MEMORANDUM

TO: Advisory Board on Radiation and Worker Health, Work Group on Metals and Controls Corp.
FROM: Robert Anigstein, SC&A, Inc.
DATE: July 26, 2019
SUBJECT: Review of NIOSH's "Metals and Controls Corp. Thorium and Welding Exposure Model"

1 Background

On April 8, 2019, the National Institute for Occupational Safety and Health (NIOSH) completed a white paper (McCloskey and Sharfi 2019) in response to two concerns raised by a petitioner for Special Exposure Cohort (SEC) Petition SEC-00236, which addressed the residual period at the Metals and Controls Corp. (M&C) in Attleboro, Massachusetts, from January 1, 1968, through March 21, 1997. These concerns included assessments of workers' exposures during welding activities and exposures to residual thorium contamination. The white paper was distributed on May 10, 2019; SC&A was tasked with reviewing the white paper on May 14.

2 Review of NIOSH White Paper

2.1 Internal Exposures to Thorium

McCloskey and Sharfi (2019) acknowledged that thorium operations occurred at M&C during the period that the facility was designated as an Atomic Weapons Employer (AWE). Their aim was to estimate internal doses to M&C workers from intakes of thorium during the residual period.

2.1.1 Inventory of Uranium and Thorium

To evaluate worker exposures to thorium at M&C, McCloskey and Sharfi (2019) reviewed a 1962 analysis of possible losses of nuclear materials and accompanying financial liabilities, performed on behalf of M&C in order to determine the need for insurance to cover such losses (ASTRA 1962). The report of this analysis included an inventory of uranium and thorium at M&C on January 1, 1962, reproduced in Table 1 of the present memo. As shown, the table includes separate listings for "Commission" and "License." "Commission" presumably means the Atomic Energy Commission. The reason for the separate listings is not clear. According to McCloskey and Sharfi, the inventory comprised 244 kg of thorium and 7,097 kg of uranium. The cited thorium inventory is the total of the amounts listed under "Commission" and "License." However, the amount of uranium cited is less than 7,854 kg, which is the total of the amounts in

these two columns. Furthermore, according to the totals listed in Table 1, the mass of the total uranium inventory is 32 times that of thorium, not 29 times as cited by McCloskey and Sharfi. These discrepancies should be resolved.

Table 1. Inventory of Special Nuclear Materials at M&C (January 1, 1962) (kg)

Material	Commission	License	Commission + License
93% Enr. U	1,264	18	—
20% Enr. U	—	71	—
3.2% Enr. U	—	1,449	—
2.2% Enr. U	—	3,932	—
1.8% Enr. U	—	363	—
Normal U	61	192	—
Depleted U	158	346	—
Total U	1,483	6,371	7,854
Thorium	198	46	244

Source: ASTRA (1992, Table 2)

Observation 1: The uranium inventory cited by NIOSH is inconsistent with that in the source document.

We make this an observation rather than a finding, because the uranium inventory is not used in the proposed NIOSH dose methodology.

2.1.2 Confirmation of Residual Thorium Contamination

McCloskey and Sharfi (2019) noted that Creative Pollution Solutions (CPS, n.d.) reported elevated levels of thorium during their 1992 survey of the burial area between Buildings 11 and 12. SC&A observed that CPS reported a soil sample containing 110 pCi/g of ^{232}Th and an equal concentration of ^{228}Th (i.e., the two isotopes were in secular equilibrium). Since, according to Sowell (1985), the onsite burials took place in 1958–1961, the material was at least 31 years old at the time of the analysis. Even if the thorium had been freshly purified in 1961, ^{228}Th would have been at ~96% of its secular equilibrium concentration at the time of the analysis, so these results are not surprising.

2.1.3 NIOSH Assessment of Uranium-to-Thorium Ratio

McCloskey and Sharfi (2019, p. 4) utilized the analyses of "samples taken of waste and materials removed from the former AWE areas and placed in the burial area" to determine an activity ratio of uranium to ^{232}Th. The authors cited 754 samples that were analyzed for both uranium and ^{232}Th. "NIOSH determined a paired activity ratio of uranium to thorium-232 for each of these samples and calculated a geometric mean ratio of uranium to thorium-232 as 9.88:1." As explained later in the white paper, NIOSH intended to apply this ratio to measured concentrations of uranium in pipe sediments to estimate the concurrent concentrations of ^{232}Th.

