Draft

Advisory Board on Radiation and Worker Health
National Institute for Occupational Safety and Health

Metals and Controls Corp. Exposure Pathway Evaluation

Contract No. 75D30119C04183
Document No. SCA-TR-2021-SEC004, Revision 0

Prepared by

Rose Gogliotti, MS

SC&A, Inc.
2200 Wilson Blvd., Suite 300
Arlington, VA 22201-3324

October 25, 2021

SC&A, Inc. technical support for the Advisory Board on Radiation and Worker Health's review of NIOSH dose reconstruction program

Document title	Metals and Controls Corp. Exposure Pathway Evaluation
Document number	SCA-TR-2021-SEC004
Revision number	0 (Draft)
Supersedes	NA
Effective date	October 25, 2021
Task manager	Rose Gogliotti, MS [signature on file]
Project manager	Bob Barton, CHP [signature on file]
Document reviewer(s)	Bob Barton, CHP [signature on file] John Mauro, PhD, CHP [signature on file]

Record of revisions

Revision number	Effective date	Description of revision
0 (Draft)	10/25/2021	Initial issue

Table of Contents

List of Tables

List of Figures

Abbreviations and Acronyms

ABRWH	Advisory Board on Radiation and Worker Health
AWE	Atomic Weapons Employer
D&D	decontamination and decommissioning
DCF	dose conversion factor
dpm	disintegrations per minute
dpm/100 cm^2	disintegrations per minute per 100 square centimeters
DR	dose reconstruction
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
EPA	U.S. Environmental Protection Agency
ER	evaluation report
FGR	Federal Guidance Report
g	gram
GM	geometric mean
GSD	geometric standard deviation
h	hour
HFIR	High Flux Isotope Reactor
HVAC	heating, ventilation, and air conditioning
keV	kiloelectron volt
m	meters
m^2	square meter
m^3	cubic meter
m^3/h	cubic meters per hour
M&C	Metals and Controls Corporation
µCi	microcurie
µg	microgram
mR	milliroentgen
mrad	millirad
mrad/h	millirad per hour
mrem	millirem
mrem/yr	millirem per year
NIOSH	National Institute for Occupational Safety and Health

ORAUT	Oak Ridge Associated Universities Team
pCi/g	picocurie per gram
RF	resuspension factor
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	technical basis document
TI	Texas Instruments
U	uranium
WG	Work Group

1 Introduction and Background

At its March 18, 2021, meeting, the Metals and Controls Corp (M&C) Work Group (WG) tasked SC&A to review each of the exposure models the National Institute for Occupational Safety and Health (NIOSH) presented in its January 21, 2021, paper, "Response to Comments from the Metals and Controls Corp. Work Group Meeting held on September 2, 2020" (NIOSH, 2021a). The paper lays out six exposure pathways that have been developed over many iterations in support of the evaluation of Special Exposure Cohort (SEC) Petition SEC-00236. These pathways include the following (numbers are assigned by SC&A for the purposes of discussion in this report):

1. Subsurface Inside
2. Subsurface Outside
3. Roof and Overhead
4. Welding
5. HVAC Maintenance
6. Remaining (nonmaintenance)

All M&C workers, irrespective of their job titles, will be assigned maintenance workers doses because it is unclear which workers were involved in various maintenance activities. Each of these pathways have internal and external exposure risks to uranium and thorium.

2 External Dose

In the SEC-00236 petition evaluation report (ER), NIOSH (2017a) proposed using dosimetry data from 1967, the last year of operations (Landauer, 1965–1974), to bound doses to workers. In this analysis, NIOSH calculated the 95th percentile of measured external doses to be 150 millirem per year (mrem/yr) (12.5 mrem/month). SC&A's (2018a) review of the ER identified a number of issues related to this calculation and how the data were being applied. NIOSH revised its approach in the September 12, 2018, M&C SEC issues matrix (NIOSH, 2018b) and derived a beta skin dose of 12 mrem/month and a penetrating dose of 4 mrem/month.

SC&A reviewed the NIOSH revised modeling in the matrix and agreed with the penetrating dose modeled. SC&A modeled beta doses and had a modestly different interpretation of beta dosimetry results. SC&A calculated a similar but lower dose of 9.7 mrem/month. The difference is modest; therefore, SC&A believes this concern is not worth pursuing further.

NIOSH's (2021a) approach mirrors the method presented in the September 12, 2018, M&C SEC issues matrix (NIOSH, 2018b). NIOSH proposes assigning the quarterly geometric mean (GM) gamma dose rate of 12 mrem/quarter (4 mrem/month) and the quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month), both with a geometric standard deviation (GSD) equal to the default value of 5 in Battelle-TBD-6000, revision 1, "Site Profiles for Atomic Weapons Employers that Worked Uranium Metals" (NIOSH, 2011). NIOSH proposes to assume a claimant-favorable gamma energy of 100 percent 30–250 kilo-electronvolts (keV) and electron energy of 100 percent >15 keV. The paper continues:

> These dose rates will be applied to the maintenance work exposures [pathways 1 through 5] with no adjustments for source-term depletion 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. For all non-maintenance work exposures [pathway 6], source-term depletion adjustments will be considered (per the guidance in ORAUT-OTIB-0070) to determine the non-maintenance exposure rates throughout the residual period [[NIOSH,] 2012]. [NIOSH, 2021a, p. 15]

SC&A's evaluation of each pathway discussed in the subsequent sections of this report includes an evaluation of the applicability of the NIOSH external dose modeling to the corresponding exposure scenario.

3 Subsurface Models

Two of the six modeled exposure pathways involve subsurface work. NIOSH (2021a, p. 14) indicates that "NIOSH will assume an occupancy rate of two months per year for subsurface work (2000 hours per year x 2/12 {fraction of year} = 333.33 hours per year)." In other words, NIOSH intends to assume a single subsurface model per individual, and "If the subsurface location (e.g., inside or outside) cannot be determined, the most claimant-favorable work location will be assigned" (p. 14).

3.1 Subsurface inside pathway

The first pathway, "subsurface inside," is used by NIOSH to model exposures caused by workers accessing materials below the concrete slab inside Building 10 and, to a lesser degree, Building 4. These exposures may have been caused by:

- workers snaking clogged pipes
- workers removing and replacing subsurface pipes
- repurposing work that required breaking the concrete slab to modify the foundation for equipment
- work inside trenches

NIOSH modeled this pathway by assuming workers are exposed to the 95th percentile of the sampled uranium results from inside the pipes in Building 10 (6,888 picocuries per gram (pCi/g)), dust loading is equal to the 95th percentile Mound air sampling, and workers spent 2 months a year performing these activities. Table 4 of NIOSH (2021a) provides an example of the doses calculated in the subsurface inside pathway. SC&A was able to replicate the calculated annual committed effective doses in table 4, as shown in example 3-1. Ingestion doses were calculated using guidance from OCAS-TIB-009 (2004). SC&A is providing this example to establish SC&A understood the assumptions NIOSH was using to calculate doses from this exposure pathway. Organ doses rather than committed effective doses are assigned in dose reconstructions (DRs) performed under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA).

Example 3-1: Annual uranium intakes and committed effective doses from subsurface inside Building 10 pathway

$$U\ inhal.intake = [U\ 95th\ Percentile] * dust\ loading * inhal.rate * occupancy\ factor$$

$$6.9 * 10^{-9} \frac{\mu\text{Ci}}{\text{ug}} * 212\ \mu \frac{g}{m^3} * \frac{1.2\ m^3}{hour} * \frac{333.33\ hours}{year} = 5.85 * 10^{-4} \mu Ci$$

$$Inhal.Committed\ Effective\ Dose = 5.85 * 10^{-4} \mu Ci * \frac{2.52 * 10^4 mrem}{\mu Ci} = 14.7\ mrem/year$$

$$U\ ingestion\ intake = ingestion\ rate * [U\ 95th\ Percentile] * occupancy\ factor$$

$$\frac{50{,}000\ \mu\text{g}}{\text{8 hour workday}} * 6.9 * 10^{-9} \frac{\mu\text{Ci}}{\text{ug}} * \frac{333.33\ hours}{year} = 1.43 * 10^{-2} \mu Ci$$

$$Ingest.Committed\ Effective\ Dose = 1.43 * 10^{-2} \mu Ci * \frac{1.81 * 10^2 mrem}{\mu Ci} = 2.6\ mrem/year$$

$$Committed\ Effective\ Dose = 14.7 \frac{mrem}{year} + 2.6 \frac{mrem}{year} = 17.3\ mrem/year$$

Using the same approach as shown in example 3-1 for uranium exposure, NIOSH will assign a thorium committed effective dose of approximately 29 mrem. Thorium exposures are specifically discussed in section 3.1.2 of this report.

3.1.1 Data supporting intake model

The data used to quantify the concentration of uranium in the pipes originates from a 1995 Weston study to characterize the drain lines for remediation (Weston, 1996a). The subsurface work environment inside Building 10 was characterized by 20 sediment samples that were collected and analyzed for isotopic uranium before remediation. According to Weston (1996a), historical information and a pilot survey of the drainage lines were used to predict how material was expected to flow through the pipes. The 13 sampling locations within Building 10 were selected based on this information. At each sampling location, the concrete above the pipe was removed and the soil was excavated just below the pipe level. A section of the pipe was cut and opened, and a sample of the sediment/pipe residues/buildup was collected and submitted for isotopic analysis. When multiple pipes were found at the sampling location, samples from each pipe were taken. Field personnel observed the fraction of the pipe that was obstructed.

Figure 1 shows a diagram of a Building 10 with designations of the areas of interest assigned in remediation. Notably, only a small section of the building (as illustrated in the site map thumbnail in bottom right corner of figure 1) was determined to be an area of interested of concern for remediation. Figure 2 shows an overlay of the locations of piping within the building according to how they were remediated following the initial sampling and subsequent surveys. The blue, diagonally striped sections (designated “Priority 1”) show sections of piping that was removed. The red, gridded sections ("Priority 2") show areas of the pipe that were remediated by flushing the pipes, then left in place. The green, horizontally striped sections ("Priority 3") show the areas of pipe that were sampled from but left in place with no subsequent remediation performed. The remainder of pipes in the building that were not designated as in an affected area were also left in place because they were not believed to be contaminated. Attachment A gives the original Weston diagrams used to create figure 2, with highlighted areas of interest.

