Draft White Paper

SC&A POSITION ON IN-VIVO THORIUM MONITORING COMPLETENESS

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SC&A Position on In-Vivo Thorium Monitoring Completeness	Page 2 of 19
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In June of 2010, SC&A transmitted its review (SC&A 2010) of the proposed National Institute for Occupational Safety and Health (NIOSH) thorium coworker model for the period of 1968–1989 (ORAUT 2008). NIOSH responded to this review in a brief informal document transmitted in February 2011 in preparation for discussions at the Work Group meeting later that month. Subsequent to the discussions at that meeting, SC&A prepared a second white paper transmitted in August of 2011 (SC&A 2011) on thorium data completeness to expand on the concerns first raised in SC&A 2010. This second white paper was discussed in depth at the August 2011 Work Group meeting. NIOSH responded to this second report in a documented response transmitted in November 2011. This white paper represents SC&A's final response and position on the issue of thorium-232 in-vivo data completeness. Note that the arguments put forth in this document are based on a general assumption that the underlying data are adequate for use in a coworker model. SC&A has identified several unresolved issues regarding data adequacy, which, if not resolved, will render moot this discussion of data completeness. Those concerns are the subject of a companion document on data adequacy.

It must be noted that the bulk of material related to thorium data completeness focuses on the years in which thorium production campaigns were undertaken at Fernald (1968–1979).[1] The three main issues discussed in this third and final SC&A white paper are as follows:

(1) Aside from 1968, thorium workers cannot be adequately identified in the in-vivo records. Therefore, it cannot be established whether their exposure potential was sufficiently monitored or can be reasonably bounded by monitoring data for non-thorium worker job types in subsequent years. Evidence in 1968 suggests that thorium workers had a higher exposure potential than non-thorium workers. This is discussed in Section 1.

(2) A large portion of the in-vivo data in mg Th is below the assumed minimum detectable activity (MDA) of 6 mg. However, workers who were involved in thorium operations have a higher proportion of samples above the MDA, which indicates they likely had a higher exposure potential than non-thorium workers. This is discussed in Section 2.

(3) Evidence suggests that thorium workers were not targeted directly for in-vivo monitoring; site-specific interviews suggest that (aside from 1968) workers were selected for "overall exposure potential, but not necessarily thorium exposure potential." Interviews also state that, "aside from 1968, no special effort was made to monitor thorium workers." This is discussed in Section 3.

Each of these issues is discussed in Sections 2 through 4, respectively. Section 1 provides a summary of SC&A's position on the issue of data completeness.

[1] While the operational period extended until 1979, in-vivo data expressed in mg Th ended in 1978, so the analyses will focus on the available mg Th data.

1.0 SC&A SUMMARY STATEMENT OF POSITION

SC&A believes that the in-vivo monitoring records for thorium are essentially complete, in that no significant chronological gaps were identified, nor is there evidence to suggest the highest exposed worker population was systematically excluded from the monitoring program. However, given the inability to identify which workers handled thorium (with the notable exception of 1968), as well as the uncertainty as to what portion of these workers were monitored for thorium exposure, SC&A believes that if the data are determined to be sufficiently accurate, NIOSH should select a sufficiently upper bound intake rate to assure that assigned doses are favorable to the entire population of potentially exposed workers. Currently, the proposed coworker model (ORAUT 2008) calculates 50^{th} and 84^{th} percentile intake values along with the associated geometric standard deviation; however, there is no specific guidance included as to how the coworker model should be applied to assure claimant favorability.

2.0 ISSUE 1 – IDENTIFICATION OF THORIUM WORKERS AND THEIR RELATIVE EXPOSURE POTENTIAL

2.1 SUMMARY OF ORIGINAL ISSUE

SC&A has previously presented analyses comparing the empirical cumulative probability distribution of lung burdens for different groups of workers, including thorium workers, chemical operators (including some thorium workers), chemical operators (excluding thorium workers), and the all worker population in 1968 (SC&A 2010 and 2011). The year 1968 was chosen as it is the only year in which there is a specific list of thorium workers, including badge number and job title (Starkey 1967). This empirical comparison of lung burdens in 1968 was the focus of NIOSH's most recent response (as discussed in Section 2.2).

In addition to this, SC&A attempted to expand the subgroup of thorium workers past 1968 to include workers who had 'thorium worker' or 'former thorium worker' written on their individual logbook sheets. One of the limitations of this type of approach is that it is not known exactly when, or for how long, each worker handled thorium. Therefore, it is not possible to tie specific monitoring results to the periods of potential thorium exposure for these workers. However, for the purposes of comparison, SC&A assumed that these workers handled thorium for their entire employment period. The results of these rank-ordered lung burdens showed visually separated curves when comparing the thorium subgroup and the other subgroups analyzed; therefore, a more robust analytical approach was adopted to statistically analyze the assumed subgroups (see Section 3.2 of SC&A 2011).

SC&A concluded that the workers identified as "thorium workers" had a higher exposure potential than workers who did not appear to work with thorium, and that adequate evidence has not been presented to assert that "thorium worker" doses are clearly bounded by the exposure potential to the chemical operator subgroup.