2.1.4 Reviewers' Comments on NIOSH Assessment of Uranium-to-Thorium Ratio

We first note that McCloskey and Sharfi (2019) did not cite the source of the sampling data used to determine the activity ratio of uranium to ^{232}Th. We presume that these data comprise radionuclide concentrations in soil samples listed by Sowell (1985, Tables 4, 5A, 6A, 11, 12A, and 13A), who reported 751 such samples, according to our count, vs. 754 samples cited by McCloskey and Sharfi. This minor discrepancy is most likely due to a clerical error—we believe that the authors utilized the Sowell data, which were cited in their previous report (McCloskey and Sharfi 2018).

A review of the Sowell (1985) data shows that the vast majority of the ^{232}Th concentrations reflect typical levels of naturally occurring thorium in uncontaminated soils. To quantify this observation, we calculated the expected distribution of naturally occurring ^{232}Th on the M&C site, based on concentrations in baseline soil samples collected off site in the Attleboro, Massachusetts, area listed by Sowell (1985, Table 1-B). The ^{232}Th concentrations in the five samples have a geometric mean of 0.81 pCi/g and a geometric standard deviation of 1.49. Assuming an underlying lognormal distribution, the upper 95th percentile of this distribution is 1.56 pCi/g, while the 99th percentile is 2.05 pCi/g.

We note that Sowell (1985, Table 4) comprised 482 samples collected at the surface at grid-line intersections in the Building 12 burial area. If the ^{232}Th concentrations were due to natural background levels, we would expect that 1% (4–5 samples) would have concentrations at or above the 99th percentile of the baseline samples. In fact, only one sample listed in Table 4, with a concentration of 2.12 pCi/g, was above this level. Similarly, Sowell (1985, Table 11) lists 139 sampling results for soil samples collected at the surface at grid-line intersections in the outdoor area surrounding Building 10. With this number of samples, we would expect one to two ^{232}Th concentrations to be at or above the 99th percentile. In fact, the highest value is 7.18 pCi/g, with a second reading of 3.11 pCi/g. All other ^{232}Th values are well below the 99th percentile. With the exception of these two readings, these values are consistent with natural background activity concentrations in soil.

Reviewing the rest of Sowell's (1985) data, we note that Table 12A, listing results for three samples collected from the top 10-cm soil layer at locations of elevated contact radiation levels near Building 10, includes one reading of 1.70 pCi/g of ^{232}Th, which is above the 95th percentile but below the 99th. However, a set of three samples cannot be used to establish an activity concentration ratio. Table 13A lists results for 24 borehole soil samples near Building 10. The highest ^{232}Th concentration is 1.25 pCi/g, which is less than the 95th percentile, contrary to the expectation that 5% (one sample) would exceed the 95th percentile background.

We therefore conclude that all the ^{232}Th data in Sowell (1985, Tables 4, 11, 12A, and 13A), with the possible exception of two samples listed in Table 11, are consistent with naturally occurring ^{232}Th in soils in the Attleboro area and cannot be used to estimate intakes of ^{232}Th originating from AWE activities. The only data that include a substantial number of samples with ^{232}Th levels significantly elevated above background are those presented by Sowell (1985, Tables 5A and 6A).

2.1.5 New NIOSH Bounding Method to Estimate Intakes of Thorium

McCloskey and Sharfi (2019), referring to their earlier report (McCloskey and Sharfi 2018), cited the 95th percentile uranium activity in the pipes under Building 10 as 6,888 pCi/g. They calculated the corresponding mass concentration of uranium, based on the specific activity of natural uranium. They assumed equal concentrations of natural uranium and ^{232}Th by mass, based on the uranium-to-^{232}Th activity ratio of 9.88:1 cited in section 2.1.3 of the present memo, and on the relative specific activities of the two radionuclides. They concluded that uranium and ^{232}Th each comprised 1% of the pipe sediments and thus 1% of the airborne dust generated from these sediments. The authors calculated an effective dose commitment of 10.42 mrem/y via the inhalation pathway, based on one month of subsurface work during each year of the residual period. Adding inadvertent ingestion, the dose was 14.78 mrem/y.

2.1.6 Reviewers' Comments on NIOSH Bounding Method to Estimate Intakes of Thorium

Assuming that the specific activity of the uranium contamination in the pipe sediments was that of natural uranium is not valid. According to Weston (1996, Table 1), the uranium isotopic ratios in the pipes indicated that in the 20 samples listed, 15 show enrichments of 1.5% to 35%, while two samples list only ^{235}U activity concentrations and no enrichment data. The remaining three samples had enrichments <0.72%, the relative abundance of ^{235}U in natural uranium. We thus conclude that most of the pipe sediments were contaminated with uranium of varying enrichments. It is therefore difficult to assign a single specific activity of uranium to these samples.

