Draft White Paper

REVIEW OF "THORIUM IN-VIVO COWORKER STUDY FOR FEMP – A PROPOSED ATTACHMENT FOR ORAUT-TKBS-0017-5, REV. 1"

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INTRODUCTION

During the Fernald Work Group meeting held on January 29, 2010, SC&A identified and the work group discussed six issues. Issue 6 is concerned with National Institute for Occupational Safety and Health's (NIOSH's) approach for reconstructing the doses to workers exposed to Th-232. This issue has two parts. The first part deals with pre-1968 breathing zone (BZ) samples and the degree to which that data can be used to reconstruct worker internal exposures to Th-232. SC&A had previously provided NIOSH with a detailed report regarding our findings on this matter, and there had been a considerable amount of material and reports exchanged between NIOSH and SC&A prior to the January 29, 2010, meeting. During that meeting, John Stiver (SC&A) provided a recap of the information exchanges that occurred to date and a detailed description of our remaining concerns. NIOSH indicated that it would provide a written response to our concerns, but we have not yet received that material from NIOSH.

The second part of this issue is the use of chest counts to reconstruct Th-232 internal exposures post-1968. Prior to the meeting, NIOSH had provided a white paper describing their approach to using these data to reconstruct worker doses to Th-232 and to build a coworker model using these data. The title of the Oak Ridge Associated Universities Team (ORAUT) white paper is *Thorium In Vivo Coworker Study for FEMP - A Proposed Attachment for ORAUT-TKBS-0017-5, Rev. 1* (hereafter referred to as the ORAUT white paper) (ORAUT 2008). At the time of the meeting, SC&A had only begun to review the ORAUT white paper and we discussed some of our initial concerns. This SC&A report presents the results of its review of ORAUT 2008. The focus of this review is on two main topics:

(1) The technical aspects and interpretation of available thorium in-vivo data. This issue is discussed in the SC&A Review Comments section, under General Comment 1.

(2) An investigation into who was monitored for thorium and whether this subgroup of workers adequately covers the potential thorium exposures encountered at the Fernald Feed Material Production Center (FMPC). This issue is discussed in the SC&A Review Comments section, under General Comment 2.

SUMMARY OF ORAUT WHITE PAPER

The purpose of the ORAUT white paper is to explain the rationale and summarize the data underlying NIOSH's proposed coworker dose model for internally deposited thorium in Fernald workers for whom no monitoring records or inadequate monitoring records exist. The pertinent exposure period is 1968–1989. An earlier document, *Analysis of Coworker Bioassay Data for Internal Dose Assignment* (ORAUT 2005), describes the general process used by NIOSH to analyze bioassay data for assigning doses to individuals based on coworker results.

The underlying data are in-vivo chest count measurements of Th-232 chain members for Fernald workers with apparent workplace exposures to thorium. The measurements were made mainly during the period 1968–1989 using the Y-12 Mobile In Vivo Radiation Monitoring Laboratory (MIVRML). NIOSH transcribed data from 6,423 records representing more than 1,300 Fernald workers, evaluated the transcribed data, modified some data, and excluded 523 samples from the statistical analysis, due to apparent unreliability or other reasons.

NIOSH found that useful amounts of chest count data are available for the years 1968 through 1988. From 1968 through 1978, the estimated thorium lung burden was reported as thorium mass (mg of Th-232) in nearly all cases. During 1979–1988, thorium lung burden was reported as activity of the Th-232 chain members Ac-228 and Pb-212 in nearly all cases. The differences in reporting conventions before and after 1978 were resolved by changing all reporting units to nCi. For the thorium data reported in mg, the mass to activity conversion assumed that all of the mass of natural thorium is associated with Th-232. The specific activity factor used for this conversion was 0.11 nCi of Th-232 per mg of natural thorium.

NIOSH generated chest count data statistics for yearly intervals, based on specifications and requirements in ORAUT (2005) and ORAUT (2006). A lognormal distribution was assumed, and the 50th and 84th percentile values were calculated.

NIOSH could not determine the measured quantities and assumptions underlying estimated lung burdens recorded as mg of thorium. Presumably, the measured quantity was gamma emissions from Ac-228 and/or Pb-212. NIOSH noted that measured activity of Ac-228 may not be a useful indicator of Th-232 activity in the lungs of Fernald workers, because chemical purification of thorium occurred as a routine part of thorium processing. Purification would remove Ac-228 and, as a result, it would take many years for Th-232 and Ac-228 to re-establish secular equilibrium after chemical separation, due to the relatively long half-life of the intermediate separated chain member Ra-228. Under these circumstances, a chest count may observe little or no Ac-228, but substantial quantities of Th-232 may nevertheless be present. On the other hand, measured activity of Pb-212 is regarded by NIOSH as a useful indicator of Th-232 activity on the theoretical basis that the activity ratio Th-228:Th-232 would never be less than about 0.422 following chemical separation of the Th-232 chain, and the activity ratio Pb-212:Th-228 is not expected to be substantially less than 1.0 in the lungs for prolonged periods. To convert in-vivo measurements recorded as Pb-212 to an estimated lung content of Th-232, NIOSH assumes a Pb-212:Th-232 ratio of 0.711 representing the midpoint between secular equilibrium (ratio of 1.0) and the minimum theoretical ratio after chemical separation of Th-232 and Th-228 from other members of the Th-232 chain.

NIOSH fit in-vivo thorium measurements (presumably referring to data for an individual worker) to a set of chronic inhalation scenarios involving Absorption Type M or Absorption Type S. A single chest count result for each period was assumed to have occurred at the midpoint of the period. A uniform absolute error of 1 was applied to all results, which thus assigned the same weight to each result.

Assumed intakes were based on patterns observed for the time-dependent in-vivo data. Periods where lung count data were similar were assumed to represent periods of constant chronic intake. The chronic intake level was changed if the in-vivo measurements indicated a significant sustained change at some point, such as a nearly monotonic increase or decrease in the in-vivo measurements over time.

Geometric standard deviation (GSD) values are equal to the 84th percentile intake rates divided by the 50th percentile intake rates. To account for errors associated with the assigned biokinetic models, a GSD of 3 was assigned.

Finally, NIOSH assumed that workers with the highest exposure potential for uranium and thorium would be counted most frequently.

1.0 SUMMARY OF FINDINGS

SC&A performed two different kinds of analyses on the thorium in-vivo data. The first relates to the quality of the data. The first eight findings relate to this analysis. The remaining findings relate to an analysis of the quantity of data, and whether the data can be related to thorium workers and are adequate for dose reconstruction and a coworker model, apart from the quality issues raised in the first eight findings.

The following findings relate to the quality of the thorium in-vivo data, based on the analysis in Section 1 of this report:

(1) The use of in-vivo samples reported in mg of Th for the period 1968–1978 might significantly underestimate the lung burden of thorium, if the result was based on the gamma activity of thorium daughters Ac-228 and/or Pb-212. See Sections 2.1 and 2.7.

(2) SC&A questions whether enough evidence exists to justify the conversion factor 1 mg Th = 0.11 nCi, based on the small number of overlapping samples in 1978–1979 that have been used to justify the factor. See Section 2.2.

(3) There is a high amount of imprecision present in the pre-1979 data, as shown in individual worker records with implausibly large changes in reported lung burden over relatively short time periods. This could be explained by varying exposures to more heterogeneous mixtures of thorium and its daughter products, but may also have implications as to the reliability of in-vivo measurements during this period. See Section 2.3.

(4) The reported thorium MDA of 6 mg appears incompatible with actual positive results reported for Fernald workers. Furthermore, the 84th percentile values presented in the coworker study were all below this 6 mg threshold, with the exception of 1968. See Section 2.4.

(5) There is no information provided on the counting time and calibration methods for measuring Pb-212, which calls into question how in-vivo results are being interpreted. See Section 2.5.

(6) Given the lack of information on the MDA and uncertainties on the significance of the in-vivo Pb-212 results, SC&A questions the credibility of the positive Pb-212 results. All derived results at the 84th percentile in the period 1978–1989 are positive results, yet are below the plausible MDAs for Pb-212. See Section 2.6.

(7) SC&A feels more justification is required to validate the assumed Pb-212:Th-232 activity ratio of 0.71 (the midpoint of the theoretical range of 0.42–1). Studies suggest the ratio shows considerable variation and, in some cases, has been found to be significantly smaller than the lower bound assumed by NIOSH of 0.42. See Section 2.7.

(8) Data for identified thorium workers suggest a large number of negative results for Pb-212, which may indicate an overestimation of the natural background component of Pb-212 and possibly a systematic underestimation of thorium lung burdens. See Section 2.8.

The following findings relate to the adequacy of data, apart from quality considerations. The analysis for these findings is in Section 3 of this report.

(1) SC&A identified two resources that cover 60 individual workers, who were designated as thorium workers either by a 1967 memo listing thorium workers (Starkey 1967), or as indicated directly on their respective in-vivo monitoring logsheets. Most, but not all, of these workers have some in-vivo thorium monitoring data. Only limited information can be derived from these resources as to when these workers were involved in thorium operations. See Sections 3.1 and 3.4.

(2) It has not been possible for SC&A to validate NIOSH's assumption that the rationale for thorium in-vivo monitoring was preferentially oriented to workers with high thorium exposure potential. The pattern of monitoring does not validate that assumption. During the production years (1968–1979), about 88% of the in-vivo samples were not related to the thorium production plants and years. In other words, only about 12% of the in-vivo thorium measurements were in plants during years when there were known thorium campaigns. There is evidence that in-vivo thorium monitoring was incidental to uranium in-vivo monitoring, rather than being directed at workers who had high exposure potential for thorium. The highest thorium readings are mainly for workers who were not identified either as thorium workers or former thorium workers. See Section 3.2.

(3) High in-vivo results for workers not identified as thorium workers may have arisen from redrumming operations; fugitive emissions in poor industrial hygiene thorium areas; handling of thorium from other sites by workers not identified as thorium workers, especially after Fernald became the national repository for thorium in 1972; or thorium operations that have not yet been identified, possibly due to the destruction of documents during declassification in the early 1970s. See Section 3.3.

(4) SC&A has performed an extensive review of documentation for FMPC available on the Site Research Database (SRDB) and has not found sufficient evidence that workers involved in thorium operations or other workers who had significant thorium exposure potential (for instance due to redrumming) can adequately be identified in years subsequent to the start of in-vivo monitoring in 1968. See Section 3.4.

(5) Plant documentation indicates poor industrial hygiene conditions prior to 1985, including in areas associated with thorium production and with thorium redrumming. Both fugitive emissions and redrumming operations likely created high episodic exposure potential, at least during some of those operations. Given the lack of data identifying these two types of exposures (other than for [redacted] redrumming workers), it is not possible to compare the intakes due to episodic exposures to those due to routine production exposures. In view of this, the assumption of chronic exposure using the in-vivo monitoring data as the mid-point of exposure may not be an appropriate basis for dose reconstruction, even for those with monitoring data; it would be even more problematic for a coworker model. See Sections 3.3 and 3.5.