2.2 SUMMARY OF NIOSH 2011 RESPONSE TO ISSUE 1

NIOSH agrees that it is not feasible to identify thorium workers in years subsequent to 1968; however, NIOSH disagrees with SC&A's analytical approach, in which the assumption was made that workers who were identified with thorium work were involved with thorium production during their entire work history for the period of interest. Specifically, NIOSH 2011 states:

> *This assumption is not in agreement with interviews where it is suggested that thorium workers were assigned based on availability and the number of people involved was variable (ORAUT, 2007, p. 23 and p. 26). Thus, any hypothesis test based on this assumption cannot be valid.*

NIOSH does agree, however, that a comparison of thorium workers in 1968 (as established by the Starkey memo) and non-thorium chemical operators is a valid test. To accomplish this, NIOSH visually analyzed Figure 1 of SC&A 2011 and performed a Kolmogorov-Smirnov (KS) test. NIOSH concluded:

> *… the KS test statistic (D) equals 0.2552 and associated p-value of 0.2054 leads to the conclusion that there is no reason to believe that thorium workers and chemical operators came from different parent populations of workers.*
> (NIOSH 2011, pg. 3)

2.3 SC&A RESPONSE TO NIOSH 2011

SC&A agrees that the assumption that identified thorium workers always worked with thorium is not probable, but disagrees with the notion that the comparison of lung burdens made using this assumption lacks validity. By making the stated assumption, SC&A has included many monitoring records in the thorium worker subgroup, which would not be reflective of thorium work and hence thorium exposure potential. The stated assumption (which essentially acts as a dilution mechanism) and associated analysis would logically underestimate the actual lung burdens associated with thorium work, since many of the records included in the thorium worker subgroup would be reflective of non thorium-related work. Therefore, while SC&A agrees that the aforementioned analysis does not represent a precise representation of thorium worker exposures, it provides a conservative basis with which to compare lung burdens between different worker groups, since the data presented for thorium workers likely underestimate the actually exposure potential.

NIOSH's position is that only the comparison between 1968 chemical operators and the thorium workers identified in the 1967 "Starkey memo" is appropriate. However, it must be understood that even this comparison requires the back extrapolation of job titles, since actual job designations were rarely recorded until 1971. Therefore, the direct comparison of chemical operators to thorium workers in 1968 is not possible without making certain assumptions. Specifically, the assumption had to be made that the chemical operators identified in 1971 and later on were also chemical operators 3 years earlier.

Nevertheless, using this back extrapolation of job titles yields a group of 25 samples taken in 1968 for 'chemical operators' who are not named in the Starkey memo as thorium workers. Notably, 10 of the 25 samples are for workers who had 'thorium worker' or 'former thorium worker' written at the top of their individual log sheets. These 10 samples comprise 10 of the top 14 lung burdens measured for this group in 1968 (and cover each of the top 5 lung burdens for this group). It has not been established that the Starkey memo is a comprehensive list of thorium workers for 1968, so it is likely that some or all of these 10 samples actually do represent thorium work. One indication in support of this is the fact that 9 of the 10 samples were associated with the Pilot Plant, with the remaining sample for Plant 8 (both areas were involved in thorium work in 1968). To put this in perspective, of the 51 thorium workers listed in the Starkey memo, only 2 workers were identified with the Pilot Plant and only 1 identified with Plant 8. Therefore, it seems probable that the Starkey memo is not a comprehensive list of thorium workers. If these 10 samples are removed from the group of non-thorium chemical operators, the resulting distribution of lung burdens would decrease markedly, as shown in Table 1.

Table 1. Comparison of Different Groups of Chemical Operator Records for 1968

Worker Grouping	# Samples	Average	Median	Max
Chemical Operators not identified with Thorium Work (either via Starkey or by individual log sheets)	15	1.35	-0.67	4.7
Chemical Operators not named in Starkey Memo	25	2.48	2	7.3
All Starkey Thorium Workers	62	3.24	3	10.2
Chemical Operators named in Starkey Memo	54	3.33	3.1	10.2

NIOSH came to their conclusion that there is no reason to believe that thorium workers and chemical operators came from different parent populations of workers based on performing the KS test on a visual interpretation of Figure 1 from SC&A 2011. However, this analysis includes the 10 chemical operator samples that have thorium worker labeled on the in-vivo log sheet. Since it is not possible to determine in these 10 cases whether the 'thorium worker' label applies to 1968 or subsequent years, it may not be appropriate to include these samples in either group for the purpose of comparison. Furthermore, SC&A does not believe that the KS test is the most appropriate metric to evaluate the two groups of workers. If the data appear to be normally distributed, then a parametric statistical comparison, such as the two sample t-test, would have greater power to detect a significant difference and thus be more claimant favorable. Other non-parametric tests also may have more power to detect differences in this setting, for example the Wilcoxon-Mann-Whitney test.

