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National Institute for Occupational Safety and Health

SC&A DRAFT REVIEW OF NIOSH'S WHITE PAPER DATED OCTOBER 24, 2018

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ABBREVIATIONS AND ACRONYMS

Board or ABRWH	Advisory Board on Radiation and Worker Health
AWE	Atomic Weapons Employer
Bq	becquerel
Ci	curie
dpm	disintegrations per minute
DTRA	Defense Threat Reduction Agency
ER	evaluation report
GSD	geometric standard deviation
HVAC	heating, ventilation, and air conditioning
MeV	mega-electron volt
M&C	Metals and Controls Corporation
mrem	millirem
µCi	microcurie
µg	microgram
NIOSH	National Institute for Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
pCi	picocurie
Ra	radium
SEC	Special Exposure Cohort
SRDB	Site Research Database
Sv	sievert
Th	thorium
U	uranium
WG	Work Group

1 PREFACE

On October 24, 2018, the National Institute for Occupational Safety and Health (NIOSH) issued a white paper, *Metals and Controls Corp. Maintenance Worker Exposure Model* (NIOSH 2018). NIOSH 2018 (also referred to herein as the "white paper") serves as a supplement to NIOSH's original evaluation of Special Exposure Cohort (SEC) Petition 00236, also referred to as the petition evaluation report (ER) (NIOSH 2017a).

The white paper focusses on specific exposure pathways identified at a series of 12 interviews with Metals and Controls Corporation (M&C) workers and other representatives held on October 24–26, 2017 (subsequent to the publication of the ER). These interviews were initiated by NIOSH based on concerns expressed by petitioners that the ER neglected to address a number of potentially important radiation exposure pathways that took place during the residual period at M&C.

The Advisory Board on Radiation and Worker Health (Board) requested that SC&A perform a review of the ER during its August 24, 2017, meeting. SC&A was fortunate in that its review of the ER was completed on February 12, 2018 (SC&A 2018a), after the interviews held on October 24–26, 2017. As such, SC&A's review of the ER benefited from the large amount of new information provided to NIOSH and SC&A during those interviews.

SC&A's February 12, 2018, review of the ER included an extensive analysis of many new exposure pathways based primarily on information acquired during the interviews held on October 24–26, 2017. The interviews, SC&A's February 12, 2018 report (SC&A 2018a), and other correspondence and meetings resulted in NIOSH issuing its October 24, 2018 white paper.

In order to facilitate discussion, the Board and its M&C Work Group requested that SC&A review the NIOSH white paper in advance of an M&C Work Group meeting November 19, 2018. SC&A issued a preliminary draft review of the NIOSH white paper for discussion purposes only prior to the November 20, 2018, meeting. During the meeting, this preliminary report was discussed with the understanding that a final draft would be issued following the meeting.

During the Work Group meeting, extensive discussions were held regarding the new exposure pathways evaluated by NIOSH in its October 24, 2018, white paper and SC&A's preliminary review. In addition, the Work Group and the petitioners, who participated in the meeting by phone, posed a number of questions and comments, many of which were not entirely addressed during the meeting. For example, the petitioners raised questions regarding the degree to which exposures to thorium could be addressed and whether internal exposures to fumes from welding in the presence of residual uranium and thorium could be addressed.

At the end of the meeting, the Work Group requested that SC&A finalize its preliminary review of the NIOSH white paper including addressing matters discussed at the Work Group meeting to the extent possible, so that it could be reviewed by NIOSH, the M&C Work Group, and the full Board prior to the full Board meeting scheduled for December 12–13, 2108, in Redondo Beach, CA. This report is provided in response to that request.

2 INTRODUCTION AND BACKGROUND

The following presents SC&A's review of the NIOSH white paper dated October 24, 2018 (NIOSH 2018). Throughout the review, commentary will be made to address the degree to which remaining Board and petitioner comments are addressed and potential new issues raised during the November 20, 2018, meeting.

As an introduction to this review, it is appropriate to review the white paper from two perspectives. The first, and most important, perspective has to do with the degree to which it is appropriate to use data collected primarily during the end of the operations period (1968) and toward the end of the residual period (in the 1980s and 1990s) to place a plausible upper bound on external and internal exposures experienced by M&C workers during the residual period, a time during which M&C workers were not aware of the presence of residual radioactive contamination both indoors and outdoors and in the above- and below-ground environment. It is not unreasonable to refer to some of these data as "substitute data"[1] when used in this context. The ability to use substitute data in this case (or surrogate data in general) is often fundamental to making judgments pertaining to SEC petition applications, especially for Atomic Weapons Employer (AWE) facilities where radiological data are often limited.

The second perspective is best to referred to as site profile issues; i.e., does NIOSH have access to sufficient data (including substitute data) and a thorough understanding of the types of worker activities that took place during the residual period to develop and implement models that can be used to reconstruct worker doses in a scientifically sound and claimant-favorable manner, taking into consideration that both SC&A and NIOSH are relying heavily on what is best referred to as substitute data?

