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Supplemental Review of M&C Work Group Issues

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Prepared by

Joe Fitzgerald, MS, MPH

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

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Table of Contents

Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
AWE	Atomic Weapons Employer
CFR	Code of Federal Regulations
cm^2	square centimeters
cpm	counts per minute
D&D	decontamination and decommissioning
DCAS	Division of Compensation Analysis and Support
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ER	evaluation report
F.R.	*Federal Register*
GM	geometric mean
GSD	geometric standard deviation
HFIR	High Flux Isotope Reactor
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
M	meter
m^3	cubic meter
M&C	Metals and Controls Corporation
µCi/mL	microcurie per milliliter
$\mu g/m^3$	micrograms per cubic meter
NIOSH	National Institute for Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
OSHA	Occupational Safety and Health Administration
pCi/g	picocuries per gram
Pu	plutonium
Rn	radon
SDMP	Site Decommissioning Management Plan
SEC	Special Exposure Cohort

SRDB	Site Research Database
TI	Texas Instruments, Incorporated
Th	thorium
U	uranium

1 Introduction and Background

The Metals and Control Corporation (M&C) Work Group has conducted an extensive review of the National Institute for Occupational Safety and Health (NIOSH) petition evaluation report (ER) for Special Exposure Cohort (SEC) Petition SEC-00236. This included a series of work group meetings beginning in 2018, supported by technical assessments and information reviews by both NIOSH and SC&A, as well as feedback from former worker interviews and petitioner comments. With NIOSH and SC&A achieving general agreement about the more prominent issues surrounding dose reconstruction for the M&C residual period (1968–1997), the work group requested one additional review by SC&A. This supplemental review[1] is intended to focus on any remaining lines of inquiry or outstanding issues relevant to the work group's final review of the SEC-00236 ER that would benefit from additional assessment.

This review is based on the available record of work group discussions, former worker input, and supporting documents, including NIOSH and SC&A reports, responses, white papers, and presentations. However, it does not represent a consensus among SC&A staff and is intended to be responsive to the work group's request for a timely and supplemental means to inform final work group deliberations on M&C. It should be emphasized that in matters of interpreting plausibility and sufficient accuracy in the context of exposure modelling and bounding assumptions, there is obviously a high degree of professional judgment involved. The purpose of this review is to consider all such interpretations so that the Advisory Board on Radiation and Worker Health (Board) is in the best possible position to complete its review of the M&C evaluation report.

It is acknowledged that reviews of Atomic Weapons Employer (AWE) sites with uranium and thorium operations are premised on a lack of source term and monitoring data during the residual period from which traditional dose estimation based on the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) can be performed. Reliance is necessarily placed on dose-bounding approaches in Battelle-TBD-6000 (NIOSH, 2011d; "TBD-6000") and ORAUT-OTIB-0070 (NIOSH, 2012a; "OTIB-0070") that are based on available operational source term data, supplemented by any remedial-related or similar data that may be available during the residual time period.

Two relevant questions can be revisited and probed for the SEC-00236 ER at this time:

1. Is there a valid basis for the application of the operational source term and survey data for M&C in this manner?

2. Are there any sufficiently intrusive or disruptive activities or conditions during the M&C residual period, or uncertainties therein, that would raise doubts about the validity of that assumed source term and the plausibility of bounding exposure pathway analyses that complement it?

[1] This review was conducted by Joseph Fitzgerald, who did not participate in SC&A's earlier review of the M&C petition evaluation report.

The following lines of inquiry serve to answer those two questions and are posited based on existing work group concerns:

1. **Line of Inquiry 1:** Are the conditions and work activities associated with the M&C residual period unusual or different such that (a) standard modeling procedures do not apply and (b) exposure potentials higher than those addressed by OTIB-0070 and TBD-6000 and supporting exposure pathway bounding analyses may have resulted?

2. **Line of Inquiry 2:** Are the exposure pathway bounding methods prescribed by the ER and subsequent NIOSH reviews appropriate and consistent with how other AWE sites have been addressed?