In the following analysis, the Shapiro-Wilk test is applied to check for normality and Levene's test is applied to check for equality of variances. The results of these preliminary tests support the use of the t-test in a parametric framework. Before applying the two-sample t-test, it is necessary to confirm that the two datasets have approximately normal distributions and approximately equal variances. As shown in Figures 1 and 2, the two distributions appear to be normally distributed with approximately equal variances. Furthermore, the Shapiro-Wilk test was applied to test for normality of the three datasets involved in the two comparisons (non-Starkey chemical operators, thorium workers, and chemical operators identified as thorium workers or former thorium workers). The test results are shown in Table 2, which indicates that

the assumption of normality cannot be rejected for any of the datasets. The normal quantile-quantile plots shown in Figures 3, 4, and 5 confirm the test results and show only small departures from normality. Levene's test was then applied to test for equality of variance. Levene's test results shown in Table 3 indicate that the assumption of equal variances cannot be rejected in either of the two comparisons.

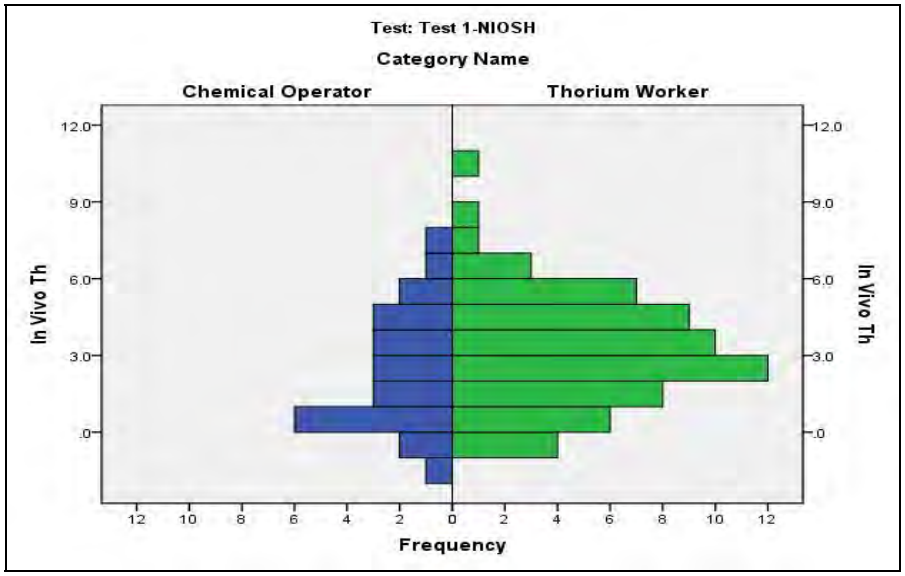

Figure 1. Comparison of Thorium Workers with All Non-Starkey Chemical Operators[2]

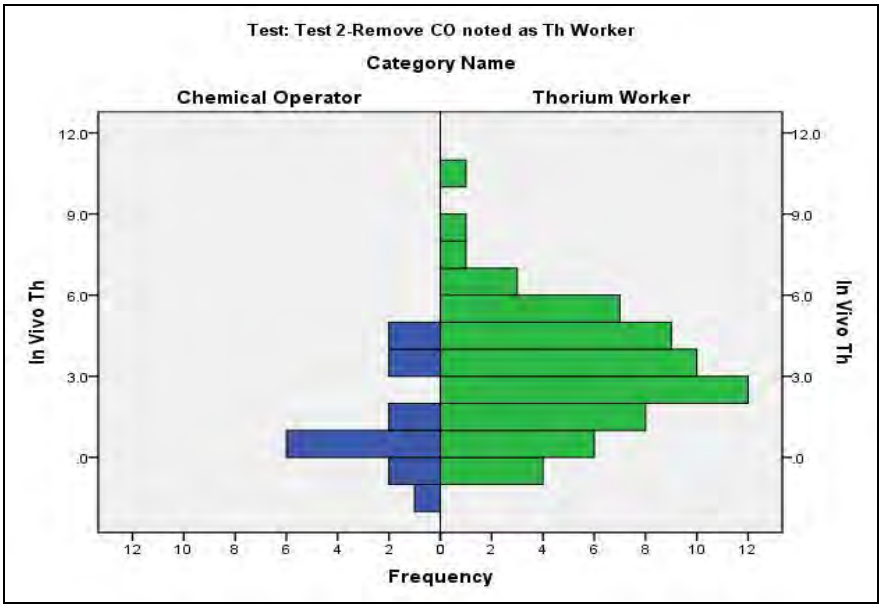

Figure 2. Comparison of Thorium Workers with Chemical Operators after Removing 10 Operators Noted as Thorium Workers

[2] The group "All Non-Starkey Chemical Operators" includes 10 samples that have "thorium worker" written at the top of the logbook sheets; it cannot be determined to what time period this label applies.