Our commentary on the white paper is organized according to the exposure scenarios used in the white paper, as follows:

- Building 10 heating, ventilation, and air conditioning (HVAC) maintenance
- Building 10 roof and overhead
- Subsurface inside Building 10
- Subsurface areas outside Building 10

These scenarios are constructs developed by NIOSH and SC&A as a means to identify categories of exposure pathways that were not adequately addressed in the initial ER and that we believe need to be addressed in order to prepare a revised ER that can be used by the Board for SEC decision-making.

[1] The term" substitute data" is used here to refer to what is often referred to as "surrogate data." However, the term surrogate data is used by NIOSH and the Board to refer to data collected from one facility that is then used to reconstruct doses at another facility, as long as the data meet the Board's surrogate data criteria. We use the term substitute data in this briefing paper when referring to data collected at one time period as a basis to reconstruct doses at another time period <u>at the same facility</u>.

Three of these exposure scenarios were addressed in SC&A's review of the original ER (SC&A 2018a). Hence, we draw heavily from that work in our review of the white paper. However, a greater effort is given to reviewing these exposure scenarios from the first perspective described above (i.e., can the substitute data be used to place a plausible upper bound on the doses experienced by M&C workers in the 1970s and 1980s?).

3 MAINTENANCE MODELS

3.1 BUILDING 10 HVAC MAINTENANCE

In its white paper, NIOSH has fully adopted SC&A's suggested approach to this exposure scenario as described in SC&A 2018a. This scenario was discussed at the November 20, 2018, Work Group meeting and appeared to be accepted by the Work Group as a scientifically sound and claimant-favorable approach to this exposure scenario.

3.2 BUILDING 10 ROOF AND OVERHEAD

Exposure to workers involved in the maintenance of roofing material and rafters in Building 10 is a new scenario not previously addressed by the ER or subsequent reports. The pathway was addressed in response to petitioner concerns. Beginning on page 11 of the white paper, NIOSH explains that, in 1982, the U.S. Nuclear Regulatory Commission (NRC) performed swipe surveys of "the roof of Building 10 near the exhaust from the high-efficiency filter system and the exhaust from the fuel manufacturing area and the ceiling, walls, and columns of the general manufacturing area (outside the fuel manufacturing area)." Hundreds of alpha, beta, and gamma surveys were performed, including 154 wipes for removable alpha and beta contamination. The implications of these statements are that the levels of contamination in the rafters and roofing of Building 10 were well characterized in the 1980s and could serve as a comprehensive database upon which to base the reconstruction of doses to M&C workers for this exposure scenario.

Page 14 of the white paper describes the models and assumptions used to reconstruct the doses to these workers. Using the alpha survey data and a 10% removable contamination assumption, NIOSH determined that the surveys revealed removable surface contamination in these areas had a geometric mean (GM) of 1.09 disintegrations per minute per 100 square centimeters (dpm/100 cm^2) and a geometric standard deviation (GSD) of 3.61 and selected a 95th percentile value of 8.99 dpm/100 cm^2 for use in deriving bounding internal exposures of workers involved in these types of maintenance activities.

For the purpose of deriving inhalation exposures due to dust resuspension during these maintenance activities, NIOSH used a resuspension factor of 1E-4/m, thereby deriving an airborne concentration of 4.05E-14 microcuries (µCi)/ml, and assumed an occupancy time of 173 hours per year. This concentration of uranium-234 (U-234) corresponds to about 0.01 millirem per hour (mrem/hr) to the lung for Type S U-234[2], an extremely small dose rate.

SC&A reviewed the contamination levels on the Building 10 roof and overhead area cited on page 14 of the NIOSH white paper. We digitized the data in the two cited references: Texas Instruments 1982, PDF p. 27, and NRC & Texas Instruments 1982–1983, PDF pp. 70–72, 75–83, 140–141. The following is a summary of that review.

[2] 0.0899 dpm/cm^2 ÷ (60 dpm/dps × 3.7E4 Bq/Ci × 1E6 ml/m^3) = 4.05E-14 µCi/ml

4.05E-14 µCi × 1.0E6 ml/m^3 × 3.7E4 Bq/µCi × 1.2 m^3/hr × 7.81E-5 Sv/Bq × 1E5 mrem/Sv = 0.014 mrem/hr

- NIOSH stated that there were a total of 285 readings. We counted 339 results including zeros. Excluding zeros, there are 265 results.

- Using a nonparametric determination of the 95th percentile, we obtained a value of total gross alpha of 117 dpm/100 cm^2. Using the NIOSH assumption that the removable activity = 10% of the total, we obtain 11.7 dpm/100 cm^2, vs. 8.99 dpm/100 cm^2 given by NIOSH. If zeros are excluded, the 95th percentile removable activity would be 12.4 dpm/100 cm^2.