3. **Line of Inquiry 3:** Are the available source term, survey data, and other information applied by NIOSH to support its dose bounding methods sufficiently accurate and plausibly applied?

While there remain open findings from past assessments for work group resolution,[2] these issues appear to have been tentatively resolved between NIOSH and SC&A and await work group review (NIOSH, 2022a, pp. 3–5). This review does not critique past SC&A reviews or issue resolution; rather, it strives to offer a fresh assessment of NIOSH's analyses and conclusions, past precedent with other AWE sites, and the available information itself.

Likewise, this review does not revisit other issues raised during the course of work group discussion (e.g., sediment reduction in drain pipes, consideration of explosions and fires, exposures to radium-226 glass beads, and exposure to thorium), because they have apparently been already addressed in discussions between the work group, SC&A, and NIOSH. While there remain some issues involving external dose assessment for the M&C residual period, this review confines itself to internal dose assessment concerns, because that has been the primary focus of the work group's concern.

[2] For example, SC&A (2021a), finding 1, "Building 10 subsurface external exposures not bounded," and SC&A (2019, 2020), finding 2, "NIOSH understated the resuspension factor related to activities accompanying welding," and SC&A's (2021b) dust loading review.

2 Summary of NIOSH Evaluation Report Conclusions for Internal Dose Reconstruction

As noted in the NIOSH ER for SEC-00236:

> During the residual radiation period from January 1, 1968 through March 21, 1997, the primary source of covered exposure that M&C employees may have been exposed to was from the previous AWE Facility weapons-related work that generated residual uranium residues. Smaller amounts of residual thorium residues were also present. [NIOSH, 2017j, p. 20]

For the operational period (1952–1967), monitoring data consist of area surface contamination surveys, analyzed for gross alpha content, with removable alpha contamination "generally below 100 dpm/100 cm^2" (NIOSH, 2017j, p. 24). From these survey data at the end of the operational period, "a resuspension factor of 10^{-6} m^{-1} was applied to the 95th percentile contamination levels (54.8 dpm/100 cm^2) to estimate an air concentration (2.47 x 10^{-15} µCi/mL or 0.00548 dpm/m^3) that would have been present at the start of the residual period (per guidance in ORAUT-OTIB-0070)" (NIOSH, 2017j, p. 27).

During the residual period itself, the first documented surface survey of these areas is dated November 1, 1982 (TI, 1982, PDF p. 12). As noted in the ER, the U.S. Nuclear Regulatory Commission (NRC) performed an "over check survey" of these same areas from January 31 to February 2, 1983 (NIOSH, 2017j, p. 24), with direct alpha measurements found to be below 175 disintegrations per minute per 100 square centimeters (dpm/100 cm^2) (with one exception) and an overall 92 percent below 50 dpm/100 cm^2 (NRC, 1983, PDF p. 11). Based on these measurements, "A resuspension factor of 10^{-6} m^{-1} was applied to the 95th percentile contamination levels (14.5 dpm/100 cm^2) to estimate an air concentration (6.53 x 10^{-6} µCi/mL or 0.00145 dpm/m^3) that would have been present on November 1, 1982" (NIOSH, 2017j, p. 28).

A source term depletion rate of 2.45×10^{-4} day^{-1} was calculated and applied to the air concentration available at the start of the residual period (0.00548 dpm/cubic meter (m^3)) to arrive at year-by-year intake rates for M&C production workers during 1968–1997.

More extensive contamination survey data are available both for non-EEOICPA covered activities and areas and for employees performing commercial work at M&C. The former cannot be assessed in the ER. While the latter would only be representative of conditions during commercial operations (or during decontamination and decommissioning (D&D)) and not those during the EEOICPA-covered residual period, the ER notes that NIOSH will not rely on them to bound doses, but "can consider these data [consisting of surface contamination surveys, air monitoring, urinalysis, and lung scans] as supporting evidence to validate the bounding method used in Section 7 of this report. (NIOSH, 2017j, p. 24).

