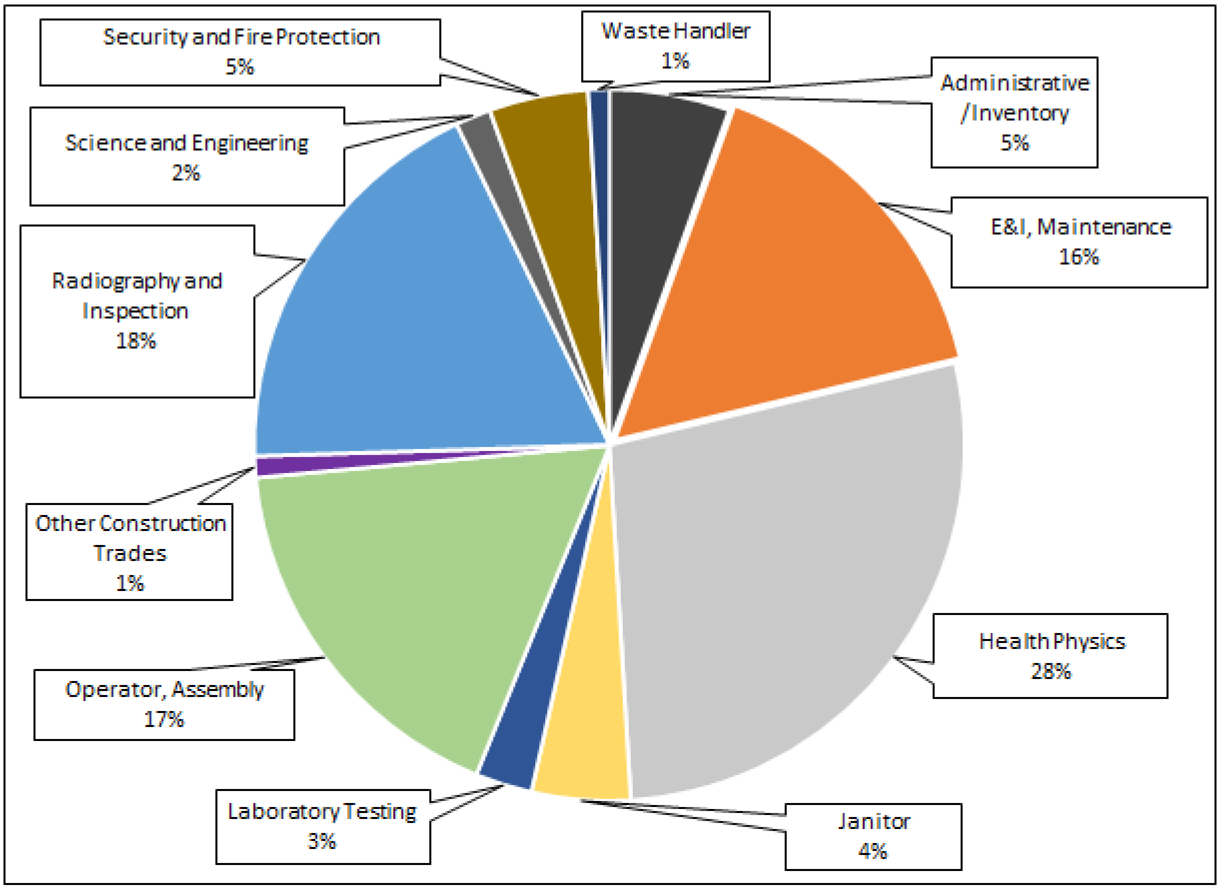
10. **Security and Fire Protection:** Such workers would routinely enter radiological areas, particularly on off-shifts, to assure security. However, the job title may also include response to incidents and nonroutine spills. Because uranium is highly pyrophoric, it is likely that fire protection would be part of the first response team for any uranium fires that occurred.

11. **Waste Handler:** Waste handlers were responsible for the movement of waste materials from the production areas to the local burial ground or other disposal areas. Often, this category would be associated with the truck drivers transporting the waste to and from

various areas on the site. However, job duties may have also included the packaging and interim storing of waste and salvage materials.

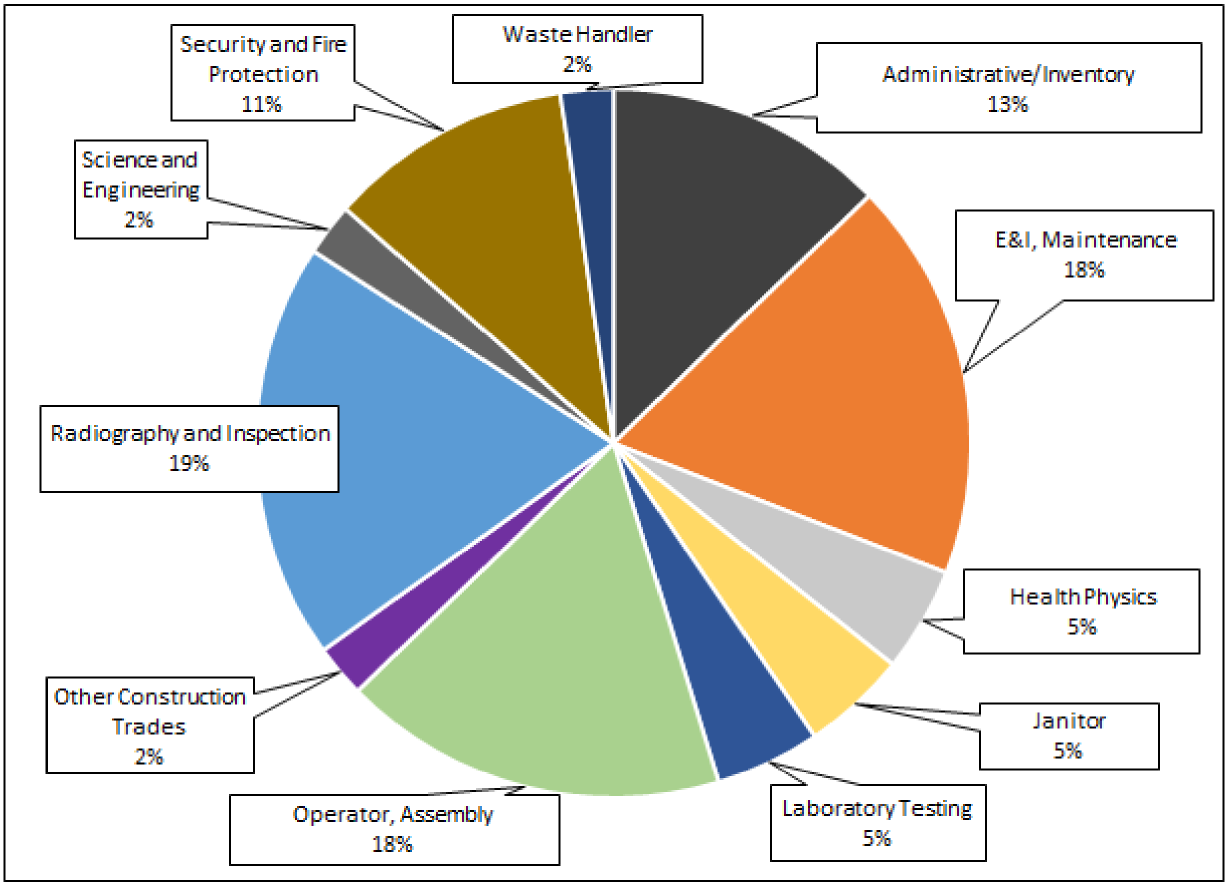
Figure 2 shows a breakdown of the number of samples that fell into each of SC&A's 11 job categorizations. As shown in the figure, the majority of observed samples were classified by SC&A as related to health physics (~28 percent), radiography/inspection (18 percent), E&I/maintenance (~16 percent), and operators/assembly (~17 percent). Such job categories would be expected to have elevated exposure potential to thorium when compared to other categories, such as administrative/inventory or science and engineering, where exposure potential would presumably be on a more limited basis. However, workers associated with security/fire protection and/or janitorial duties may have encountered short-term but higher exposure potential situations required of first response duties or irregular decontamination activities and thus should not be discounted.