Table 2. Shapiro-Wilk Test of Normality for Defined Groups of Workers

Test	Category Name	Shapiro-Wilk		
		Statistic	df	Sig.
Test 1 – NIOSH Test Subgroups	Chemical Operator	.955	25	.328
	Thorium Worker	.970	62	.133
Test 2- NIOSH Subgroups with 10 COs noted as Th Workers Removed	Chemical Operator	.906	15	.118
	Thorium Worker	.970	62	.133

Table 3. Levene's Test for Equal Variance

Test	Levene's Test for Equality of Variances	
	F	Sig.
Test 1-NIOSH	0.695	0.407
Test 2-Remove CO noted as Th Worker	0.602	0.440

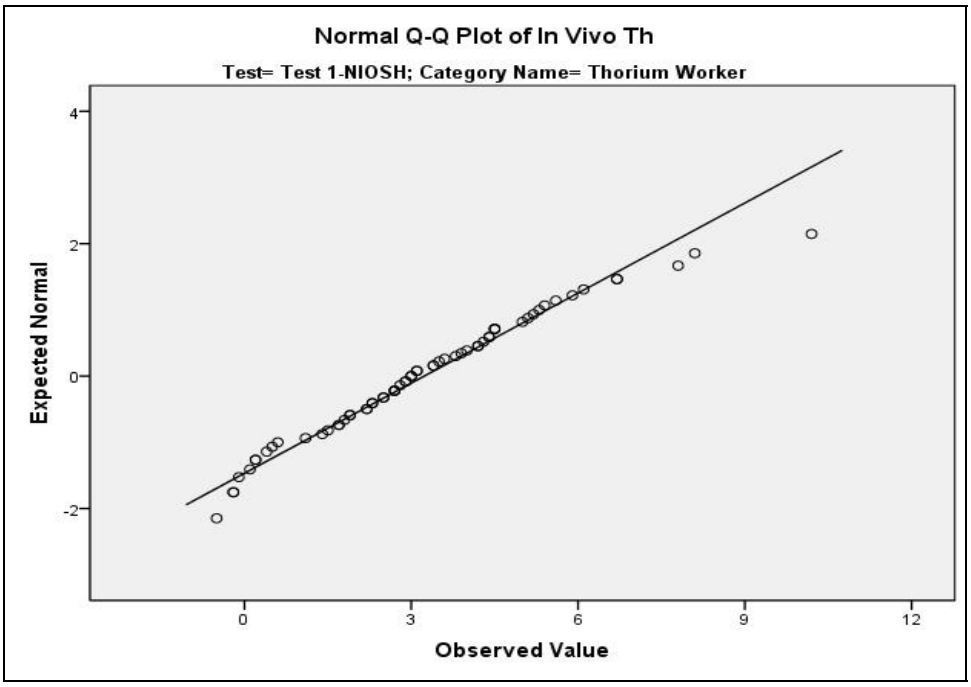

Figure 3. Normal Quantile-Quantile Plot of Samples from Thorium Workers

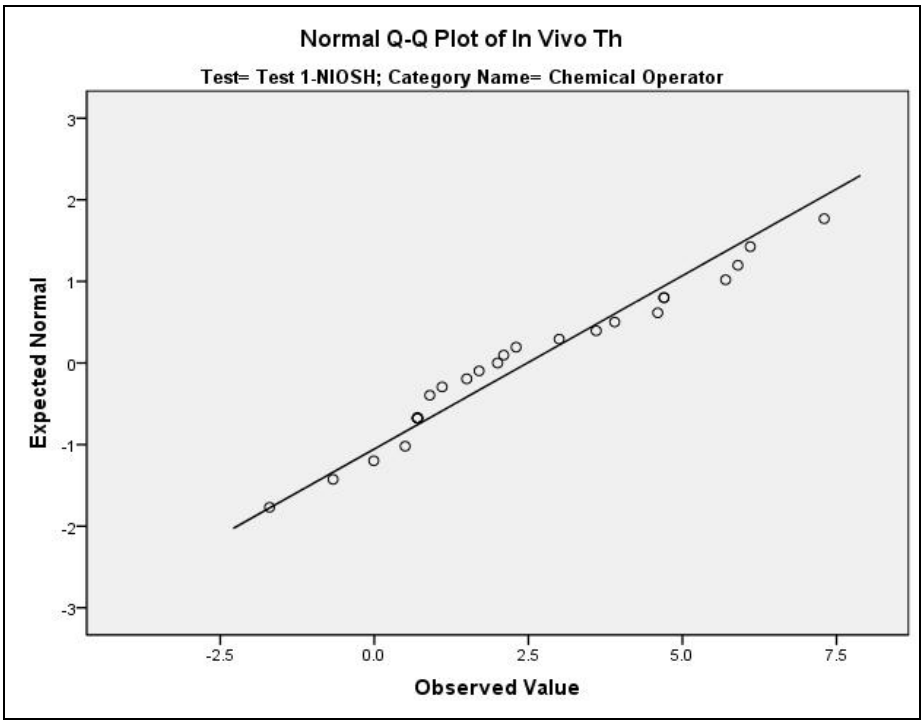

Figure 4. Normal Quantile-Quantile Plot of Samples from Chemical Operators

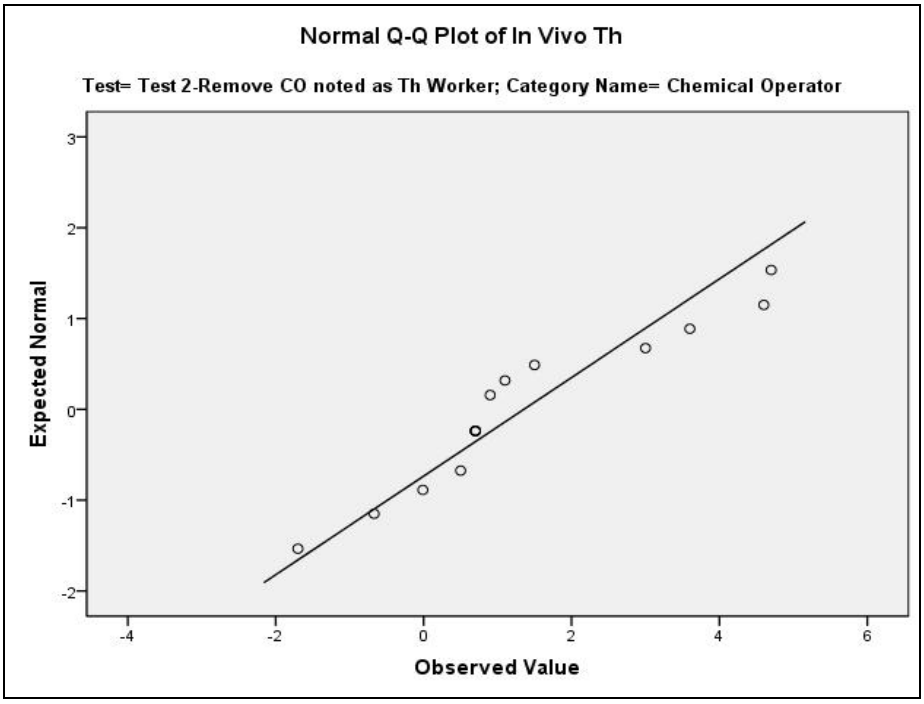

Figure 5. Normal Quantile-Quantile Plot of Samples from Chemical Operators after Removing 10 Operators Noted as Thorium Workers

In the following analysis, the KS, Wilcoxon-Mann-Whitney, and t-tests are used to compare the two groups of workers. The comparison of the two datasets defined by NIOSH using the KS test is shown in the upper part of Table 3. The KS test has a p-level of 0.15, which indicates that the two distributions have no significant differences. The lower part of Table 4 shows the KS test result when the 10 questionable samples are removed. In this case the p-level falls to 0.003, providing strong evidence that the thorium worker distribution is significantly higher than the chemical operator distribution.

Table 4. Two-sample Kolmogorov-Smirnov (K-S) Test Results

Test	Test Statistics[a]	Worker Category	In-Vivo Th
Test 1 - NIOSH	Most Extreme Differences	Absolute	.270
	Kolmogorov-Smirnov	Positive	.070
	Z	Negative	-.270
	Asymp. Sig. (2-tailed)		1.138
	Total		**.150**
Test 2 - Remove CO noted as Th Worker	Most Extreme Differences	Absolute	.524
	Kolmogorov-Smirnov	Positive	.000
	Z	Negative	-.524
	Asymp. Sig. (2-tailed)		1.820
	Total		**.003**

a. Grouping Variable: Worker Category