- Assuming a lognormal distribution of the nonzero values, we can derive a 95th percentile value of 10.5 dpm/100 cm^2 by multiplying the GM of 2.126 (not 1.009 as given by NIOSH) by 1.645 × GSD of 2.87.

- Another approach would be to use regression of order statistics, which allow for the inclusion of zeros (i.e., non-detects). Although we have not performed that calculation, it would increase the 95th percentile of 10.5 dpm/100 cm^2 given above.

Though our review of the data do not exactly match those derived in the white paper, we believe that this strategy for deriving the inhalation doses to M&C workers for this scenario is scientifically sound and claimant favorable. The NIOSH calculation files were provided to SC&A subsequent to this analysis; however, they have not been fully reviewed at the time of publishing.

During the May 3 and November 20, 2018, meetings, Work Group members raised questions regarding the representativeness of the data in terms of where and over what time period the data were collected. In particular, one Board member asked whether some of the measurements were collected on the roof outdoors, where weathering would remove the contamination, reducing its representativeness with respect to exposures to workers performing maintenance indoors in the rafters and upper levels close to the ceiling. SC&A revisited the Site Research Database (SRDB) and found a Texas Instruments Incorporated report sent to the NRC dated May 17, 1982, *Request for Termination of Nuclear Regulatory Commission SNM-23* (NRC & Texas Instruments 1982–1983). The report presents measurements of direct alpha, removable alpha, and beta/gamma radioactivity on all surfaces and radioactivity of the coatings for the general manufacturing floor, the north wall, the east wall, and the south wall below and above 1.5 meters to the ceiling, including the ceiling surface, paint, pipes (including 1.5 m high to the ceiling), columns (including 1.5 m to the ceiling), and bus bolts throughout the facility (including the AWE and High Flux Isotope Reactor areas). Most of the measurements were indoors, but some measurements were also outdoors on the roof. All the data collected are tabulated by grid location in a series of appendices to the report. It is important to note that the measurements were made in support of a request for license termination. Page 5 of the report states that “No cleaning prior to measuring for radioactivity was performed in the Metallagraphic and Chemical Laboratories.” Hence, the data represent the radiological condition as they were at the time of the measurements. SC&A believes that this report represents a comprehensive radiological characterization of the facility at the time of these measurements and that they primarily represent indoor levels of contamination, including the upper levels of Building 10.

3.3 SUBSURFACE BUILDING 10

Page 5 of the white paper presents a detailed description of the subsurface activities that took place in Building 10 during the residual period. SC&A concurs with this description. The white paper addresses both the internal and external exposures associated with these activities. SC&A also reviewed these pathways in SC&A 2018a.

3.3.1 Internal Exposure

The white paper made substantial revisions to the methods originally used in the ER for this scenario; the main change is that the white paper uses a subsurface contamination level that is at the upper 95th percentile of the contamination levels observed in the subsurface conduits as opposed to median values observed in the subsurface soil. SC&A concurs with this strategy, which is the strategy adopted in Section 2.3.1 of SC&A 2018a. Differences in the calculated 95th percentile are explained by SC&A using additional sampling results and not assuming normality in the data. Table 1 compares the modeling assumptions employed in SC&A's 2018 petition ER review (SC&A 2018a) to those in the white paper for this exposure scenario.

Table 1. Comparison of Key Modeling Assumptions Used by SC&A (SC&A 2018a) and by NIOSH in the White Paper for Reconstructing Internal Doses to Subsurface Workers in Building 10

Parameter	SC&A 2018a	10/24/2018 White Paper
Contamination level	5,878.1 pCi/g	6,887.84 pCi/g
Dust loading	200 $\mu g/m^3$	220 $\mu g/m^3$
Breathing rate	2.5 m^3/hr	1.2 m^3/hr
Exposure duration	184 hr/yr	173 hr/yr
U inhalation rate	20 Bq/yr	Not provided
Dose	15.6 mrem/yr effective dose commitment	Not provided

As indicated in Table 1, the key assumptions used by NIOSH and SC&A to reconstruct the internal doses to M&C workers involved in subsurface maintenance and repurposing activities are similar and within the range we consider acceptable with respect to modeling of this nature. Certainly, it is appropriate to discuss these differences at part of a discussion of site profile issues. However, this paper is focused on SEC issues. Hence, it is appropriate to question whether the basic data used to derive the subsurface contamination levels, which were obtained primarily during the 1990s, are sufficient to reconstruct exposures to M&C workers throughout the residual period. This question goes to the heart of an SEC determination.