Furthermore, there is no straightforward method of calculating a ratio of uranium-to-^{232}Th activity from the Sowell (1985) data. These data list activity concentrations of only two uranium isotopes: ^{235}U and ^{238}U—there are no data on ^{234}U. Examining the only two data sets that include a substantial number of samples with ^{232}Th levels significantly elevated above background, we find that the average ^{235}U activity concentrations in Table 5A to be 24% of the ^{238}U concentrations, while the average ^{235}U concentrations in Table 6A are 12% of those of ^{238}U. Since the ^{235}U activity in natural uranium is 4.6% of ^{238}U, one cannot assume the isotopic abundance of natural uranium to estimate the missing ^{234}U data nor the total uranium activities in these soil samples.

2.1.7 Alternate Method for Estimating ^{232}Th Intakes by Workers Performing Subsurface Maintenance Inside Building 10

To overcome the difficulties discussed above, we propose an alternate method of estimating ^{232}Th intakes by workers performing subsurface maintenance inside Building 10. Since the volume-weighted average of the ^{235}U activity concentrations in the samples from the pipes under Building 10 (Weston 1996, Table 1) is almost twice that of ^{238}U, and since there are 20 activity measurements of this isotope vs. 18 of ^{238}U, the ^{235}U activity concentrations potentially constitute a more robust data set for estimating the corresponding ^{232}Th activities. To derive a 95th percentile ^{235}U activity concentration, we ranked the activity concentrations in the 20 samples, shown in the first column of Table 2 of the present memo. The second column lists the volume of the residue corresponding to each sample (Weston 1996, Table 5). The third column

lists the cumulative volume: each entry is the sum of the corresponding entry in column 2 plus all the previous entries in that column. We calculated the 95th percentile volume as 881,184 mL (927,562 mL × 0.95 = 881,184 mL). We then used linear interpolation to derive the 95th percentile ^{235}U concentration (i.e. the concentration corresponding to 95% of the cumulative volume) of 1,529pCi/g.

Table 2. U-235 Activity Distribution in Pipe Sediments under Building 10

U-235 (pCi/g)	Volume (mL)	CVD [a] (mL)
0.15	1,977	1,977
0.80	16,062	18,039
0.84	62,087	80,126
1.1	6,178	86,304
1.4	8,031	94,335
1.5	37,067	131,401
1.6	2,471	133,872
1.8	4,633	138,506
2.6	16,371	154,877
4.2	37,067	191,944
5.4	32,124	224,068
13	4,633	228,701
17	24,248	252,949
21	6,178	259,127
21	200,160	459,287
30	43,553	502,840
36	37,067	539,907
53	123,556	663,462
193	86,180	749,642
2000	177,920	927,562

Source: Weston 1996

[a] Cumulative volume distribution: sum of corresponding entry in col. 2 plus all the previous entries in that column

Sowell (1985, Table 5A), "Radionuclide Concentrations in Soil Samples Collected from Locations of Elevated Contact Radiation Levels - Building 12 Burial Area," reports ^{235}U and ^{232}Th concentrations in samples from 18 locations at depths varying from 2 to 40 cm. To use the ^{235}U activity concentrations in this table to predict the ^{232}Th levels in the pipes, we needed to establish a relationship between the two sets of data. We calculated the correlation coefficient, *R*, between the ^{235}U activity concentrations in these 18 samples and the ^{232}Th concentrations in the same samples and derived a value of $R = -0.16$. The negative correlation indicates that high ^{235}U concentrations are more likely to coincide with low ^{232}Th levels, and vice versa. We therefore concluded that the data in Table 5A are not a suitable basis for estimating ^{232}Th intakes based on measured ^{235}U activities.

The remaining data set is Sowell (1985, Table 6A). Table 6A, "Radionuclide Concentrations in Borehole Soil Samples from Building 12 Burial Area," lists ^{235}U and ^{232}Th concentrations in 88 core samples taken from 25 boreholes. For the ^{235}U concentrations that were listed as less than a

given value, we assigned one-half that value to the given sample. The correlation coefficient between the ^{235}U activity concentrations in these samples and the ^{232}Th concentrations in the same samples, *R*, equals 0.0969. The probability that this correlation is due to chance is 18.5%. Although the correlation is not as strong as might be desired, we nevertheless conclude that these data constitute the best available basis for using uranium activities to estimate ^{232}Th intakes.[1]