Figure 1. Areas in Building 10 identified from characterization surveys as being affected

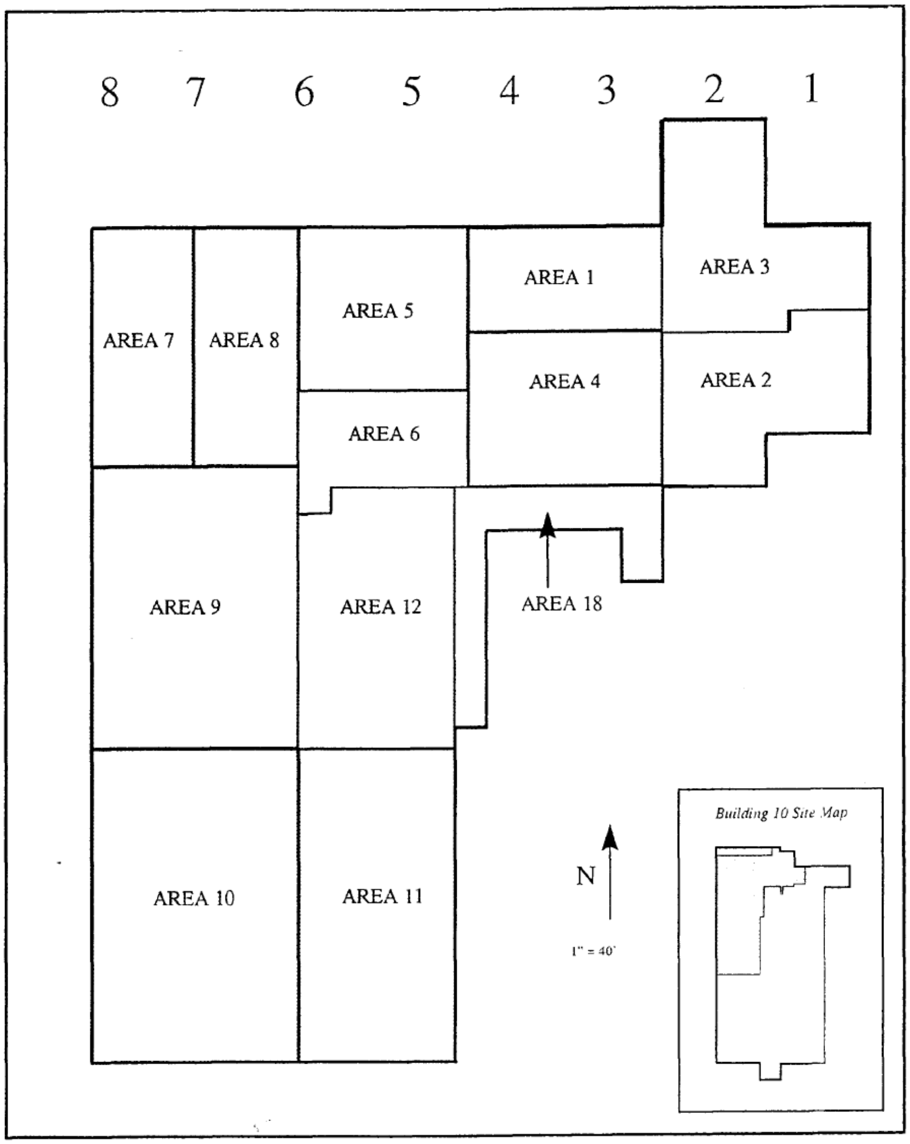
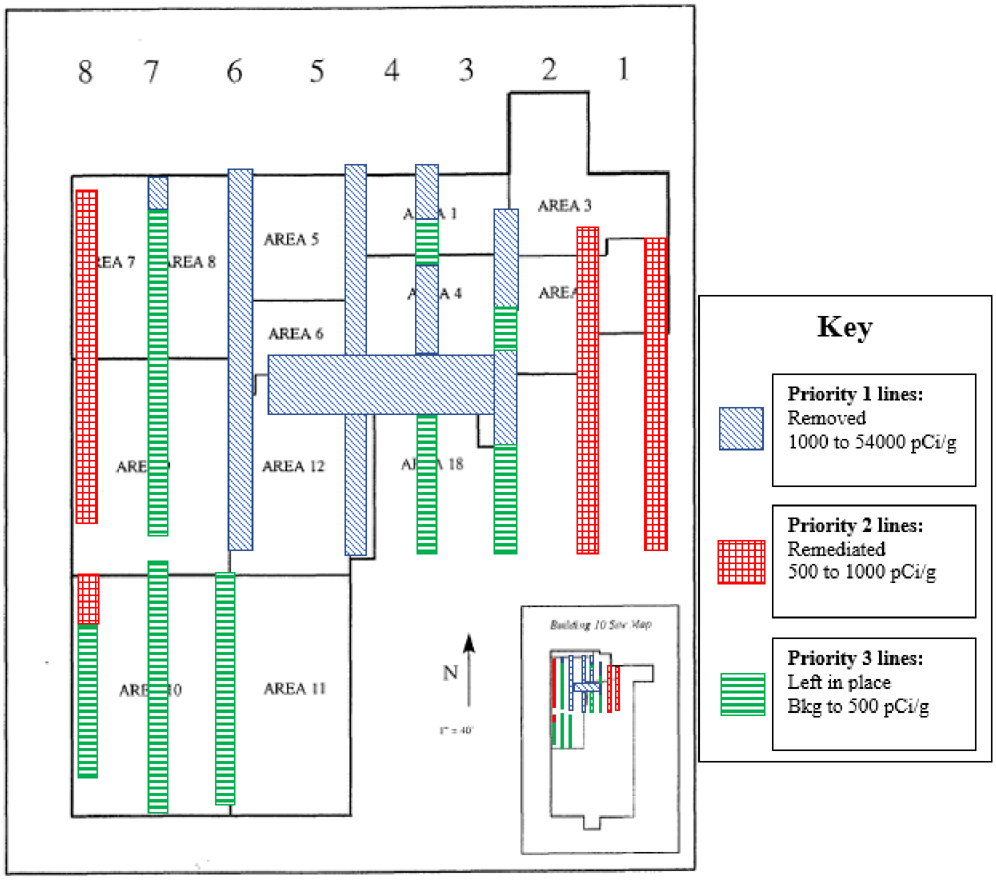


Figure 4. Building 10 - Affected Areas

Source: Weston (1996b), figure 4, PDF p. 15.

Figure 2. Approximate drainage pipe locations within Building 10 and total uranium concentrations



Source: Aggregate of Weston (1996b), figures 4 (PDF p. 15), 5.3 (PDF p. 175), 5.4 (PDF p. 176), and 5.5 (PDF p. 178).

Table 1 shows the results of the Weston (1996a) sampling. Analysis of the sampling data shows that 11 of the 20 samples identified total activity concentrations of below 200 pCi/g, and 17 of the 20 samples identified activity concentrations of below 850 pCi/g. The 95th percentile value obtained from the study was larger than all but two of the hundreds of isotopic samples taken across the entire site.

Table 1. Summary of Weston (1996a) drainage pipe sampling data

Parameter	Concentration of total uranium (pCi/g)
95th percentile	6,887.84
50th percentile	185.82
Minimum	9.75
Maximum	53,224.7

Other that the 1995 Weston drainage line survey (Weston, 1996a), additional drainage line samples were conducted on the priority 2 and priority 3 drainage lines in subsequent characterization efforts. Since these samples were conducted on pipes already deemed to be lower activity lines, SC&A believes it is appropriate to omit including these samples as a means of bounding materials in the pipes. Inclusion of these additional results would bias the sample results low. SC&A is unaware of any other samples with reported isotopics from within the Building 10 drainage lines.

3.1.2 Thorium assumption

Unlike the other exposure models for M&C that have thorium and/or gross alpha measurements, the subsurface Building 10 model is supported by only uranium data. There are no thorium or gross alpha measurements in the pipes. NIOSH's (2021a) response paper also suggests that it can bound Building 10 subsurface thorium exposures by assuming the subsurface pipes contained equivalent amounts by weight of natural uranium and thorium-232 (NIOSH, 2021a, p. 11):

> Since the specific activity of natural uranium is 6.83E5 pCi/g [NIOSH 2006], the 95th percentile concentration (6,888 pCi/g) corresponds to approximately 1% natural uranium by weight in the sediment. Therefore, NIOSH can assume the Building 10 subsurface sediments were contaminated with 1% of the specific activity of thorium-232 (1.1 E5 pCi/g) per gram of sediment. Using this approach, NIOSH calculated a concentration of 1,109 pCi/g and will use it to bound thorium exposures [NIOSH 2019, PDF p. 8].

SC&A (2020b) evaluated this approach most recently in July 2020 and presented two alternative approaches to model thorium concentrations using outdoor data. The WG discussed this review during the September 2, 2020, WG teleconference meeting (M&C WG, 2020). The thorium doses from SC&A's alternative approaches bracket the doses expected from NIOSH's thorium model. At that time, WG members expressed concerns that the outdoor data ratios of thorium to uranium are not representative of the ratios inside Building 10 pipes.

SC&A acknowledges that there is limited information about the time periods and types of waste that are associated with the outdoor contamination such that is difficult to establish with a high degree of precision a relationship between the activities seen outside and those found in the pipes within Building 10. The NIOSH approach avoids establishing this relationship by assuming equivalent amounts of uranium and thorium. SC&A also acknowledges that it is clear from multiple reports and inventory information (ASTRA, 1962) that uranium operations far exceeded thorium operations. SC&A believes there is no evidence that suggests that equal weights of thorium should be expected when uranium is present; however, there is not sufficient information to establish that it could not be that high. It is reasonable to conclude that it is unlikely that thorium weights would be greater than uranium weights. Therefore, given the uncertainties associated with the thorium-to-uranium ratios present on site and the fact that we cannot rule out a 1:1 mass ratio of uranium to thorium, the NIOSH approach is claimant favorable.

3.1.2.1 Concerns expressed by work group and petitioners

The petitioners and M&C WG have raised concerns about how representative the results of the 1995 drainage survey are of potential exposures experienced by maintenance workers throughout the residual period. These concerns included the possibility that materials within the pipes were diluted by water and solids flowing through the pipes throughout the residual period. They also include the possibility that materials were removed from the pipes by snaking and pipe replacement that altered the distribution within the drainage system.