SC&A's overall conclusions regarding the adequacy of data (i.e., setting aside issues related to quality of data) are that the findings taken together indicate that (1) there are significant issues that NIOSH has not yet addressed that raise questions about its ability to construct a coworker model, (2) there is no clear explanation for the fact that most of the high thorium results in the production period are in plants and years when there was no documented thorium production, and (3) there appears to be insufficient documentation so far for identifying the workers with exposure potential to thorium, making it unclear to whom the coworker model would be applied.

2.0 SC&A REVIEW COMMENTS – GENERAL COMMENT 1

NIOSH's interpretation of in-vivo thorium measurements for Fernald workers may substantially underestimate the actual lung content of Th-232 + Th-228 in many cases, particularly for the period 1968–1978, when in-vivo measurements were reported as mg of thorium.

2.1 UNCERTAINTY IN INTERPRETATION OF DATA FOR THE PERIOD 1968–1978

NIOSH takes the estimated thorium lung burdens for the period 1968–1978 (recorded as mg of thorium) at face value. Statements made in the Occupational Internal Dose TBD ORAUT-TKBS-0017-5 (2004) and in the ORAUT white paper indicate, however, that the in-vivo measurements for this period are most likely based on gamma emissions from Ac-228, which may have been present in the lungs at far lower concentrations than Th-232 in many cases:

- Page 22 of ORAUT-TKBS-0017-5: "The thorium results are questionable because of the lack of information for readily interpreting them (e.g., there is no information regarding the in-vitro separation method or counting procedure/equipment, nor is there information regarding the assumptions made to derive the in-vivo results).
- Page 35 of ORAUT-TKBS-0017-5: "Thorium-232 and Th-228 activities were determined based on equilibrium assumptions and detection of their progeny, most likely Ac-228 for Th-232, but Pb-212 may have been used for assessment of both Th isotopes."
- ORAUT white paper: "Because of the relatively long half-life of Ra-228, the parent of Ac-228, and the fact that chemical purification of thorium occurred as a routine part of thorium processing, the measured activity of Ac-228 is unlikely to be a useful indicator of Th-232 activity at FMPC, especially in a generalized use such as this coworker study."
- As indicated in Figure 2 of the ORAUT white paper, several years are required for Ac-228 to approach secular equilibrium after chemical separation of the Th-232 chain. For example, the activity ratio Ac-228:Th-232 in the lungs would be only about 0.06 at 6 months after inhalation of initially pure thorium, and about 0.11 at 1 year, assuming no migration of in-growing Ac-228 from Th-232.

As illustrated in Figures 1 and 2, in-vivo data for some Fernald workers recorded as mg of thorium show a nearly monotonic increase over a substantial portion of the observation period. These patterns of time-dependent measurements could arise from any number of different exposure scenarios, such as increasing levels of exposure to thorium over time, or chronic intake of highly insoluble forms of thorium at a nearly constant rate. They are also consistent with the assumption of a continually increasing activity of Ac-228 in the lungs resulting from its in-growth after intake of thorium that has been chemically separated from its chain members. In this case, the estimated intake of Th-232 by the worker based on the in-vivo measurements reported as mg of thorium could greatly underestimate the actual intake of Th-232. For the thorium worker population as a whole, use of unadjusted in-vivo measurements reported as mg of thorium may be expected to result in a lesser, but perhaps still sizable, underestimate of average intake, if measurements of Ac-228 were indeed used to represent the Th-232 content of the lungs.

The in-vivo data for workers indicated in Figures 1 and 2 and later figures in this review are from a set of 60 thorium workers[1] identified by SC&A as an aid in the evaluation of NIOSH's proposed method of dose reconstruction and development of a coworker model. The method of determination of this set of thorium workers is described later in this review.

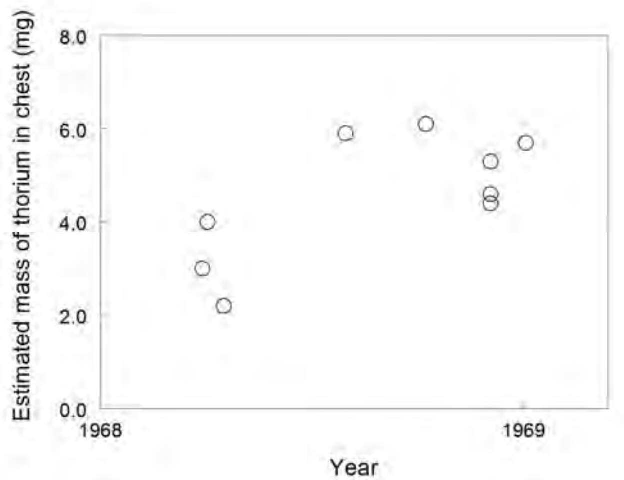

Figure 1: In-vivo Data for a Fernald Worker, Recorded as mg of Thorium

The data are consistent with the assumption of inhalation of chemically separated thorium (among many exposure scenarios), assuming the measured quantity is the level of gamma emissions from Ac-228.

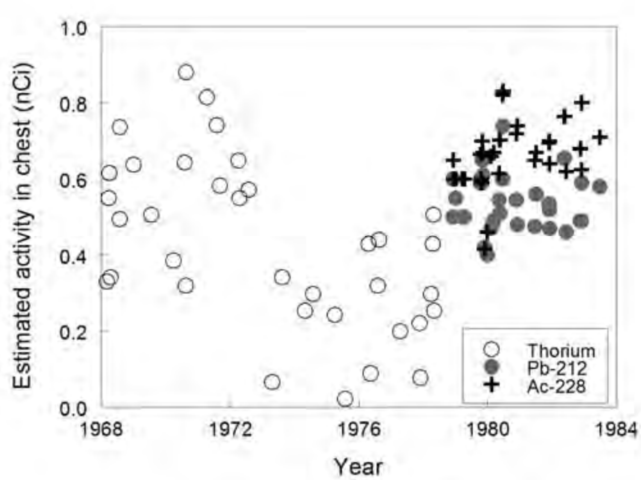

Figure 2: In-vivo Data for a Fernald Worker, Recorded as mg of Thorium

The data after the early 1970s are consistent with the assumption of inhalation of chemically separated thorium (among many exposure scenarios), assuming the measured quantity is the level of gamma emissions from Ac-228.

[1] Note: Only 49 of the 60 workers identified as thorium workers could be found in the in-vivo database.

Substantial errors in estimated intakes of Th-232 based on in-vivo data recorded as mg of thorium may also arise, due to disequilibrium between Th-232 and Pb-212, as indicated by experimental data for rats (Stradling et al., 2001). These data are discussed in a later subsection that addresses uncertainties associated with in-vivo data reported as activity of Pb-212 (1979–1988).

2.2 CONSISTENCY OF PRE-1979 AND LATER IN-VIVO THORIUM DATA

The ORAUT white paper states that, "A minor overlap in reporting conventions occurred between 1978 and 1979." That is, in each of these years, some in-vivo thorium measurements were reported as mg of thorium and some were reported as nCi Pb-212 and nCi Ac-228. Later in the white paper, a broad agreement (up to factor-of-3 differences) in either 50th percentile or 84th percentile thorium chest burdens in each of these 2 years based on the two different reporting conventions is used as support for this conversion factor 1 mg of thorium = 0.11 nCi proposed in the ORAUT white paper. For 1978, NIOSH identified only 36 measurements on 31 workers that were reported as activities of Pb-212 and Ac-228. For 1979, NIOSH identified only 15 measurements on [redacted] workers that were reported as mg of thorium. SC&A has been able to identify only 22 individual in-vivo samples (representing [redacted] workers) that have reported results for Th, Ac-228, and Pb-212 in the same count. Thus, the comparison is for small numbers of measurements on persons with potentially different tasks and job locations, and would appear to offer little support for the proposed conversion factor.

Data for 15 individual workers with in-vivo thorium data before and after the change in reporting convention were examined by SC&A to determine whether the data reported in mg of thorium merge reasonably well with the post-1978 measurements of Ac-228 and Pb-212 after application of the conversion factor 1 mg Th = 0.11 nCi. The data for some subjects were found to merge reasonably well around the transition period, as illustrated in Figure 3, while data for others were inconclusive. A discontinuity between the 1968–1978 and 1979–1988 datasets was evident in one case (Figure 4).

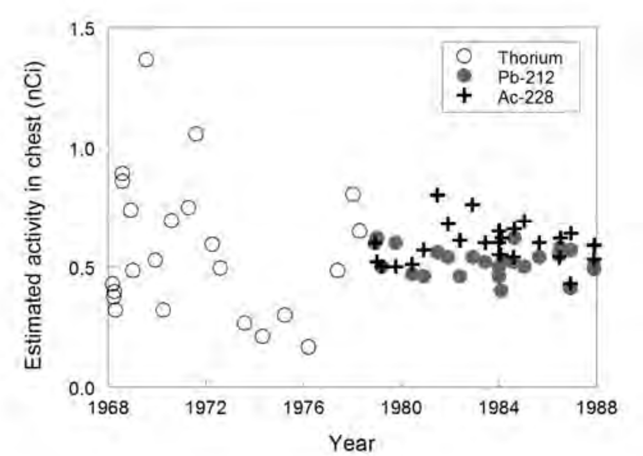

Figure 3: Example of In-vivo Data for a Fernald Worker showing a Reasonably Continuous Transition of pre-1979 In-vivo Measurements with Later Measurements, using the Conversion Factor 1 mg Th = 0.11 nCi for pre-1979 Data Proposed by NIOSH

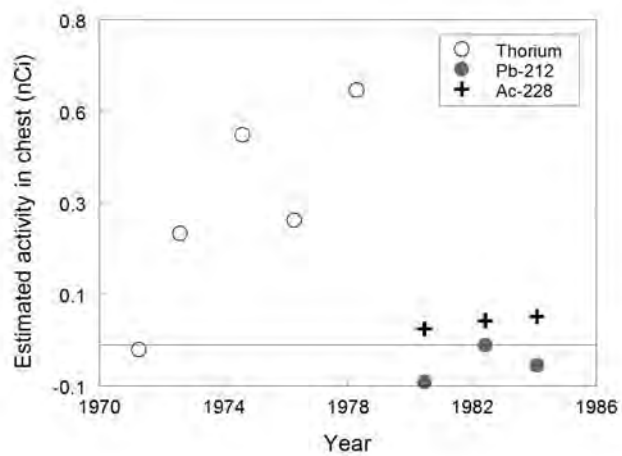

Figure 4: In-vivo Data for a Fernald Worker for whom pre-1979 Data Clearly Do Not Merge with Later Data

Furthermore, SC&A identified 22 entries that reported both Th (mg) and Pb-212 (nCi), which allows for the direct comparison shown in Table 1. The equivalent thorium activity was calculated from both the thorium mass (by multiplying by 0.11 nCi/mg) and the Pb-212 activity (by dividing by the assumed equilibrium factor of 0.71). The last column in the table presents the ratio of these calculated activities. As seen in this column, the ratio of calculated activities fluctuates significantly, with no observable pattern.