Figure 2. Breakdown of the number of in vivo samples by SC&A job category in claimant subpopulation



However, perhaps a more useful metric than the number of samples is the number of workers in each job classification. Figure 3 presents the number of monitored workers in each of SC&A's job classifications during the period from August 1979 through December 1986. Similar to the analysis of total samples shown in figure 2, the job classifications of radiography and inspection (~19 percent), E&I/maintenance (~18 percent), and operator/assembly (~18 percent) in figure 3 also constituted the largest proportions of monitored workers. Unlike the analysis shown in figure 2, the proportion associated with health physics decreased to just 5 percent of the monitored individuals, while the proportion of security/fire protection more than doubled. This indicates that while health physicists may have been sampled more frequently, the number of individuals sample was not as significant.

Figure 3. Breakdown of the number of individual workers by SC&A job category in claimant subpopulation



For the purpose of coworker modeling, the number of samples is of far less importance than the number of individuals. The time weighted one-person-one-statistic (TWOPOS) methodology for analyzing coworker data was developed, at least in part, to mitigate such data dominance issues. TWOPOS values were calculated on an annual basis for each claimant in the subpopulation, as presented in table 5, which also shows TWOPOS estimates for the entire monitored population. Notably, the maximum observed in vivo measurements for Ac-228 and Pb-212 were for claimants whose job was classified as "operator/assembly." On average, the category of E&I/maintenance had higher results than the all-worker category for both Ac-228 and Pb-212.

However, the job categories of laboratory testing and waste handling showed elevated Ac-228 results compared to the more commonly sampled job classifications. In addition, janitorial jobs and security/fire protection workers showed elevated Pb-212 results in comparison to the other job classifications.

In summary, it is difficult to ascertain a specific trend among the different job classifications and their respective TWOPOS monitoring estimates. However, it is perhaps more important to note that this evaluation does not suggest a monitoring program that systematically missed the highest exposed job categories that might preclude the use of such data in coworker evaluations. In SC&A's opinion, it is more likely that the monitoring program signifies "routine, representative" sampling of the workforce as described in NIOSH (2015) and quoted in section 3.3 of this report.

Table 5. Summary of TWOPOS results (nCi) by job title for claimant subpopulation

Job category	# of TWOPOS values	Average Ac-228 (nCi)	Rank order 95th percentile Ac-228 (nCi)	Max Ac-228 (nCi)	Average Pb-212 (nCi)	Rank order 95th percentile Pb-212 (nCi)	Max Pb-212 (nCi)
Radiography and Inspection	55 (23.5%)	0.034	0.100	0.109	0.077	0.222	0.308
Operator, Assembly	49 (20.9%)	0.020	0.100	0.243	0.079	0.199	0.600
E&I, Maintenance	48 (20.5%)	0.035	0.100	0.200	0.120	0.217	0.500
Health Physics	19 (8.1%)	0.035	0.086	0.100	0.087	0.211	0.238
Administrative/Inventory	16 (6.8%)	0.028	0.100	0.100	0.069	0.200	0.200
Janitor	14 (6.0%)	0.013	0.065	0.100	0.123	0.245	0.300
Security and Fire Protection	14 (6.0%)	0.000	0.000	0.000	0.121	0.235	0.299
Laboratory Testing	8 (3.4%)	0.068	0.186	0.200	0.114	0.200	0.200
Science and Engineering	5 (2.1%)	0.020	0.080	0.100	0.060	0.180	0.200
Other Construction Trades	3 (1.3%)	0.000	0.000	0.000	0.066	0.180	0.199
Waste Handler	3 (1.3%)	0.067	0.180	0.200	0.033	0.090	0.100
All workers	**817 (N/A)**	**0.028**	**0.100**	**0.243**	**0.092**	**0.211**	**0.600**

Observation 5: Analysis of available job title information for claimants included in the available thorium in vivo dataset suggests that the monitoring program can be best described as "routine, representative sampling." SC&A did not identify any evidence that the monitoring program systematically excluded workers with higher exposure potential that might preclude the use of such data in coworker modeling.

3.3.2 Evaluation by department code

Although the specific work area or operation was not designated in the available in vivo dataset, department code was specified with each sample. Consequently, a relative quantitative analysis by department was feasible to evaluate the representativeness of the dataset. Overall, there were 54 unique department codes[2] identified in the in vivo data from August 1979 through the end of 1986. However, just over two thirds of the in vivo records were associated with just 5 of the 54 observed department codes (2373, 2387, 2713, 2091, and 2654). Table 6 displays a simple

[2] Department codes were in the format XXXX-X; however, for the purposes of this analysis, only the first four characters were used in establishing a unique department.

quantitative analysis[3] of the 17 department codes that represent greater than 1 percent of the total in vivo samples (combined, they represent ~88 percent of the total records). The remaining 37 department codes not shown in table 6 each individually made up less than 1 percent of the total in vivo records.

Table 6. Department codes with greater than 1 percent of the total in vivo samples

Dept. code	Total records (% of total)	Average Ac-228 result (nCi)	Rank order 95th percentile Ac-228 result (nCi)	Max Ac-228 result (nCi)	Average Pb-212 result (nCi)	Rank order 95th percentile Pb-212 result (nCi)	Max Pb-212 result (nCi)
2373	297 (28.5%)	0.044	0.200	0.400	0.092	0.300	0.500
2387	141 (13.5%)	0.028	0.100	0.200	0.061	0.200	0.300
2713	115 (11.0%)	0.020	0.100	0.300	0.069	0.300	0.400
2091	95 (9.1%)	0.014	0.100	0.200	0.075	0.200	0.300
2654	54 (5.2%)	0.020	0.100	0.200	0.080	0.200	0.500
2617	27 (2.6%)	0.022	0.100	0.200	0.133	0.200	0.300
2705	25 (2.4%)	0.036	0.100	0.200	0.104	0.300	0.400
2388	23 (2.2%)	0.013	0.100	0.100	0.100	0.300	0.400
2389	22 (2.1%)	0.032	0.100	0.200	0.050	0.100	0.200
7000	22 (2.1%)	0.123	0.395	0.500	0.132	0.390	0.500
2015	19 (1.8%)	0.016	0.100	0.100	0.105	0.300	0.300
2301	19 (1.8%)	0.032	0.110	0.200	0.068	0.200	0.200
2014	17 (1.6%)	0.035	0.100	0.100	0.065	0.200	0.200
2367	12 (1.2%)	0.083	0.380	0.600	0.092	0.370	0.700
2089	11 (1.1%)	0.027	0.100	0.100	0.055	0.150	0.200
2377	11 (1.1%)	0.018	0.100	0.100	0.155	0.350	0.400
7410	11 (1.1%)	0.018	0.100	0.100	0.036	0.100	0.100
Remaining dept.	**122 (11.7%)**	**0.039**	**0.100**	**0.600**	**0.087**	**0.295**	**0.600**
All records	**1,043 (100%)**	**0.033**	**0.195**	**0.600**	**0.083**	**0.300**	**0.700**

SC&A was unable to locate documentation to definitively identify the observed department codes with the actual department names and/or associated projects or campaigns. However, evidence suggest that department code 2373 (the largest portion of in vivo samples at ~29 percent) may be associated with health physics (Scott, 1977; "JL Master Location Description," 1985). This would be consistent with the large proportion of health physics-related samples identified for the monitored claimant subpopulation shown in figure 2 (section 3.3.1). This department code also was associated with elevated average and rank-ordered 95th percentile in vivo results when compared to the overall sample population. However, beyond this department code, there is little to indicate an overall trend between the most frequently sampled departments and the magnitude of the sample results. Similar to the analysis of job titles among

[3] Unlike the quantitative analysis of job titles in section 3.3.1, the department code analysis did not calculate TWOPOS results for individuals within each department but rather evaluated each sample independently.

the monitored claimant population, the analysis of departmental codes suggests a routine, representative monitoring program as described by NIOSH (2015) and quoted in section 3.3 of this report. SC&A does not believe the evidence suggests that a more highly exposed department was systematically excluded or undersampled in the available dataset.

Observation 6: Analysis of available departmental information included in the thorium in vivo dataset suggests the monitoring program is likely best described as "routine, representative sampling." SC&A did not identify any evidence that the monitoring program systematically excluded departments with higher exposure potential that might preclude use of such data in coworker modeling.

4 Evaluation of Additional Internal Exposure Sources

In addition to internal exposures to thorium, dose reconstruction feasibility must also be established for other contaminants present at the facility. These include uranium (section 4.1) and other less common radionuclides, such as exotic and/or transuranic material (section 4.3). It should be noted that monitoring coverage for uranium was of particular concern to the SEC-00250 petitioner and the Advisory Board, as discussed during the August 2019 ABRWH meeting; section 4.2 discusses this issue.

