MEMORANDUM

TO: Savannah River Site Work Group
FROM: SC&A, Inc.
DATE: October 11, 2018
SUBJECT: SC&A Review of RPRT-0081 Methods for Thoron Dose Reconstruction

Introduction and Background

The National Institute for Occupational Safety and Health (NIOSH) issued Addendum 3 to its evaluation of Special Exposure Cohort (SEC) Petition SEC-00103 for the Savannah River Site (SRS) on November 20, 2012 (NIOSH 2012), which dealt specifically with the feasibility of dose reconstruction of thorium exposures from October 1, 1972, through December 31, 2007. Subsequently, SC&A reviewed this addendum and identified 32 total findings (SC&A 2013). One of the 32 findings (Finding 4) concerned the potential radon-220 (also known as "thoron") exposures at SRS during the period under evaluation. Specifically, Finding 4 of SC&A 2013 (p. 10) states:

> *Finding 4: NIOSH has not discussed the radon-220 source term derived from the storage of thorium-232. The radon-220 dose could be important in some circumstances where there was significant residual thorium or where thorium was stored in significant amounts. This includes at least two high-level waste tanks.*

This finding was first discussed at the teleconference meeting of the SRS Work Group on February 26, 2014. At that time, the discussion centered around a 1997 study (Sigg et al. 1997) of thoron releases and associated exposure levels at the H-Area Tank Farms (specifically, Tanks 12 and 15). These areas are particularly important due to the large amounts of thorium in storage and thus the most likely source of thoron emissions and associated exposure potential. While the source term would not appreciably change during the period 1972–1997, SC&A raised concerns that thoron emissions in the late 1990s may not reflect the exposure potential from the earlier periods due to the potential for modification of engineering controls that may have altered the exposure potential to thoron from the periodic venting of the tanks.

Rather than attempt to characterize any changes in the tank farm equipment and engineering controls, NIOSH proposed to perform additional data captures at SRS to obtain a set of representative air sampling reports from the relevant tank farm areas. This data could then be used to evaluate the thoron exposure potential during years prior to the 1997 study, which was proposed for use in dose reconstruction. Specifically, NIOSH stated during the SRS Work Group meeting on February 26, 2014:

Our path forward would be for us to go to the site and take a representative sampling of air samples over time from the tank farm area and evaluate those initial counts, the six-hour counts, the 24-hour counts, and come up with what the thoron component of the total radon would be. And that would be the dose we would assign to the workers in that area. [ABRWH 2014, p. 178]

Subsequently, NIOSH produced ORAUT-RPRT-0081, *Appropriateness of Using 1997 Gross Alpha Air Sampling Data as a Method of Bounding Thoron Intakes at the SRS H-Area Tank Farm Between 1972 and 1994*, Revision 00 (NIOSH 2017a; hereafter "RPRT-0081"), which calculated the lognormal distributions of the air concentration due to thoron for three different periods (1982–1983, 1984–1985, and 1990) for comparison to the 1997 data (Sigg et al. 1997). The results of the air sample analysis were presented in Table 3-1 of RPRT-0081 and are reproduced in Table 1, below, for convenience

Table 1. Results of NIOSH's Analysis of Air Sampling Data at Thorium Locations at the SRS Tank Farm (from NIOSH 2017a, Table 3-1)

Evaluated Period	Geometric Mean (µCi/cm^3)	95th Percentile (µCi/cm^3)	99th Percentile (µCi/cm^3)
1982–1983	1.24×10^{-12}	9.03×10^{-12}	2.05×10^{-11}
1984–1985	3.97×10^{-12}	2.89×10^{-11}	6.58×10^{-11}
1990	8.98×10^{-13}	6.95×10^{-12}	1.62×10^{-11}
1997	2.84×10^{-11}	2.67×10^{-9}	1.76×10^{-8}

Based on the data analysis shown in Table 1, RPRT-0081 (pp. 11–12) concludes:

Air concentrations of thoron measured at H Area tanks in the 99th-percentile for the periods 1982-83, 1984 to 1985 and 1990 are less than 1% of the derived air concentration for thoron when its progeny are present (9.0×10^{-9} µCi/cm^3). The majority of the data used to arrive at these values are from measurements taken at the point of exhaust, maximizing the concentrations compared to open air.... the exhaust values represent a conservative upper bound of potential thoron progeny exposures…

NIOSH concludes that concentrations of thoron daughters reported in the 1997 study are sufficient to bound thoron exposures of workers in thorium storage areas.