During the worker interviews held on October 24–26, 2017, one of the personnel interviewed, who was involved in the characterization and remediation activities that took place during the 1990s, indicated that it was their judgement that the subsurface contamination levels beneath Building 10, in the conduits, and in the outdoor environment were likely representative of the contamination levels present at these locations throughout the residual period when M&C personnel were involved in maintenance and repurposing activities. However, as indicated in SC&A's September 2018 memo (SC&A 2018b), one of our concerns is that, in the process of performing maintenance and repurposing activities, some of the contaminated material may have been inadvertently targeted and removed by M&C workers. In order to help offset this concern, SC&A recommended the use of a set of assumptions that are extremely bounding; i.e., that all subsurface work was performed by the same individual and that the worker was in intimate contact with the upper 95t[h] percentile concentration of radionuclides observed in the subsurface conduits for the entire time subsurface work was being performed.

SC&A would also like to point out that page 13 of the white paper refers to the following:

> *On January 31-February 2, 1983, the NRC performed a closeout inspection of facilities formerly engaged in AWE operations, including a review of the licensee's survey report and independent measurements in Building 10. The inspection involved 43 direct inspection hours by two NRC region-based inspectors and included verification surveys of the former fuel vault ceiling and walls. Nine hundred thirty-eight individual, direct alpha, beta-gamma, and gamma radiation measurements were taken in the AWE areas. Direct alpha measurements did not exceed 175 dpm/100cm^2 (92.6% < 50 dpm). The NRC concluded that fixed and removable contamination levels inside the AWE areas, measured during their inspection, were comparable to those in the M&C closeout survey (NRC & Texas Instruments 1982-1983, PDF pp. 6-9).*

Though these measurements did not include the indoor and outdoor subsurface environment, they are indicative of the time-integrated activity deposited on above-grade surfaces in Building 10 and, therefore, are indicative of radioactive residue that may have become airborne during the myriad of activities in Building 10, both chronic and episodic, from the end of AWE operations until 1983. One could argue that, if a substantial amount of contaminated residue was inadvertently removed in Building 10 during maintenance and repurposing activities during the residual period from 1968 up to the early 1980s, one would expect that the contamination levels observed in the surveys performed in 1983 would have been substantively different than the contamination levels observed in the surveys performed at the end of AWE operation. SC&A recognizes that these data only cover the time period from 1968 to 1983 and are not all encompassing with respect to other buildings and the outdoor environment. However, they represent one set of data that help provide reasons to believe that the data collected not only in the 1980s but also in the 1990s can be used as substitute data for use in reconstructing doses to M&C workers during the entire residual period.

In order to assist the Work Group in assessing this important SEC issue, we refer the Board to *Final Draft: Criteria for the Use of Surrogate Data*, prepared by the ABRWH Work Group on Use of Surrogate Data, May 14, 2010.

The Board's surrogate data criteria (ABRWH Surrogate Data WG 2010) are used to help the Board in making decisions regarding whether data collected at one facility could be used as a basis for reconstructing doses at another facility. Though not directly applicable to M&C issues, it is useful as an aid to explore the degree to which the M&C data collected in the 1980s and 1990s could be used to represent the entire residual period. A number of important points can be made for using these data, as follows:

- NIOSH is using the high end of the 1990 data (95th percentile data), which comports with surrogate data Criterion 2, Exclusivity Constraints (ABRWH Surrogate Data WG 2010).

- Relatively high chronic dust loading (220 µg/m^3) were assumed, especially considering that there is evidence that the soil beneath Building 10 was generally moist.

- NIOSH is assuming that the same person is performing subsurface maintenance and repurposing activities, when our worker interviews revealed that many different M&C workers performed subsurface work during the residual period.

- The data collected by the NRC in 1983 compare well with the data collected in the M&C closeout surveys (see above).

- The actual bioassay data collected for remediation workers performing the surveys and remediation in the 1990s reveal internal exposures that are well below the doses associated with the modeling assumptions used in the white paper (i.e., in Table 1 above, SC&A estimates an internal dose for subsurface exposures of M&C workers of 15.6 mrem/yr effective dose commitment, as compared to the exposure limits for cleanup workers in the 1990s of 20 mrem/quarter, which were never exceeded.

It is also noteworthy that the bounding doses provided in this report for the various scenarios and exposure pathways are all quite small. A review of the transcripts of many full Board meetings reveals that very low doses were taken into consideration in SEC decision-making.

Taken in combination, SC&A believes that the methods and assumptions used by NIOSH in the white paper to reconstruct doses to M&C workers involved in subsurface maintenance and repurposing activities in Building 10 during the residual period are scientifically sound and claimant favorable.