For dose reconstruction methods, the ER noted:

> All of the surface contamination surveys used to create these bounding methods were initially analyzed for gross alpha content; therefore, NIOSH will choose the most claimant-favorable isotope of thorium or uranium when estimating worker

> doses. For thorium, both natural and triple-separated mixtures will be considered. [NIOSH, 2017j, p. 27]

For the residual period itself, contamination measurements were taken on site involving an uncovered operation in Building 10 (the High Flux Isotope Reactor (HFIR)-related support work), and commercial-based D&D activities in the 1980s and 1990s. These are used by NIOSH, respectively, to make the case for the conservatism of its modeled soil contamination level (NIOSH, 2021a, pp. 7–8) and to validate its dose bounding methods. (NIOSH, 2017j, p. 24).

For internal dose reconstruction for the M&C residual period, NIOSH "concludes that there are methods available in Battelle-TBD-6000, NUREG/CR-5512, and ORAUT-OTIB-0070, as well as available surface-contamination data, air-monitoring data, and operational descriptions, so that internal radiation doses can be reconstructed with sufficient accuracy for all employees during the period under evaluation" (NIOSH, 2017j, p. 30).

Following the issuance of the ER, NIOSH developed six exposure pathway models for maintenance work activities that were described by M&C interviewees. NIOSH described this work as "although . . . sporadic and sometimes emergent in nature, it exposed workers in a manner that did not agree with the method described in the SEC-00236 ER (i.e., surface contamination resuspension)" (NIOSH, 2018, p. 2). These exposure pathways, for which bounding exposure models are provided, are heating, ventilation, and air conditioning (HVAC) maintenance, subsurface inside, subsurface areas outside, roof and overhead area, welding operations, and remaining exposures.

NIOSH acknowledged that the default dust-loading value of 100 micrograms per cubic meter ($\mu g/m^3$) suggested in OTIB-0070 and NUREG/CR-5512 (NRC, 1992), which was intended for a screening analysis for a long-term average, would not be appropriate for the intrusive subsurface work that former M&C workers described. Instead, a dust-loading factor of 212 $\mu g/m^3$ was determined based on air sampling performed during excavation at the Mound Plant and was applied as "data from another facility to completely develop [the] exposure model" (NIOSH, 2020d, p. 9).

3 Response to Lines of Inquiry

The following subsections respond to the work group's overarching concerns about conclusions in the ER for internal dose reconstruction for the residual period at M&C, as well as the work group's subsequent deliberations.

3.1 Line of inquiry 1

Are the conditions and work activities associated with the M&C residual period unusual or different such that (a) standard modeling procedures do not apply and (b) exposure potentials higher than those addressed by OTIB-0070 and TBD-6000 and supporting exposure pathway bounding analyses may have resulted?

A key concern raised by the work group was whether "maintenance work performed at M&C is unique, and therefore, standard modeling procedures do not apply" (NIOSH, 2020a, slide 3). NIOSH's response is, in part, that "M&C operations were similar to operations at [other AWE sites]" and the "methods proposed for M&C by NIOSH and SC&A are similar and consistent with those previously approved by the Board" (NIOSH, 2020a, slide 12).

3.1.1 Uniqueness of AWE sites with defined SEC classes

On the question of uniqueness, NIOSH concludes that "it is clear these three residual periods [for Norton Company, Linde Ceramics, and Vitro Manufacturing] added to the SEC were for sites with unusual work activities with high dose potential for which NIOSH was unable to evaluate the source term; this is not the case at M&C" (NIOSH, 2020a, slide 9).

The question of AWE uniqueness in the context of the applicability of the OTIB-0070 standard model and the feasibility of dose reconstruction is clearly a subjective one: There are no defined criteria, other than demonstrating that worker activities and conditions during the residual period may not be consistent with, or cannot be satisfied by, such modeling approaches.[3] Such inconsistency could come from disruptive or intrusive worker activities or conditions leading to elevated exposure to contamination "with high dose potential" that (a) cannot be bound with sufficient accuracy due to unknown or uncertain source terms or exposure potential or (b) cannot be plausibly bound using data from other worker populations due to lack of job-specific information (these issues are further addressed in sections 3.2.2 and 3.3). From past AWE experience, these SEC-relevant activities have been typically associated with facility renovation, dismantlement, and remediation.