4.1 Uranium data overview

Uranium and its associated isotopes constitute the overwhelming majority of radioactive substances handled at Y-12. As such, the internal monitoring program was focused on both in vitro and in vivo monitoring for uranium during the period of interest. In 2005, NIOSH developed coworker intakes based on uranium urinalysis data, available in the Y-12 occupational internal dose technical basis document[4] (NIOSH, 2012a). The coworker intakes were based on a database of monitoring results through 1988 that was compiled as part of an epidemiological study performed by the Center for Epidemiological Research at the Oak Ridge Institute for Science and Education.

SC&A had previously reviewed this coworker model and identified five main findings (SC&A, 2007), which were subsequently taken up by the ABRWH Subcommittee for Procedure Reviews (SCPR) of which only one of the five remains in progress. The remaining finding (finding 4) reads:

> NIOSH did not use the fact that urine samples were collected on a Monday morning, after a minimum of 48-hours absence from the work area. The model used by NIOSH was a chronic constant daily intake of uranium. . . . SC&A has concluded that the approach taken by NIOSH is not claimant favorable. . . . SC&A recommends that the intake rates should be recalculated using the fact that urine samples were collected after a minimum of 48-hours absence from the work area. [SC&A, 2007, p. 130]

[4] The coworker intakes were originally developed in ORAUT-OTIB-0029 (NIOSH, 2005) and were eventually merged with the occupational internal dose technical basis document (NIOSH, 2012a).

This finding is still under discussion by the SCPR as of the writing of this report. It is important to note that all NIOSH coworker models are currently undergoing revision based on the ABRWH acceptance of the "Draft Criteria for the Evaluation and Use of Coworker Datasets" (NIOSH, 2015). Such a revision to the coworker model will require addressing the previous SC&A finding discussed here as well as the general criteria for coworker models described by NIOSH (2015): completeness, adequacy, representativeness, and stratification.

While it is inappropriate to draw conclusions on the application of the coworker evaluation criteria to Y-12 at this stage, SC&A believes that several aspects are informative in the context of SEC-00250. For example, a comparison of the amount of urinalysis data used in the formulation of coworker intakes to the amount of urinalysis results reported by the health physics branch can inform the reader as to whether gaps in the data exist that might preclude feasible dose reconstruction. Such a comparison for the period of interest is presented in figure 4 and figure 5.

Figure 4. Comparison of urinalysis totals between health physics quarterly reports and results available for coworker modeling

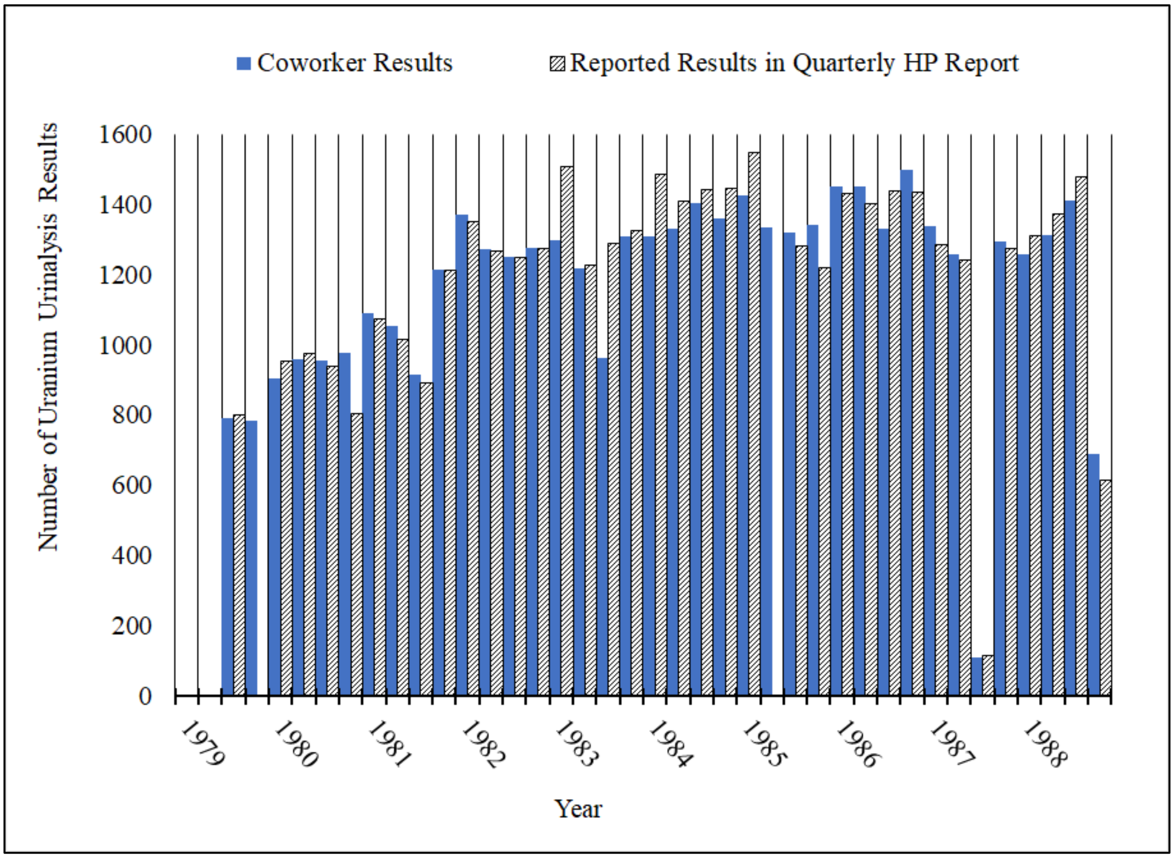
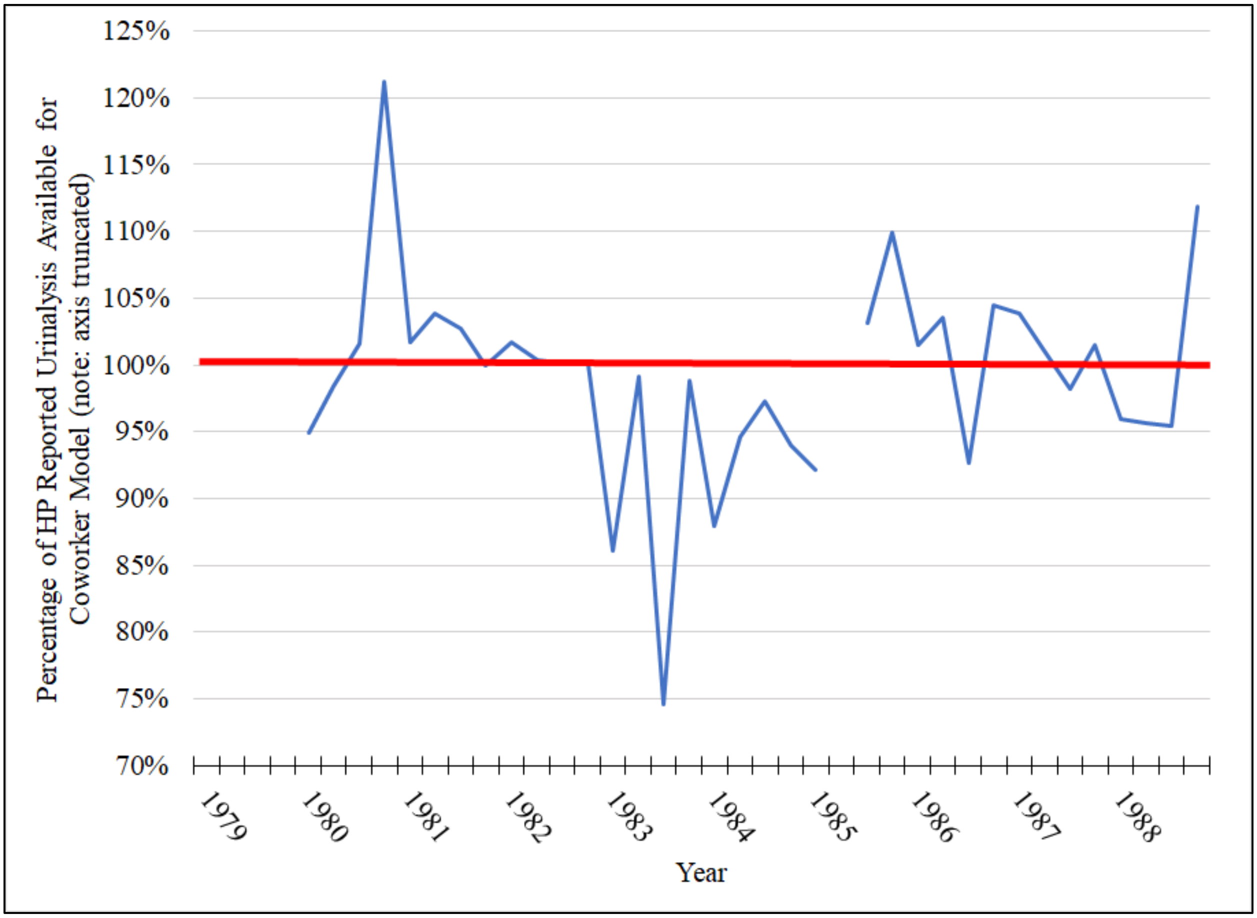


Figure 5. Percentage of health physics reported urinalysis samples available for coworker analysis



Note: Y-axis displaying the percentage of samples has been truncated to show greater detail.