3.3.2 External Exposures

Page 15 of the white paper describes the methods used by NIOSH to reconstruct external exposures to M&C workers during the residual period as follows:

> *Film badges at the end of AWE operations (i.e., 1967) were processed quarterly by Landauer (Landauer 1967). NIOSH will use all of the 1967 results and determine the quarterly, GM dose, and the GSD. Since the maintenance work lasted no more than two months per year, external exposures will be assigned at the rate of two thirds the quarterly dose rate determined for the beginning of the residual period using the quarterly GM dose and GSD. No source-term depletion will be applied because of the potential for the maintenance area environments (e.g., inside clogged drains, rafters) to be less impacted by environmental reduction factors and routine cleaning.*

As described in SC&A 2018a, SC&A is uncomfortable with the use of film badge data collected during the AWE period as the underpinning for reconstructing external doses to M&C workers during the residual period, because there was no AWE fuel on site during the residual period. One can argue that the film badge data reflect external exposures during the AWE period that are due to many sources of exposures, including handling fuel and also any maintenance and repurposing activities that took place during the AWE period. Therefore, one could argue that the film badge data, as used in the NIOSH white paper, bound the external exposures during the residual period. This is likely true, but the activities related to fuel handling during the AWE period are unrelated to maintenance and repurposing activities that took place during the residual period. Hence, SC&A cannot accept the use of the film badge data as a reasonable basis for assigning external doses to M&C workers during the residual period. Instead, we suggest that NIOSH supplement the film badge strategy by modeling the external exposures associated with the radionuclide concentrations used to derive internal exposures associated with subsurface activities beneath Building 10, for reasons similar to those described above for internal exposures. This would involve using MCNP or other external dosimetry models, where it is assumed that M&C workers during the residual period were in close proximity to the upper-end concentrations of radionuclides in the subsurface environment in Building 10 (e.g., the upper 95th percentile values).

As an example of this strategy and as a means to assess the potential magnitude of the doses reconstructed in this manner, SC&A examined data on the highest levels of residual radioactive contamination that we found in the available documents. These were the residues found in the subsurface drains in Buildings 4 and 10. Weston (1996) listed the activity concentrations of the three naturally occurring uranium isotopes in the sediment or pipe scale in 22 pipes at 15 locations, along with the volume of contaminated material in each pipe. Since some of these pipes were leaking and could have potentially contaminated the surrounding soil, we analyzed the following set of bounding scenarios. We assumed that a worker stood during the entire work year on soil contaminated to an infinite depth with the same isotopic concentrations as one of the sampled materials. Such a hypothetical scenario bounds the exposures that workers may have experienced when excavating and opening these drain pipes during the residual period. (Such activities were reported by former M&C workers during the interviews conducted by NIOSH, Oak Ridge Associated Universities Team, and SC&A personnel in Mansfield, Massachusetts, on October 24–26, 2017 [NIOSH 2017b].)

In performing the analyses, we assumed that the U-235 and U-238 in the soil were in full equilibrium with their short-lived progeny. We calculated the effective dose and skin dose, using the dose coefficients for exposure to soil contaminated to an infinite depth tabulated in Federal Guidance Report (FGR) No. 12 (EPA 1993). We ranked the effective doses and skin doses corresponding to each of the 22 locations, along with the cumulative volumes of pipe scale or sediment in each pipe, and calculated the dose corresponding to 95% of the cumulative volume by linear interpolation. In this manner, we derived 95th percentile <u>annual doses</u> of 153 mrem effective dose and 390 mrem skin dose. Assuming the same worker was involved in subsurface activities for 1 month per year, the bounding annual penetrating and skin dose to such a hypothetical worker would be 153/12 = 12.75 mrem/yr and 390/12= 32.5 mrem/yr, respectively. Coincidentally, these values are similar to the values derived by NIOSH using film badge data from the AWE period.

3.4 External Exposures – Direct Skin Contact

Workers involved in subsurface work in Building 10 would likely have been in direct contact with soil, which could have been contaminated. This type of exposure to skin is different from that described above, which involved direct external exposure at a distance of 1 meter. A comprehensive review of this subject is provided in DTRA 2010. This report was prepared for the military in matters related to the contamination of military and civilian personnel to direct fallout and to deposited fallout, including the accumulation of contaminated soil on skin and clothing when in direct contact with contaminated soil. It is this later topic that has use in this particular application. Pages 125–126 of DTRA 2010 state the following:

> *Black (1962) measured the accumulation of dirt on clothing, bare skin, and skin under clothing of military personnel who wore full combat fatigues and while crawling under simulated combat conditions on bare dry soil or dry grass. Accumulation of dirt on clothing was a factor of 10 to 125 higher than on skin under clothing or near clothing (on the wrist and around the neck).*
>
> *Measured accumulations of soil on clothing were 13 mg cm^{-2} at the knees, 8 mg cm^{-2} at the elbows, 5 mg cm^{-2} on the back and under the belt in front, 1 mg cm^{-2} on the chest and under the belt in back, and 0.5 mg cm^{-2} at the armpits, inside of the elbow, at the side of the neck, and around the ankles. Soil loading increased if clothing was moist. The maximum soil loading on clothing that did not appear to be "caked" was 5 mg cm^{-2}.*
>
> *Data summarized above suggest that a maximum credible soil loading on clothing might be about 10 mg cm^{-2}. However, the soil loading can vary greatly from one area of the body to another. In addition, soil loadings in some scenarios (e.g., digging trenches or installing equipment in the field) could be substantially less than values measured by Black (1962) under conditions of combat crawling, which involves extensive contact with the ground surface. Therefore, judgment generally would be required in selecting an appropriate soil loading.*

Given our understanding of the contamination levels in subsurface soil, the soil contamination on clothing and skin, as described above by Black (1962), can be used to reconstruction dose rates to the skin of subsurface workers at M&C during the residual period. SC&A suggests that these types of exposures should be explicitly considered in the dose reconstructions performed by NIOSH.