For example, for the Norton Company AWE, facility dismantlement activities (1958–1962) during the residual period proved disruptive enough to have "altered the materials present and

[3] Regarding the applicability of OTIB-0070, NIOSH notes that "although the procedures used by NIOSH [2012a] appear to be designed for routine exposures, NIOSH and the Board have adapted and relied upon them to bound non-routine exposures, such as those that occurred during M&C maintenance, or at other AWEs with foundries and steel mills" (NIOSH, 2020b, p. 13). While standard modeling procedures encompass these additional bounding analyses for source terms not addressed by OTIB-0070 resuspension assumptions for routine exposures, this question of uniqueness goes to whether M&C maintenance worker activities were sufficiently different or disruptive to obviate the applicability of this approach for such non-routine exposures.

placed employees close to the disturbed materials" (NIOSH, 2020a, slide 7). This brought into question the assumed source term based on the original gross alpha air monitoring results from the end of the operations period that were used for OTIB-0070 resuspension modeling. NIOSH concluded that "those data [from the operations period] cannot be assumed to bound all radioactive contamination and radiological contamination levels that could have arisen from the dismantling, clean-up, packaging and burial processes which were documented to have generated dust" (NIOSH, 2011a, p. 27). Fundamental to this SEC conclusion was the lack of source term, air monitoring, or worker monitoring data for these residual period activities, and evidence that "teardown and clean-up significantly altered the materials present and placed employees close to the disturbed materials" (NIOSH, 2020a, slide 7).

For the Linde Ceramics Plant, the Board recommended, and an SEC class was designated, for all workers during the "renovation" phase of activities (1954–1969), within the residual period for that site (1954–2006). This renovation phase followed initial site cleanup and "could have caused the resuspension of fixed contamination," and NIOSH found it is "reasonable to assume that this renovation work could have resulted in elevated airborne radioactivity" (NIOSH, 2011b, p. 22). The ER noted that "specific work details, including documentation of the actual start and end dates of renovation, dust control measures, location of work, and occupancy of areas are not available" (NIOSH, 2011b, p. 22). Fundamental to the Board's conclusion and recommendation was the lack of a plausible bounding exposure estimate that could be applied site wide for all non-D&D workers during the renovation period, given the lack of information on what work those workers performed and under what exposure conditions (ABRWH, 2011, pp. 122–124; NIOSH, 2020a, slide 6).

For Vitro Manufacturing, extensive remediation activities took place during the residual period (1960–1965) involving the remediation, transfer, and burial of residue uranium-processing waste. NIOSH found that "employees at the facility had potential for exposure to radiological source materials stored in open residue piles susceptible to contamination spread, and to radiological materials during decontamination and decommissioning activities including the eventual burial of the residue piles" (NIOSH, 2011c, p. 4). NIOSH's SEC conclusion was founded on not having "access to personnel monitoring, workplace monitoring, or source term data to estimate unmonitored internal and external exposures" (NIOSH, 2011c, p. 5).

From its review and comparison of the M&C residual period to that of other AWEs (NIOSH, 2020b) on the question of M&C's uniqueness, NIOSH concluded:

> M&C operations were similar to operations at these other sites. Uranium was machined at most of these sites; thorium is documented to have been at over half of them. Residual-period tasks performed by workers at these other sites, including contaminated soil excavation and welding and torch-cutting in contaminated areas, have been evaluated. The pathways leading to internal exposures from alpha-emitting radionuclides such as uranium and thorium are identical for workers at all of these sites: the inhalation and ingestion of resuspended, contaminated dust. [NIOSH, 2020b, p. 13]

However, NIOSH also acknowledged that, based on the 2017 former worker interviews, "the information [received] indicated that the workers at M&C conducted more intrusive work into subsurface areas than previously considered in the ER" (Division of Compensation Analysis and Support (DCAS), 2017, p. 1). As already noted, this led NIOSH to develop exposure pathway bounding analyses to address specific M&C maintenance worker exposures that could not be addressed by the resuspension model in OTIB-0070.