Table 1: Comparison of Calculated Thorium Activities Based on Thorium Mass (mg) and Pb-212 Activity (nCi)

Reported Thorium Result (mg)	Equivalent Activity Calculated by Thorium Mass (nCi)*	Reported Pb-212 Activity (nCi)	Equivalent Activity Calculated from Pb-212 Activity (nCi)**	Ratio of Thorium Activities
-5.00	-0.55	-0.04	-0.06	0.10
-0.60	-0.07	-0.08	-0.11	1.71
-0.54	-0.06	-0.18	-0.25	4.27
-0.16	-0.02	-0.16	-0.23	12.80
-0.12	-0.01	0.06	0.08	-6.40
-0.05	-0.01	-0.05	-0.07	12.80
-0.01	0.00	-0.01	-0.01	12.80
0.01	0.00	-0.06	-0.08	-76.82
0.30	0.03	0.15	0.21	6.40
1.81	0.20	-0.10	-0.14	-0.71
2.10	0.23	0.19	0.27	1.16
2.10	0.23	0.25	0.35	1.52
2.10	0.23	0.27	0.38	1.65
2.10	0.23	0.28	0.39	1.71
2.10	0.23	0.29	0.41	1.77
2.10	0.23	0.30	0.42	1.83
2.10	0.23	0.40	0.56	2.44

Table 1: Comparison of Calculated Thorium Activities Based on Thorium Mass (mg) and Pb-212 Activity (nCi)

Reported Thorium Result (mg)	Equivalent Activity Calculated by Thorium Mass (nCi)*	Reported Pb-212 Activity (nCi)	Equivalent Activity Calculated from Pb-212 Activity (nCi)**	Ratio of Thorium Activities
2.10	0.23	0.40	0.56	2.44
2.10	0.23	0.40	0.56	2.44
2.20	0.24	-0.10	-0.14	-0.58
4.30	0.47	-0.04	-0.06	-0.12
5.10	0.56	-0.04	-0.06	-0.10

*Calculated by multiplying thorium mass by assumed specific activity of 0.11 nCi per mg of thorium
**Calculated by dividing Pb-212 activity by the assumed equilibrium ratio of 0.71

2.3 APPARENTLY HIGH IMPRECISION IN PRE-1979 IN-VIVO THORIUM MEASUREMENTS

For some Fernald workers, the in-vivo measurements recorded as mg of thorium show implausibly large changes for inhaled thorium over brief time periods. For example, [redacted] had an estimated chest burden of 10.2 mg Th on [redacted], but only 0.2 mg Th about 40 days later. As illustrated in Figures 3 and 5, the data recorded as mg of thorium generally are more variable over time than the later data recorded as activities of Ac-228 and Pb-212. This could be related to improvements in the measurement techniques over time, but could also be the result of changes in the nature of the work or the forms of thorium handled. Thorium processing at Mound was completed in 1979, with exposure from that time being limited to repackaging and shipping operations (ORAUT-TKBS-0017-5). It may be that the equilibrium assumptions used to interpret in-vivo data are more nearly correct for thorium workers overall for the period 1979–1988 than for the period 1968–1978, when workers could have encountered more heterogeneous materials and more widely varying activity ratios of members of the Th-232 chain.

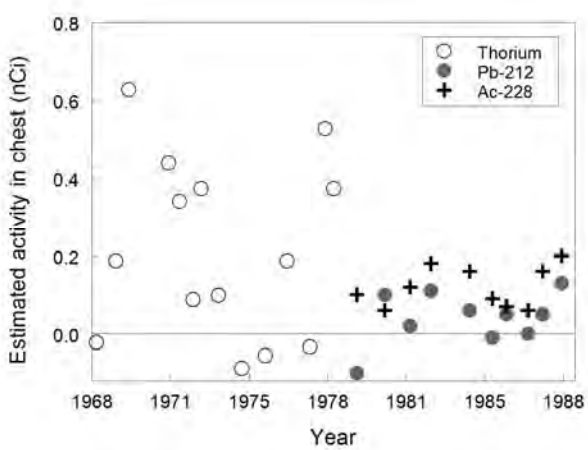

Figure 5: Data for a Thorium Worker Illustrating the Typically Higher Variability of In-vivo Thorium Measurements Recorded as mg of Thorium than of Later Measurements Recorded as Activities of Ac-228 and Pb-212

2.4 INCOMPATIBILITY OF FERNALD IN-VIVO THORIUM DATA RECORDED AS MG OF THORIUM WITH THE MDA FOR TH-232 GIVEN IN ORAUT-TKBS-0017-5

The Internal Dosimetry TBD ORAUT-TKBA-0017-5 gives an MDA of 6 mg for Th-232 for the external counting method used at Fernald. It is not explained how this MDA was derived, nor which nuclide was used to derive the MDA or the counting time, if there was a standard counting time. On page 6 of ORAUT 2008, a table of in-vivo counting statistics is given. Table 1 of ORAUT 2008 shows that the 84th percentiles for all years except 1968 are below the 6 mg MDA. The results that exist for thorium are not compatible with the 6 mg MDA.

2.5 LACK OF INFORMATION ON THE MIVRCL SYSTEM AND CALIBRATION FOR PB-212

The Occupational Internal Dosimetry TBD, ORAUT-TKBS-0017-5, gives the following information, on page 36, item 5.3.8:

> *The In Vivo Examination Center (IVEC) operated at the FCP from 1989 to 2001, a subject with a* [redacted] *chest wall thickness had the MDAs listed in Table 5-26 at the 95% confidence interval for a 3,600 sec count. The previous mobile counting system, which serviced Fernald from 1968 to 1989, provided reports to the site. However, no system performance characteristics have been discovered to date.*

There is no information on the counting time for the earlier system. There is also no information on the calibration of Pb-212 for lung counting, including influence from cross irradiation from bone.

2.6 LACK OF INFORMATION ON THE MDA AND UNCERTAINTIES ON THE SIGNIFICANCE OF THE IN-VIVO PB-212 RESULTS

The Occupational Internal Dosimetry TBD, ORAUT-TKBS-0017-5, page 36, Table 5-26, assigns an MDA equal to 6 mg for Th-232 for the period 1968–1989, assumed to correspond to 0.66 nCi. Using the 0.711 equilibrium factor suggested in NIOSH's white paper, this MDA corresponds to about 0.5 nCi of Pb-212. Table 2 of the white paper (page 7) gives the in-vivo lung counting statistics for 1978–1989. All 84th percentiles are below the MDA, and in many years, the values are one order of magnitude below the MDA. The MDA for Pb-212 (about 0.5 nCi) is an acceptable value, although there is a lack of information on the counting time. NRPB Publication 57, 2004, cites 20 Bq (0.54 nCi) as an acceptable MDA for Pb-212.

Some laboratories present an MDA of about 8–9 Bq (about 0.21–0.25 nCi), for an 8" × 4" detector, 60-min counting time, in a shielded room whole-body counter installation. Other laboratories report the same limit for germanium detectors, 30-min counting time, in a shielded whole-body counter installation.

In the O-Drive, a 1979 Union Carbide document about Mobile Counter sensitivities (Union Carbide 1979) states that the sensitivities of the Mobile Counter, calculated for the 95% confidence level, taken to be 1.96 sigma, were derived by calculating the standard deviations from source and control subject runs. The two were mathematically combined using the relationship $\sigma_t = (\sqrt{\sigma_s^2 + \sigma_c^2})$, where σ_t is the total standard deviation, σ_s is the source run standard deviation, and σ_c is the control run standard deviation. The sensitivity for Pb-212 is listed as 0.23 nCi.[2] The counting time is listed as 2,000 sec.

All 84th percentiles reported in Table 2 of NIOSH's white paper are below the MDA of 0.21 nCi, and in many years, the values are 1 order of magnitude below the MDA.

SC&A questions the significance and creditability of the positive Pb-212 results, since all 84th percentiles in the period 1978–1989 are positive results and are below plausible MDAs.

2.7 EQUILIBRIUM, ACTIVITY RATIOS, AND INTERPRETATION OF PB-212 RESULTS, 1978–1988

NIOSH applies the activity ratio Pb-212: Th-232 = 0.711 as the midpoint of the theoretical range 0.422–1.0. The lower bound 0.422 is the theoretical minimum activity ratio Th-228: Th-232 following chemical separation of Th-232 and Th-228 from the other chain members. It is assumed that Th-232 chain members produced in the lungs after inhalation of Th-232 will have the same kinetics as Th-232 in the lungs.

Autopsy data for thorium workers in general are not entirely consistent with this hypothetical lower bound ratio Th-228:Th-232. For example, in lung tissues from [redacted] thorium workers, the ratio Th-228:Th-232 was in the range 0.24–0.47 and averaged 0.35 (Stehney and Lucas 2000). On the other hand, the average ratio Th-228:Th-232 was 0.93 in the insoluble residue in the lungs of [redacted] persons exposed to monazite ore and thorium (Lucas and Stehney 1988).

Stradling et al. (2001) measured the activity ratio Th-232:Pb-212 in lungs of rats exposed to Th-232 + Th-228 by intratracheal administration. The ratio Th-232:Pb-212 was determined as a function of time following administration of different chemical forms and masses of thorium. Results are summarized in Figures 6 and 7. For most of the tested forms and masses of thorium, the ratio is substantially greater than predicted from theoretical disequilibrium fractions and the assumption that all chain members have the same kinetics in the lungs. Large activity ratios Th-232:Pb-212 even occurred in some cases for highly insoluble particles containing thorium as dioxide. The investigators conjectured that migration of the short-lived progeny occurred as some combination of diffusion of Rn-220 and recoil of the progeny due to alpha particle decay, as both mechanisms have been observed in vitro. These results seem pertinent to evaluation of thorium exposure at Fernald, where the main chemical forms of thorium associated with thorium plant processes were listed by NIOSH (ORAUT 2004) as thorium metal, ThO_2, $Th(OH)_4$, and $ThNO_3$.

[2] The lead isotope mass number is not given in the document. We assume it is lead-212.

