MEMO

TO: Fernald Work Group
FROM: Joyce Lipsztein, SC&A
DATE: January 30, 2012
SUBJECT: SC&A Final Position on the Th-232 In-vivo Data Quality and Adequacy for FEMP Workers

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INTRODUCTION

This memo presents SC&A's final position and conclusions regarding the quality and adequacy of Th-232 in-vivo data for use in reconstructing internal doses to workers at Fernald. Specifically, this memo focuses on the period of 1968–1978, when thorium lung burdens were reported in units of mg of Th.

A considerable amount of material and reports have been exchanged between NIOSH and SC&A on the usability of chest count data to reconstruct Th-232 internal exposures for monitored and unmonitored workers starting in 1968. The original coworker model was delivered in 2008 titled: *Thorium In Vivo Coworker Study for FEMP – A Proposed Attachment for ORAUT-TKBS-0017-5, Rev. 1, 2008* (ORAUT 2008). In response, SC&A prepared a white paper review of the NIOSH coworker study in June of 2010 (SC&A 2010). Subsequent to this initial review, there have been several work group discussions and exchanges of information in the form of additional white papers and informal responses. The timeline of discussions and additional responses is summarized as follows:

- February 2, 2011: NIOSH releases its initial response to SC&A's review in two documents; *FMPC In Vivo Chest Count Bias Adjustment* (NIOSH 2011a) and *Response to SCA comments on Fernald Th232 coworker study* (NIOSH 2011b).
- February 8, 2011: SC&A review and NIOSH responses first discussed at the work group meeting.
- April 19, 2011: Issues are further discussed at the work group meeting. This work group meeting was the first instance in which the chest count data were discussed in detail.
- May 23, 2011: NIOSH releases report entitled, *FMPC – Mobile In Vivo Radiation Monitoring Laboratory Calibration and Data Interpretation – Draft 01* (NIOSH 2011c).
- August 3, 2011: SC&A releases second white paper, *SC&A Response to NIOSH White Paper on FMPC Mobile In Vivo Radiation Monitoring Laboratory Calibration and Data Interpretation and Associated References* (SC&A 2011), in response to previously released NIOSH documents.
- August 8, 2011: Recent exchange of white papers and documented responses are discussed at work group meeting

- November 10, 2011: NIOSH releases white paper response titled, *NIOSH Response to SC&A Response to NIOSH White Paper on FMPC MIVRML Calibration*, Rev. 00. (NIOSH 2011d).

The exchange of information that NIOSH provided in 2011 has been especially informative regarding the new documentation uncovered for the MIVRML, which was not available at the time of SC&A's initial review (SC&A 2010). NIOSH has presented a thorough and intense review of documentation related to the potential use of Th-232 chest count data. SC&A has performed a detailed examination of all the documents provided by NIOSH and has concluded that monitoring results provided in milligrams of thorium cannot be quantified with sufficient accuracy in terms of real exposures to be used to bound thorium lung burdens, body burdens, or doses in an Special Exposure Cohort (SEC) context for the period of 1968–1978.[1] The following Sections (1–4) detail SC&A's findings related to the adequacy of the thorium in-vivo monitoring for reconstructing internal doses. Section 1 describes the inherent uncertainty in measuring thorium using chest counting techniques. Section 2 discusses the proposed use of statistical models to demonstrate the adequacy of the thorium data as presented in NIOSH 2011d. Section 3 discusses some observed inconsistencies in the worker records that illustrate the uncertainties associated with in-vivo monitoring for thorium. Section 4 presents some additional issues related to the uncertainty of thorium measurements that were discussed in NIOSH 2011d.

1.0 SC&A FINDINGS ON THE SIGNIFICANCE AND UNCERTAINTY INVOLVING THORIUM IN-VIVO RESULTS

1.1 FINDING 1.1

SC&A has been unable to locate any documentation demonstrating how the results given in mg of thorium were derived for the time period of 1968–1978. Documentation made available by NIOSH did not refer to the methods used specifically for in-vivo monitoring of FMPC workers. Because Th-232 could not have been measured directly, measurements were done using one or more of the gamma-emitting daughter products. However, it is not clear which daughter radionuclide(s) was used to derive the stated results in mg of thorium. Actinium-228 (Ac-228), Pb-212, Tl-208, or some combination of these daughter products could have been used to estimate the lung burden of thorium. NIOSH 2011b assumes that measurements of the Th-232 daughter product Pb-212 were used to develop the lung burdens of thorium, yet provides no supporting documentation to verify this key assumption.