Observation 7: Completeness analysis of the uranium data from August 1979 through December 1988 showed that on a quarterly basis, the percentage of available data in comparison to period health physics reports ranged from 75 percent to 121 percent of the reported totals. The average over all evaluated quarters was 98.4 percent. Completeness analysis after this period is not currently feasible.

Unfortunately, the urinalysis dataset does not appear to have identifying information that would allow for a job title or department analysis such as was conducted in sections 3.3.1 and 3.3.2 of this report for thorium. Each result is associated with an “employee number”; however, these numbers appear to be unique to the original epidemiological study rather than a worker identification number that was actually in use at the Y-12 plant.

Finding 3: Analysis of job title or other characteristics of the monitored population is not possible at this time in the uranium urinalysis dataset used in the Y-12 coworker model. Therefore, neither the evaluation of the representativeness of the dataset, nor the evaluation of the potential need for stratification of the uranium coworker model, is currently feasible.

In addition to the uranium urinalysis data used in coworker modeling, Y-12 also used in vivo methods to monitor for uranium. Figure 6 shows the number of uranium in vivo measurements reported in the quarterly health physics reports for comparison with the reported in vitro data from August 1979 through 1988. As shown in the figure, urinalysis was the primary method of uranium monitoring at Y-12.

Figure 6. Reported uranium monitoring by quarter for in vitro and in vivo methods

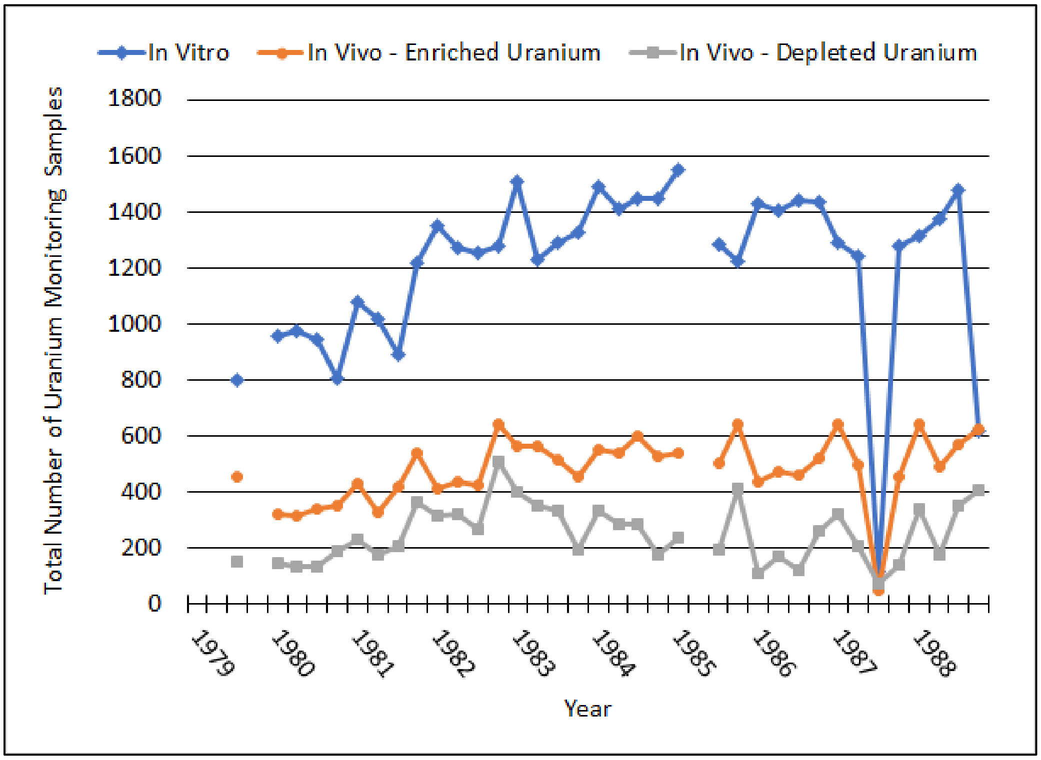


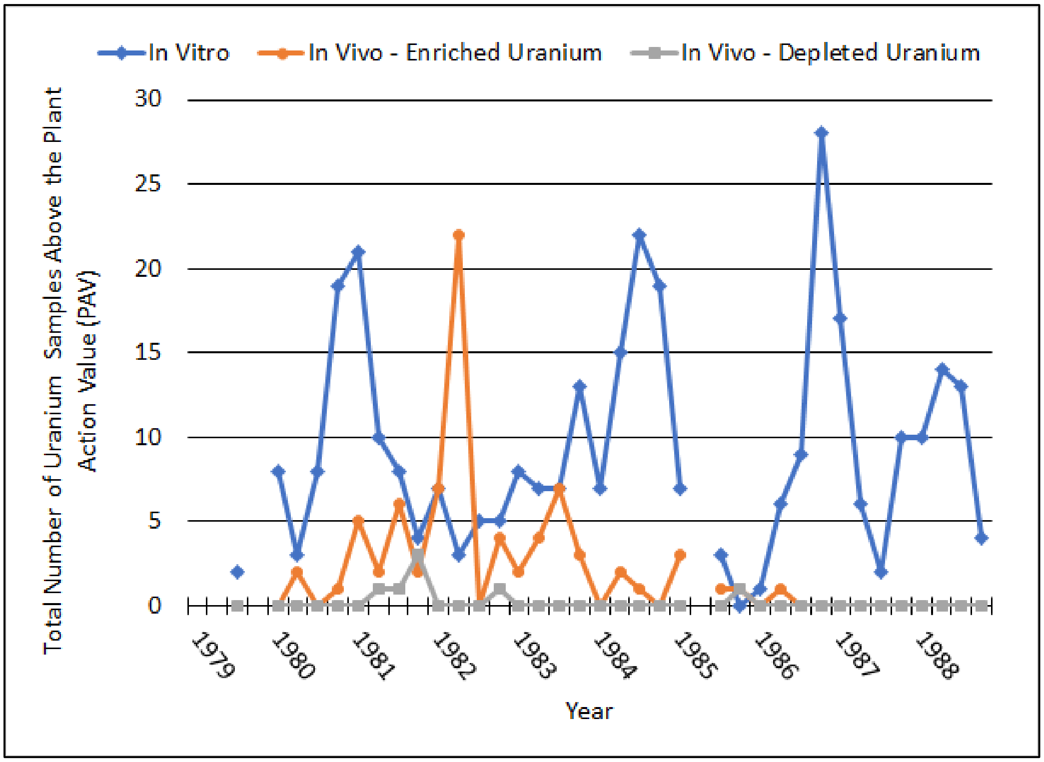
Figure 7 shows the number of in vitro and in vivo monitoring results that were above the plant action value (PAV) for Y-12. The PAV was designed to be a threshold value above which further investigation of the results, job duties, exposure configurations, and protective measures were deemed warranted by the site. PAVs at Y-12 were set to 110 disintegrations per minute per day (dpm/d) for urinalysis and 200 micrograms for enriched uranium. These values were set so as not to exceed 15 rem to the critical organ (lung or kidney) assuming typical enrichments, solubility type, and biological half-life (Union Carbide, 1981).[5]

Based on figure 7, it is clear that a larger number of workers exceeded the PAV for urinalysis during more quarters than the number of workers exceeding the in vivo PAV. However, this was not always the case, as the number of workers exceeding the enriched uranium PAV for in vivo monitoring during the second quarter of 1982 (22 total) was significantly larger than the number of workers exceeding the urinalysis PAV (three total). The number of depleted uranium in vivo

[5] As noted in several of the quarterly monitoring reports, PAVs were set at 110 dpm/d for urinalysis and 200 micrograms for in vivo, while 220 dpm/d for urinalysis and 240 micrograms in vivo roughly correspond to 15 rem to the critical organ (lung or kidney).

measurements exceeding the PAV was always bounded by either the urinalysis or enriched uranium in vivo data for all quarters in which such data were tabulated and available to SC&A.