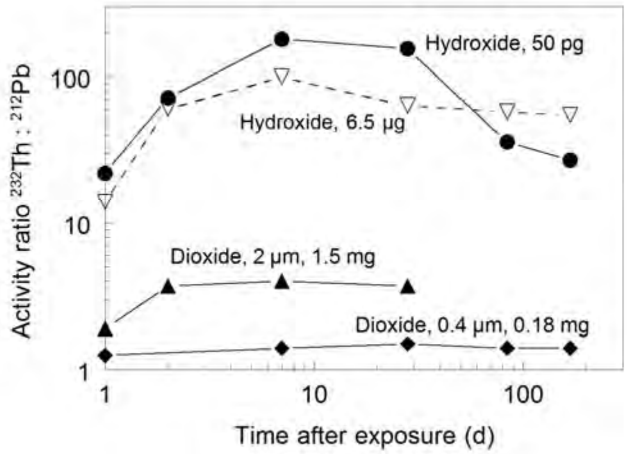

Figure 6. Activity Ratio Th-232:Pb-212 in Lungs of Rats as a Function of Time after Intratracheal Instillation of Different Masses of Th-232 + Th-228 as Thorium Dioxide or Hydroxide

(Data from Stradling et al. 2001)

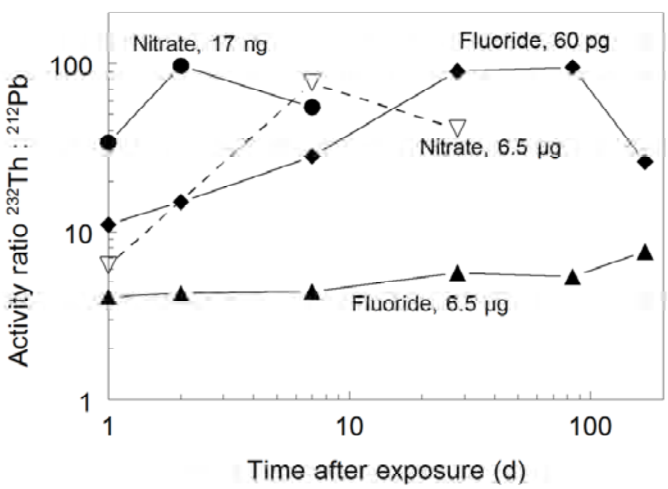

Figure 7. Activity Ratio Th-232:Pb-212 in Lungs of Rats as a Function of Time after Intratracheal Instillation of Different Masses of Th-232 + Th-228 as Thorium Nitrate or Fluoride

(Data from Stradling et al. 2001)

2.8 POSSIBLE OVERESTIMATES OF BACKGROUND FOR PB-212

For several individuals in a group of 60 workers identified by SC&A as thorium workers at the start of the in-vivo thorium monitoring program, all or nearly all measurements specifically identified as Pb-212 measurements are negative, as illustrated in Figures 8 and 9. This suggests an overestimate of natural background for Pb-212 and hence a potential systematic underestimate of lung burden of Th-232, based on in-vivo measurements of Pb-212.

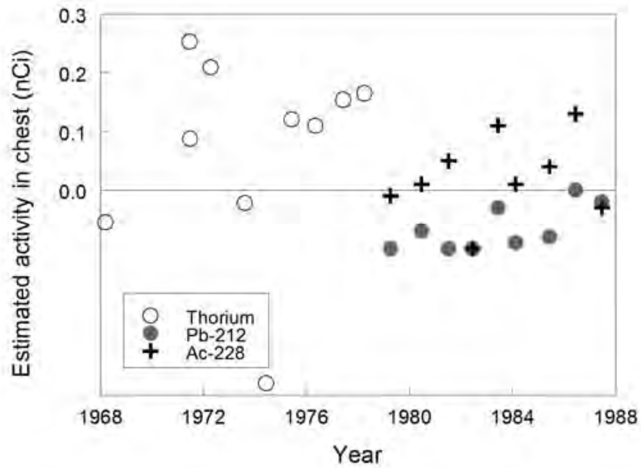

Figure 8. Example of a Thorium Worker for Whom Nearly All In-vivo Pb-212 Measurements are Negative

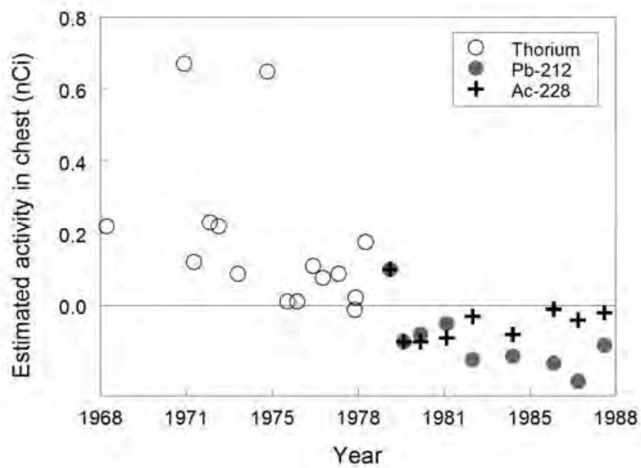

Figure 9. Example of a Thorium Worker for Whom Nearly All In-vivo Pb-212 Measurements are Negative

3.0 SC&A REVIEW COMMENTS – GENERAL COMMENT 2

NIOSH has not demonstrated that the in-vivo thorium monitoring was preferentially oriented to workers with high exposure potential. Data indicate that thorium monitoring may have been incidental to uranium in-vivo monitoring. Most of the above MDA results during the production period are not for identified thorium workers or former thorium workers, nor are they for thorium production plants and years. Furthermore, there exists the potential for episodic thorium exposure to workers involved in redrumming operations, which occurred periodically for decades, or episodic exposure due to fugitive emissions. NIOSH has not demonstrated that a chronic exposure model would be valid for episodic exposures. Significant issues remain that raise questions about NIOSH's ability to construct a coworker model and whether the available data are adequate for that purpose.

In this section, we will take thorium lung burden data at face value (i.e., we set aside the quality issues discussed in Section 1) and examine the characteristics of measurements of workers identified as thorium workers and others who were not so identified in any document that SC&A found, but who were monitored for thorium. This allows at least a partial examination of the adequacy of data for thorium dose reconstruction and for creating a coworker model.

3.1 IDENTIFICATION OF THORIUM PRODUCTION WORKERS AND ASSOCIATED DATA

SC&A identified only two sources for identifying thorium production workers.

- A list of thorium workers compiled by Bob Starkey, dated December 26, 1967 (referred to as the 'Starkey memo' in this report), lists 51 individuals (Starkey 1968).
- A compilation of in-vivo logsheets that have 'Th worker' ([redacted] individuals) or 'former Th worker' (17 individuals) written on them. (The document has no cover sheet and no author. It contains Privacy Act-protected data, and is located on the O-Drive.)

There was some overlap between the two resources, so there are 60 total individuals identified between the 2 documents. These two resources are discussed in the following two subsections. Here we note that the number of these individuals who were employed during the 1968–1989 period declined steadily during the 1968–1979 production period. The proportion of those still working who were monitored was generally in the 60% to 80% range, with the notable exceptions of 1969 and 1970. Figure 10 shows the number of the 60 thorium workers employed in each year of the MIVRML operation, as well as the percentage of those employed that also had a non-blank entry for either 'Th,' 'Pb212,' or 'Ac228' in that year.

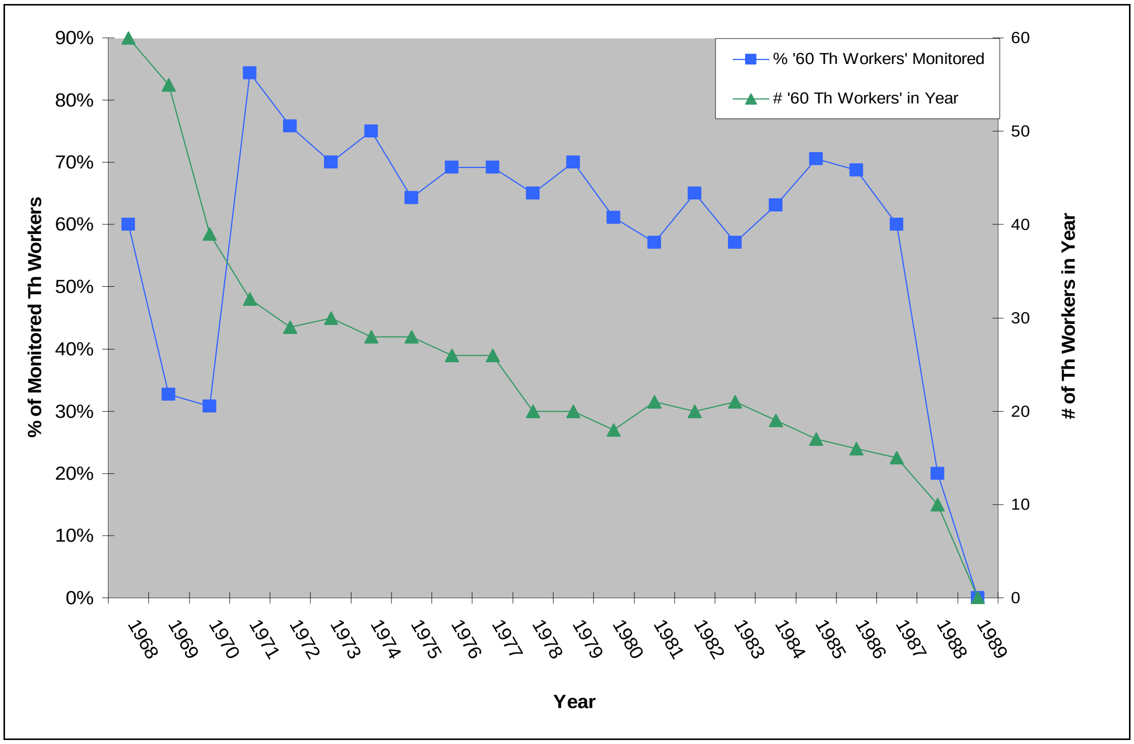

Figure 10. For the '60 Th workers' Identified by SC&A, the Number Employed by Year and the Percentage Monitored by Year

3.1.1 Starkey Memo

The Starkey memo was written late in December of 1967 and identifies 51 individuals who are designated as thorium workers. It is plausible that these workers were identified as thorium workers for the coming year; however, it is also possible they were simply the thorium workers for the previous year (1967). Of these 51 workers, approximately 55% were monitored for thorium in 1968. Given that 168 workers were monitored for thorium in 1968, and that just over half of the 51 workers identified as thorium workers for that time were monitored in that year, it appears that the ORAUT white paper statement that, "Workers identified to have potential exposures to thorium were given priority for counting during the first use of the MIVRML" is not fully borne out by the data (ORAUT 2008, p. 4). We assume that the phrase, "the first use of the MIVRML," refers to the first year of its use for thorium data, which was 1968. Overall, 78% of those identified in the Starkey memorandum were monitored for thorium at some point during their employment, and the rest have no monitoring for thorium during their career.