One possibility is that the gamma emissions from both Ac-228 and Pb-212 were used to develop the values in milligrams of thorium. One indication of this possibility is the fact that these isotopes were measured and reported in the period after 1978, instead of the previously reported "mg of Th." This may be further evidenced by a handwritten document from 1976 titled, *Lung Counter Thorium Calibration Runs, March 26, 1976* (Author Unknown 1976). This document describes a case in which the ratio of Pb-212/Ac-228 activities was used to derive the age of the

[1] 1968–1978 encompasses the monitoring period when lung burdens were reported in the units of mg thorium.

thorium source after purification, and to derive the conversion of the measured Ac-228 activity to a thorium activity and associated mass (mg).

This handwritten document also demonstrates the large uncertainties in derived thorium lung burdens that rely on equilibrium ratio estimates, which are, in turn, based on Ac-228 and Pb-212 measurements. The in-vivo results for Pb-212 in this particular case were 2.85 nCi and 3.15 nCi, with an average of 3.0 nCi. The results for Ac-228 were 2.75 nCi and 2.8 nCi, with an average of 2.78 nCi. The ratio of the average results (Pb-212/Ac-228) was equal to 1.08, which indicates that the age of the source was approximately 4.3 years after purification, and that the associated thorium burden was 56 mg. The document further states that if the ratio (Pb-212/Ac-228) was assumed to be equal to 1, the calculated thorium burden would decrease to 27.6 mg. Due to the large uncertainties in lung burden estimates that result from small measurement variability, **the paper suggests that the assignment of lung burdens should be based on previous knowledge of source separation times, which could likely be obtained from the health physics department**.

In SC&A's view, many relevant questions remain that have not been sufficiently answered, such as:

- Were the burdens derived in the 1968–1978 period based on the ratio of Pb-212/Ac-228 or only one daughter product?
- Were they based on knowledge of the age of the source? To what degree were the assignments of body burdens dependent on the person in charge of the measurements?
- Were the assumptions potentially different before and after 1976 (when the handwritten document discussed above was produced)?

It is worthwhile to mention that there are no results equal to 27.6 mg or 56 mg of thorium in any thorium results currently available to NIOSH and SC&A, so it is unclear whether this type of analysis represents a Fernald worker.

1.2 FINDING 1.2

NIOSH 2011d, Section 3.1, states that most of the monitoring data represent "analytical background," and that this indicates that these records represent normal thorium lung burdens for a population of unexposed workers. It appears that NIOSH is positing that because the results are by and large below the minimum detectable activity (MDA) for the MIVRML counting system, it can be inferred that the workers were unexposed and that their intakes are characterized by a null distribution. Such an inference holds true only if the counting system is sufficiently sensitive to accurately measure intakes that result in meaningful doses.

To demonstrate the dosimetric significance of chest burdens at or near the stated MDA of 6 mg thorium, SC&A quantified organ doses that could have been accrued under four different exposure scenarios. For a 6mg Th-232 chest burden result taken at face value (without contesting its significance), SC&A has estimated the corresponding committed equivalent dose to bone surface and to the lungs for various exposures scenarios for Type M intakes of the

radionuclide. It is further assumed that the thorium exposure was only due to exposures of Th-232 and Th-228, without the intake of the progeny. Except for freshly purified sources, the calculated doses are underestimations, as the doses due to simultaneous intake of the daughters are not taken into account. The scenarios are based on possible exposure times and possible in-vivo chest monitoring intervals after exposures for workers at FMPC.

Scenario 1: Worker exposed during 30 days to thorium Type M compounds (worked with thorium during 30 days):

1.a Worker monitored 60 days after first day of exposure (30 days after last day of exposure):
Bone Surface Committed Equivalent dose: 1.3 Sv
Lung Committed Equivalent Dose: 0.1 Sv

1.b Worker monitored 90 days after first day of exposure (60 days after last day of exposure):
Bone Surface Committed Equivalent dose: 1.7 Sv
Lung Committed Equivalent Dose: 0.15 Sv

1.c Worker monitored 180 days after first day of exposure (150 days after last day of exposure):
Bone Surface Committed Equivalent dose: 3.2 Sv
Lung Committed Equivalent Dose: 0.3 Sv

1.d Worker monitored 270 days after first day of exposure (240 days after last day of exposure):
Bone Surface Committed Equivalent dose: 5.6 Sv
Lung Committed Equivalent Dose: 0.5 Sv