SC&A acknowledges that there are uncertainties that impact the materials found in the subsurface environment at M&C. These uncertainties include but are not limited to how often the subsurface pipes were used, the flow rate of the pipes, the typical pH of the materials moving through the pipes, and how often and where the materials in the pipes were disturbed. With currently available information, it is not possible to succinctly quantify possible dilutions caused by these actions. However, SC&A believes it is reasonable to assume it is a non-zero number. Similarly, it is not possible to quantify what exact concentrations of material were in the pipes accessed by maintenance workers during *each individual extraction*. SC&A believes it is possible to *bound* the exposures workers may have received in any given year, such that no worker received a higher dose in the aggregate over the course of a year. In NIOSH's initial white paper on subsurface exposures (NIOSH, 2018a), NIOSH indicated that the geometric mean of the subsurface data would be used to quantify activities within the pipes. At that time, SC&A expressed concerns based on a similar justification as the petitioner, and NIOSH increased the value to the upper 95th percentile (NIOSH, 2018c, 2018d). SC&A believes the upper 95th percentile is bounding for the following reasons:

- Building 10 was a large building (over 15,000 square feet). Only a fraction of the subterranean pipes under Building 10 were identified as possibly affected (i.e., contaminated). Figure 1 shows the footprint inside Building 10 that the affected areas were believed to cover. Figure 2 shows the footprint of pipes identified to be potentially contaminated. These were the only pipes sampled from during the Weston 1995 study (Weston, 1996a). The rest of the building's subterranean pipes were not sampled. From that study and subsequent efforts, Weston determined that roughly a third of the originally sampled pipes needed no remediation of any kind, and they were left in place (shown in green boxes with horizontal stripes in figure 2).

- The NIOSH model assumes that all materials below the concrete slab in Building 10 have an activity concentration equal to the upper 95th percentile activity concentration inside the pipes. This means NIOSH will assume every worker, every time they access any part of the subterranean environment, encounters only the 95th percentile for the duration of the exposure.

    – All material in all pipes within Building 10 is assumed to be contaminated at the upper 95th percentile. As shown in figure 1 of the SC&A (2020a) roadmap, most of the samples taken to quantify the activities are orders of magnitude lower that the 95th percentile that NIOSH intends to apply.

    – All soils below the slab are assumed to be at the same activity concentration. In effect, this assumes that the pipes leaked to a degree that the material inside the pipes and the soils surrounding those pipes have the same levels of contamination. In reality, the soils surrounding the pipes were most likely contaminated to a lesser degree than the materials in the pipes. Most pipes were identified to be "2 to 3 feet (ft) below facility grade" (Weston, 1996b, PDF p. 171). The volume of the soils surrounding the pipes is substantially greater than the materials in the pipes such that any digging activity would dilute the airborne activities. The only soil sample that SC&A is aware of inside Building 10 was taken from the soils surrounding the pipe where the fuel pin was found. Inside that cast iron pipe that had the fuel pin, the total uranium concentration was found to be 53,000 pCi/g (i.e., around 10 percent pure natural uranium). The soils surrounding that pipe were found to have a total uranium concentration of 2,000 pCi/g (Weston, 1996a). Although this is a single data point, it lends credence to the notion that it is conservative to assume equal levels of contamination.

SC&A believes the impacts of the conservativeness of the assumptions applied to the model are greater than the impacts of the uncertainties associated with material dilution and extraction. Taken in combination, SC&A believes that the methods and assumptions used by NIOSH (2021a) to reconstruct internal doses to M&C workers involved in subsurface maintenance and repurposing activity in Building 10 during the residual period are scientifically sound and claimant favorable.

For perspective, it is also important to consider comparable dose reconstruction situations for residual periods at other Atomic Weapons Employer (AWE) sites. SC&A examined several AWE SEC discussions to identify situations in which little or no usable data are available from the end of operations and residual data taken many years into residual operations were deemed acceptable. In SC&A's opinion, the most comparable scenario occurred for Linde Ceramics regarding the reconstruction of internal dose for periodic entry into subsurface utility tunnels. In this case, the residual period[1] not already covered by an SEC was 1970 through mid-2006. Surface survey contamination data taken in 2001 (specifically, surface external beta measurements) were used to develop a 95th percentile surface contamination in the tunnels. This, along with typical breathing rates (1.2 cubic meters per hour (m^3/h)), a resuspension factor (10^{-6} per meter (m^{-1})), and an occupancy factor (50 percent exposure time to maintenance workers), was used to develop acceptable bounding intakes. It is notable that these derived intakes were used for the entire evaluated period without correction for degradation over time (~31 years between 1970 and 2001).

Another comparable dose reconstruction methodology for AWE sites during the residual period was used for Chapman Valve. At this site, two residual periods exist: May 1, 1949, through December 31, 1949, and January 1, 1991, through December 31, 1993. No usable air sampling data were available for the residual periods, so intakes were derived using survey results taken in 1992. Specifically, the highest of 30 direct reading alpha measurements were used with a resuspension factor of 10^{-6} m^{-1}, breathing rate of 1.2 m^3/h, and an exposure time of 2,000 hours. The resulting intake was applied for the entire period from 1949 through 1993. No adjustments were made to the intake rate due to degradation over time (over 40 years).

[1] The Linde Ceramics residual period is characterized by two distinct time periods: (1) the decontamination and decommissioning (D&D) and renovation period (1954–1969) and (2) the remaining residual period (1970–2006). SEC-00107 was granted for the D&D and renovation period (1954–1969).

3.1.3 External dose rate

NIOSH proposes assigning a quarterly GM gamma dose rate of 12 mrem/quarter (4 mrem/month) and a quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month), both with a GSD equal to the Battelle-TBD-6000 default value of 5 (NIOSH, 2011). To benchmark this value against the potential magnitude of the doses from exposures to materials inside pipes, SC&A examined data on the highest levels of residual radioactive contamination found in the available documents. Weston (1996a) listed the activity concentrations of the three naturally occurring uranium isotopes in the sediment or pipe scale in 22 pipes at 15 locations inside Buildings 4 and 10, 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, SC&A 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 drainpipes during the residual period.

In performing the analyses, SC&A assumed that the uranium-235 (U-235) and U-238 in the soil were in full equilibrium with their short-lived progeny and calculated the effective dose and skin dose from a year of standing on contaminated soil, using the dose coefficients for exposure to soil contaminated to an infinite depth tabulated in Federal Guidance Report (FGR) No. 12 (EPA, 1993). SC&A ranked the effective doses and skin doses corresponding to each of the 22 sampling locations, along with the cumulative volumes of pipe scale or sediment in each pipe, and calculated the dose corresponding to 95 percent of the cumulative volume by linear interpolation. In this manner, SC&A derived 95th percentile *annual* doses of 153 mrem effective dose and 390 mrem skin dose. Assuming the same worker was involved in subsurface activities for 2 month per year, the bounding annual penetrating and skin dose to such a hypothetical worker would be 153*2/12 = 25.5 mrem/yr (NIOSH's model assumes 8 mrem/yr) and 390*2/12 = 65 mrem/yr (NIOSH's model assumes 24 mrem/yr), respectively.

Finding 1: Building 10 subsurface external exposures not bounded

SC&A finds that NIOSH's proposed external dose rate assumptions are inconsistent with the contamination levels assumed for the subsurface of Building 10. SC&A's independent calculations suggest dose rates from the modeled pathway are expected to be substantially greater. NIOSH's 2017 SEC ER proposed using the 95th percentile dosimetry values (with adjustments for missed dose) of 200 mrem/year (16.7 mrem/month). SC&A believes it is more appropriate to assign elevated subsurface exposures inside Building 10 using the 95th percentile of the dosimetry with occupancy adjustments.

3.2 Subsurface outside pathway

Remediation activities at M&C identified that the soils surrounding Building 10, the burial grounds, and other outdoor areas were contaminated. It is also known that on at least two occasions during the residual period, workers excavated the soil in these areas. According to the worker interviews, smaller scale soil penetrations may have also occurred.

To model subsurface exposures, NIOSH will use the upper 95th percentile value (117.86 pCi/g for the dose calculations for uranium and 87.5 pCi/g for thorium) from outside soil sampling, a dust loading equal to the 95th percentile Mound air sampling, and the assumption that maintenance workers spent 2 months a year performing these activities. Table 4 of NIOSH (2021a) provides an example of the doses calculated in the subsurface outside pathway. SC&A was able to replicate the calculated annual committed effective doses in table 4, as shown in example 3-2. SC&A is providing this example to establish SC&A understood the assumptions NIOSH was using to calculate doses from this exposure pathway. Organ doses rather than committed effective doses are assigned in DRs performed under EEOICPA.

Example 3-2: Annual uranium intakes and committed effective doses from subsurface outside pathway

$$U\ inh.intake = [U\ in\ soil] * dust\ loading * inhalation\ rate * occupancy\ factor$$

$$1.18 * 10^{-10}\,\frac{\mu\text{Ci}}{\text{ug}} * 212\ \mu\frac{g}{m^3} * \frac{1.2\ m^3}{hour} * \frac{333.33\ hours}{year} = 1.00 * 10^{-5}\mu Ci$$

$$Inhal.Committed\ Effective\ Dose = 1.00 * 10^{-5}\mu Ci * \frac{2.52 * 10^4\ mrem}{\mu Ci}$$
$$= 0.25\ mrem/year$$

$$uranium\ ingestion\ intake = ingestion\ rate * [U\ in\ soil] * occupancy\ factor$$

$$\frac{50{,}000\ \mu\text{g}}{8\ \text{hour workday}} * 1.18 * 10^{-10}\,\frac{\mu\text{Ci}}{\mu\text{g}} * \frac{333.33\ hours}{year} = 2.46 * 10^{-4}\mu Ci$$

$$Ingest.Committed\ Effective\ Dose = 2.46 * 10^{-4}\mu Ci * \frac{1.81 * 10^2 mrem}{\mu Ci}$$
$$= 4.44 * 10^{-2}\ mrem/year$$

$$Committed\ Effective\ Dose = 0.25\,\frac{mrem}{year} + 4.44 * 10^{-2}\,\frac{mrem}{year} = 0.3\ mrem/year$$

Thorium exposures are calculated in a similar fashion by replacing uranium values with applicable thorium values. This results in a committed effective dose equivalent of 2.3 mrem/yr.