SC&A examined the 1968 in-vivo monitoring for these 51 thorium workers and compared it to all those monitored in 1968. The results are shown rank ordered in Figure 11.[3] Based on Figure 11, those workers designated as thorium workers in the Starkey memo have higher in-vivo thorium results in 1968 than the monitored worker population as a whole in 1968. However, the interpretation of this fact is complicated by the fact that almost 75% of the samples associated with these thorium workers indicate the employee was working in either Plant 5 or Plant 9, though no known thorium operations were undertaken in either plant at this time (Morris 2008). Please refer to Table 2 in Section 3.2 of this report for a list of years and plants where thorium is known to have been produced.

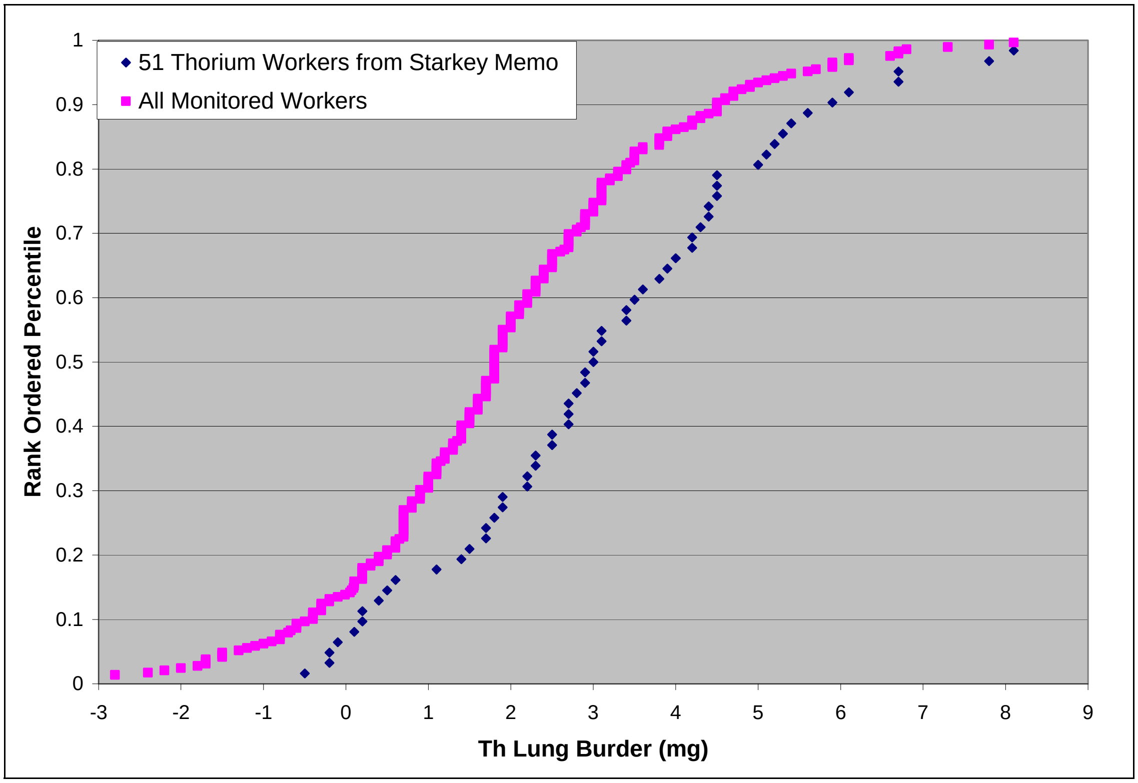

Figure 11. Rank Ordered 1968 Thorium Lung Burden (in mg Th) for 51 Thorium Workers Identified in Starkey Memo Compared to All Monitored Workers in 1968

[3] Excel database "Composite In Vivo with E Brackett 01-08-07 final approved database," in the O Drive/ AB Document Review/Fernald/FMPC MIVRML 1968–1987, which summarizes the in-vivo count data, hand written results contained in the files FEMP 1, FEMP 2, FEMP 3, FEMP 3a, FEMP 4, FEMP 5, FEMP 6, FEM 7, FEMP 8, FEMP 9, FEMP 10, FEMP 11, FEMP12, FEMP 13, FEMP 14, FEMP 15, FEMP 16, FEMP 17, FEMP 18, FEMP 19, FEMP 20, and FEMP 21. SC&A has not verified if all data were copied into the Excel database, nor the degree of accuracy in the transcription. However, through the course of this investigation, there have been instances noted where an Ac-228 and a Pb-212 result in the hardcopy were incorrectly transcribed as a Th and Ac-228 in the database. Other less important discrepancies were identified, such as incorrect badge numbers or reference page numbers in the hardcopy.

3.1.2 Thorium Workers Identified by Individual In-vivo Logsheets

As stated previously, 26 workers had the label 'thorium worker' or 'former thorium worker' written at the top of their individual in-vivo logbook records. It is currently not known what the difference between a 'thorium worker' and a 'former thorium worker' is, nor is it clear how this label applies to the individual samples and employment periods. The 26 individual workers represent 305 samples during the thorium production period (1968–1979). However, only 21% of these 305 samples were associated with plants where production was known to occur. Furthermore, 12 of the 26 workers (approximately 46%) do not appear to have any samples taken at known thorium production plants.

The in-vivo logsheets also contain data on the plants associated with the in-vivo samples and, of course, the dates of the sampling. It is therefore possible to compare the in-vivo results for the 26 workers identified in the logsheets as thorium and former thorium workers with those for workers not so identified. The 305 records for the 26 workers are broken into two parts; those associated with thorium facilities, and those that indicate a plant or area of the site not known to be directly involved in thorium production. Figure 12 shows almost all the data points for the 26 workers and all workers monitored for thorium. The scale for thorium is cut off at 8 mg in Figure 12, but 24 data points are above this figure.[4] Figure 13 includes all data points, including the very highest thorium measurements above 8 mg.

As is clear from Figure 12, the thorium worker records associated with thorium production facilities are generally higher than non-production facilities, except at the higher end of the measurement results. At the upper end of the Figure 12, the higher values of thorium lung burdens are those for "thorium workers" or "former thorium workers" in non-thorium facilities. Furthermore, the very highest results, from 6 mg to 32.5 mg of thorium, shown in Figure 13, are mainly for workers who are not identified as thorium workers or former thorium workers. Specifically, the NIOSH in-vivo thorium database shows that there were 76 in-vivo thorium measurements in the production period at or above the MDA of 6 mg. Of these 76 measurements, only 20 (just over ¼) are identified in the in-vivo records as measurements for thorium or former thorium workers. Furthermore, only 9 of the 76 measurements, or about 12%, are identified with thorium production plants and years.

The tendency for higher results in non-thorium plants and non-thorium production periods may be due to one or more factors, such as exposures resulting from redrumming operations, fugitive emissions, thorium production operations that have not yet been identified, or some other factor or some combination of factors (see Section 3.3).

[4] One high result of 303 mg has been omitted as an erroneous outlier in this analysis. Also the lowest negative result of -117.8 mg was not included. SC&A has not analyzed this issue here, because it does not affect the analysis in this section.

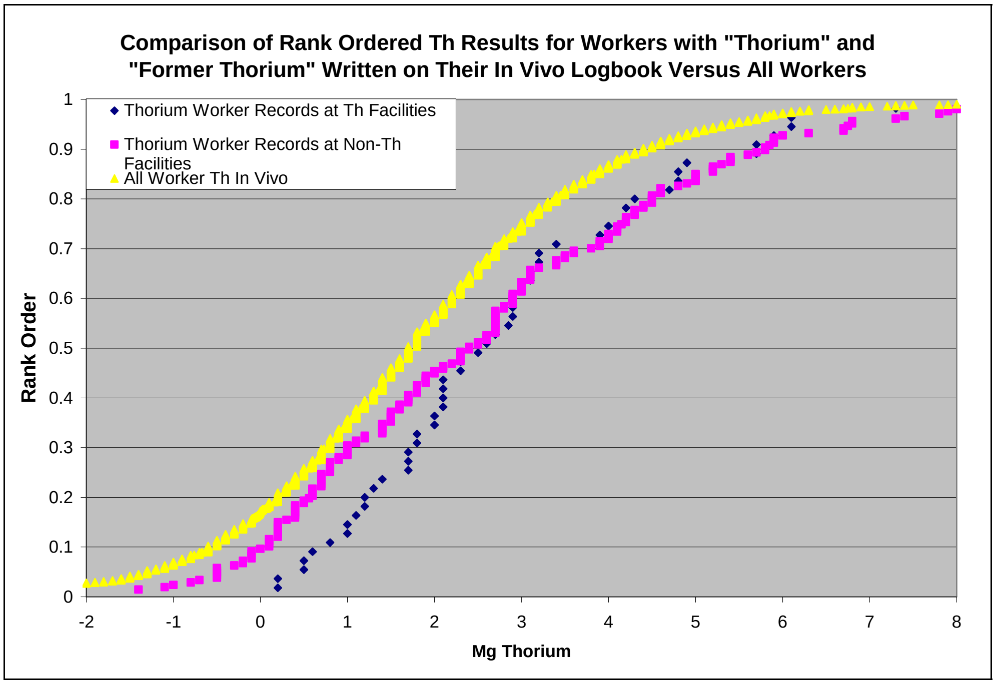

Figure 12. Rank Ordered In-vivo Results (mg of Th) for All Monitored Workers and Thorium Workers (at both Thorium Production Facilities and Non-production Facilities) for the Thorium Production Period (1968–1979)

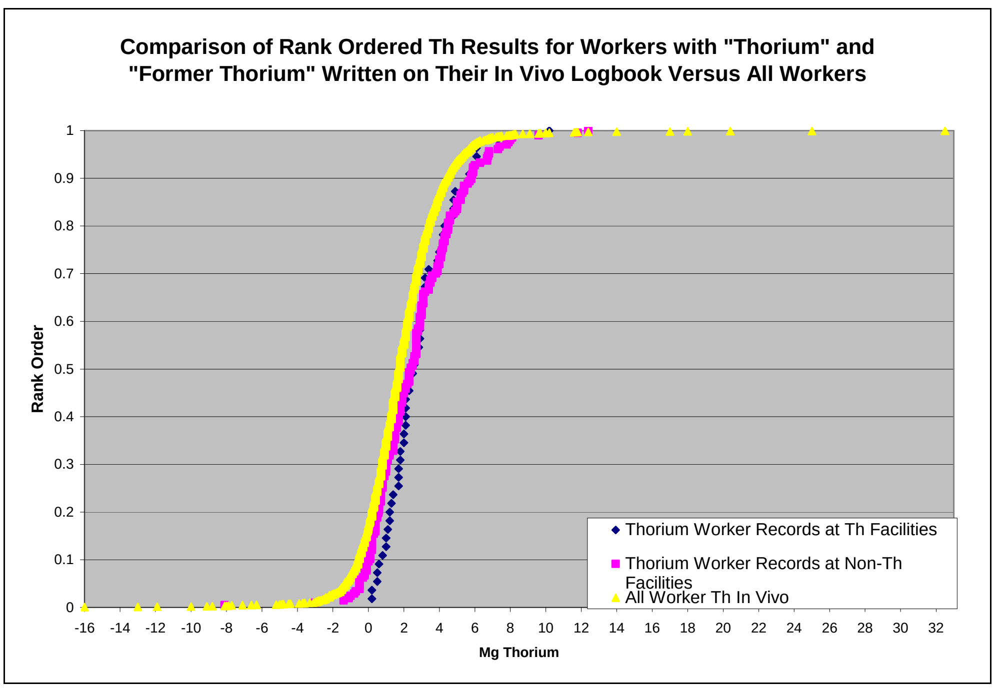

Figure 13. Rank Ordered In-vivo Results (mg of Th) for All Monitored Workers and Thorium Workers (at both Thorium Production Facilities and Non-production Facilities) for the Thorium Production Period (1968–1979)

Data on the 26 “thorium workers” and “former thorium workers” (as identified by their logsheets) for the known production period are displayed by year in Figure 14. It is clear that for most years, the highest in-vivo results are for former thorium workers, as compared to thorium workers. Furthermore, there is no information on the period of time the former thorium workers were exposed to thorium. Also, SC&A has discovered no specific criteria on what was meant by the classification ‘thorium worker’ or on the period of time that workers in this classification were exposed. There is also no definition of the term “former thorium worker.” This creates a problem on how these data should be interpreted for a coworker model.