At its 122nd meeting, the Advisory Board on Radiation Worker Health (ABRWH 2018) tasked SC&A with reviewing the methodology and rationale presented in RPRT-0081; this memorandum presents SC&A's review of that document.

Discussion

While SC&A's original concerns centered around changes in engineering controls occurring at the tank farms prior to the extensive study of thoron exposure in 1997 (Sigg et al. 1997), SC&A agreed that a more pragmatic approach to the issue would be to capture a representative number of air sample results from the tank farms that could be used to directly characterize the relevant exposure potential to thoron and its progeny over time. As stated in the introduction, NIOSH evaluated data from three different time periods—1982–1983, 1984–1985, and 1990—to characterize the thoron levels at the tank farm for the period from late 1972 through 1995.[1] However, the stated time periods do not cover the entirety of the years stated. Table 2 shows the air sampling references analyzed in RPRT-0081 and the actual temporal coverage of NIOSH's source data, which represents only ~8% of the period of interest (October 1, 1972–December 31, 1995).

Table 2. Temporal Coverage of Air Sampling Data Evaluated in RPRT-0081

Time Period	Cited Reference	Actual Temporal Coverage
1982–1983	DuPont 1982–1983	1/4/1982, 2/8/1982–1/19/1983
1984–1985	DuPont 1984–1985	12/26/1984–9/11/1985
1990 *	WSRC 1990a; WSRC 1990b **	12/27/1989–2/28/1990; 12/17/1990–1/2/1991

* While RPRT-0081 indicates the air sampling data were all from 1990, a small fraction of air samples were from late 1989 and early 1991.
** WSRC = Westinghouse Savannah River Company.

RPRT-0081 did note that sporadic air sampling data was captured for the period 1974–1979; however, the data did not provide the requisite level of detail to allow for evaluation of thoron exposure potential. It is unknown if additional air sampling data are available for the relevant areas of the tank farms that might be used to better characterize the temporal gaps in the analysis presented in RPRT-0081.

Observation 1: To characterize and bound potential thoron exposures for the period October 1972–1995, NIOSH analyzed data from three periods: 1982–1983, 1984–1985, and 1990. However, the actual temporal coverage of the data constitutes only approximately 8% of the period of interest. It is not known whether additional air sampling data are available to evaluate the temporal gaps in the NIOSH's analysis.

SC&A acknowledges that the data comparison presented for the years that were analyzed demonstrates that the 1996 derived thoron exposures significantly bound the limited earlier data by an order of magnitude or more for these periods. Therefore, further data capture and analysis may not be deemed necessary to assure the approach is bounding.

SC&A compiled the air sampling data for the three evaluated periods period as cited in RPRT-0081 and used the methods outlined in ORAUT-RPRT-0084, *Two-Count Filter Method for Measurement of Thoron Progeny in Air*, Revision 00 (NIOSH 2017b), to determine the airborne concentration of lead-212 (Pb-212). NIOSH (2017b) provides the following equation to determine the airborne concentration of Pb-212 (C_{Pb}):

[1] The data proposed for dose assignment presented in Sigg et al. 1997 were taken in January, March, June, October, and November 1996.