3.2.1 Data supporting model

Considerable surface and subsurface soil data were collected in many outdoor areas in the 1980s by the NRC and again in the1990s in support of license termination. NIOSH’s October 24, 2018, white paper indicates that 2,391 soil samples were collected prior to remediation, 1,629 samples were analyzed for gross alpha, and 762 samples were collected for uranium and thorium and analyzed using isotopic identification (NIOSH, 2018d, p. 8). SC&A received a copy of the NIOSH spreadsheet used to analyze the isotopic data in November 2018. The data supporting the outdoors subsurface characterization comes from several data sources, as shown in table 2.

Table 2. Data sources used for outside subsurface modeling

SRDB Ref. ID	Outside location
94371	Building 10 perimeter
94371	Burial Area
164755	Burial Area
161141	Stockade and Rail Spur
161141	Building 10 perimeter and zirconium burn area
165968	Metals Recovery Area

3.2.2 Concerns expressed by work group

In a January 12, 2021, email (Beach, 2021), WG members raised the concern that the "Debris buried in the burial site was not representative of radioactive materials (U and Th) handled throughout the AWE operational period (1952-67), but was a selective sample of those materials, largely from 1958-1961." NIOSH responded to this concern and similar concerns raised in the September 2020 meeting (M&C WG, 2020) in a memorandum dated February 8, 2021 (NIOSH, 2021b). SC&A agrees with the WG members' concern that the data from the waste and associated contamination in the burial grounds are representative of only a subset of the work performed during operations. The wastes do not capture the entirety of the operations period. However, SC&A does not believe this represents a DR infeasibility. Although the data do not represent all of the operations period, they do represent the remaining source term on site throughout the residual period. The burial grounds data are not being used to characterize the work from the AWE operational period (SEC-00149 was granted January 9, 2010, to cover AWE operations at M&C). The burial grounds sampling data represent material that was on site and thus potentially excavated during the residual period. Thus, SC&A believes it is appropriate to include the data when modeling exposures during the residual period. NIOSH has elected to not use any outdoor data to quantify thorium concentrations inside Building 10; therefore, there is no need to qualify the representativeness of thorium-to-uranium ratios obtained from these data.

The January 2021 WG email also raised the concern that the burial ground data may not be representative of the exposures experienced by workers because there were known disturbances during the residual period. There are two known major soil disturbances to the burial grounds: (1) soil grading in 1968 following the construction of Building 12 and (2) the installation of the compressed airline in 1980.

Although the exact date is not known, the soil grading in 1968 (Texas Instruments Incorporated (TI), 1994, PDF p. 35) took place early in the residual period, which extends from January 1, 1968, through March 21, 1997 (SEC-00149). Any materials dispersed in 1968 throughout the site would be the same materials that workers were exposed to during the remainder of the residual period. SC&A believes that, because this disturbance happened early in the residual period, soil sampling from the burial area in the 1980s and 1990s is representative of potential exposures encountered by maintenance workers.

The installation of the compressed airline between Buildings 11 and 12 was done in August 1980. This airline was installed below grade and required a trench to be dug, part of which dug through a section of the burial site. According to a 1981 NRC inspection report (NRC, 1981, PDF p. 128), the area that was dug up was "slightly contaminated" and "a trained health physicist, surveyed the material dug up and placed any contaminated materials into 55 gallon drums. Eleven 55 gallon drums were sent to the Barnwell, South Carolina, burial site on October 31, 1981." The remaining soils were reburied on the eastern edge of the developed portion of the site. This area was later surveyed during remediation, but levels of radioactivity detected were below applicable NRC release criteria and thus it did not require remediation (TI, 1996, PDF p. 33). Based on these accounts, only a small amount of contaminated material was removed from the site. The burial ground is large in comparison to the small amount of material displaced by the trench. SC&A does not believe that this removal altered the distribution of the materials in the burial grounds significantly enough to make later surveys not representative of the earlier exposure potential.

3.2.3 External dose rate

NIOSH proposes assigning a quarterly GM gamma dose rate of 12 mrem/quarter (4 mrem/month) and a quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month), both with a GSD equal to the Battelle-TBD-6000 default value of 5 (NIOSH, 2011). To benchmark this value against the known activities in the outside subsurface environment, SC&A calculated external dose rates from the burial grounds, which have the highest activities identified outside at M&C.

SC&A determined the dose rates to a worker in an excavated area at the burial ground by first calculating 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. SC&A 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. Assuming the 95th percentile of these 28 results and that a worker was exposed for 333.33 hours/year, their annual effective dose from this pathway would have been approximately 3.5 mrem. This dose is less than half of the NIOSH suggested value of 8 mrem per year. Therefore, SC&A finds the NIOSH assumptions to be bounding and claimant favorable when applied to the outside subsurface pathway.

3.3 Subsurface occupancy

NIOSH (2021a, p. 14) indicates that:

> NIOSH will assume an occupancy rate of two months per year for subsurface work (2000 hours per year x 2/12 {fraction of year} = 333.33 hours per year). If the subsurface work area (e.g., inside or outside) cannot be determined, the most claimant-favorable work location will be assigned.

In other words, NIOSH intends to assume a single subsurface model per individual. NIOSH will choose a model based on the subsurface work area scenario that the DR determines to be the most likely the energy employee experienced: If the exposure location (e.g., inside or outside) cannot be determined, the most claimant-favorable work location will be assigned. When considering the wealth of evidence at the site, SC&A questions the decision to limit occupancy to either inside or outside. SC&A has not seen evidence that justifies the assumption that workers who performed surface work inside did not also participate in outdoor excavations and vice versa.

Observation 1

SC&A reviewed the claimant interviews and does not believe that there is sufficient evidence to limit any individual's subsurface exposures to a single subsurface scenario. The interviews indicate that, irrespective of an individual's job title, they may have been asked to complete any task on site. SC&A believes that means an individual could have participated in both indoor and outdoor subsurface scenarios within a year.

3.4 Dust loading for subsurface activities

NIOSH indicates it will use a dust loading of 212 micrograms per cubic meter (µg/m^3) for subsurface work that originates from air sampling data collected during remediation activities at Mound. The applicability of this value to use at M&C to represent both indoor and outdoor dust loads will be evaluated in a separate SC&A review document.

4 Roof and Overhead

It is known from the worker interviews and petitioner statements that the roof and overhead areas inside Building 10 required frequent maintenance during the residual period. Since these maintenance-related activities could have potentially removed materials with the highest concentrations, NIOSH will use the 95th percentile removable contamination level of 8.99 disintegrations per minute per 100 square centimeters (dpm/100 cm^2), a resuspension factor (RF) of 10^{-4} per meter (m), and a breathing rate of 1.2 m^3/h and will assume maintenance workers spent 1 month a year (166.67 hours) performing these activities. Table 4 of NIOSH (2021a) provides an example of the doses calculated in the roof and overhead pathway. SC&A was able to replicate the calculated annual committed effective doses in table 4, as shown in example 4-1 for uranium. SC&A is providing this example to establish SC&A understood the assumptions NIOSH was using to calculate doses from this exposure pathway. Organ doses rather than committed effective doses are assigned in DRs performed under EEOICPA.

Example 4-1: Annual uranium intakes and committed effective doses from roof and overhead pathway

$$U\ inh.intake = removable\ alpha * RF * occupancy\ factor * inhalation\ rate$$

$$8.994 \frac{dpm}{100cm^2} * \frac{\mu Ci}{2{,}220{,}000\ dpm} * \frac{10{,}000\ cm^2}{m^2} * \frac{10^{-4}}{m} * \frac{167.67\ hours}{year} * 1.2 \frac{m^3}{h} = 8.15 * 10^{-6}\ \mu Ci/year$$

$$U\ inh.dose = 8.15 * 10^{-6}\ \mu Ci/year * \frac{2.52 * 10^4 mrem}{\mu Ci} = 0.2\ mrem/year$$

$$uranium\ ingestion\ intake = ingestion\ rate * removable\ alpha * occupancy\ factor$$

$$\frac{10^{-4}\ m^2}{hour} * 89.94 \frac{dpm}{100cm^2} * \frac{\mu Ci}{2220{,}000\ dpm} * \frac{10000cm^2}{m^2} * \frac{48\ hours}{year} = 1.94\ * 10^{-5}\ \mu Ci/year$$

$$\text{U ingestion dose} = 1.94 * 10^{-5}\,\frac{\mu Ci}{year} * \frac{1.81 * 10^{2} mrem}{\mu Ci} = 1.23 * 10^{-3}\ mrem/year$$

$$inhalation\ dose + ingestion\ dose = 0.20\,\frac{mrem}{year} + 1.23 * 10^{-3}\,\frac{mrem}{year} = 0.21\ mrem/year$$

Thorium doses are calculated by replacing the uranium dose conversion factors (DCFs) with thorium DCFs and result in a committed dose calculation of less than 1 mrem. Since the results are gross alpha, NIOSH will assign the most claimant-favorable mixture of thorium or uranium.

4.1 Data supporting the intake model

NIOSH used 285 grid average alpha survey data to quantify the removable contamination found in the roof and overhead areas. These surveys were completed in 1982 in support of license termination at M&C. According to NIOSH's (2021a) response paper (p. 12):

> Ten of these survey results are from the walls and ceiling of the Unclad Fuel Manufacturing Area . . . and 275 are from the Clad Fuel Manufacturing Area on the ceiling, pipes, buss ducts, wall, and columns (1.5 meters high to ceiling), and the roof near the ventilation exhaust ducts. These surveys were performed by M&C and verified by NRC inspectors [[NRC & TI, 1982–1983], PDF pp. 70–72, 75–83, 140–141].

It is worth noting these surveys were completed before the positive temperature coefficient powder explosion that is believed to have occurred in the late 1980s or early 1990s. Therefore, the subsequent cleanup activities reported by an interviewee (NIOSH, 2017b, PDF pp. 9–10) did not impact the readings. These results were from direct probe measurements; therefore, NIOSH indicated it will assume that 10 percent of the measured activity was associated with removable activity per the guidance in ORAUT-OTIB-0070 (NIOSH, 2012).