Figure 7. Number of uranium results reported above the plant action value for in vitro and in vivo monitoring results



Observation 8: The Y-12 coworker model currently uses uranium urinalysis results in developing unmonitored intakes. Urinalysis was the primary method for monitoring for uranium exposure at Y-12, and it appears to have captured the more highly exposed workers as demonstrated by the number of workers exceeding the plant action value. However, there was a substantial amount of in vivo monitoring as well. Such in vivo monitoring should be discussed in the context of developing coworker exposures to assure that the chosen method is claimant favorable.

4.2 Applicability of uranium data to Machinist job category

As noted in Section 1, the SEC-00250 petitioner for Y-12 and the ABRWH expressed concern during the August 2019 ABRWH meeting about uranium monitoring coverage for workers defined as “Machinists” (ABRWH, 2019). This section provides additional analysis of the uranium monitoring data characteristics for workers designated as “Machinists.”

Up until the fourth quarter of 1984, the quarterly health physics reports would provide average uranium air concentrations for the three primary uranium operations defined in those reports as follows (Union Carbide, 1980, p. 5):

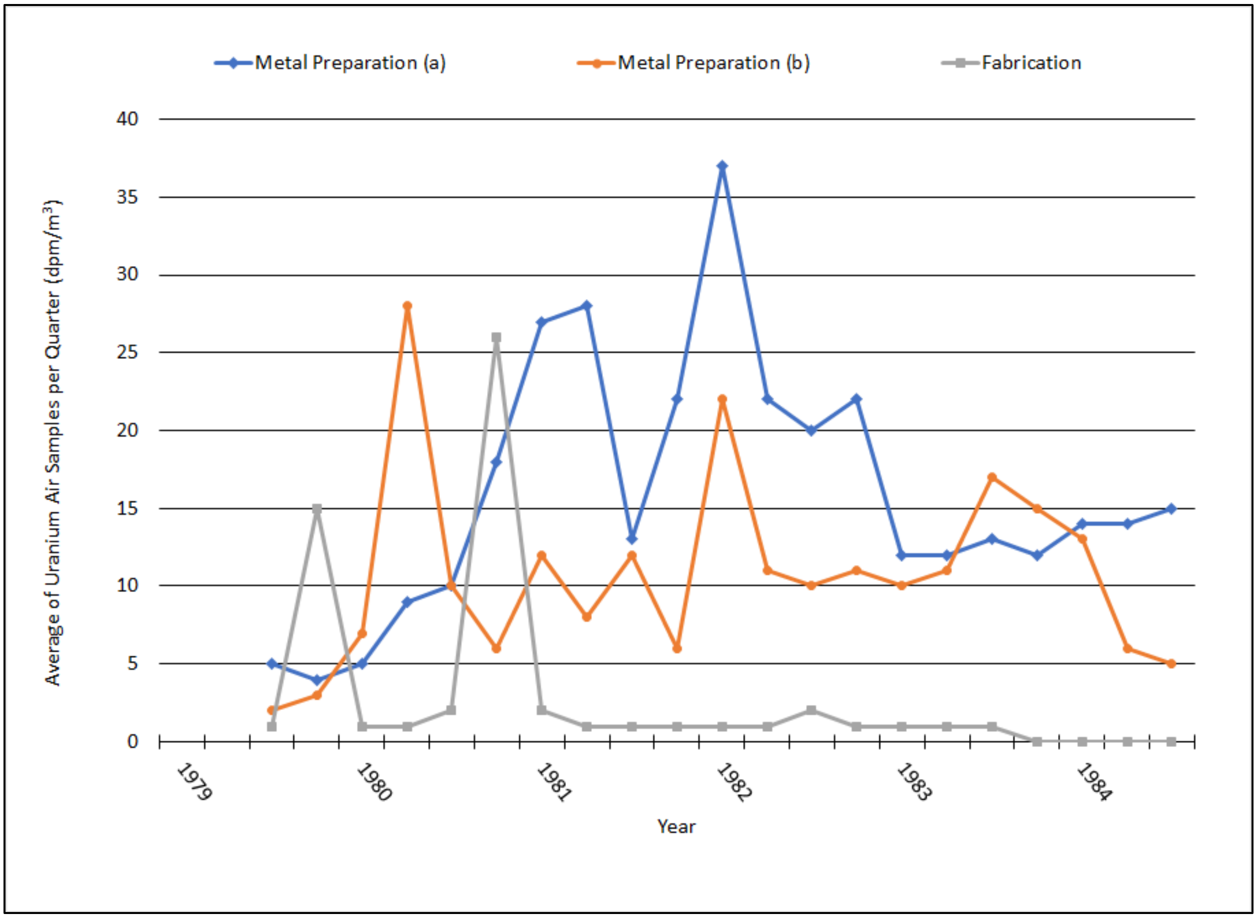
- Metal Preparation[a]: “Chemical processes, casting operations, rolling and forming in highly enriched areas”

- Metal Preparation[b]: "Chemical recovery processes in partially enriched and SRO areas"
- Fabrication: "Machining operations in highly enriched areas"

Figure 8 presents a comparison of the average uranium air concentrations for these three categories. As shown in the figure, the average uranium air samples associated with fabrication operations (defined in the quarterly reports as "machining operations in highly enriched areas") are nearly all bounded by the metal preparation categories. The exceptions are in the fourth quarters of 1979 and 1980. No explanation was provided in the quarterly reports for the observed increase in air concentrations for the uranium fabrication operation during these periods. The overall average for the period in which average air concentrations were reported for these three categories of uranium work indicate 15.9 dpm per cubic meter (m^3), 10.7 dpm/m^3, and 2.8 dpm/m^3 for metal preparation[a], metal preparation[b], and fabrication, respectively.

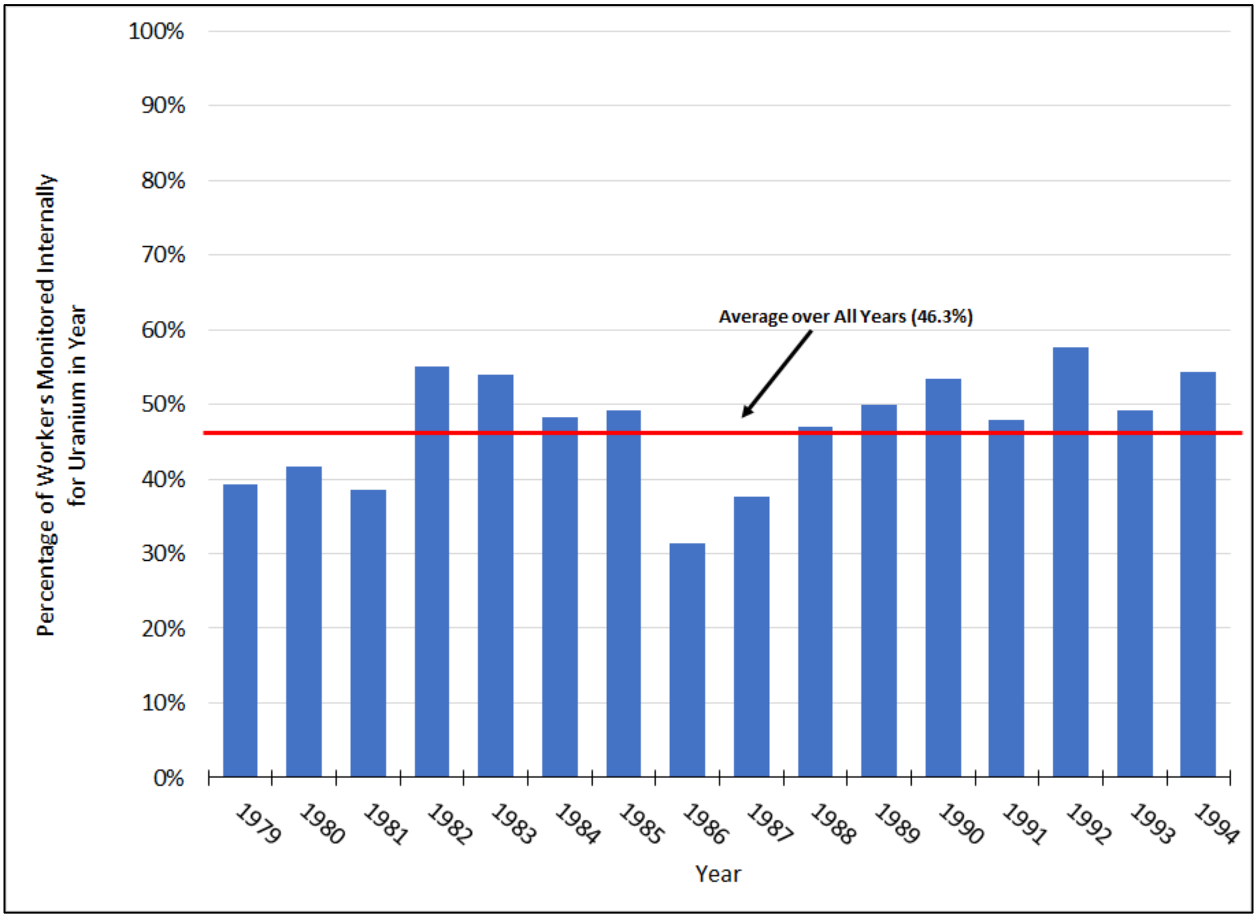
Observation 9: Average uranium air concentrations provided for three categories of uranium operations in the quarterly health physics reports indicate that "fabrication" (which is described as machining operations in enriched uranium areas) was consistently bounded by the other two operational categories (both of which are labelled "metal preparation").