We calculated the ratios of the ^{232}Th concentrations to the corresponding ^{235}U concentrations in the 88 samples described by Sowell (1985, Table 6A)[2] and derived a geometric mean of 4.062 from these 88 ratios. Applying this ratio to the 95th percentile ^{235}U concentration of 1,529 pCi/g in the pipe sediments, we obtained a ^{232}Th concentration of 6,211 pCi/g in the pipe residues. Applying the 95th percentile dust loading of 2.2×10^{-4} g/m^3 cited by McCloskey and Sharfi (2018), we obtained an air concentration 1.366 pCi/m^3. Assuming that workers were exposed to this activity concentration for one month each year, we estimated an inhaled intake of 275 pCi (10.2 Bq) per year, which led to an effective dose of 53.7 mrem/y from this pathway. According to OCAS-TIB-009 (Neton 2004, p. 4), the daily ingestion rate "can be approximated by assuming it to be 0.2 times the activity per cubic meter of air." Applying this guidance, we obtain an effective dose from ingestion of ^{232}Th of 0.02 mrem/y. Our total effective dose from both pathways is more than 3-fold higher than the dose of 14.78 mrem/y cited by McCloskey and Sharfi (2019).

Finding 1: NIOSH underestimated the ^{232}Th concentration in the sediments and residues in the pipes under Building 10, leading to an underestimate of ^{232}Th intakes by workers performing subsurface activities.

2.2 Internal Exposures from Welding

McCloskey and Sharfi (2019) described the NIOSH bounding method for estimating internal exposures from welding during the residual period at M&C. The scenario applies only to maintenance workers who performed welding tasks. The authors estimated that workers spent approximately 4 h per month on welding activities. We reviewed the reference cited for this estimate (ORAUT 2017) and could not find any discussion that documented that assumption.

Observation 2: NIOSH should clarify the source of the 4-h-per-month time estimate.

In calculating the airborne activity concentration, McCloskey and Sharfi (2019) adopted a resuspension factor (RF) of 10^{-4}, then increased it by a factor of 10 to incorporate a dispersibility factor cited in NUREG-1400 (Hickey, et al. 1983). The authors used these values to calculate an airborne concentration of 4.05×10^{-12} µCi/mL gross alpha. Furthermore, based on an annual exposure duration of 48 h, and assuming the entire activity to be ^{234}U, they calculated an

[1] Comparisons of ^{232}Th concentrations to those of ^{238}U or to the sums of the ^{235}U + ^{238}U concentrations yielded lower values of *R*.

[2] Sowell (1985, Table 6A) actually presents results for 89 samples, but concentrations of ^{235}U and ^{232}Th are shown in only 88 cases.

effective dose delivered by the inhalation pathway to a worker performing welding of 5.88 mrem. They calculated an additional dose of 16.77 mrem/y from ^{232}Th and its progeny.

We believe that the highly dispersive nature of the activities accompanying welding—grinding and wire brushing to achieve a clean surface—should be modeled using the highest reported RF in an indoor environment. According to OTIB-0070 (Sharfi 2012, Table 3-1), "vigorous sweeping by two workmen" resulted in RFs of 1.02×10^{-2} to 4.2×10^{-2}. We recommend a rounded value of 10^{-2}, at the lower end of the range, since it is unlikely that the grinding and brushing occupied the entire time the worker was involved in the welding activities. This would lead to a 10-fold increase in the inhaled intakes estimated by McCloskey and Sharfi (2019).

Finding 2: NIOSH understated the resuspension factor related to activities accompanying welding.

We verified that the airborne activity concentration and the effective dose from ^{234}U via inhalation reported by McCloskey and Sharfi (2019) were consistent with their stated surficial activity concentrations, RF, and exposure duration. However, we do not understand the basis for the additional dose from the inhalation of ^{232}Th: If all the alpha activity were due to ^{234}U, there would have been no thorium. Since there does not appear to be any straightforward means of apportioning the surficial activity among the uranium and thorium isotopes, the activity should be assigned to whichever radionuclide results in the highest dose in a given case. This would be consistent with the authors' statement (p. 5): "For those areas where gross alpha contamination surveys are available, NIOSH will continue to estimate worker doses using the most claimant-favorable isotope of thorium or uranium." Since the intakes in the welding scenario are based on the 95th percentile value derived from gross alpha contamination surveys, this procedure should be applied.

Observation 3: In estimating doses from the welding scenario, NIOSH should assign doses using the most claimant-favorable isotope of thorium or uranium, selected from isotopes known to have been used at M&C.

3 Summary and Conclusions

We find that NIOSH has developed plausible approaches to modeling exposures of M&C workers to residual ^{232}Th contamination and to modeling work activities related to welding. We disagree with some of the parameters and assumptions that NIOSH used to implement its approach. However, we believe that these issues can be resolved. These therefore constitute site profile rather than SEC issues.

4 References

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