1.e Worker monitored 1 year after first day of exposure (235 days after last day of exposure):
Bone Surface Committed Equivalent dose: 9.7 Sv
Lung Committed Equivalent Dose: 0.8 Sv

Scenario 2: Worker Exposed during 90 days to thorium Type M compounds:

2.a Worker monitored 180 days after first day of exposure (90 days after last day of exposure)
Bone Surface Committed equivalent dose: 2.6 Sv
Lung Committed Equivalent Dose: 0.24 Sv

2.b Worker monitored 270 days after first day of exposure (180 days after last day of exposure):
Bone Surface Committed Equivalent dose: 4.6 Sv
Lung Committed Equivalent Dose: 0.4 Sv

2.c Worker monitored 1 year after first day of exposure (275 days after last exposure day)
Bone Surface Committed Equivalent Dose: 8 Sv
Lung Committed Equivalent Dose: 0.7 Sv

Scenario 3: Worker Exposed during 180 days to thorium Type M compounds:

3.a Worker monitored 270 days after first day of exposure (90 days after last day of exposure):
Bone Surface Committed Equivalent dose: 3.3 Sv
Lung Committed Equivalent Dose: 0.3 Sv

3.b Worker monitored 1 year after first day of exposure (185 days after last day of exposure):
Bone Surface Committed Equivalent dose: 6 Sv
Lung Committed Equivalent Dose: 0.5 Sv

Scenario 4: Worker Exposed during 365 days to thorium Type M compounds:

Worker monitored 1 day after last day of exposure:
Bone Surface Committed Equivalent dose: 2.6 Sv
Lung Committed Equivalent Dose: 0.2 Sv

SC&A has demonstrated in these examples that intakes at or near 6 mg can result in very high [**Sv-level (100 rem)**] **organ doses**. Clearly then, the workers had significant exposure potential, but the MIVRML counting system was not adequately sensitive to quantify those intakes.

The 11 graphs presented by NIOSH (NIOSH 2011d) representing thorium chest counts of Fernald workers show that most of the results were positive, but well below the stated MDA. Depending on the exposure time of the workers and the interval between exposure and monitoring, positive but unquantified results might be associated with very high doses. For example, for Scenarios 3.b and 1.d, a 1-mg chest burden result might be associated with about 1-Sv bone surface equivalent dose. For Scenarios 1.e and 2.c, a 1-mg chest burden will be associated with a bone surface equivalent dose higher than 1 Sv.

In summary, SC&A finds NIOSH's contention that the thorium results that were below the 6 mg detection limits indicate that workers were "clean" and only exposed to normal background exposures to be highly questionable.

1.3 FINDING 1.3

It is not clear to SC&A how results below the 6 mg MDA were calculated. Thorium burdens presented in units of mg had to be calculated through the measurements of the daughters. If the ratio of activities of Pb-212/Ac-228 was used to calculate the age of the thorium source, it would not be possible to correctly calculate the age using Pb-212 and Ac-228 results that essentially represent electronic background noise.

The document *Counter Thorium Calibration Runs, March 26, 1976* (Author Unknown 1976) is the only document that exemplifies the use of daughter's activities to calculate thorium lung burdens. The activity/mass of thorium was assigned using Ac-228 measurement. When Ac-228 is used, an underestimation of the thorium burden by a factor of more than 100 can occur. The underestimation of thorium activity by the measurement of Ac-228 activities is illustrated in Figure 3 of NIOSH 2011c, as a function of time after purification of the source. This underestimation was also discussed in SC&A 2010, which states:

> *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.*

Further complicating the issue are uncertainties related to the biokinetics of the thorium progeny in the lung, as explained in Finding 1.4.

1.4 FINDING 1.4

There are many difficulties associated with the measurement of thorium daughter nuclides. One of the main problems is the equilibrium ratio in the lung. The quantity of daughter radionuclides retained in the lung from a Th-232 intake depends in part on the equilibrium conditions of the original outside source. In addition, the daughters' physico-chemical behavior does not follow the parent nuclide. Even in its most soluble form, there is generally a long-term retention of thorium in the lungs following its intake. In contrast, thorium daughter products, such as radium and lead, are more readily absorbed from the respiratory tract into systemic circulation. This is true for the daughters that are inhaled together with the original thorium, and also for the daughters that are formed within the lung. Even for the slow dissolving components of Type S material, decay products formed by alpha emission that escape the particulate substrate will behave like a more soluble form in the lung (Type M, for example). Thus, the daughter nuclides, whether formed within the lung or inhaled with the original source, will leave the lung at a higher rate than the thorium itself, and thorium lung burdens based on gamma emissions from those daughter products retained in the lung will be underestimated.