Figure 8. Average uranium air concentration (dpm/m³) for three primary uranium operations reported in quarterly health physics reports



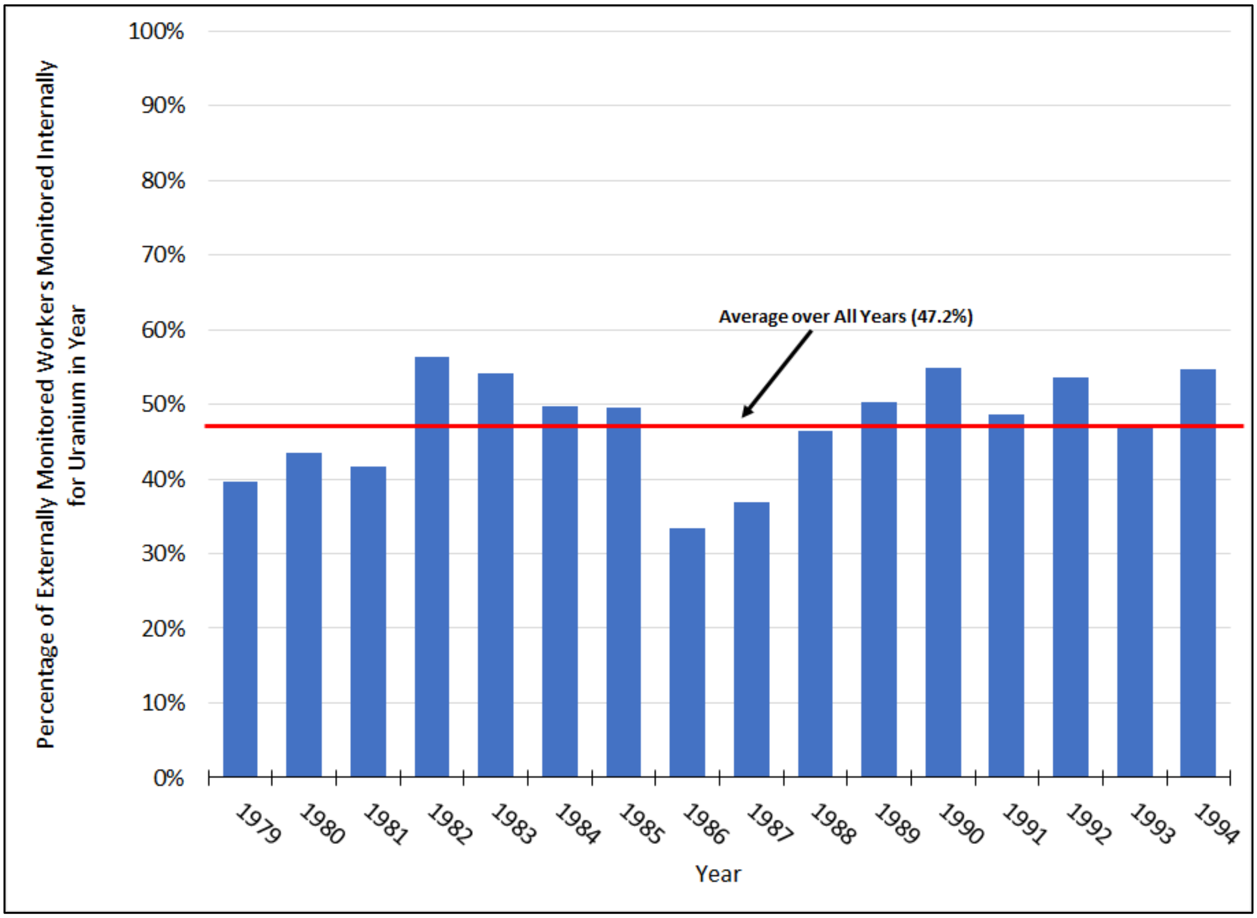
In addition to evaluating the average air sampling data provided for machining operations versus other uranium operations, SC&A examined the uranium-monitoring characteristics of 236 Y-12 claimants who reported their job title solely as "Machinist" during the SEC-00250 time period (August 1979 through December 1994). Figure 9 compares the number of Machinist claimants with covered employment against the available uranium monitoring records for the individual EEs. As shown in the figure, the number of Machinist claimants monitored for uranium by year generally fluctuated between 40 and 60 percent. The lowest percentage of monitored workers was 31.3 percent in 1986, with the highest observed value occurring in 1992 (57.6 percent monitored). The average over all years was just over 46 percent.

Figure 9. Percentage of "Machinist" claimants with covered employment who were monitored internally for uranium by year



However, in order to better account for actual exposure potential, SC&A performed a second analysis that only considered Machinist claims who were monitored externally (either by film badge or thermoluminescent dosimeter) during the given year. The rationale behind this revised analysis is that workers who were monitored externally may have had a greater potential for internal uranium exposure and thus should likely have been monitored. Conversely, workers who were not monitored externally likely did not have a significant internal exposure potential to uranium and therefore may not have actually required internal monitoring. The results of this second analysis are shown in figure 10. The results in figure 10 are remarkably consistent with the results observed in the employment-only analysis shown in figure 9. The percentage of monitored workers generally fluctuated between 40 and 60 percent. The minimum observed percentage was 33.3 percent in 1986, and the maximum was 56.3 percent in 1982. The average over all years increased slightly to 47.2 percent.

Figure 10. Percentage of "Machinist" claimants who were monitored externally and monitored internally for uranium by year