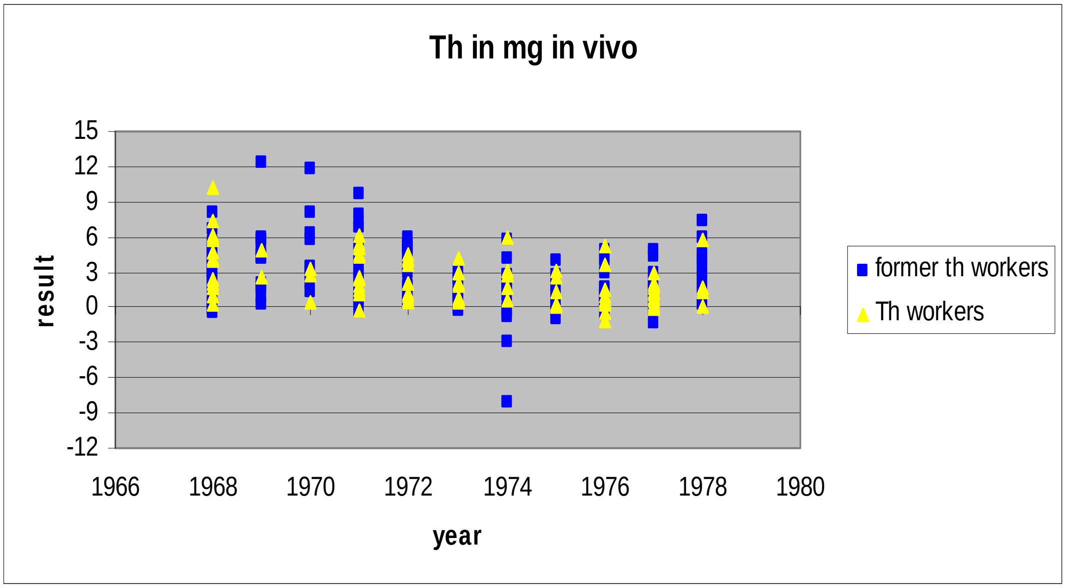

Figure 14. In-vivo Results in mg of Thorium for 9 “Thorium Workers” and 17 “Former Thorium Workers” as Identified by Their Individual Logbooks

Figure 15 compares the data in mg of thorium by year for the “thorium workers” and “former thorium workers” with all in-vivo data for all workers monitored for thorium. It shows that in most years, the very highest results were for workers who were neither identified as “thorium workers” nor “former thorium workers.” Moreover, most of these were associated with non-thorium production plants and times (see discussion in this section above; Section 3.2, Table 2; and Sections 3.3 and 3.5).

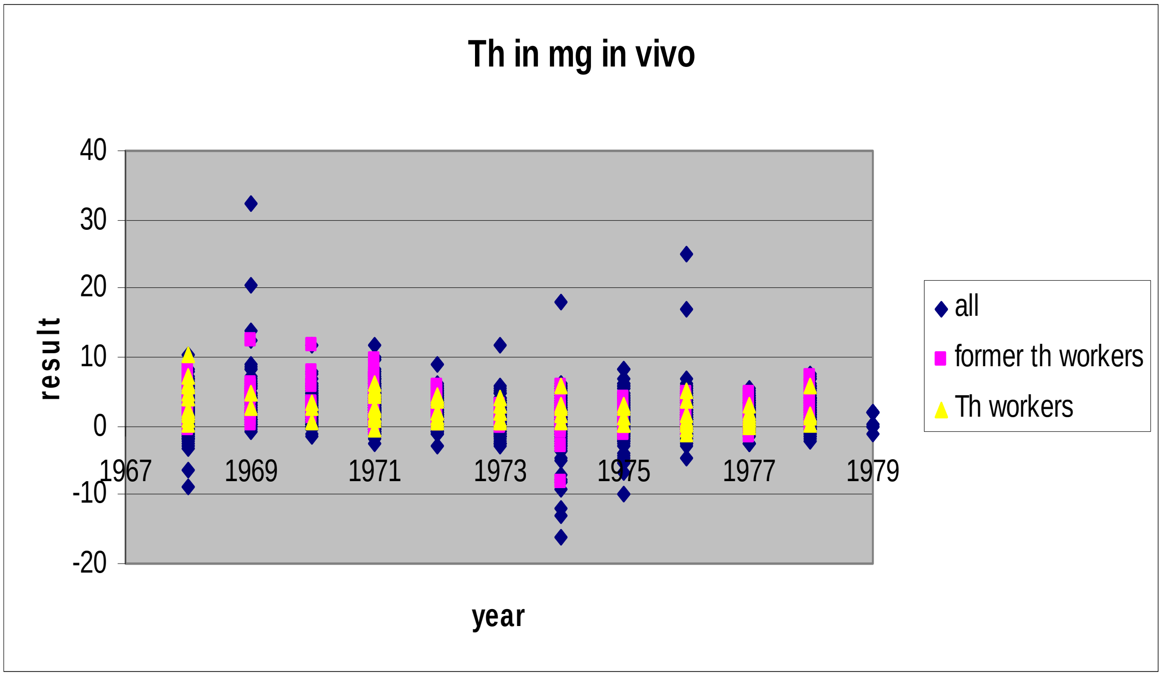

Figure 15. Comparison of In-vivo Data in mg of Thorium from the Identified "Thorium Workers" and "Former Thorium Workers" with All In-vivo Results Found in NIOSH's Excel Database

3.2 IN-VIVO MONITORING BY PLANT DURING THORIUM PRODUCTION PERIODS

Independently of the specific identification of thorium workers, SC&A examined whether there was in-vivo monitoring coverage for plant areas that were known to process thorium compounds by year. Information regarding which plants were involved in thorium production by year is provided in Morris 2008. Table 2 lists the number of thorium in-vivo samples associated with each plant and year, and also indicates the percentage of the total in-vivo samples taken in that year. Entries in Table 2 shown in bold and italicized represent plants and years where known thorium campaigns occurred. The data from Table 2 are also shown visually in Figure 16. It is important to note that the presence of sampling data for a particular plant and year that processed thorium does not necessarily mean the sampling was performed on the workers directly involved in thorium production.

As shown in Table 2, the majority of known thorium production operations during the in-vivo monitoring period occurred in Plant 1 and the Pilot Plant, with scattered campaigns in other plants in 1968–1971. There are two instances where thorium production has been identified in a plant/year in which no thorium in-vivo data have been identified; Plant 1 (1969) and Plant 3 (1968). On average, only about 12% of the in-vivo monitoring data points are associated with thorium production plants and times, though the timing of the sampling in relation to the thorium campaigns within these plants has not been established. Similar to the findings of the Starkey memo (and shown in Table 2 and Figure 16), a large fraction of in-vivo sampling was performed for Plant 5, where there is no current evidence that thorium operations occurred. This indicates that thorium monitoring may not have been focused specifically on thorium operations or on workers who were involved in thorium operations in the years when they were taking place. SC&A explored whether the thorium monitoring may have been incidental to uranium monitoring, rather than targeted specifically at workers who were involved in processing and handling thorium in the plants and the periods when they did such thorium-related work. This appears to have been the case. This is indicated by the fact that 95% of all in-vivo monitoring contained both a uranium and thorium result, and 5% contained only uranium results. Moreover, there were no instances of in-vivo results containing only thorium data.

The coworker model proposed by NIOSH does not distinguish between workers in the thorium plants and those who were not associated with thorium production in a particular year (ORAUT 2008). This appears to be linked to the following assumption:

> *The memo explains that those workers with the highest uranium and thorium exposure potential would be counted most frequently and those with virtually no exposure potential would not be routinely counted at all.* [ORAUT 2008, p. 4]

All plants at Fernald processed uranium, which was the main material processed. Typically, it was processed throughout the year. In-vivo monitoring for uranium may have been done on workers with the highest uranium exposure potential or in plants with higher dust measurements.[5] The mere fact that thorium data were collected along with uranium data does not indicate that workers with the highest thorium exposure potential were monitored. This may not have been the case, since the in-vivo thorium monitoring appears to have been incidental to uranium monitoring. About 88% of the in-vivo counts were taken at times and in areas where there was no thorium production (see Table 2). Furthermore, there appears to be no systematic identification of thorium workers, and not all workers who were identified as thorium workers were monitored. Finally, the very highest results for thorium lung burden in the 1968–1979 production period are for workers who were not identified as thorium workers or former thorium workers in the documents discussed above. This includes almost three-fourths of the results above the MDA. NIOSH has not established that the workers with the highest exposure potential to thorium were monitored. Based on the available information so far, it may not be possible to establish who they were and whether they were monitored. Indeed, as discussed above and below, the whole question of identification of workers who had significant thorium exposure potential is a complex and, as yet, unresolved issue.