As an example of this type of calculation, Appendix A presents a report previously prepared by SC&A in support of M&C Case Tab 510. In that review, we cite work that provides estimates of the doses to skin from direct deposition of U-238 on skin, along with its short-lived progeny. An estimate is provided of 40 mrem/h per 10,000 dpm/cm^2. This value can serve as a dose conversion factor for this exposure pathway.

Using the information cited above, an upper end dose rate to skin from beta emitters from U-238 plus short-lived progeny deposited directly onto the skin of subsurface workers can be estimated using the following assumptions:

- Upper end soil contamination level = 5,878.2 pCi/g

- Soil contamination level on skin or clothing of 10 mg/cm^2, corresponding to a thickness of less than 0.01 cm assuming a bulk soil density of 1.3 g/cm^3 (see page 16, Table 2.1 of Yu et al., 1993).

- A skin dose conversion factor of 40 mrem/hr per 10,000 dpm/cm^2

- Approximate range of betas particles in soil of:

  R (g/cm^2) = Emax/2

  Since Emax for Th-234 (the major beta emitter from the short-lived progeny of U-238 (see page 8-88 of Shleien et al. 1998) is about 0.2 mega-electron volts (MeV), the range in soil can be approximated as 0.2 MeV/2 = 0.1 g/cm^2.

Using these assumptions, the dose rate to the skin can be derived as follows:

5,878.1 pCi/g × 1.3 g/cm^3 × 0.01 cm × 0.037 dps/pCi = 2.8 dps/cm^2
2.8 dps/cm^2 × 60 dpm/dps × 40 mrem/hr ÷ 10,000 dpm/cm^2 = 0.67 mrem/hr to skin

3.5 Subsurface Areas Outside of Building 10

Page 6 of the white paper begins the discussion of this exposure scenario. Again, it is appropriate to divide the discussion between internal and external exposures.

3.5.1 Internal Exposures

In many respects, this scenario is similar to the Building 10 subsurface scenario, except workers were likely standing on contaminated soil as much as full time (though likely considerably less) and workers involved in subsurface activities for limited time periods. Standing on contaminated soil was likely associated with lower exposures rates because the workers would have been walking around and not always exposed to areas with elevated soil contamination; however, exposure times would have been much larger than those associated with subsurface activities.

For workers involved in subsurface activities, the workers were likely exposed to higher soil contamination levels (e.g., possibly working in close proximity to the upper 95th percentile subsurface outdoor radionuclide concentrations for the entire time they was involved in subsurface work). However, the durations of such exposures were likely limited (i.e., about 1 month per year). A reasonable strategy would be to assume 2,000 hours per year exposure to the average soil contamination levels above ground and perhaps 1 month per year in close proximity to higher end soil concentrations (e.g., the 95th percentile outdoor subsurface soil contamination levels) for subsurface activities outdoor.

The NIOSH white paper effectively adopts this strategy. However, we need to take a close look at the data and assumptions used in the white paper to ensure that the actual approach employed is scientifically sound, claimant favorable, and, that, if substitute data were used, the data are reasonable as applied to this exposure scenario.

As described beginning on page 6 of the white paper, considerable surface and subsurface data were collected in many outdoor areas in 1984 by the NRC and again in the early 1990s in support of license termination. Page 8 of the white paper states that 2,391 soil samples were collected prior to remediation and that 1,629 samples were analyzed for gross alpha, and 762 samples were collected for uranium and thorium and analyzed using isotopic identification.

The white paper explains that NIOSH compiled these data in a spreadsheet and determined that the gross alpha and uranium concentrations in the soil had a GM of 9.54 picocuries per gram (pCi/g), a GSD of 4.61, and a 95th percentile concentration of 117.86 pCi/g. In a similar manner, the gross alpha and thorium concentrations were compiled and had a GM of 4.57 pCi/g, a GSD of 6.02, and a 95th percentile value of 87.55 pCi/g, which was used as the basis for deriving external exposures outdoors.

As described in the white paper, there were many locations outdoors where the subsurface and surface soils were contaminated. In addition, there is evidence that the soils were excavated and moved about during the residual period. Hence, as is the case for subsurface activities in Building 10, it is reasonable to ask whether these data can be used as a substitute for the contamination levels outdoors in the above- and below-ground environment during the residual period as a basis for reconstructing the external and internal doses to workers. SC&A believes that these data can be used in this manner for the same reasons described above in the discussion regarding subsurface activities inside Building 10.