NIOSH provided SC&A with the NIOSH calculation files supporting its assessment in November 2018. SC&C reviewed the files and found that, in general, the direct probe grid averages were as described by NIOSH. SC&A noted that eight of the grid averages were reported as direct alpha measurements from the bus ducts when they actually represent removable alpha measurements from the bus ducts. Although these data are still relevant, it is inappropriate to treat the data as a direct measurement instead of removable contamination. Complicating the calculation, NIOSH identified the minimum in the dataset from these swipe data (1.7 dpm/100 cm^2) and used it to replace all reported zeros instead of the higher minimum (3.65 dpm/100 cm^2). Correcting for these minor errors, SC&A calculated a removable contamination GM of 1.34 dpm/100 cm^2 with a GSD of 2.98. This is very similar to the GM of 1.09 dpm/100 cm^2 with a GSD of 3.61 dpm/100 cm^2 calculated by NIOSH. Because the GSD calculated by NIOSH was higher, the NIOSH-calculated 95th percentile, 8.99 dpm/100 cm^2, is greater than the SC&A-calculated value of 8.06 dpm/100 cm^2. These differences are modest, and the NIOSH value is larger, so SC&A determined that these differences and minor errors have no adverse effect on the roof and overhead dose reconstruction pathway.

4.2 Concerns expressed by M&C Work Group

While evaluating the SEC petition, M&C Work Group members raised questions about the representativeness of the data in terms of where and over what time period the data were collected. In particular, one Advisory Board on Radiation and Worker Health member asked whether some of the measurements were collected on the roof outdoors, where weathering would remove the contamination and thus reduce their representativeness with respect to exposures to workers performing maintenance indoors in the rafters and upper levels close to the ceiling.

SC&A revisited the file of reports and correspondence associated with the M&C request for termination of NRC License SNM-23 (NRC & TI, 1982–1983). These documents present measurements of direct alpha, removable alpha, and beta/gamma radioactivity and are the primary reference NIOSH used to support characterization on the roof and overhead models. Most of the direct measurements used in modeling were indoor measurements done on the ceiling and other overhead areas and thus were not impacted by outdoor weather, but some of the measurements were also outdoors on the roof. Direct measurements were taken by representatives of TI at 45° increments from 0.5-, 1.0-, and 2-meter distances on the roof around the exhaust from the high-efficiency filter system. Additionally, TI representatives took direct measurements on the roof around the exhaust from the fuel manufacturing area at distances of 1, 2, and 4 meters. SC&A believes the point of discharge of the exhaust system is the most logical pathway for material to deposit on the roof. In its original 1982 report requesting license termination, TI indicated:

> No cleaning prior to measuring for radioactivity was performed on the roof of Building 10 as the regular monitoring of the two exhausts from the fuel manufacturing area have always showed essentially background radioactivity in the air being discharged. [NRC & TI, 1982–1983, PDF p. 60]

Therefore, the data represent the radiological condition as they were at the time of the measurements. This also provides some evidence that the site was regularly monitoring roof areas for contamination during the residual period. Following the application for license termination, the site was audited by the NRC inspectors from August 31- September 2, 1982. The inspection involved two regional NRC inspectors who each spent 32 hours inspecting the site. At the conclusion on the inspection, they noted that “Fixed and removable contamination levels measured during the inspection are comparable to those in the licensee’s close-out survey” (NRC & TI, 1982–1983, PDF p. 20]. This provides further reassurance that the survey results were confirmed by regulators in 1982.

A total of 40 direct measurements were performed on the roof by TI. Assuming 10 percent removable contamination, SC&A calculates a GM of 2.6 dpm/100 cm^2 and a 95th percentile of 29.0 dpm/100 cm^2, roughly double the amount modeled by NIOSH for the aggregate roof and overhead model. Since the roof is subject the weather, it would be reasonable to assume source term depletion occurred over the roughly 14 years of the residual period between monitoring, assuming zero contribution from activities related to the High Flux Isotope Reactor (HFIR) during the residual period. SC&A notes that the direct alpha roof measurements suggest that at least some portions of the roof had more contamination than the overhead areas. These differences are small but suggest that the roof at the upper 95th percentile is not bounded by the combined roof and overhead model. Despite this, the resulting doses from a roof only model are still small (<1 mrem in 1982). If another pathway were created, the occupancy factor would have to be reduced, which would further reduce the doses.

4.3 External exposures from roof and overhead pathway

NIOSH proposes assigning a quarterly GM gamma dose rate of 12 mrem/quarter (4 mrem/month) and a quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month), both with a GSD equal to the Battelle-TBD-6000 default value of 5 (NIOSH, 2011). For the roof and overhead pathway, NIOSH intends to assume 1 month of occupancy, so an annual penetrating dose of 4 mrem and a skin dose of 12 mrem will be assigned for this pathway. NIOSH proposes assuming a claimant-favorable gamma energy of 100 percent 30–250 keV and electron energy of 100 percent >15 keV with no source term depletion.

As a check, SC&A modeled doses from exposure to the roof activities, which had the highest dose rates identified by surveying. SC&A calculated the 95th percentile of these direct alpha readings to be 186 dpm/100 cm^2 (18,600 dpm per square meter (dpm/m^2)). Assuming the contamination to be due to natural uranium in equilibrium with its short-lived progeny, SC&A applied the DCF of 3.94×10^{-10} milliroentgen (mR)/h per dpm(α)/m^2 listed in Battelle-TBD-6000, revision 1 (NIOSH, 2011, table 3.10), to obtain an exposure rate of 7.33×10^{-6} mR/h, which is undetectable in the presence of natural background. Assuming an exposure duration of 166.67 hours/year, SC&A derived an annual exposure of 0.001 mR, which is far below the minimum exposure that needs to be considered in a DR. The corresponding beta skin dose rate, based on the DCF of 3.82×10^{-8} millirad per hour (mrad/h) per dpm(α)/m^2 listed by NIOSH (2011a, table 3.10), is 0.12 mrad/year, which is below the 1 mrem/year threshold for radiation doses that need to be addressed by a DR. This suggests the proposed NIOSH assumptions for external dose bound the likely exposures during the roof and overhead work.

5 Welding

It is known from petitioner statements that welding activities inside and on the roof of Building 10 occurred during the residual period. Since these maintenance-related activities could have potentially suspended materials with the highest concentrations, NIOSH will assume that 100 percent of the 95th percentile direct measurement roof and overhead contamination is removable (89.94 dpm/100 cm^2). NIOSH indicates it will assume all workers spent 48 hours a year performing these activities and apply a resuspension factor of 10^{-3}/m. Table 4 of NIOSH (2021a) gives an example of the doses calculated in the welding pathway. SC&A was able to replicate the calculated annual committed effective doses in table 4, as shown in example 5-1. SC&A is providing this example to establish SC&A understood the assumptions NIOSH was using to calculate doses from this exposure pathway. Organ doses rather than committed effective doses are assigned in DRs performed under EEOICPA.

Example 5-1: Annual uranium intakes and committed effective doses from welding pathway

$$U\ inh.intake = removable\ alpha * RF * occupancy\ factor * inhalation\ rate$$

$$89.94\,\frac{dpm}{100cm^2} * \frac{\mu Ci}{2{,}220{,}000\;dpm} * \frac{10{,}000\;cm^2}{m^2} * \frac{10^{-3}}{m} * \frac{48\;hours}{year} * 1.2\,\frac{m^3}{h} = 2.33 * 10^{-4}\;\mu Ci/year$$

$$U\;inhalation\;dose = 2.33 * 10^{-4}\;\mu Ci/year * \frac{2.52 * 10^4\;mrem}{\mu Ci} = 5.88\;mrem/year$$

$$uranium\;ingestion\;intake = ingestion\;rate * removable\;alpha * RF * occupancy\;factor$$

$$\frac{10^{-4}\;m^2}{hour} * 89.94\,\frac{dpm}{100\;cm^2} * \frac{\mu Ci}{2{,}220{,}000\;dpm} * \frac{10{,}000\;cm^2}{m^2} * \frac{48\;hours}{year} = 1.94\; * 10^{-5}\;\mu Ci/year$$

$$U\;ingestion\;dose = 1.94\; * 10^{-5}\;\mu Ci/year * \frac{1.81 * 10^2 mrem}{\mu Ci} = 3.52 * 10^{-3}\;mrem/year$$

$$inhalation\;dose + ingestion\;dose = 5.88\,\frac{mrem}{year} + \;3.52 * 10^{-3}\,\frac{mrem}{year} = 5.88\;mrem/year$$

Thorium doses are calculated by replacing the uranium DCFs with thorium DCFs, resulting in a committed dose calculation of 17 mrem per year. Since the data used to support the model come from direct measurements of gross alpha, NIOSH will assign the most claimant-favorable mixture of thorium or uranium.

5.1 Data supporting welding intake model

The data supporting the welding pathway are identical to the data used in the roof and overhead model previously evaluated in section 4.1; however, NIOSH assumes 100 percent of contamination is removable (rather than 10 percent assumed in the roof and overhead model). These data are equally applicable to the welding scenario because welding would have occurred in the same areas as the roof and overhead work.

5.2 Concerns raised by work group and SC&A

According to NIOSH (2021a, p. 13),

> NIOSH modeled exposures for the entire overhead area uniformly using a 10^{-4} resuspension factor. NIOSH is aware that good work practice requires clean bare metal before welding, which can include wire brushing and grinding. NIOSH believes this weld-preparation work to be the portion of the welding task capable of generating the highest airborne concentration. Also, NUREG-1400 [NRC 1993] Section 1.2.3 indicates that a dispersibility factor of 10 should be used to model intakes involving grinding operations. Therefore, NIOSH will increase the resuspension factor and apply a value of 10^{-3} to the 95th-percentile total contamination level.

SC&A raised a concern (finding 2) in its 2019 (SC&A, 2019a) and 2020 (SC&A, 2020b) reviews of welding and thorium activities that a resuspension factor of 10^{-3}/m may not be adequate to represent the dust generated by grinding and wire brushing to prepare a surface for welding. The work group members echoed this concern during the September 2, 2020, M&C Work Group meeting (M&C WG, 2020). To date, this issue has not been resolved. SC&A agrees that this is a "TBD issue" rather than an SEC issue.

5.3 External exposures from welding

The external exposure potential from welding is comparable to the roof and overhead pathway SC&A evaluated in section 4.3 of this report, with shorter occupancy times. Due to the heat and nonradiological hazards associated with welding, it is reasonable to assume personal protective equipment was used that would have provided shielding, though no reduction in dose rate is assumed for this pathway. External doses from welding activities are believed to be below the threshold for inclusion in a DR.

NIOSH proposes assigning a quarterly GM gamma dose rate of 12 mrem/quarter (4 mrem/month) and a quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month), both with a GSD equal to the Battelle-TBD-6000 default value of 5 (NIOSH, 2011). For the welding pathway, for which NIOSH intends to assume 48 hours of occupancy, an annual penetrating dose of approximately 1 mrem and a skin dose of 3.5 mrem will be assigned. This is larger than the SC&A-modeled external doses; therefore, SC&A believes the NIOSH model is bounding for the welding exposure pathway.