In addition, the solubility of the daughters formed within the lung might be different from the daughters that were inhaled. Also, it is likely the residence time in the lung of Ac-228 and of Pb-212 may be different. The translocation of thorium daughters in the lung was discussed in detail in SC&A 2011.

1.5 FINDING 1.5

The problem of translocation, as discussed in Finding 1.3, was already known at the time of the in-vivo measurements and is explained in the paper by West (1965). The West paper, which was discussed in SC&A 2011, describes the problem of the different rates of translocation of daughters from the lung in the following manner:

> *A third factor complicating the interpretation of personnel monitoring results is the probability of the metabolic or physical translocations of daughters away*

> *from the location of the parent stored in the body. Such translocation can affect the reliability and sensitivity of the in vivo interpretation if the gammas measured are those from daughters subject to translocation. On the other hand, translocation could be used in dose estimates if the amount of translocated daughters eliminated from the body can be related to the amount of parent remaining.* (West 1965)

NIOSH 2011d attempts to disqualify the importance of this problem by citing the following from the West document: "in vivo measurements are 'primarily qualitative' but can be 'made quantitative by establishing or estimating thorium to daughter ratios" (West 1965). NIOSH further states that they have evaluated and quantified these limitations, and that bounding, claimant-favorable ratios and correction factors for use in a thorium coworker model were provided. SC&A does not agree with this position. SC&A firmly believes that for the period in which measurement results were given in mg of thorium (1968–1978), it is not possible to infer the raw measurements of the daughter nuclide(s) that are required in order to compute the thorium lung burden. In fact, it is currently unknown if one or more daughters were actually measured. Thus, any assumptions that are based on unknown raw measurements cannot be reasonably established.

It is noteworthy that for the 1979–1988 period, when activity results of Ac-228 and Pb-212 are available, SC&A believes that it might be possible to assign bounding claimant-favorable conditions to calculate the lung burdens. However, SC&A has not yet seen any such calculations or assumptions; the assumptions to date have been related to the age of the external source.

1.6 FINDING 1.6

A careful examination of the available in-vivo files for Fernald workers shows that thorium burdens were not used to quantitatively relate the measured burdens to limits for restriction of exposure. Instead, monitoring records appear to indicate that the objective was to obtain uranium lung burdens in order to calculate the percentage of the maximum permissible lung burden (MPLB) they represented. There were no similar calculations identified for thorium.

SC&A has examined a list of in-vivo thorium results above 6 mg of thorium (the assumed MDA), which amount to a total of 75 results from 59 workers. About 70% of the measurements did not have a follow-up sample taken within a 6-month period. For the workers that were monitored more than once within a 6-month period, there was no apparent relation between the value of the first result and the increased frequency of monitoring.

SC&A has also examined the hardcopy NOCTS files of 15 claimants identified from the list of 59 workers that had results above 6 mg of thorium. None of the worker files contained any attempt to calculate the % of MPLB for thorium. Conversely, almost all the workers had calculations of the % of MPLB for uranium. Furthermore, almost all of the in-vivo monitoring results that were repeated within a period of 6 months were geared to the calculation of % of the uranium MPLB.

SC&A concludes that the results of thorium in-vivo monitoring from these files were not used to calculate the workers' exposures or an associated percentage of the applicable restriction limits for thorium at the time. Based on the currently available records, the results appear to have only been used qualitatively, as indicated in West (1965).

2.0 DISCUSSION OF THE USE OF STATISTICAL MODELS TO ESTABLISH THE ADEQUACY OF IN-VIVO DATA PROVIDED IN MILLIGRAMS OF THORIUM

In the first few pages of NIOSH 2011d, NIOSH presents several graphs of standard normal quantiles versus thorium chest burdens in milligrams (mg) for thorium results for the years 1968–1978. The graphs show that the sub-MDL results appear to be normally distributed, which one would expect, with a small number of values that fall above the normal probability line and that may represent real (though qualitative) thorium intakes. NIOSH draws the following conclusion from these graphical representations:

> *The significant feature of these plots is the large number of persons (2617) counted over these time periods which were measured below the MDA. Most of these counts are analytical background and this indicates that these were workers that were "clean" and represent normal thorium burdens that are in workers that were not exposed.*

As noted above in Finding 1.2, SC&A believes this statement to be misleading. In reality, the preponderance of sub-MDA values reflects an insufficiently sensitive measurement system, because intakes at values below 6 mg can nonetheless result in Sv-level organ doses. In addition, the normal thorium lung content in non-exposed populations is around 3 µg (Iyengar et al. 2004, Ibrahim et al. 1983), 3 orders of magnitude lower than the mg amount, reported for FMPC workers.