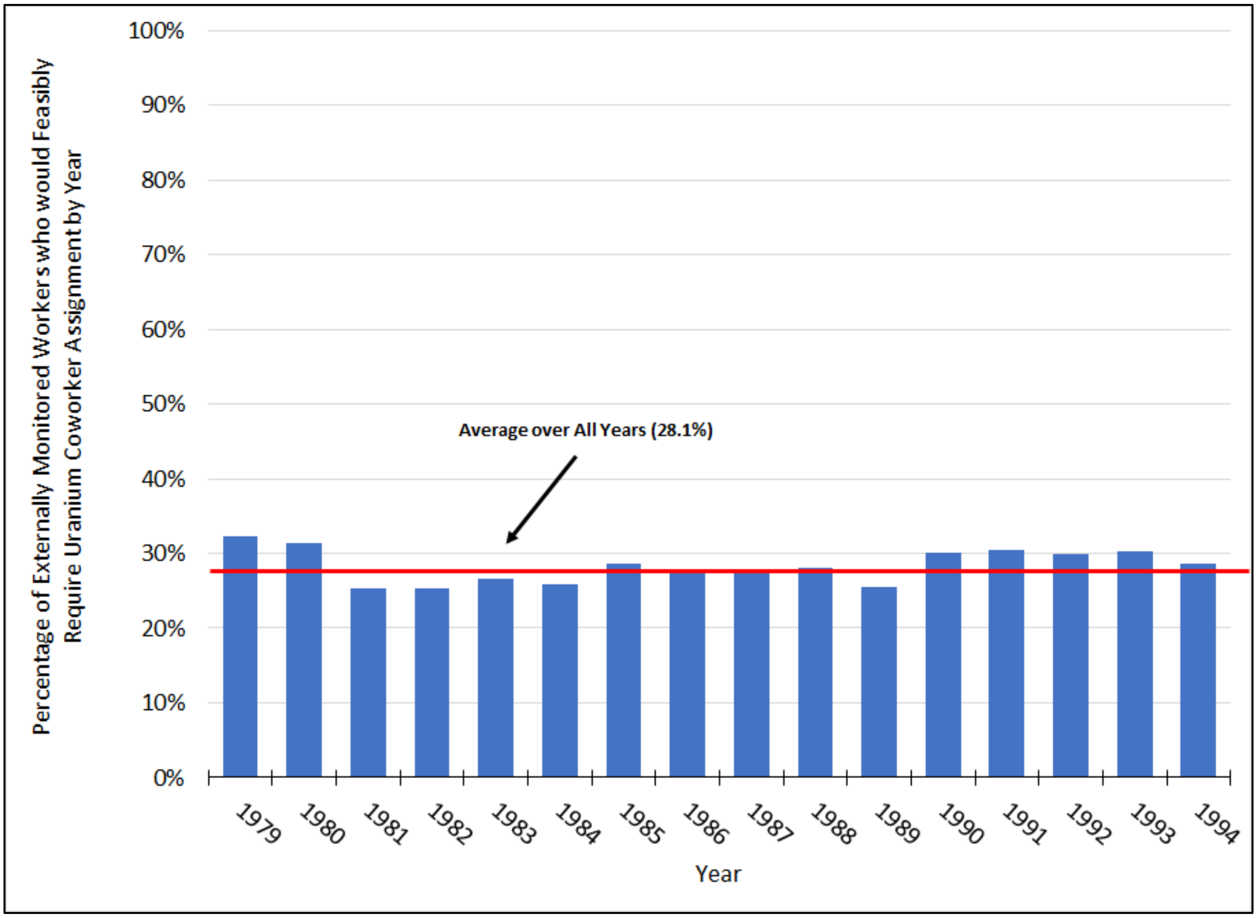


Finally, SC&A analyzed the Machinist claimant population to determine the number of workers monitored externally by year who would feasibly require an internal coworker dose assignment during that year (i.e., the worker was monitored externally; however, available internal monitoring records for that individual are insufficient to reconstruct internal dose during that year). For the purposes of coworker determination, SC&A considered periods longer than 2 years without an in vivo result to be unmonitored as prescribed by NIOSH (2018d). However, all periods prior to a uranium urinalysis sample were considered "monitored" and therefore would not require coworker dose assignment.

Figure 11 shows the annual breakdown by year for externally monitored machinist claims likely requiring coworker dose assignment. As the figure shows, the percentage of Machinist claimants who would theoretically require a coworker dose assignment by year fluctuated between approximately 25 and 32 percent. The average over all years was 28.1 percent.

When considering externally monitored Machinists over all evaluated years (i.e., not evaluated on an annual basis), 51.1 percent of externally monitored claims would not require any coworker assignment, 24.7 percent would require coworker assignment for all externally monitored years, and 24.3 percent would require at least partial coworker assignment based on their external monitoring records.

Figure 11. Percentage of "Machinist" claimants who would feasibly require uranium coworker assignment by year



Observation 10: Evaluation of claimant monitoring records, for workers who are identified only as machinists and who were monitored externally, found that 40–60 percent were also monitored for uranium by year. When considering whether claimant Machinists would theoretically require application of a coworker model during dose reconstruction, SC&A found that around 51 percent would not require any coworker assignment, around 24 percent would require partial coworker assignment, and around 25 percent would require coworker assignment for all externally monitored years.

4.3 Treatment of other radionuclides

In addition to uranium and thorium dose reconstruction feasibility at the Y-12 Plant, many other radionuclides were handled that warrant consideration. These additional radionuclides include fission products, activation products, and other exotic radionuclides. On March 29, 2018, NIOSH issued ORAUT-RPRT-0090, revision 00, "Monitoring Feasibility Evaluation for Exotic Radionuclides Produced by the Oak Ridge National Laboratory Isotopes Division" (NIOSH, 2018e; hereafter "RPRT-0090"). RPRT-0090 defers the use of plutonium-241 (Pu-241) to the Y-12 site because it was processed and handled at the Y-12 campus. The following subsections outline SC&A's review of the ER in view of its use of the methodologies recommended in RPRT-0090 for exotic radionuclides.

4.3.1 Treatment of plutonium-241

RPRT-0090 states (p. 25):

> The one remaining [radionuclide] (Pu-241) was processed and handled on the Y-12 campus. Because associated exposure would have occurred at the Y-12 campus further analysis will be included in a Y-12 specific evaluation.
>
> . . . .
>
> The one remaining [radionuclide] (Pu-241) was processed and handled on the Y-12 campus and as such, not addressed further in this document.

RPRT-0090 gives the following results for Pu-241 in table 7-2 on page 31 for the 1955–1969 period:

- No Pu-241 was in inventory for 1957, 1958, 1960, and 1961.
- For 1968 and 1969, Pu-241 was present in inventory, a bioassay method was available to detect it, and sample results for that particular bioassay method are available.
- For 1955, 1956, 1959, and 1962–1967, Pu-241 was present in inventory, but an additional analysis was necessary to determine if the radionuclide represented an infeasibility from a monitoring perspective.

RPRT-0090 gives the following results for Pu-241 in table 7-2 on page 37 for the 1970–1988 period:

- No Pu-241 was in inventory for 1976, 1987, and 1988.
- For 1970–74, 1977–1979, and 1981–1985, Pu-241 was present in inventory, a bioassay method was available to detect it, and sample results for that particular bioassay method are available.
- For 1975, 1980, and 1986, Pu-241 was present in inventory and a bioassay method was available to detect it, but no sample results for that particular bioassay method are available.

RPRT-0090 does not list Pu-241 along with Pu-240 and Pu-242 on pages 88 and 89 as a radionuclide that required no further analysis (i.e., Pu-241 does need further analysis, but it has been deferred to the Y-12 site).

4.3.2 Y-12 ER use of ORAUT-RPRT-0090

The Y-12 ER (NIOSH, 2019) refers to RPRT-0090 in the following contexts.

The ER summary section (p. 5) states:

> NIOSH has determined that there are currently sufficient calutron-cyclotron-related radioisotope data to estimate the maximum internal potential exposure to members of the evaluated class during the period from January 1, 1977 through December 31, 1994 for Isotopes Group workers on the Y-12 campus based on the evaluation contained in ORAUT-RPRT-0090.

Section 5.2.1.3, "Radionuclides Produced and/or Handled by the Isotopes Group" (pp. 28–29), states:

> The Isotopes Group produced and/or handled 213 individual radionuclides at facilities on both the ORNL X-10 footprint and that of Y-12. Y-12 separations facilities could have been used to process materials produced at X-10 reactors. Material transfers between Isotopes Group facilities located at Y-12 and ORNL X-10 were common. For this reason, with some exceptions, it can be generally assumed that all of the materials detailed in ORAUT-RPRT-0090 may have been present in Isotopes Group facilities on the Y-12 campus (particularly the Conversion Laboratory). A detailed list of the radionuclides handled is contained in Table 6-3 of ORAUT-RPRT-0090. Radiological properties of these materials are detailed in Attachment B of that same document.

Section 5.2.2.1, "Photon" (p. 30), states:

> Photo emissions information on radionuclides handled at Isotopes Group facilities is discussed in detail in ORAUT-RPRT-0090 (Tables 7-4 and Attachment B).

Section 5.2.2.2, "Beta" (p. 30), states:

> Beta emissions information on radionuclides handled at Isotopes Group facilities is discussed in detail in ORAUT-RPRT-0090 (Tables 7-4 and Attachment B).

Section 7.2.3, "Methods for Bounding Internal Dose at the Y-12 Plant" (p. 41), states:

> The following subsections summarize the methods for bounding internal dose from uranium and thorium at Y-12.
>
> Principal sources of internal radiation for members of the evaluated class include inhalation and ingestion during processing operations related to uranium, thorium (and progeny), and calutron-cyclotron-related radioisotopes. Based on the evaluation documented in ORAUT-RPRT-0090, *Monitoring Feasibility Evaluation for Exotic Radionuclides Produced by the Oak Ridge National Laboratory Isotopes Division*, the ORNL X-10 monitoring program encompassed the wide range of radionuclides that were produced by the Isotopes Group,

including those produced and handled at the Isotopes facilities located on the Y-12 campus.