The test statistics for the Wilcoxon-Mann-Whitney test are shown in Tables 5 and 6. The Wilcoxon-Mann-Whitney test shows the same result as the KS test. The test indicates no significant difference (p=0.197) using the two datasets defined in NIOSH's recent response, while the thorium worker distribution is significantly higher (p=0.006) when the 10 questionable samples are removed.

Table 5. Wilcoxon-Mann-Whitney Test Summary

Test	Worker Category	N	Mean Rank	Sum of Ranks
Test 1 - NIOSH	In-vivo Th Thorium Worker	62	46.22	2865.50
	Chemical Operator	25	38.50	962.50
	Total	87		
Test 2 - Remove CO noted as Th Worker	In-vivo Th Thorium Worker	62	42.44	2631.00
	Chemical Operator	15	24.80	372.00
	Total	77		

Table 6. Wilcoxon-Mann-Whitney Test Statistics

Test		In Vivo Th
Test 1 - NIOSH	Mann-Whitney U	637.500
	Wilcoxon W	962.500
	Z	-1.290
	Asymp. Sig. (2-tailed)	**.197**
Test 2 - Remove CO noted as Th Worker	Mann-Whitney U	252.000
	Wilcoxon W	372.000
	Z	-2.740
	Asymp. Sig. (2-tailed)	**.006**

Grouping Variable: Worker Category

Since the two distributions appear to be approximately normally distributed, one additional comparison was conducted using a parametric statistical test, the two-independent-samples t-test. As stated previously, Levene's test indicates equal variances. None-the-less, two versions of the t-test are reported in Table 7; one using the assumption of equal variances, and a second assuming unequal variances. The results of the equal-variance t-test confirm the results of the nonparametric KS and Wilcoxon-Mann-Whitney tests. The equal-variance t-test indicates no significant difference (p=0.160) when the two datasets defined by NIOSH are compared, while the thorium worker distribution mean is significantly higher than the chemical operator distribution mean (p=0.003) when the 10 questionable CO samples are removed. As suggested by Levene's test result, the t-test with unequal variances produces very similar results for both comparisons.