6 HVAC Maintenance

To model heating, ventilation and air conditioning (HVAC) maintenance exposures, NIOSH assumes that 1 hour per year is required for performing these activities. Table 4 of NIOSH (2021a) provides an example of the doses calculated in the subsurface outside pathway. Using the calculation in example 6-1, SC&A was initially unable to replicate the calculated annual committed effective doses given in table 4. SC&A contacted NIOSH regarding this discrepancy and discovered NIOSH inadvertently used a 48-hour/year occupancy rather than the intended 1 hour per year in their calculations. NIOSH confirmed 1 hour per year was the intended occupancy factor. Thus, the HVAC values in table 4 were 48 times larger than intended.

Example 6-1: Annual uranium intakes and committed effective doses from HVAC maintenance

$$[uranium\ estimated] = alpha\ surface * RF * \text{Dust Loading in Building 10}$$

$$12.3\,\frac{\text{dpm}}{100\ \text{cm}^2} * \frac{10{,}000\ cm^2}{m^2} * \frac{10^{-5}}{m} * \frac{m^3}{100\ \mu g} = \ 1.23 * 10^{-4} dpm/\ \mu g$$

$$U\ inhal.intake = [U\ estimated] * \text{Dust Loading in vent} * \text{inhal. rate} * \text{occupancy factor}$$

$$\frac{1.23 * 10^{-4} dpm}{ug} * \frac{100{,}000\ \mu g}{m^3} * 1.2\,\frac{m^3}{hour} * \frac{1\ hour}{year} = 14.76\ dpm/year$$

$$14.76\ dpm/year * \frac{\mu Ci}{2{,}220{,}000\ dpm} * \frac{2.52 * 10^4\ mrem}{\mu Ci} = 0.168\ mrem/year$$

$$U\ ingestion\ intake = ingestion\ rate * U\ surface\ activity * occupancy\ factor$$

$$\frac{50{,}000\ \mu\text{g}}{8\ \text{hour workday}} * \frac{1.23 * 10^{-4} dpm}{\mu g} * \frac{\mu Ci}{2{,}220{,}000\ dpm} * \frac{1\ hour}{year} = 3.46 * 10^{-7} \mu Ci$$

$$2.46 * 10^{-4} \mu Ci * \frac{1.81 * 10^{2} mrem}{\mu Ci} = 6.27 * 10^{-5}\ mrem/year$$

$$inhalation\ dose + ingestion\ dose = 0.168 \frac{mrem}{year} + \ 6.27 * 10^{-5} \frac{mrem}{year}$$
$$= 0.168\ mrem/year$$

6.1 Data supporting the intake model

NIOSH (2021a, p. 13) indicates that NIOSH will use “7,765 gross-alpha swipe data collected at the end of AWE operations in 1966 and 1968.” These samples were taken near the end of operations inside Building 10 and represent removable contamination found at the site during operations. At the end of the AWE operations period, the non-HFIR areas were cleaned and released for use. This cleaning would be expected to reduce the contamination during the residual period

Limited sampling results exist during the residual period that can be clearly linked to non-HFIR activities prior to the 1982 site characterization associated with license termination. In January and February 1983, NRC inspectors (NRC & TI, 1982–1983, PDF pp. 9–14) made 938 direct alpha, beta-gamma, and gamma measurements in 67 grid blocks in Building 10 outside of HFIR, 9 grid blocks in Building 4, and 2 grid blocks in Building 3. The NRC inspectors reported that “Direct alpha measurements did not exceed 175 dpm/100cm^2 (92.6% ≤ 50 dpm)” (PDF p. 11) inside Building 10 (measurements taken in non-HFIR areas). Assuming 10 percent of the direct measured activity was removable, the maximum seen in 1983 is comparable to the GM of the operation period swipe samples, 12.3 dpm/100 cm^2. The NRC inspectors also took 81 swipe samples. The only two samples inside Building 10 in excess of 10 dpm/100 cm^2 were 20.3 dpm/100 cm^2 and 11.2 dpm/100 cm^2, both of which are also comparable to the GM used by NIOSH. SC&A believes the consistency of these values supports NIOSH’s use of the late operations period swipe sample data to bound residual period exposures.

6.2 External exposures from HVAC maintenance

NIOSH proposes assigning a quarterly GM gamma dose rate of 12 mrem/quarter (4 mrem/month) and a quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month). For the HVAC maintenance pathway, which NIOSH intends to assume 1 hour of occupancy per year, an annual penetrating dose and skin dose of less than 1 mrem is assigned.

SC&A modeled external doses to a worker changing HVAC filters to compare the doses to the NOSH doses. Such a worker could potentially receive a skin dose from airborne contaminated dust settling on their skin during this operation. Using conservative assumptions about the dust loading and specific activity, the settling velocity recommended by Battelle-TBD-6000 (NIOSH, 2011), and the skin dose rates discussed in Appendix C to SC&A's (2018a) initial ER review, SC&A finds that the annual skin dose from this pathway is much less than 1 mrem. Therefore, the NIOSH-proposed values are comparable to the SC&A-modeled doses.

7 Remaining Exposures

NIOSH assumes the balance of a worker's employment (remaining period) was spent on site on tasks in the generally accessible parts of the site. These exposures are referred to as "non-maintenance," which is somewhat of a misnomer in terms of work function. They are intended to refer to all other work activities that are not covered by the other defined pathways. These exposures include work and maintenance activities that occurred in the parts of M&C that were generally accessible to all workers on most days. NIOSH (2021a, p. 14) indicates that dose will be assigned as follows:

> For exposures incurred by workers for the balance of the year, NIOSH will use the GM (12.3 dpm/100cm^2) . . . . Using this GM surface contamination value and a 10^{-5} resuspension factor, the gross alpha airborne concentration in Building 10 was calculated to be 0.0123 dpm/m^3. Source-term depletion adjustments (per the guidance in ORAUT-OTIB-0070) will be considered to determine the non-maintenance exposure rates throughout the residual period.

Table 4 of NIOSH (2021a) provides an example of the doses calculated in the remaining pathway. SC&A was able to approximately replicate the calculated annual committed effective doses in table 4 (<1 mrem), as shown in example 7-1. SC&A is providing this example to establish SC&A understood the assumptions NIOSH was using to calculate doses from this exposure pathway. Organ doses rather than committed effective doses are assigned in DRs performed under EEOICPA.

Example 7-1: Maximum annual uranium intakes and committed effective doses from non-maintenance activities (remaining period)

$$uranium\ inhalation\ intake = alpha\ surface * RF * \text{breathing rate} * occupancy\ factor$$

$$12.3\,\frac{\text{dpm}}{100\ \text{cm}^2} * \frac{10{,}000\ cm^2}{m^2} * \frac{\mu Ci}{2{,}220{,}000\ dpm} * \frac{10^{-5}}{m} * \frac{1.2\ m^3}{hour} * \frac{1{,}451\ hours}{year} = 9.65 * 10^{-6}\ \mu Ci/year$$

$$U\ inhalation\ dose = 9.65 * 10^{-6}\ \mu Ci/year * \frac{2.52 * 10^4\ mrem}{\mu Ci} = 0.24\ mrem/year$$

$$uranium\ ingestion\ intake = ingestion\ rate * U\ surface * occupancy\ factor$$

$$\frac{10^{-4}\ m^2}{hour} * 12.3\,\frac{dpm}{100\ cm^2} * \frac{\mu Ci}{2{,}220{,}000\ dpm} * \frac{10{,}000\ cm^2}{m^2} * \frac{1{,}451\ hours}{year} = 8.03 * 10^{-5}\ \mu Ci/year$$

$$U\ ingestion\ dose = 8.03\ *10^{-5}\ \mu Ci/year * \frac{1.81 * 10^{2}\ mrem}{\mu Ci} = 1.46 * 10^{-2}\ mrem/year$$

$$inhalation\ dose + ingestion\ dose = 0.243\frac{mrem}{year} +\ 0.015\frac{mrem}{year} = 0.26\ mrem/year$$

Thorium doses are calculated by replacing the uranium DCFs with thorium DCFs, resulting in a committed dose calculation of approximately 1 mrem per year maximum. NIOSH indicates that, since the results are gross-alpha, NIOSH will assign the most claimant-favorable mixture of thorium or uranium.

7.1 Data source

NIOSH (2021a, p. 13) indicates that NIOSH will use "7,765 gross-alpha swipe data collected at the end of AWE operations in 1966 and 1968." This is the same data source evaluated in section 6.1 of this report.

7.2 External dose from remaining period

NIOSH proposes assigning a quarterly GM gamma dose rate of 12 mrem/quarter (4 mrem/month) and a quarterly GM skin dose rate of 36 mrem/quarter (12 mrem/month), both with a GSD equal to the Battelle-TBD-6000 default value of 5 (NIOSH, 2011). For the remaining period of time not modeled by other pathways (non-maintenance exposures), this equates to a total annual penetrating dose of 35 mrem/year and a skin dose of 105 mrem/year, when prorating to 1,451 hours per year. NIOSH proposes assuming a claimant-favorable gamma energy of 100 percent 30–250 keV and electron energy of 100 percent >15 keV. NIOSH (2021a, p. 15) states:

> For all non-maintenance work exposures, source-term depletion adjustments will be considered (per the guidance in ORAUT-OTIB-0070) to determine the non-maintenance exposure rates throughout the residual period.

SC&A believes it is appropriate to apply the penetrating dose rate of 4 mrem/month and beta dose rate of 12 mrem/month to the remaining period (non-maintenance exposures).