The ER does not mention Pu-241 specifically in its text. RPRT-0090 only contains radionuclide information through 1988; it does not extend through 1994.

4.3.3 Summary of SC&A's review findings concerning ORAUT-RPRT-0090 and the SEC-00250 ER

Table 7-2 (p. 51) of the ER summarizes NIOSH's recommendations concerning the feasibility of completing dose reconstructions for employees at Y-12 for the periods January 1, 1977–July 31, 1979, August 1, 1979–December 31, 1986, and January 1, 1987–December 31, 1994. The main points from table 7-2 that are applicable to the use of methodologies recommended in RPRT-0090 are:

- Dose reconstructions are not feasible for the period January 1, 1977–July 31, 1979, because of lack of feasibility of reconstructing doses from thorium. Doses for internal intakes from calutron-cyclotron-related radioisotopes are reconstructable.
- Dose reconstructions are feasible for the period August 1, 1979–December 31, 1986, for all internal and external exposures, including internal intakes from calutron-cyclotron-related radioisotopes (which operations ended on December 31, 1983).
- Dose reconstructions are feasible for the period August 1, 1979–December 31, 1986, for all internal and external exposures except for thorium, which is presently under evaluation by NIOSH. Internal intakes from calutron-cyclotron-related radioisotopes are not applicable during this period because the operations ended on December 31, 1983.

In SC&A's review of the Y-12 ER, SC&A identified the following potential issues directly related to RPRT-0090:

Observation 11: SC&A has several open findings and observations for RPRT-0090 pertinent to the ER. These findings are currently under the purview of the Board for consideration.

SC&A has previously reviewed RPRT-0090 and issued on October 9, 2018, the report, "SC&A'S Evaluation of RPRT-0090, 'Monitoring Feasibility Evaluation for Exotic Radionuclides Produced by the Oak Ridge National Laboratory Isotopes Division,' Revision 00" (SC&A, 2018). The Y-12 ER relies heavily on RPRT-0090 for analysis of intakes of calutron-cyclotron-related radioisotopes for the Isotopes Group workers. Therefore, the feasibility of dose reconstruction for the radioisotopes involved at Y-12 could be dependent upon the resolution of SC&A's findings and observations for RPRT-0090.

Finding 4: Plutonium-241 is not addressed in the Y-12 SEC-00250 evaluation report, though inability to reconstruct internal exposure to Pu-241 formed part of the basis of SEC-00251, which immediately precedes the SEC-00250 evaluation period.

RPRT-0090 defers the use of Pu-241 to Y-12 and indicates that Pu-241 intake analysis will be addressed in a specific Y-12 evaluation. This was not addressed in the ER's analyses of calutron-cyclotron-related radioisotopes for the Isotopes Group workers. The results of the Pu-241 analysis could impact the feasibility of dose reconstructions for Y-12 workers for the period August 1, 1979–December 31, 1986.

Observation 12: Post-1983 Isotopes Group radioisotope exposures were not addressed in the Y-12 SEC-00250 evaluation report. In particular, the ER does not address residual exposures to contaminated areas and process equipment.

The ER states on page 51 that the Isotopes Group calutron and cyclotron operations on the Y-12 campus ended on December 31, 1983. However, the residual periods and the decontamination and decommissioning periods for specific facilities at Y-12 used by the Isotopes Group were not addressed. These additional periods beyond 1983 would involve cleanup of radioisotopes handled by the Isotopes Group at Y-12, as well any postoperational equipment and waste management associated with them.

5 Summary Listing of Findings and Observations

SC&A's review of the Y-12 Plant SEC-00250 ER yielded the following four findings and 12 observations:

Finding 1: Available documentation only reports the number of quarterly thorium in vivo measurements up through the third quarter of 1981. For this limited time period, the completeness of in vivo thorium data available for dose reconstruction was approximately 95 percent. Direct evaluation of the completeness and availability of thorium in vivo records after this time is not currently possible.

Finding 2: Information on the annual processing and throughput of thorium materials at the Y-12 plant is currently unavailable to supplement the thorium monitoring completeness evaluation. Evidence suggests that such throughput information was once tabulated in existing documentation. However, it is likely the information was redacted from the original source documentation and thus is not available for analysis at this time.

Finding 3: Analysis of job title or other characteristics of the monitored population is not possible at this time in the uranium urinalysis dataset used in the Y-12 coworker model. Therefore, neither the evaluation of the representativeness of the dataset, nor the evaluation of the potential need for stratification of the uranium coworker model, is currently feasible.

Finding 4: Plutonium-241 is not addressed in the Y-12 SEC-00250 evaluation report, though inability to reconstruct internal exposure to Pu-241 formed part of the basis of SEC-00251, which immediately precedes the SEC-00250 evaluation period.

Observation 1: Although SC&A uncovered additional information concerning process departments and areas associated with thorium work, no definitive list was identified to aid in assessing the scope of thorium monitoring at the Y-12 plant. Sought-after documentation might have included those workers actually classified as thorium workers in addition to department and work area designations. Such information would have aided in evaluating the monitoring program's effectiveness and representativeness.

Observation 2: The in vivo monitoring program using the stationary count facilities at the Y-12 Plant employed essentially identical methods and equipment as the Mobile In Vivo Radiation Monitoring Laboratory (MIVRML), which was likewise developed at Y-12. The Board has previously evaluated the adequacy of the MIVRML system at the Fernald site and found it to be a reasonable and scientifically accurate monitoring methodology for use in EEOICPA.

Observation 3: SC&A's evaluation of the potential for bias in the data identified a negative bias in the Ac-228 data for the years 1981–1986 and Pb-212 for 1981–1984. NIOSH should consider developing adjustment factors to assure any negative bias in the reported results is correctly accounted for in a claimant-favorable manner.

Observation 4: Evidence suggests additional Pb/Ac in vivo data may be available that were not considered in the SEC-00250 ER due to their in vivo "type" designation. Limited analysis of omitted data discovered for January 1983 suggests the data are comparable to, or in some cases greater than, the current database values under consideration. NIOSH should consider capturing and analyzing any additional data unless sufficient justification exists for omitting such monitoring results.

Observation 5: Analysis of available job title information for claimants included in the available thorium in vivo dataset suggests that the monitoring program can be best described as "routine, representative sampling." SC&A did not identify any evidence that the monitoring program systematically excluded workers with higher exposure potential that might preclude the use of such data in coworker modeling.

Observation 6: Analysis of available departmental information included in the thorium in vivo dataset suggests the monitoring program is likely best described as "routine, representative sampling." SC&A did not identify any evidence that the monitoring program systematically excluded departments with higher exposure potential that might preclude use of such data in coworker modeling.

Observation 7: Completeness analysis of the uranium data from August 1979 through December 1988 showed that on a quarterly basis, the percentage of available data in comparison to period health physics reports ranged from 75 percent to 121 percent of the reported totals. The average over all evaluated quarters was 98.4 percent. Completeness analysis after this period is not currently feasible.

Observation 8: The Y-12 coworker model currently uses uranium urinalysis results in developing unmonitored intakes. Urinalysis was the primary method for monitoring for uranium exposure at Y-12, and it appears to have captured the more highly exposed workers as demonstrated by the number of workers exceeding the plant action value. However, there was a substantial amount of in vivo monitoring as well. Such in vivo monitoring should be discussed in the context of developing coworker exposures to assure that the chosen method is claimant favorable.

Observation 9: Average uranium air concentrations provided for three categories of uranium operations in the quarterly health physics reports indicate that "fabrication" (which is described as machining operations in enriched uranium areas) was consistently bounded by the other two operational categories (both of which are labelled "metal preparation").

Observation 10: Evaluation of claimant monitoring records, for workers who are identified only as Machinists and who were monitored externally, found that 40–60 percent were also monitored for uranium by year. When considering whether claimant Machinists would theoretically require application of a coworker model during dose reconstruction, SC&A found that around 51 percent would not require any coworker assignment, around 24 percent would require partial coworker assignment, and around 25 percent would require coworker assignment for all externally monitored years.

Observation 11: SC&A has several open findings and observations for RPRT-0090 pertinent to the ER. These findings are currently under the purview of the Board for consideration.

Observation 12: Post-1983 Isotopes Group radioisotope exposures were not addressed in the Y-12 SEC-00250 evaluation report. In particular, the ER does not address residual exposures to contaminated areas and process equipment.

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