Table 7. Two-Independent-Samples t-Test for Equality of Means

Test		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Test 1-NIOSH	Equal Variances Assumed	1.417	85	.160	.7547	.5325	-.3040	1.8134
	Equal Variances not Assumed	1.378	41.935	.175	.7547	.5476	-.3504	1.8598
Test 2-Remove CO noted as Th Worker	Equal Variances Assumed	3.052	75	.003	1.8808	.6162	.6532	3.1084
	Equal Variances not Assumed	3.408	24.705	.002	1.8808	.5519	.7435	3.0182

3.0 ISSUE 2 - NUMBER OF POSITIVE RESULTS IDENTIFIED DURING THE PRODUCTION PERIOD

3.1 SUMMARY OF ORIGINAL ISSUE

SC&A 2011 noted that less than 3% of the identified chest counts (given in mg of Th) were at or above the stated MDA of 6 mg, which might call into question how useful the dataset is in developing a viable coworker model. SC&A also noted that the percentage of samples with positive chest counts (results greater than 6 mg Th) was higher for workers associated with thorium operations than other worker groups. Specifically, SC&A 2011 states:

> *Approximately 7% of the samples taken for thorium workers were at or above the assumed MDA, while about 3% of those for chemical operators were above the MDA (this is slightly higher than the percentage for all workers, at 2.8%).*
> (SC&A 2011, pg. 25)

It is important to note that the 'thorium workers' as referenced above refer to both the list of Starkey workers in 1968, as well as all workers who had 'thorium worker' or 'former thorium worker' written on their logbook sheets. It was assumed in the prior analysis that all workers who were associated with thorium work handled the material throughout their employment. It is important to note that this assumption was brought into question by NIOSH in Section 3 of NIOSH 2011 and was discussed in Sections 2.2 and 2.3 of this document.

3.2 SUMMARY OF NIOSH 2011 RESPONSE TO ISSUE 2

In Section 4 of NIOSH's response, it is stated that the value of the MDA and the relative magnitude of results in relation to the stated MDA are not relevant in the formulation of a coworker model. All of the data (no matter if it is positive, below the MDA, or even negative) is compiled and analyzed without any censorship. NIOSH also responds to Finding 8 from SC&A 2010 regarding an apparent negative bias in the Pb-212 chest count data and summarizes their approach to correcting the negative bias via an adjustment factor.

3.3 SC&A RESPONSE TO NIOSH 2011

The policy of including all available monitoring data without any form of censorship is a global dose reconstruction issue and therefore is outside the scope of this discussion of data completeness. SC&A notes, however, that the inclusion of sub-MDL data in coworker model construction does not imply that such data have meaning in regard to intake. That topic is investigated in depth in SC&A's analysis of data adequacy. Furthermore, the use of an adjustment factor on the Pb-212 chest count results was not the subject of Finding #2 of SC&A 2011 and does not apply to chest count data given in mg of Th.

The main issue, as presented above, is the higher proportion of 'thorium workers' who had results above the stated MDA of 6 mg as compared to the 'chemical operator' and 'all worker' groups. This piece of evidence was offered to indicate that workers who handled thorium had higher exposure potential than workers who did not. However, as noted in Section 2.1 above, the analysis originally assumed that all workers who were labeled as thorium workers at some point during the period of interest were thorium workers throughout their employment. SC&A's position on the validity of any analyses based on this assumption is discussed in Section 1.3 of this report and will not be repeated here.

Nevertheless, SC&A has compiled the data at or above the MDA for the known thorium workers (as listed in the Starkey memo) versus the 'all worker' and 'chemical operator' groups for 1968 only, the results of which are shown below in Table 8. Based on Table 8, it still appears that workers who handle thorium have a higher exposure potential than those who do not. In fact, the identified chemical operators who were not identified with thorium work (either by the Starkey memo or individual logbooks) did not have any positive results in 1968. The only chemical operators (2) who had positive results in 1968 (that were not listed in the Starkey memo) had 'thorium worker' written at the top of their in-vivo logbook sheets.

Table 8. Summary of 1968 Records at or Above the Stated MDA of 6 mg Th

Worker Grouping	# Samples	# Positive Samples	% Positive Samples	Average	Median	Max
Chemical Operators not identified with Thorium Work (either via Starkey or individual in vivo log sheets)	15	0	0%	NA	NA	NA
Chemical Operators not named in Starkey Memo	25	2*	8.0%	6.7	6.7	7.3
All 1968 Monitored Workers	290	10	3.5%	7.24	6.75	10.2
All Starkey Thorium Workers	62	6	9.7%	7.6	7.25	10.2
Chemical Operators named in Starkey Memo	54	6	11.1%	7.6	7.25	10.2

*Note: both positive results in this category were workers labeled as 'Thorium Worker' on their in-vivo log sheets; however, they were not contained in the Starkey list.