Internal outdoor doses could also be evaluated using these soil concentrations and appropriate dust loadings (e.g., 200 $\mu g/m^3$) and exposure durations of perhaps 2,000 hours per year outdoors above ground and perhaps 1 month per year outdoors in the subsurface environment. SC&A did not perform these calculations, since our goal at this time is to demonstrate that such doses can be reconstructed in a scientifically sound and claimant-favorable manner.

SC&A suggests that NIOSH derive the upper 95th percentile of the radionuclide concentrations observed in subsurface samples, along with an exposure duration of perhaps 200 hours per year and a dust loading of about 200 $\mu g/m^3$ as the basis for estimating internal doses associated with outdoor subsurface work.

As an example of such a calculation, Table 2 presents a compendium of outdoor and indoor data. Among the highest 95th percentile uranium concentrations is 273.15 pCi/g collected in the metals recovery area. The inhalation effective dose commitment to a worker exposed 2,000 hours per year to resuspended uranium, where the dust loading was chronically 200 $\mu g/m^3$ would be as follows:

$$273.15 \text{ pCi/g} \times 200 \text{ µg/m}^3 \times 1.2 \text{ m}^3\text{/hr} \times 2{,}000 \text{ hr/yr} \times 9.4\text{E-6 Sv/Bq} \times 0.037 \text{ Bq/pCi} \times 1\text{E-6 g/µg} \times 1\text{E5 Sv/mrem} = 4.56 \text{ mrem/yr}$$

3.5.2 External Exposures

The external dose rates at the Building 12 burial ground are based on the soil sample analyses reported by Sowell (1985). Using the 473 sets of surface soil sample analyses for U-235, U-238, thorium-232 (Th-232), and radium-226 (Ra-226), we calculated an annual effective dose of 5.32

mrem to a worker exposed to the soil having the average concentrations of these four radionuclides and their radioactive progenies, based on the external dose coefficients listed in FGR 12 for soil of infinite extent contaminated to an infinite depth. (Contamination that extends >15 cm essentially constitutes an infinite depth for external dose rate calculations.) U-235, U-238, and Ra-226 were assumed to be in full secular equilibrium with their short-lived progenies, while Th-232 was assumed to be in equilibrium with its entire decay chain.

We also determined the dose rates to a worker in an excavation at the burial ground. We first calculated the weighted average concentrations of radionuclides reported by Sowell (1985) for core samples collected at 28 locations for which core sample data were reported at two or more depths. We then calculated the dose rates that would be experienced by a worker exposed to an infinite layer of soil contaminated at the concentrations equal to those of the core samples, again using the FGR 12 external dose coefficients. We then selected the 95th percentile of these 28 results. Assuming a worker was exposed for 200 h/yr, their annual effective dose from this pathway would have been 2.08 mrem. If we assume that they spent 90% of their working hours on the surface and the remaining 10% in an excavation, their total annual external effective dose would have been 6.87 mrem.

In the above analyses, we used the burial ground data provided by Sowell (1985) as the basis for demonstrating a valid strategy for reconstructing external exposures outdoors, both above and below ground. In preparing this report, SC&A analyzed the calculation files provided by NIOSH in Table 2. These data have not yet been independently evaluated by SC&A; however, they are summarized as provided for preliminary analysis. As may be noted, the data for the burial site is at the high end of the reported soil concentrations. Certainly, other assumptions can be made. However, the important point is that it is plausible to assign a bounding dose to workers involved in this exposure scenario.

Table 2. Summary of Available Indoor and Outdoor Surface and Subsurface Soil Contamination Data

Location	Min	Median	GM	95th Percentile	Max
Subsurface inside building 10 pCi/g gross alpha and U Total	9.75	146	185.52	5,878.1	53,224.7
Outside Building 10 (all locations) pCi/g – Uranium	2.00	7.18	9.54	174	13,468
Outside Building 10 (all locations) pCi/g – Thorium	0.02	0.87	4.57	2.16	10,240
Building 10 perimeter and zinc bun area – Uranium	2.00	5.92	6.89	46.95	5,877.8
Building 10 perimeter and zinc bun area – Thorium	0.02	0.83	0.81	1.46	7.18
Burial area – Uranium	2.42	7.26	11.08	150.54	13,468
Burial area – Thorium	0.10	0.89	1.04	2.88	10,240
Stockade and Rail Spur – Uranium	2	2	7.43	129.3	3,000
Metals Recovery Area – Uranium	2	18	14.06	273.15	1,680

4 FINAL COMMENTS

We believe that SC&A's analyses reveal that a considerable body of data is available characterizing the nature and extent of radionuclide contamination indoors and outdoors and in the above- and below-ground environment during the residual period. In addition, our example dose calculations demonstrate that the potential doses to M&C workers involved in maintenance and repurposing activities during the residual period were quite low, even using highly conservative assumptions. Therefore, we conclude that doses to M&C workers during the residual period, including workers involved in maintenance and repurposing activities, can be reconstructed in a scientifically sound and claimant-favorable manner by using upper end values of the contamination levels measured during the 1980s and 1990s, along with appropriately conservative assumptions regarding airborne dust loadings and exposure durations.