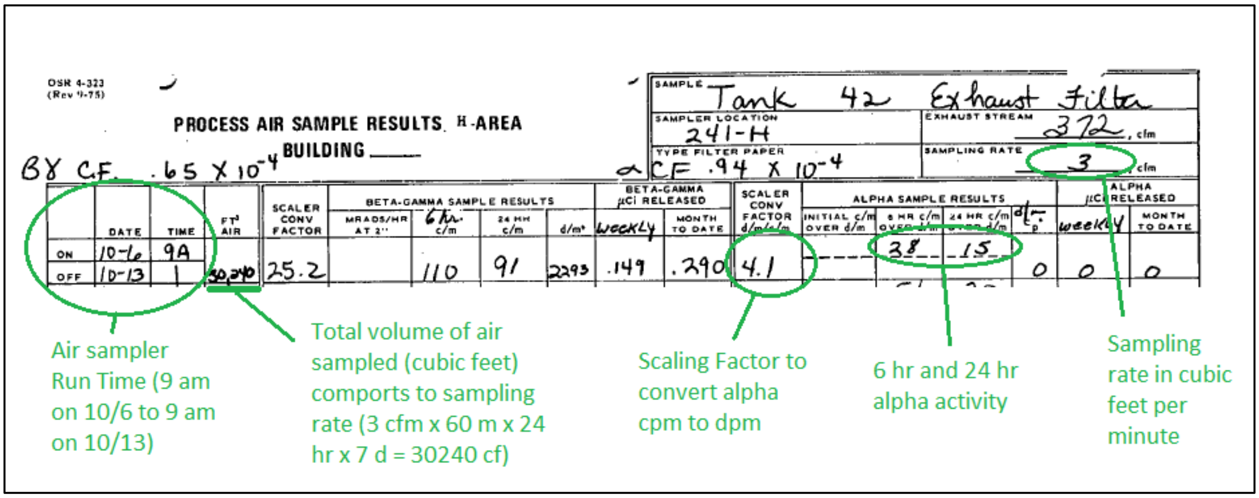
$$C_{Pb} = \left(\frac{\lambda_{Bi} - \lambda_{Pb}}{\lambda_{Bi}}\right) * \frac{(A_{24} - A_6)}{(e^{-\lambda_{Pb}*24} - e^{-\lambda_{Pb}*6})} * \frac{\lambda_{Pb}}{F * \left(1 - e^{-\lambda_{Pb}} * T\right)}$$

where:

C_{Pb}	=	airborne concentration of Pb-212 (picocurie per liter [pCi/L])
λ_{Bi}	=	decay constant for bismuth-212 (Bi-212) (0.687 per hour [hr])
λ_{Pb}	=	decay constant for Pb-212 (0.065 per hr)
A_{24}	=	total alpha activity at 24 hours (pCi)
A_6	=	total alpha activity at 6 hours (pCi)
F	=	flow rate of air sampler (L/hr)
T	=	collection time for the air sampler (hr)

Figure 1 shows an example air sample record from Dupont 1982–1983.

Figure 1. Example Air Sampling Record for Tank 42 from the H-Area Tank Farms in October 1982 (Dupont 1982–1983)



To obtain the alpha activity in pCi from the example record in Figure 1, the values provided in counts per minute (cpm) are first multiplied by the scaling factor (4.1) to obtain the disintegrations per minute (dpm) and then divided by 2.22 dpm/pCi. This yields the following values of alpha activity:

$A_6 = (28 \times 4.1) / 2.22 = 51.7$ pCi
$A_{24} = (15 \times 4.1) / 2.22 = 27.7$ pCi

The flowrate of the air sampler (F) in L/hr can be obtained by multiplying the reported flow rate of 3 cubic feet per minute (ft^3/min) by 28.32 L/ft^3 and 60 min/hr, which yields the value:

$F = 3 \times 28.32 \times 60 = 5{,}097$ L/hr

Finally, the value for the collection time is simply the number of hours between 9:00 am on October 6, 1982, and 9:00 am on October 13, 1982 (168 hours of collection time). Therefore, the concentration of Pb-212 can be calculated using the NIOSH 2017b formula as follows:

$$C_{Pb} = \left(\frac{0.687 - 0.065}{0.687}\right) * \frac{(27.7 - 51.7)}{(e^{-0.065*24} - e^{-0.065*6})} * \frac{0.065}{5{,}097 * (1 - e^{-0.065*168})} = 5.9x10^{-4} pCi/L$$