4.0 ISSUE 3 – MONITORING CRITERIA FOR INCLUSION IN THE MIVRML LUNG COUNT PROGRAM

4.1 SUMMARY OF ORIGINAL ISSUE

Aside from the relative magnitude of lung burdens observed for thorium workers, the other major facet of data completeness is the monitoring coverage for the highest exposed group. It was SC&A's contention that, aside from 1968, the thorium in-vivo monitoring program was not focused on thorium workers, but rather the much larger uranium operations at the site. One indication that this might be the case is the fact that thorium chest counts are always coupled with uranium lung counts; the reverse is not always true.

In addition, Section 3.2 of SC&A 2010 analyzed the in-vivo records by plant number and found no specific bias towards plants and times with thorium operations. In fact, there were a couple of instances where plants and years with thorium operations had no in-vivo samples taken. Most of the samples were taken for Plant 5, which had no known thorium operations during the period of interest.

SC&A 2011 performed another scoping test to characterize thorium monitoring practices in Section 4 of that report. In this test, SC&A plotted the relative lung burdens for individual workers versus the number of times that the worker was monitored to establish if there is a discernible correlation between the magnitude of results and the number of times the worker was targeted by the in-vivo program. While the results of that analysis showed very weak correlation coefficients across the board for both uranium and thorium, thorium showed a slightly negative

correlation when analyzing the median and average lung burdens, while uranium showed a slightly positive correlation.

4.2 SUMMARY OF NIOSH 2011 RESPONSE TO ISSUE 3

NIOSH presents a specific site interview that sheds light into how workers were selected for inclusion in the MIVRML monitoring program. The concluding statements of the interview portion are recreated here:

> *[Interviewer #1]: It would be helpful to find that* [Starkey memo]. *I want to validate that people chosen for lung counts were chosen for overall exposure potential, not especially for thorium exposure potential.*
>
> *[Manager #1]: That is correct.*
>
> *[Interviewer #1]: So thorium operators would be included in that group?*
>
> *[Manager #1]: For the initial visit of the mobile counter, there was an effort to get the people on [name redacted]'s list through the in vivo counter. After getting through this list, no special effort was made to count thorium workers in subsequent visits.* (NIOSH 2011, pg. 6)

Using this interview, NIOSH concludes:

> *Based on this information the hypotheses posited by SC&A, that a worker's monitoring frequency and the relative magnitude of the lung burden results must necessarily be correlated, is moot.*

NIOSH then states that the basis for SC&A concluding that there was no positive linear correlation between the number of times a worker was monitored for thorium intake and the actual magnitude of the results is statistically lacking. NIOSH concludes with the following statement:

> *In support of this finding SC&A provides linear fits to data sets. Figure 8 from the SC&A report is shown below to illustrate the misleading nature of this assertion. NIOSH does not believe that the fit of a line to the data, including the outlier point near 33 mg, adequately captures the trend present in the data."* (NIOSH 2011, pg. 6)

Figure 8 from SC&A 2011 is recreated for reference below as Figure 6 of this report.