SC&A also notes that the graphs are based on mg thorium results without the benefit of substantiating Ac-228 and Pb-212 measurements, as discussed in detail in the preceding paragraphs. That is, the results are taken at face value and are presumed to be sufficiently accurate representations of worker intakes. SC&A reiterates that the graphs are based on values that cannot be reconstituted in terms of the raw data that was used at the time workers were monitored. That is, the statistical analysis was performed on values that cannot be related to actual exposures/intakes. As stated previously in Finding 1.6, SC&A believes that the thorium in-vivo results reported in mg were intended to be qualitative in nature, and were not meant to quantitatively represent thorium exposures. The corollary is that conclusions regarding accrued exposures and doses cannot be drawn from the mg thorium results, because there is currently no supporting data upon which to base these conclusions.

3.0 INCONSISTENCIES IDENTIFIED IN INDIVIDUAL WORKER FILES WHICH DEMONSTRATE THE UNCERTAINTY IN MEASUREMENTS GIVEN IN MILLIGRAMS OF THORIUM

3.1 FINDING 3.1

For many workers that were measured more than one time within a 6-month period, the values obtained are not consistent with the expected residence time in the lung, as explained in Section 2.3 of SC&A 2010. NIOSH's response to this finding was that there are high imprecisions from the measurements below the limits of detection (NIOSH 2011c). NIOSH used an example given by SC&A, in which a measurement result of 10.2 mg is followed by one taken after 41 days with a result of 0.2 mg. NIOSH stated that 40 days after monitoring, a result below the 6-mg detection limit is expected for Type M thorium compounds. Notwithstanding the large imprecisions in measurements below the MDA, SC&A does not agree with this last assertion on the basis of known biokinetic processes.

Assuming the thorium solubility was Type M, the minimum expected result 41 days after the 10.2 mg measurement would be 6.00 mg, which is at the presumed MDA. This expected result is much different from the 0.2 mg listed in the in-vivo records. In addition, the 6.0 mg value was calculated by assuming that the 10.2 mg result was obtained 1 day after the potential exposure. If, in reality, the monitoring took place at a later time after exposure, the expected thorium lung burden would be higher than 6.0 mg.

SC&A would like to reinforce this point with data taken from another worker who was monitored on March 22, 1976, and had a 25 mg thorium lung burden result. This worker was monitored again on July 12, 1976, with a thorium result of 0.03 mg. With the given time interval, the maximum expected decrease for Type M material would be about 32%. This would lead to a result of approximately 8 mg and not the stated value of 0.03 mg. This is an example where both the first measurement result and the expected one are higher than the 6 mg "detection limit."

3.2 FINDING 3.2

SC&A 2010, Section 2.2, contains 22 entries that were identified as reporting both Th (mg) and Pb-212 (nCi) results, which allows for the direct comparison of the two values. These entries were shown in Table 1 of SC&A 2010. The values of Th (mg) and the raw results for Pb-212 were recreated below as Table 1, adding Ac-228 raw results, dates, and locations of workers. The three highest thorium results and two other positive thorium results had corresponding negative Pb-212 measurements. This casts serious doubt on the assumption that Pb-212 results were used to calculate the thorium values in mg.

Three positive thorium results were taken in the period 1968–1978. One of the results, 4.3 mg of thorium, was reported on April 26, 1971. The corresponding Pb-212 result was negative (-0.04nCi), but the Ac-228 activity was reported as positive (0.05 nCi), although probably below the MDA. A result equal to 2.2 mg Th-232 was reported in April 13, 1977, which had corresponding negative results for Pb and Ac-228 (-0.1 nCi for both).

On the other hand, there were 9 positive results equal to 2.1 mg of thorium reported in June and October 1979 that had corresponding Ac-228 and Pb-212 positive results. Lead-212 (Pb-212) activity results ranged from 0.19 to 0.40 nCi, while Ac-228 results ranged from 0.33 to 0.7 nCi. Only one Pb-212 result was below the 1987 MDAs of 0.23 nCi for Pb-212 and 0.24 nCi for Ac-228, as reported in NIOSH 2011c. The 9 reported lung burdens of 2.1 mg of thorium are below the assumed MDA of 6 mg. **Based on those 9 results, dates, and workers' locations, there is no apparent relation of the thorium mass results with Ac-228 or Pb-212 activities**.