To convert the Pb-212 concentration to microcuries per cubic centimeter ($\mu Ci/cm^3$), the above value must be divided by 10^3 cm^3/L and divided by 10^6 pCi/μCi, which results in the following airborne concentration:

$$C_{Pb} = 5.9\times10^{-4} / 10^3 / 10^6 = 5.9\times10^{-13}\ \mu Ci/cm^3$$

SC&A's full analysis of the cited air sampling references in RPRT-0081 is shown in Tables 3–5 for each period and measurement location evaluated. Table 6 shows a comparison of the period totals to the proposed thoron levels in 1996 for use in dose assignment. Notably, the number of air sampling results evaluated in SC&A's assessment was greater than the number reported in RPRT-0081. For example, for the period 1982–1983, SC&A evaluated 210 air sample results while RPRT-0081 appears to have evaluated 184. Similarly, SC&A evaluated 211 and 160 air sample results for the periods 1984–1985 and 1990, while NIOSH only reported 184 and 134 samples for these same periods, respectively. The source of the discrepancy in total available air sample results available for analysis is not known at this time.

Table 3. Overview of SC&A Analysis of DuPont 1982–1983 Air Sampling Data at the Relevant Locations of the Tank Farms

Measurement Location	Number of Samples Analyzed	Average Pb-212 Concentration ($\mu Ci/cm^3$) *	Maximum Pb-212 Concentration ($\mu Ci/cm^3$)
Tank 13 General Air	3	4.07×10^{-11}	1.06×10^{-10}
Tank 13 Other	8	1.92×10^{-11}	4.57×10^{-11}
Tank 14 General Air	21	7.96×10^{-13}	5.63×10^{-12}
Tank 14 Other	14	1.56×10^{-12}	4.55×10^{-12}
Tank 15 Berm Area	32	1.00×10^{-12}	9.15×10^{-12}
Tank 15 General Air	30	6.21×10^{-13}	7.68×10^{-12}
Tank 15 Other	11	1.14×10^{-12}	3.17×10^{-12}
Tank 42 Annulus	46	1.15×10^{-11}	7.03×10^{-11}
Tank 42 Exhaust	45	1.54×10^{-11}	2.64×10^{-10}
Total	210	7.61×10^{-12}	2.64×10^{-10}

* Zero results censored at 0.2×10^{-12} $\mu Ci/cm^3$ are not included.

Table 4. Overview of SC&A Analysis of DuPont 1984–1985 Air Sampling Data at the Relevant Locations of the Tank Farms

Measurement Location	Number of Samples Analyzed	Average Pb-212 Concentration ($\mu Ci/cm^3$) *	Maximum Pb-212 Concentration ($\mu Ci/cm^3$)
Tank 11 Exhaust	28	5.54×10^{-12}	1.08×10^{-11}
Tank 12 Exhaust	37	5.56×10^{-12}	2.54×10^{-11}
Tank 14 Exhaust	35	4.07×10^{-12}	1.16×10^{-11}
Tank 15 Exhaust	37	1.25×10^{-11}	4.92×10^{-11}
Tank 42 (Primary)	37	8.70×10^{-12}	1.52×10^{-11}
Tank 42 (Annulus)	37	3.66×10^{-12}	9.44×10^{-12}
Total	211	6.75×10^{-12}	4.92×10^{-11}

* Zero results censored at 0.2×10^{-12} $\mu Ci/cm^3$ are not included.

Table 5. Overview of SC&A Analysis of WSRC 1990a and WSRC 1990b Air Sampling Data at the Relevant Locations of the Tank Farms