Throughout this report, SC&A identified issues that should be explicitly addressed in the ER and its amendments, taking advantage of the various reports prepared by NIOSH and the insightful contributions provided by the petitioners, especially those provided during the interviews held on October 24–26, 2017 and during the M&C Work Group meetings held on May 3, 2018, and November 20, 2018. SC&A made every attempt to characterize the numerous exposure scenarios and pathways that M&C workers might have experienced during normal work activities and during maintenance and refurbishing activities that took place during the residual period. We believe that there might have been other exposure scenarios not explicitly addressed by NIOSH and SC&A. However, because of the range of scenarios that we have addressed and the conservative assumptions used in characterizing and reconstructing doses associated with these scenarios, we believe that we have been able to assign scientifically sound and claimant-favorable bounding doses that M&C workers might have experienced during the residual period. However, during the November 20, 2018 Work Group meeting, the petitioner raised two new pathways that they believed were not adequately addressed by previous models; i.e., thorium exposures and welding scenarios.

SC&A believes that, though the NIOSH ER explicitly accounts for internal thorium exposures by performing internal dose calculations assuming the limiting radionuclide (i.e., uranium or thorium), NIOSH and SC&A did not explicitly address external exposures to thorium progeny. Our modeling of external exposures explicitly included U-238 and its short-lived progeny, U-234, and U-235 and its short-lived progeny, because the progeny of U-234 (i.e., Th-230) serves as a "block" to subsequent gamma- and beta-emitting progeny due to Th-230's 7.7E4 year half-life. However, in the case of Th-232, it is likely that all of its progeny grew in during the residual period and contributed to external dose. Though the dosimetry programs performed during the 1990s in support of final site cleanup give no evidence that such exposures might have been of some significance, the ER and its amendment should explicitly consider this pathway.

With respect to welding, though NIOSH and SC&A addressed a very broad range of internal exposure scenarios and used claimant-favorable assumptions, we did not address some of the unique characteristics associated with welding metals that might be contaminated with radionuclides. For example, welding generates fumes with very small particle sizes that should be evaluated as part of the ER and its amendments.

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APPENDIX A: INDEPENDENT VERIFICATION OF SKIN DOSE FROM URANIUM DUST

Prepared by Michael W. Mallett, September 15, 2013

An independent verification of skin dose from uranium dust contamination was performed. The original dose estimate was previously reported by Thomas and Bogard (1994). The report estimated the skin dose from U-238 in secular equilibrium with short-lived daughters Th-234 and Pa-234m to be 40 mrem/h per 10,000 dpm/cm^2. This result was computed using VARSKIN (version 1).

The analysis reported here was performed using both VARSKIN (version 4) and MCNP (version 5). Both results indicate the dose reported by Thomas and Bogard to be a conservative overestimate of the skin dose.

VARSKIN Method

Using the current version of VARSKIN (version 4), the dose to the skin was calculated using a disc source 100 cm^2 in area with no air gap thickness (i.e., contamination directly on the surface of the skin). The dose was averaged over 100 cm^2. The resultant skin dose calculated at a depth of 7 mg/cm^2 was 35 mrem/h per 10,000 dpm/cm^2. The difference from the previously reported value is attributed to different beta spectra in the VARSKIN data tables.

MCNP Method

Using MCNP, the dose to the skin was determined utilizing a 30 cm diameter ICRU sphere per the method reported by Endo et al (2011). The material specifications were defined in ICRU 39. The source term was the photon and beta emissions of U-238 in secular equilibrium with short-lived daughters Th-234 and Pa-234m emitted isotropically from a planar surface source uniformly distributed over the sphere. The skin dose was computing using the *F8 tally (pulse height tally, energy deposited in cell) averaged over a 10 mm-thick concentric shell within the sphere centered at a depth of 0.07 mm. The tally sampling was based on the model previously reported by Ilas et al. (2008). The resultant skin dose was calculated as 20 mrem/h per 10,000 dpm/cm^2.

Validation of the VARSKIN code using MCNP has been previously reported (Hamby et al 2011). Disc source geometries indicated excellent agreement between the two methodologies. The methodology used by Hamby et al. was a limited-scale geometry (1-mm diameter disc) and thus generated an upper range to the calculated skin dose as compared with the large-scale geometry reported here.

Both the VARSKIN method and MCNP method results reported here suggest the estimated skin dose due to uranium dust reported by Thomas and Bogard is a conservative overestimate.

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