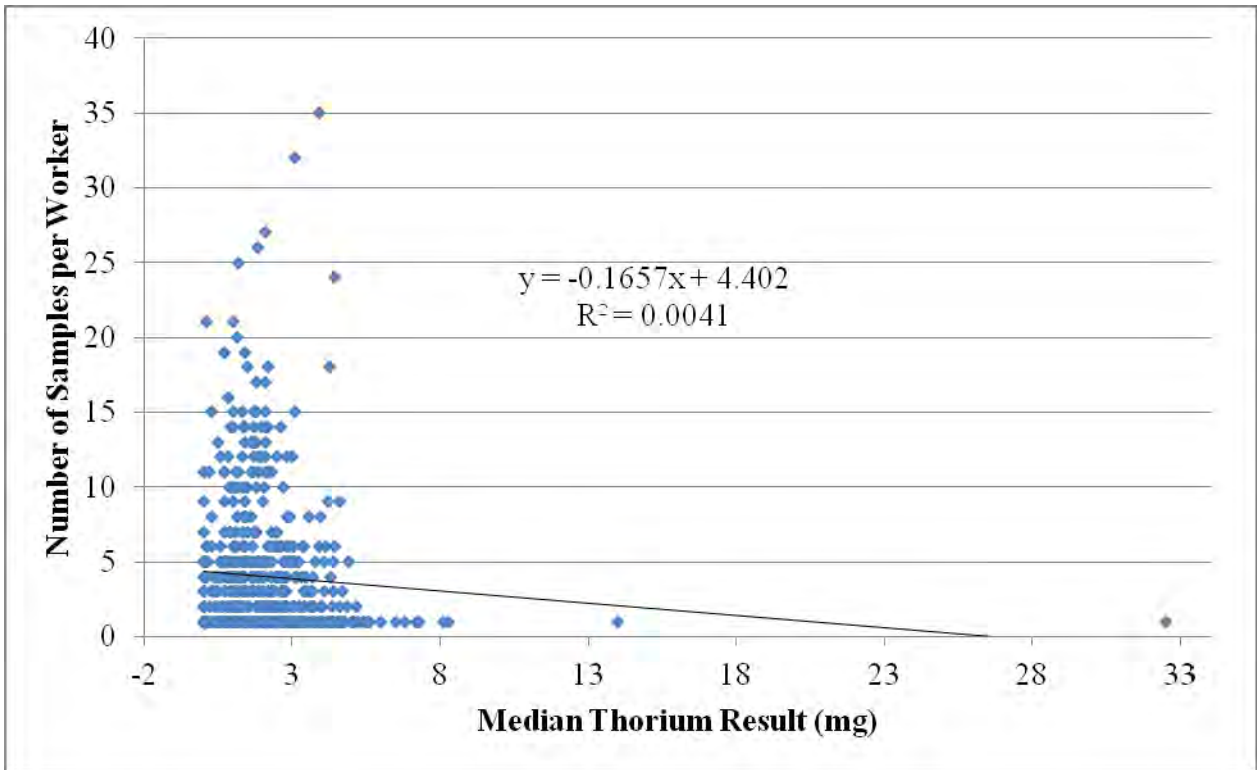

Figure 6. Recreation of Figure 8 from SC&A 2011 as Cited in NIOSH 2011

4.3 SC&A RESPONSE TO NIOSH 2011

NIOSH and SC&A appear to agree that the in-vivo monitoring program was not focused on thorium workers, with the exception of 1968 when there was a distinctive effort to get the thorium workers counted. However, to put this in perspective, Starkey's list of thorium workers contained 51 individuals and only about half of these workers (roughly 55%) were actually monitored in the first year of MIVRML operation. In subsequent years, the percentage of thorium workers monitored was probably much less. In addition, SC&A agrees in principle that "people chosen for lung counts were chosen for overall exposure potential, not especially for thorium exposure potential" (NIOSH 2011, p. 6).

As noted in SC&A's most recent response on data adequacy, hardcopy in-vivo records often show calculations estimating lung burdens for uranium over a number of years for comparison with established max permissible lung burden levels. No such calculations or comparisons for thorium results were found, which is indicative of the monitoring focus on uranium intakes and not thorium. Furthermore, SC&A found no evidence that positive thorium samples were followed up with multiple measurements, in order to adequately characterize the potential thorium intake. SC&A's belief remains that workers were most likely targeted if they had significant exposure potential to uranium during uranium operations, which constituted the vast majority of radiological operations at Fernald.

With regard to the linear correlation analysis, SC&A acknowledges that this only represents a first-order characterization study to attempt to gain insight into the monitoring practices beyond

the available anecdotal evidence. The limited conclusions drawn from such an analysis were simply that in this scoping calculation, no evidence was found to suggest workers with relatively high thorium lung burdens also had a higher number of lung counts taken. Also, there was certainly no evidence that workers with relatively high thorium lung burdens had more samples taken than workers with similarly high uranium lung burdens.

The overall value and significance of conclusions derived from such a limited scoping calculation is certainly debatable; however, SC&A disagrees with the notion that the analysis was misleading because it included certain outlier values in the linear fits (i.e., "the point near 33 mg"). In SC&A's original report (SC&A 2011), the issue of outlier values was discussed on pages 30 and 31 with the following statement and related calculations:

> *As noted in Table 16, there were three outlier values (taken for U-235* [3635 ug], *U* [1186 mg], *and Th* [32.5 mg]*) in which a worker had an unusually high result with few (sometimes only 1) measurements taken. Since no direct evidence could be found to invalidate these results, they are included in the Figures 9-38 analyses.* ***However, to give the reader an idea of how the linear correlations change if those three samples are omitted, the linear trend lines and associated correlation coefficients are recalculated in Table 17.*** *As seen in Table 17, the correlations increase markedly for the maximum uranium (U and U-235) categories, as well as the median uranium (U) category, in comparison to Table 16 values. The correlation between the maximum thorium values increased, though the average and median correlations remained slightly negative.* (SC&A 2011, pg. 30)

The portions of Tables 16 and 17 from SC&A 2011 covering the results in mg of Th are recreated in Table 9.

Table 9. Recreation of the Thorium (mg of Th) Sections of Tables 16 and 17 from SC&A 2011 Showing Calculated Linear Trend Lines both with and without Identified Outlier Value

Measured Radionuclide	Linear Trend Formula and Correlation Coefficients		
	Average	Median	Maximum
Mg of Th (including outlier – from Table 16)	$y = -0.0475x + 4.179$ $R^2 = 3E\text{-}04$	$y = -0.1657x + 4.402$ $R^2 = 0.0041$	$y = 0.6643x + 1.8825$ $R^2 = 0.1375$
Mg of Th (excluding outlier – from Table 17)	$y = -0.0183x + 4.1133$ $R^2 = 3E\text{-}05$	$y = -0.2155x + 4.4886$ $R^2 = 0.0042$	$Y = 0.8224x + 1.392$ $R^2 = 0.1743$

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