Measurement Location	Number of Samples Analyzed	Average Pb-212 Concentration ($\mu Ci/cm^3$) *	Maximum Pb-212 Concentration ($\mu Ci/cm^3$)
Tank 11 Annulus GA	9	1.17×10^{-12}	5.57×10^{-12}
Tank 11 Unspecified	8	1.51×10^{-12}	9.11×10^{-12}
Tank 12 Annulus GA	9	1.69×10^{-12}	9.05×10^{-12}
Tank 12 Unspecified	8	4.38×10^{-12}	1.52×10^{-11}
Tank 13 General Area	18	7.05×10^{-13}	2.85×10^{-12}
Tank 13 Unspecified	8	1.26×10^{-12}	5.67×10^{-12}
Tank 14 General Area	18	1.32×10^{-12}	9.05×10^{-12}
Tank 14 Unspecified	8	6.87×10^{-12}	3.80×10^{-11}
Tank 15 Annulus GA	9	1.76×10^{-12}	6.96×10^{-12}
Tank 15 Unspecified	8	9.24×10^{-12}	3.98×10^{-11}
Tank 40 Annulus GA	8	1.25×10^{-11}	6.17×10^{-11}
Tank 40 General Area	9	1.56×10^{-12}	8.36×10^{-12}
Tank 40 Primary GA	8	3.37×10^{-13}	1.52×10^{-12}
Tank 42 Annulus GA	8	8.68×10^{-12}	2.28×10^{-11}
Tank 42 Primary GA	8	1.70×10^{-12}	7.59×10^{-12}
Tank 51 Annulus GA	8	5.43×10^{-12}	2.09×10^{-11}
Tank 51 Primary GA	8	1.40×10^{-12}	7.08×10^{-12}
Total	160	3.24×10^{-12}	6.17×10^{-11}

* Zero results censored at 0.2×10^{-12} $\mu Ci/cm^3$ are not included.

Table 6. Comparison of SC&A Analysis of Earlier Time Periods to the 1996 Thoron Levels Proposed for Dose Reconstruction

Time Period	Average Air Concentration	95th Percentile	99th Percentile	Maximum Air Concentration
SC&A Analysis of 1982–1983	7.61×10^{-12}	Not Calculated	Not Calculated	2.64×10^{-10}
SC&A Analysis of 1984–1985	6.75×10^{-12}	Not Calculated	Not Calculated	4.92×10^{-11}
SC&A Analysis of 1990	3.24×10^{-12}	Not Calculated	Not Calculated	6.75×10^{-11}
NIOSH Proposed Dose Reconstruction Analysis based on 1996 Data	2.84×10^{-11} *	2.67×10^{-9}	1.76×10^{-8}	Not Presented

* This value represents the geometric mean rather than the arithmetic average

As shown in Tables 3–6, the average thoron levels prior to 1996 are at least a factor of four lower than the geometric mean presented in Table 3-1 of RPRT-0081. Furthermore, the maximum observed values during the evaluated periods are at least an order of magnitude lower than the 95th percentile value calculated for 1996 (at the 99th percentile, the difference is nearly two orders of magnitude).

Observation 2: Based on the comparison of the limited air sampling data for the period of interest, it is clear that the 1996 thoron assessments bound the exposure potential for the earlier periods evaluated in RPRT-0081.

Finally, RPRT-0081 does not specify how NIOSH intends to assign thoron exposures to the relevant claimant population at SRS. RPRT-0081 (p. 12) states:

> *NIOSH concludes that concentrations of thoron daughters reported in the 1997 study are sufficient to bound thoron exposures of* ***workers in thorium storage areas***. [Emphasis added.]

It is not clear if this methodology is intended to apply only to tank farm workers or any worker in an area of SRS where thorium might have been stored. Additionally, it is not clear whether NIOSH intends to assign the geometric mean, the 95th percentile, or the 99th percentile as presented in Table 3-1 of RPRT-0081. RPRT-0081 should explicitly define how the proposed dose reconstruction approach would be implemented.

Observation 4: RPRT-0081 should explicitly define how the proposed thoron exposures would be implemented in an actual dose reconstruction (e.g., the magnitude of exposure and workers/locations included).

Conclusion

SC&A noted significant temporal gaps in the analysis of air monitoring reports for the period from October 1, 1972, to the end of 1995 because NIOSH only analyzed approximately 8% of the relevant time period. However, SC&A acknowledges that the calculated airborne concentrations reported in Table 3-1 of RPRT-0081 (and shown in Table 1 of this memo) are significantly lower during the sampled periods prior to 1996; therefore, additional data capture and analysis are likely unnecessary as the 1996 thoron characterization represents a bounding scenario for dose reconstruction. If it is determined that the 1996 thoron exposure values are appropriate for dose reconstruction, NIOSH should specify how it intends to implement the proposed approach as it pertains to magnitude of exposure and location of affected workers.

References

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