Another positive thorium result, listed as 0.3 mg reported on April 6, 1977, does not provide any information on how the actual thorium results were calculated. The corresponding values were 0.15 nCi for Pb-212 and 0.06 nCi for Ac-228. The highest value in Table 1 is 5.10 mg of thorium, reported on June 4, 1980. The corresponding Pb-212 result was negative (-0.04) and the Ac-228 result was 0.01 nCi.

The contemporaneous results of Ac-228, Pb-212, and Th-232 shown in Table 1 demonstrated how difficult it is to try to reconstruct the workers' exposures based solely on thorium results given in mg. They further show that the quantitative significance of the thorium results in mg is indeterminable.

Table 1: Comparison of Contemporaneously Reported Thorium Mass (mg), Pb-212 and Ac-228 Activities (nCi)

Reported Thorium Result (mg)	Reported Pb-212 Activity (nCi)	Reported Ac-228 Activity (nCi)	Monitoring Date	Location or Plant #
-5.00	-0.04	-0.02	8/29/1974	7 or Pilot
-0.60	-0.08	0.03	06/08/88	Maintenance
-0.54	-0.18	-0.01	06/12/86	5
-0.16	-0.16	-0.09	06/23/87	5
-0.12	0.06	0.01	07/10/73	6
-0.05	-0.05	0.02	05/02/87	Maintenance
-0.01	-0.01	0.05	12/09/86	No Information
0.01	-0.06	-0.08	05/02/77	Mech
0.30	0.15	0.06	04/06/77	6
1.81	-0.10	0.04	08/09/85	5
2.10	0.25	0.35	06/02/79	7 or Pilot
2.10	0.30	0.5	06/09/79	7 or Pilot
2.10	0.40	0.7	06/12/79	7 or Pilot
2.10	0.40	0.65	06/19/79	7 or Pilot
2.10	0.40	0.5	10/08/79	4
2.10	0.19	0.33	10/22/79	4
2.10	0.27	0.33	10/29/79	4
2.10	0.28	0.41	10/17/79	4
2.10	0.29	0.39	10/15/79	4
2.20	-0.10	-0.1	04/13/77	Mech
4.30	-0.04	0.05	04/26/71	Inspection
5.10	-0.04	0.01	06/04/80	Mech

4.0 ADDITIONAL UNCERTAINTIES DISCUSSED IN NOVEMBER 2011 NIOSH'S WHITE PAPER

4.1 FINDING 4.1

The issue of calibration phantoms was discussed in Section 3.2 of SC&A 2011, with a subsequent response from NIOSH provided in NIOSH 2011d, page 15. SC&A agrees that it is possible to assign a suitable geometric standard deviation that would cover uncertainties derived from the system calibration using the REMAB phantom. The REMAB phantom was used from the early 1970s to 1983. However, no information was provided to address the uncertainties related to the phantom used in the period prior to this, 1968–1970.

4.2 FINDING 4.2

The issue of the assumed equilibrium ratio of 0.42 Th-232/Th-228 was discussed in Section 3.6 of SC&A 2011, with a subsequent response provided in NIOSH 2011d, page 17. SC&A agrees with the response provided by NIOSH; however, the problem remains that in the period from 1968–1978, only results in mg of thorium are provided, with no associated Pb-212 component. As detailed in the previous sections, those results cannot be reconstructed, and it is not known if Pb-212 was used to calculate Th-232 exposures. If Ac-228 was used without Pb-212, the thorium lung burden could be underestimated by a factor of 100 or more. In addition, the biokinetics of the daughters are different from the parent, which most likely translates into further underestimation of the thorium lung burden and of the exposures.

CONCLUSION

SC&A believes that coworker models can only yield meaningful results when they are based on quantities that have some inherent meaning in terms of intakes experienced by workers. The existing documentation on the mg thorium data is inconsistent and does not clarify how the thorium values were calculated from the measured daughter products. The values in mg of thorium might have been underestimated by a factor of 100 or more. In summary, SC&A believes that the thorium lung burdens reported in units of mg from 1968–1978 cannot be reconstructed or associated with meaningful intakes and are, therefore, not sufficiently accurate to be used by NIOSH to derive thorium intake rates.

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