Table 3 shows the magnitude of in-vivo counting results at the 50^{th} percentile for the plants involved in thorium production as a ratio of the 50^{th} percentile for all monitored workers. Table 4 presents similar information at the 84^{th} percentile. These two tables show that in the vast majority of cases for Plant 1, Plant 2/3, and Plant 8, the ratios are close to 1 (within 10% of 1) or less than 1. In these cases, the fact that a monitored worker was in one of these plants where

[5] SC&A has not investigated whether the workers with in-vivo monitoring for uranium had the highest exposure potential for uranium. This is not relevant to the present report. Moreover, NIOSH is proposing to use urinalysis data for its uranium coworker model; hence, the issue of uranium in-vivo monitoring potential is not germane in the SEC context.

thorium was processed has essentially no value in creating a claimant-favorable coworker model, much less in establishing a bounding intake value. In fact, in these cases, the results indicate that the thorium exposures in the plants not involved in thorium production were generally higher than those that were. In the case of the single year of production in Plant 6, the results are higher for thorium workers (both median and 84th percentile). The Pilot Plant monitoring data indicate higher 50th percentile values in most, but not all, years than all monitored workers. As noted above, almost three-fourths the values at or above the MDA of 6 mg were for workers who are not designated as thorium workers or former thorium workers in any document that SC&A has found. It is also important to note that the number of data points in the thorium production plants is quite small (less than 10) in several years. Taken together, it is not apparent how these data can be used to create a bounding intake, or even consistently claimant-favorable intake estimates.

In this context, it is important to note again that the source of the higher thorium lung burdens at the upper end of the distribution for workers in non-thorium production plants and years has not been established. It could be due to episodic operations, such as redrumming, episodic exposure to fugitive emissions, production operations for which records have not been discovered [possibly due to the destruction of "a large number of records and files…in the early 1970s during declassification efforts" (ORAUT 2004, p. 18)], or handling of incoming thorium shipments from the time Fernald became the national storage site for thorium-232 in 1972 (ORAUT 2004, p. 19) by workers not identified as thorium workers. In view of these uncertainties, the assignment of intake values to workers would also pose significant problems.

Table 2. Number of Th In-vivo Samples by Plant and Year, and the Percentage of Total Thorium In-vivo Samples by Year

Year	Number of In-vivo Results (Th) by Plant and Year, [Number (%)]													
	Pilot Plant	**Plant 1**	**Plant 2**	**Plant 2-3**	**Plant 3**	**Plant 4**	**Plant 5**	**Plant 6**	**Plant 7**	**Plant 8**	**Plant 9**	**"Mech"**	**Other**	**Unknown**
1968	***17 (5.4%)***	***8 (2.6%)***	1 (0.3%)	***4 (1.3%)***	***0 (0.0%)***	5 (1.6%)	76 (24.3%)	19 (6.1%)	16 (5.1%)	***39 (12.5%)***	35 (11.2%)	22 (7.0%)	61 (19.5%)	10 (3.2%)
1969	***3 (3.3%)***	***0 (0.0%)***	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (2.2%)	50 (54.3%)	0 (0.0%)	3 (3.3%)	***4 (4.3%)***	10 (10.9%)	8 (8.7%)	6 (6.5%)	6 (6.5%)
1970	***13 (7.4%)***	***8 (4.5%)***	0 (0.0%)	0 (0.0%)	0 (0.0%)	22 (12.5%)	43 (24.4%)	***13 (7.4%)***	13 (7.4%)	***16 (9.1%)***	11 (6.3%)	15 (8.5%)	21 (11.9%)	1 (0.6%)
1971	***27 (4.2%)***	***19 (3.0%)***	24 (3.8%)	32 (5.0%)	2 (0.3%)	23 (3.6%)	68 (10.7%)	78 (12.2%)	27 (4.2%)	***27 (4.2%)***	22 (3.4%)	136 (21.3%)	137 (21.5%)	16 (2.5%)
1972	***21 (7.6%)***	***10 (3.6%)***	19 (6.9%)	26 (9.5%)	1 (0.4%)	18 (6.5%)	38 (13.8%)	22 (8.0%)	21 (7.6%)	0 (0.0%)	11 (4.0%)	56 (20.4%)	30 (10.9%)	2 (0.7%)
1973	***12 (5.5%)***	***11 (5.0%)***	3 (1.4%)	34 (15.5%)	0 (0.0%)	7 (3.2%)	41 (18.6%)	16 (7.3%)	12 (5.5%)	0 (0.0%)	12 (5.5%)	46 (20.9%)	24 (10.9%)	2 (0.9%)
1974	***14 (4.7%)***	***12 (4.1%)***	0 (0.0%)	38 (12.8%)	0 (0.0%)	23 (7.8%)	36 (12.2%)	17 (5.7%)	14 (4.7%)	0 (0.0%)	20 (6.8%)	79 (26.7%)	42 (14.2%)	1 (0.3%)
1975	***3 (1.3%)***	***9 (3.8%)***	0 (0.0%)	56 (23.7%)	0 (0.0%)	15 (6.4%)	27 (11.4%)	11 (4.7%)	3 (1.3%)	0 (0.0%)	10 (4.2%)	63 (26.7%)	38 (16.1%)	1 (0.4%)
1976	***4 (1.8%)***	***9 (4.1%)***	0 (0.0%)	47 (21.4%)	0 (0.0%)	7 (3.2%)	35 (15.9%)	9 (4.1%)	3 (1.4%)	12 (5.5%)	7 (3.2%)	60 (27.3%)	27 (12.3%)	0 (0.0%)
1977	***22 (10.0%)***	***6 (2.7%)***	0 (0.0%)	23 (10.5%)	0 (0.0%)	6 (2.7%)	35 (16.0%)	11 (5.0%)	22 (10.0%)	6 (2.7%)	9 (4.1%)	49 (22.4%)	25 (11.4%)	5 (2.3%)
1978	***21 (9.9%)***	***5 (2.3%)***	0 (0.0%)	6 (2.8%)	0 (0.0%)	6 (2.8%)	42 (19.7%)	15 (7.0%)	21 (9.9%)	6 (2.8%)	6 (2.8%)	48 (22.5%)	36 (16.9%)	1 (0.5%)
1979	***17 (8.3%)***	***4 (2.0%)***	0 (0.0%)	7 (3.4%)	0 (0.0%)	20 (9.8%)	39 (19.0%)	7 (3.4%)	17 (8.3%)	1 (0.5%)	12 (5.9%)	40 (19.5%)	38 (18.5%)	3 (1.5%)
Total	174 (5.6%)	101 (3.3%)	47 (1.5%)	273 (8.8%)	3 (0.1%)	154 (5.0%)	530 (17.1%)	218 (7.0%)	172 (5.5%)	111 (3.6%)	165 (5.3%)	622 (20.0%)	485 (15.6%)	48 (1.5%)

Note: ***Bold and italicized*** entries represent plants and years in which known thorium campaigns were undertaken. Plant data were compiled by NIOSH as part of the thorium in-vivo data compilation. Timeline is from Morris 2008.

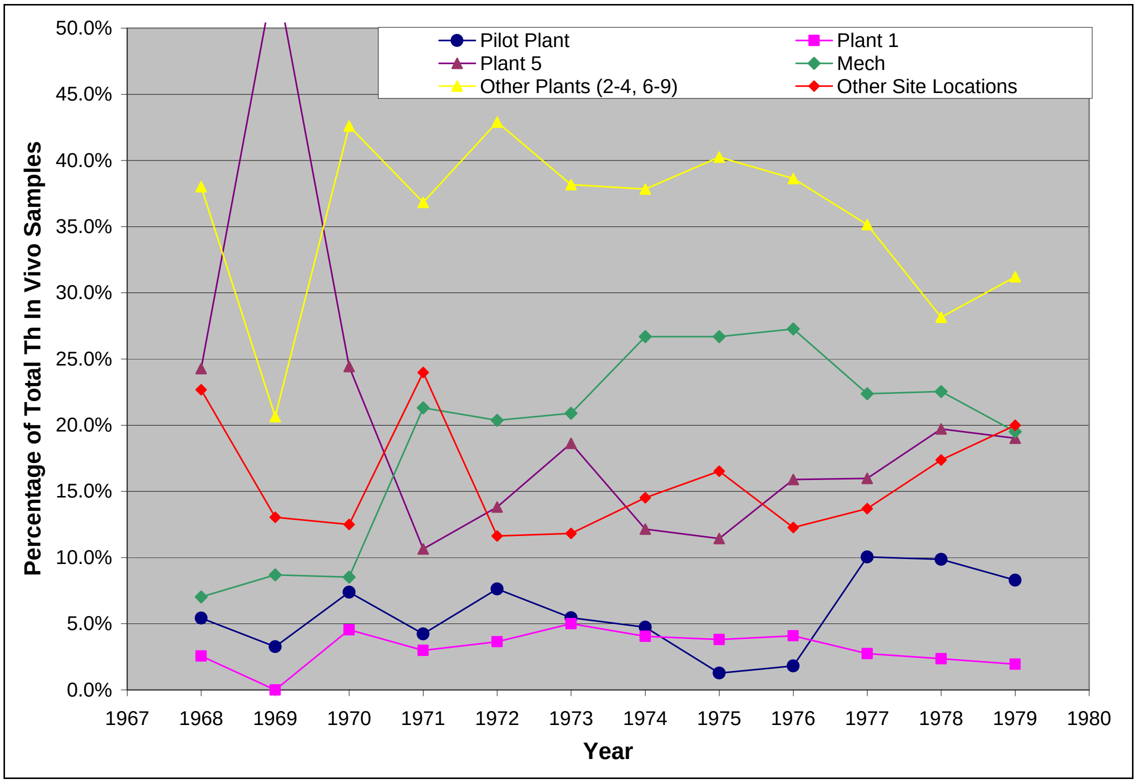

Figure 16. Percentage of the Total In-vivo Thorium Samples by Plant for the Year

Table 3. Ratio of In-vivo Results (mg Th) for Thorium Production Plants versus All Monitored Workers at the 50th Percentile

Year	All Monitored Workers (mg/Th)	Ratio: Production Plant/All Workers					
		Pilot Plant	Plant 1	Plant 2/3	Plant 3	Plant 6	Plant 8
1968	1.80	1.75	1.00	0.28	NR	–	1.00
1969	2.60	1.08	1.01	–	–	–	0.42
1970	2.10	1.38	0.10	–	–	1.90	0.86
1971	2.30	1.24	0.85	–	–	–	0.91
1972	2.00	0.78	1.25	–	–	–	–
1973	1.60	1.63	1.28	–	–	–	–
1974	1.05	0.95	1.05	–	–	–	–
1975	1.00	0.00	0.70	–	–	–	–
1976	1.20	2.58	0.17	–	–	–	–
1977	1.00	1.70	0.30	–	–	–	–
1978	1.90	1.50	1.16	–	–	–	–
1979	2.10	0.52	1.00	–	–	–	–
Average Ratio:		1.26	0.82	0.28	–	1.90	0.80

*NR indicates that no records were available for comparison

Table 4. Ratio of In-vivo Results (mg Th) for Thorium Production Plants versus All Monitored Workers at the 84th Percentile