SC&A is aware of additional direct survey measurements from the 1982 survey performed by TI and verified by NRC inspectors (NRC & TI, 1982–1983). As a check, SC&A assessed the results of 40 sets of alpha direct measurements performed on the floors areas inside Building 10 by TI (1982, appendix A, section 4.2.2, PDF p. 28). According to TI (1982, PDF p. 7), "TI selected the floors of areas identified as processing unclad materials for these measurements because floors represent the worst condition for holding residual radioactivity." For each area, TI listed the maximum activity and the average of all measurements in the given area. SC&A calculated the 95th percentile of these average grid readings to be 234.44 dpm/100 cm^2 (23,444 dpm/m^2). Assuming the contamination to be due to natural uranium in equilibrium with its short-lived progeny, SC&A applied the DCF of 3.94×10^{-10} mR/h per dpm(α)/m^2 from Battelle-TBD-6000 (NIOSH, 2011, table 3.10) to obtain an exposure rate of 9.24×10^{-6} mR/h, which is undetectable in the presence of natural background. Assuming an exposure duration of 1,451 hours/year, SC&A derived an annual exposure of 0.0134 mR, which is far below the minimum exposure that needs to be considered in a DR. The corresponding beta skin dose rate, based on the DCF of 3.82×10^{-8} mrad/h per dpm(α)/m^2 listed by NIOSH (2011, table 3.10), is 1.30 mrad/year, which is just above the 1 mrem/year threshold for radiation doses that need to be addressed by a DR. This suggests that the proposed NIOSH assumptions for external dose bound the likely exposures during the remaining period.

8 Conclusions and Recommendations

SC&A reviewed each of the six exposure pathways described by NIOSH (2021a). This review identified one finding and one observation, both of which relate to subsurface exposure modeling. With the modifications suggested in the finding and observation, SC&A believes internal and external doses from each maintenance exposure pathway can be bounded.

SC&A recommends NIOSH develop guidance for dose reconstructors that allows modification to the established occupancy factors if statements in the computer-assisted telephone interview or evidence in the energy employee's employment records suggest a different breakdown of work may be more appropriate. SC&A also recommends that NIOSH include guidance to help dose reconstructors prorate doses for partial years of employment. SC&A is unaware of any other AWE sites with many exposure pathways where precedent has been set for the treatment of partial years of employment. Developing guidance would help ensure partial years of employment are treated consistently in all M&C cases. SC&A recommends prorating all occupancy factors based on partial years of employment.

9 References

ASTRA, Inc. (1962). *Analysis of possible nuclear material losses and possible liabilities associated with present fuel manufacturing at Metals & Controls, Inc., Attleboro, Massachusetts* (ASTRA 410-6.2). SRDB Ref. ID 013612

Beach, J. (2021, January 12). *M&C update* [Email communication to M&C Work Group and associated staff].

Creative Pollution Solutions, Inc. (CPS). (1992). *Radiological characterization of Texas Instruments, Incorporated Attleboro industrial facility, Attleboro, Massachusetts*. SRDB Ref. ID 164755

R. S. Landauer Jr. & Co. (1965–1974). Landauer external dosimetry reports [Metals and Controls Corp. Matteson, IL]. SRDB Ref. ID 13654

Metals and Controls Corporation Work Group. (2020). *Wednesday, September 2, 2020* [Transcript of teleconference meeting]. https://www.cdc.gov/niosh/ocas/pdfs/abrwh/2020/wgtr090220-508.pdf

National Institute for Occupational Safety and Health. (2004). *Estimation of ingestion intakes* (OCAS-TIB-009, rev. 0). https://www.cdc.gov/niosh/ocas/pdfs/tibs/oc-t9-ro.pdf

National Institute for Occupational Safety and Health. (2006). *Site profile for Atomic Weapons Employers that worked uranium and thorium metals* (Battelle-TBD-6000, rev. F0; PNWD-3738, rev. 0). https://www.cdc.gov/niosh/ocas/pdfs/arch/bat-6000-r0.pdf

National Institute for Occupational Safety and Health. (2011). *Site profiles for Atomic Weapons Employers that worked uranium metals* (Battelle-TBD-6000, rev. 1). https://www.cdc.gov/niosh/ocas/pdfs/tbd/bat-6000-r1.pdf

National Institute for Occupational Safety and Health. (2012). *Dose reconstruction during residual radioactivity periods at Atomic Weapons Employer facilities* (ORAUT-OTIB-0070, rev. 01). https://www.cdc.gov/niosh/ocas/pdfs/tibs/or-t70-r1.pdf

National Institute for Occupational Safety and Health. (2017a). *SEC petition evaluation report Petition SEC-00236*. https://www.cdc.gov/niosh/ocas/pdfs/sec/metcont/metconter-236.pdf

National Institute for Occupational Safety and Health [2017b]. Documented communication SEC-00236 with [Former Worker #5] on Metals and Controls Corporation, October 24, 2017. SRDB Ref. ID 169916

National Institute for Occupational Safety and Health. (2018a, April 23). *Metals and Controls Corp. subsurface exposure model* [White paper]. https://www.cdc.gov/niosh/ocas/pdfs/dps/dc-metcontsubexmod-042318-508.pdf

National Institute for Occupational Safety and Health. (2018b, September 12). *Metals and Controls Special Exposure Cohort (SEC 236) issues matrix*. https://www.cdc.gov/niosh/ocas/pdfs/dps/dc-metcontimsec236-101218-508.pdf

National Institute for Occupational Safety and Health. (2018c, October 18). *NIOSH response to the SC&A review of the NIOSH white paper dated April 23, 2018* [Memorandum]. https://www.cdc.gov/niosh/ocas/pdfs/dps/dc-metcont-101818-508.pdf

National Institute for Occupational Safety and Health. (2018d, October 24). *Metals and Controls Corp. maintenance worker exposure model* [White paper]. https://www.cdc.gov/niosh/ocas/pdfs/dps/dc-metcontmaintwem-102418-508.pdf

National Institute for Occupational Safety and Health. (2019, April 8). *Metals and Controls Corp. thorium and welding exposure model* [White paper]. https://www.cdc.gov/niosh/ocas/pdfs/dps/dc-mccthweldexpmodel-040819-508.pdf

National Institute for Occupational Safety and Health (NIOSH). (2021a, January 21). *Response to Comments from the Metals and Controls Corp. Work Group meeting held on September 2, 2020* [Response paper]. https://ftp.cdc.gov/pub/FOIAREQ/184642_red-508.pdf

National Institute for Occupational Safety and Health. (2021b, February 8). *Response to comments related to soil disturbances at the burial ground* [Memorandum]. https://ftp.cdc.gov/pub/FOIAREQ/184829-508.pdf

Roy F. Weston, Inc. (Weston). (1996a, January). *Texas Instruments Incorporated, Attleboro Facility: Building interiors remediation drainage system characterization*. SRDB Ref. ID 165965

Roy F. Weston, Inc. (1996b, October). *Texas Instruments Incorporated Attleboro, Massachusetts: Remediation of building interiors Buildings 4, 5, and 10* (version 1.0). SRDB Ref. ID 114246

SC&A, Inc. (2018a). *Review of SEC petition evaluation report SEC-00236 Metals and Controls Corporation* (SCA-TR-2018-SEC001, rev. 0). https://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/177000_red-508.pdf

SC&A, Inc. (2019a, July 26). *Review of NIOSH's "Metals and Controls Corp. thorium and welding exposure model"* [Memorandum]. https://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/177001-508.pdf

SC&A, Inc. (2020a). *Issues resolution roadmap for Metals and Controls Corporation SEC Petition-00236* (SCA-TR-2020-SEC002, rev. 0). https://ftp.cdc.gov/pub/FOIAREQ/179901-508.pdf

SC&A, Inc. (2020b, July 8). *Reply to NIOSH "Metals and Controls Corp. thorium and welding exposure model"* [Memorandum]. https://ftp.cdc.gov/pub/FOIAREQ/182528-508.pdf

Sowell, L. L. (1985). *Radiological survey of the Texas Instruments site Attleboro, Massachusetts* (RSAP/SMPB-8). SRDB Ref. ID 94371

Texas Instruments Incorporated. (1982, November 2). Letter to U.S. Nuclear Regulatory Commission. SRDB Ref. ID 024623

Texas Instruments Incorporated. (1994). *Supplement to the 1992 remediation plan*. SRDB Ref. ID 114177

Texas Instruments Incorporated. (1995a). Exhibit no 4 Metals Recovery Area appendix D radiological survey results. SRDB Ref. ID 165968

Texas Instruments Incorporated. (1995b). *Radiological surveys of open land areas*. SRDB Ref. ID 161141, PDF pp. 989–1166

Texas Instruments Incorporated. (1996). *Request for reimbursement of costs arising out of the decontamination and decommissioning of the Texas Instruments Incorporated facility in Attleboro, Massachusetts*. SRDB Ref. ID 163071

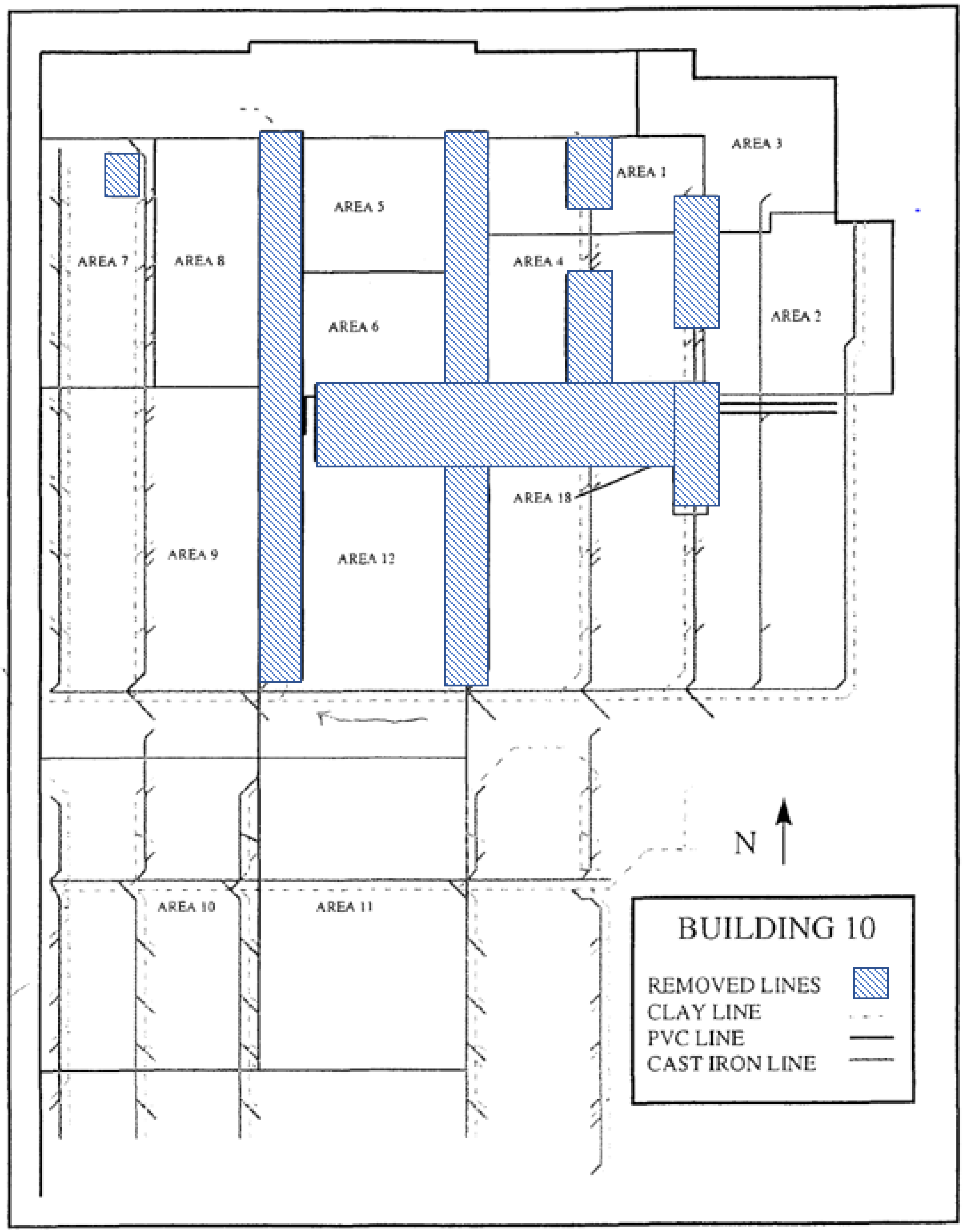
U.S. Environmental Protection Agency (EPA). (1993). *External exposure to radionuclides in air, water, and soil* (Federal Guidance Report No. 12, EPA-402-R-93-081). https://www.epa.gov/sites/production/files/2015-05/documents/402-r-93-081.pdf