Year	All Monitored Workers (mg/Th)	Ratio: Production Plant/All Workers					
		Pilot Plant	Plant 1	Plant 2/3	Plant 3	Plant 6	Plant 8
1968	3.80	1.57	0.76	0.74	NR	–	0.89
1969	5.79	0.68	NR	–	–	–	0.79
1970	4.22	0.95	0.49	–	–	1.25	0.73
1971	4.10	1.16	0.97	–	–	–	0.73
1972	3.70	0.73	0.83	–	–	–	–
1973	3.10	1.21	0.92	–	–	–	–
1974	3.14	1.00	1.50	–	–	–	–
1975	3.20	0.71	0.84	–	–	–	–
1976	3.50	2.39	0.75	–	–	–	–
1977	2.60	1.08	0.72	–	–	–	–
1978	4.10	1.04	0.93	–	–	–	–
1979	2.10	1.00	NR	–	–	–	–
Average Ratio:		1.13	0.87	0.74	–	1.25	0.79

*NR indicates that no records were available for comparison

3.3 EPISODIC EXPOSURE POTENTIAL INVOLVING THE REDRUMMING OF THORIUM MATERIALS

The disposition of stored thorium compounds at Fernald was a significant concern at various times during site operations, as it was found that the containers storing the thorium materials often degraded quickly, due to environmental factors and the corrosive nature of the material. Therefore, repackaging and redrumming the stored thorium material was a necessary activity at the site and created the potential for exposure to thorium. A 1965 memo notes the continuing problem of drum condition, as well as the problems associated with repackaging:

> *The thorium residue drums are disintegrating.* [Redacted] *started redrumming these residues but was stopped by the IH&R Department due to high levels of contamination arising from dust generated by the redrumming operation… About 30% of the drums are so corroded that they cannot be lifted off their pallets without falling apart. This is the fourth time that this material has been redrummed.* [DeFazio 1965]

A 1968 memo regarding problems with thorium processing, in particular drumming operations, states:

> *As you well know, most of our air dust problems at the FMPC over the years have resulted from drumming and dumping dry materials. Any time that we can eliminate either of these operations our air dust problems become greatly lessened.* [Starkey 1968]

Minutes from a 1972 meeting, as well as a memo from 1979 regarding the transfer of thorium drums, document the ongoing problem of degradation of thorium drums:

> *A substantial number of drums containing thorium residues on inventory north of Plant 9 are deteriorating (primarily the T007 and T067 material) to the point that many require immediate redrumming.* [Neblett 1972]

> *We recommend that the thorium residues be disposed of as set forth in Item 1.*[6] *We feel environmentally that this is the better method and the most practical way of containing the material in one area for future recovery. The drums are starting to deteriorate and if one of the alternatives necessitating drum handling is selected, the abuse from the barrel rotator could create punctures, promote dusting, thus environmental problems.* [Wright 1979]

Sources show that in late 1987, a plan was implemented to repackage thorium materials contained in the Plant 8 silo and two thorium storage bins that were identified as having questionable structural integrity (Clark et al. 1989). A 1985 document (Mengel 1985) contains six BZ air sampling results for [redacted] workers involved in thorium redrumming. Importantly, Mengel 1985 states that all [redacted] workers involved in that particular redrumming operation wore respiratory protection; the document notes that time-weighted BZ samples indicate that levels were below the DOE limit for "soluble" thorium.[7]

It is clear that there were concerns over the integrity of thorium containers throughout the period of interest. SC&A's interviews of workers has indicated that the respiratory protection was not always used when required, even, for instance, by chemical operators. Indeed, available documentation indicates that the use of respirators may not have provided consistent protection or any protection at all, at least up to 1980, since there were no procedures to ensure that respirators were being cleaned prior to reuse (Leist 1980). But, as noted above, there is also evidence that respiratory protection was used in mid-1985. This improved industrial hygiene situation should be viewed in the context of the DOE headquarters site-wide safety inspection of Fernald in February 1985. Furthermore, SC&A worker interviews also indicate that there were changes in regard to worker protection practices starting with the new contractor in 1986 (SC&A 2006, Attachment 4, and Section 3.5 below). Evidence of poor industrial hygiene conditions prior to 1985 is provided below in Section 3.5. Hence, the evidence for 1985 of respirator use during a redrumming operation and the resulting relatively low intakes cannot be back-extrapolated prior to 1985. NIOSH does not assume respirator use in its dose reconstruction (SC&A 2006, Attachment 2); SC&A is in agreement with this assumption.

There are no systematic data on whether the workers who were involved in redrumming activities were adequately monitored for potential thorium intakes, or even whether they were monitored with any consistency at all during the decades of periodic redrumming operations.

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[6] Item 1 stipulates that the drummed material be buried with the "contents intact;" however, documentation describing the actual operation could not be located.

[7] The term "soluble" is used in Mengel 1985. Currently, only Types M and S are recognized for thorium compounds. The DOE limit was 66 dpm/m^3 for "soluble thorium in a controlled area" (Mengel 1985).

Since the badge numbers for the [redacted] workers who were involved in the [redacted] redrumming operation are available (Mengel 1985), SC&A checked the NIOSH in-vivo data compilation for their thorium-232 records. [Redacted] of the [redacted] had in-vivo data in [redacted] (below the detection limit) and [redacted] had no data in [redacted] (though there was one result in [redacted] below the detection limit). This should not be a surprise, in view of their use of respirators with radionuclide filter cartridges in a post-headquarters-inspection work environment. Time-weighted air concentrations during the [redacted] redrumming were measured and were below the maximum allowable concentration.

It is possible that some of the higher intakes for monitored workers in non-thorium areas may have been associated with redrumming operations, but this cannot be established with the available data. The redrumming workers who had these episodic exposures have not been identified, other than the [redacted] workers during a single redrumming operation in [redacted] discussed above.

Given the lack of identification of redrumming workers and the associated in-vivo data, the relative exposure potential of redrumming workers either to thorium production workers or to all monitored workers cannot be established with the data available at present. In particular, the results for the [redacted] redrumming workers cannot be back-extrapolated. As noted above, SC&A has not investigated whether redrumming operations were systematically noted in logbooks along with measurements. None of the [redacted] workers identified in the [redacted] document has a job description in the coworker database indicating redrumming as an occupation of activity. The ORAUT white paper (ORAUT 2008) does not address the redrumming issue.

The redrumming issue is also important to assessing the feasibility of a coworker model, because exposures were episodic and, at least in some cases prior to 1985, likely to have been high, as indicated by the pre-1985 documents quoted above. The NIOSH assumption that exposures occurred at the mid-point of the period between samples (ORAUT 2008, p. 11) would also inappropriate for such episodic exposures. (Also see Section 3.5 below.)

3.4 FEASIBILITY OF IDENTIFYING ADDITIONAL THORIUM WORKERS

As noted in Section 3.1, two main resources were identified that listed thorium workers; the Starkey memo (1968) and a compilation of in-vivo logbook sheets that had ‘thorium worker’ and ‘former thorium worker’ handwritten on the top of the record. A major limitation of the Starkey memo is that it only identifies those thorium workers at the end of 1967 (likely for 1968 campaigns), and does not indicate how long these workers handled thorium after this period.

A search of available records for Fernald in the SRDB was undertaken to see if additional documentation exists that identifies the workers who handled thorium during later years. No evidence was found in this query to suggest that the documentation exists to identify additional workers who were involved in thorium production campaigns or who handled thorium materials.

As stated in Section 3.3, a document was found that listed the names of [redacted] workers involved in a thorium redrumming operation in [redacted]; however, such documentation of workers involved in redrumming appears to be the exception rather than the rule. Another document from late August 1989 identifies workers who are to be trained in the thorium overpacking process (Westinghouse 1989); however, no such documentation could be identified for earlier periods to identify specific workers. At this time, SC&A has not found sufficient documentation or evidence that thorium workers can be identified for the years of interest, with the partial exception of 1968 (from the Starkey memo) and the 26 workers identified via production period in-vivo logsheets.

3.5 POTENTIAL INADVERTENT EXPOSURE TO NON-THORIUM WORKERS

Documentation suggests several problems arising from thorium operations that may have created an exposure potential to workers in the vicinity, but not directly involved in thorium activities. A document from 1970 notes significant industrial hygiene problems related to thorium metal production:

> *Probably the worst housekeeping problem in the facility is the Ball Mill. This equipment leaks excessively at practically every joint. All horizontal surfaces have a thick covering of dust. In operation, this dust becomes airborne and adds to the dust coming from the leaks. Since the ventilation is inadequate and there is no proper enclosure, a bucket was placed under the largest leak to help contain the spilled dust… During the operation of removing the calcined ThF_4 and CaF_2 from the retorts, the stack of trays is left standing on a skid near the south annex door. The door is left open to aid in cooling the trays. The wind coming through the door blows the loose powder from the trays and spreads it generously through the annex. Removing the trays from the support requires heavy effort and this dislodges more powder to be spread by the wind… In every inspection, it has been noticed that thorium containing material was spilled in many locations.* [Ross 1970]

The problems associated with health and safety practices, such as excessive dust and disregard for safety procedures, were documented in 1980 during a week-long appraisal of the FMPC health protection program conducted by Oak Ridge Office (ORO). The results of this health and safety review are summarized in Leist 1980. The review identified several instances of workers in dusty areas not utilizing proper ventilation or respirators. Specifically, the appraisal stated the following conclusions:

- *… there were basic defects in our health and safety concepts. Further, that they had noted willful disregard of NLO regulations for health and safety and would conclude that management is not committed to this end.*
- *NLO should retrain on the use of respirators…NLO has no respirator recycling check procedures to insure they are being cleaned properly.*

- *NLO has no routine area radiation monitoring plan and we should institute one… NLO's air monitoring program is minimal and should be expanded to avoid exposures.*
- *The appraisers found a basic lack of concern for spills clean-up and longer term exposure in the plants and a lack of reflection of Management's concern in this area with the line people. The appraisers also feel that our safety programs are not being implemented.* [Leist 1980]

Thorium production campaigns ended in 1979, so are not directly covered by this health physics appraisal; however, it cannot be assumed a priori that conditions were better in the earlier period without direct evidence. Later in the 1980s, the air monitoring program was characterized as follows:

> *When WMCO began administration of the DOE contract for operation of the Feed Materials Production Center in January of 1986, the FMPC air sampling program was very limited. WMCO has aggressively upgraded the air sampling program by providing written procedures, introducing continuous sampling, posting all 'Airborne Radioactivity Areas' at 10 percent of the established limit, setting up Beta and Alpha CAMs to provide real time monitoring, requiring respiratory protection in all 'Airborne Radioactivity Areas' and providing continuous radon/thoron working level monitoring.* (Rogers 1989)

Given the industrial hygiene problems documented in 1980 and the air monitoring program that, as late as 1986, was described as "limited," it is possible that workers passing through thorium areas were exposed to contaminated dusts that may or may not have been monitored for thorium during the period of interest (1968–1989). It is not clear to what extent these potential exposures might be covered by the in-vivo program.

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