U.S. Nuclear Regulatory Commission. (1981, June 2-12). Texas Instruments Incorporated *Inspection Summary* (Report No 70-33/81-07) [PDF pp. 121–129]. https://semspub.epa.gov/work/01/209715.pdf

U.S. Nuclear Regulatory Commission (NRC) & Texas Instruments. (1982–1983). *Request for termination of Nuclear Regulatory Commission License SNM-23* [Compilation of reports and memoranda from various dates throughout 1982 and 1983]. SRDB Ref. ID 24651

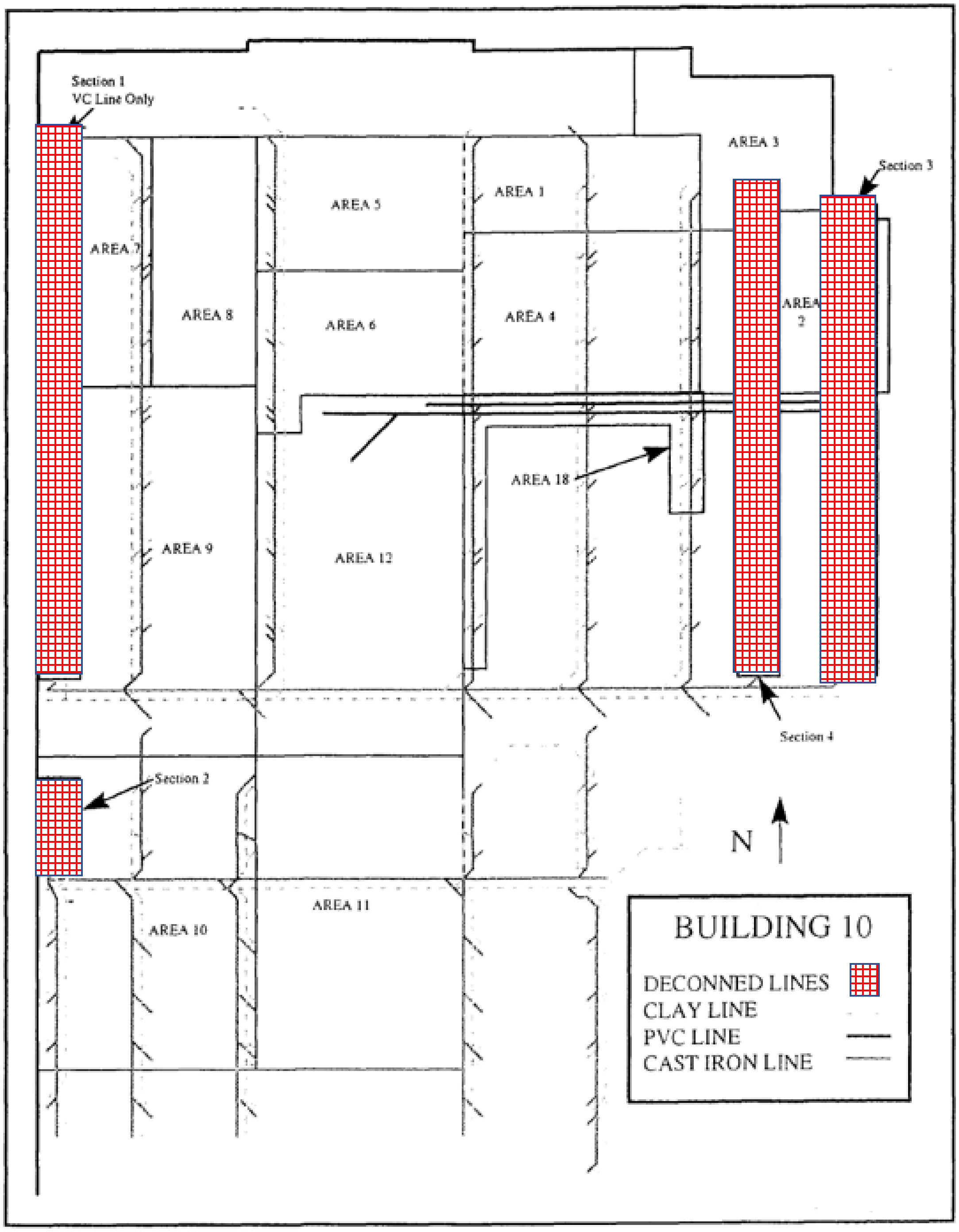
Attachment A: Building 10 Pipes Remediation

Figure A-1. Building 10 removed drain lines



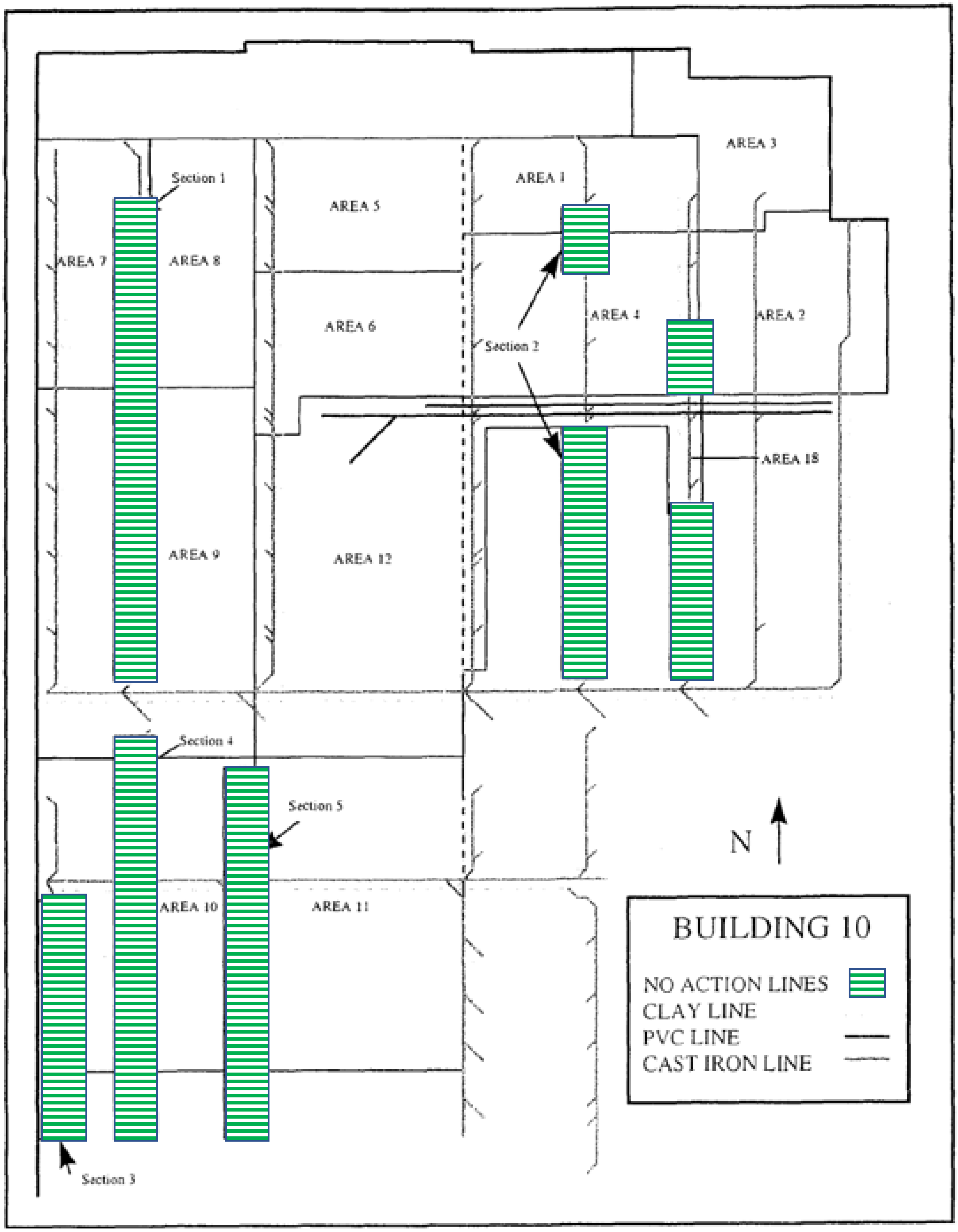
Source: Adapted from Weston (1996b), figure 5.3 (PDF p. 175).

Figure A-2. Remediated drain lines



Source: Adapted from Weston (1996b), figure 5.4 (PDF p. 176).

Figure A-3. Drain lines left in place in affected areas



Source: Adapted from Weston (1996b), figure 5.5 (PDF p. 178).