3.1.2 Uniqueness of M&C work activities

The key issue before the work group, then, is why and how M&C is different from these AWE sites (or conversely, similar to those in the SEC) in terms of "unusual work activities with high dose potential for which NIOSH was unable to evaluate the source term" (NIOSH, 2020a, slide 9).

As pointed out by petitioners in affidavits, interviews, and oral and written statements, M&C workers conducted frequent routine and nonroutine maintenance work during the residual period that involved often intrusive and disruptive activities for which there was a potential for radiological intakes. These activities included drilling, sawing,[4] and jackhammering concrete slab flooring; subsurface drain cleaning and repair work involving radioactive sediments; subsurface and rooftop installation of site utility services; working on, in, and around contaminated mechanical equipment; working in utility manhole and trench networks; and excavating contaminated soils, including those adjacent to and potentially within an existing radioactive waste burial site and encompassing locations where "radioactive waste byproducts" were historically managed (Elliott, 2017, p. 1).

Much of the utility services in Building 10 "had to be in the floor because of the overhead cranes" (NIOSH, 2017i, p. 16), necessitating frequent subsurface excavation to service and install utilities such as air and electrical conduits and drain lines. The work involved considerable time, usually days, but sometimes a week at a time (DCAS, 2017, p. 2) and up to 6 months for one project (NIOSH, 2017i, p. 11), working underground in manholes, trenches, sewers, and other confined spaces, with varying levels of contamination. As noted by a former worker, "you could be in a manhole for a week if there was a problem" (NIOSH, 2017a, p. 15), and "we were in trenches and manholes our whole working lives" (NIOSH, 2017a, p. 3). A supervisor noted: "We worked in the trenches. We cut trenches. We made trenches" (NIOSH, 2017i, p. 5). Notably, there was no air monitoring performed prior to worker entry into these manholes and other spaces[5] (NIOSH, 2017a, p. 14). Replacement and servicing of utility lines, such as air lines, took place in contaminated subsurface locations, reportedly including near and through a radioactive waste burial ground (NIOSH, 2017b, pp. 9–11). Work within the trenches included digging, sawing, drilling, grinding, and welding (Elliott, 2022, pp. 1–2), and for drain line unclogging, use of hand-cranked and power snakes (NIOSH, 2017i, p. 7).

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[4] While concrete floor sawing, itself, was often outsourced to third-party, outside contractors, M&C maintenance workers also performed this function for excavations (Elliott, 2022).

[5] As an exception, confined space air sampling was performed for entry into deep concrete pits in Building 10, e.g., where "slitting equipment" was located ("it was the only time we used to call Health and Safety"), but only for deprived oxygen purposes (NIOSH, 2017i, pp. 5–6).

When doing roof and truss penetrations for utility lines, preparation for welding activities would include blowing off accumulated dust with a compressed air tank, followed by prepping the truss beams with a wire brush, and then grinding it (NIOSH, 2017c, p. 8).

Interviewed former maintenance workers spoke of cleaning out blocked drain lines from Building 10 on a regular basis:

> I would say that there were dozens of times that I worked over there. A lot of times when we worked over there, it would take days to finish a job. You had to find where the blockage was, saw cut the floor, break up all of the concrete with a sledge hammer, excavate it, get down in there and cut the line with a snap cutter, replace the line, fill it all in again with soil, and then pour the cement. [NIOSH, 2017c, p. 6]

In terms of exposure potential, a health physicist who worked onsite during D&D made this distinction between how maintenance workers at M&C handled drain lines versus later commercial remediation workers:

> I think that one of the differences that I would suggest is that these remediation workers are not handling the material inside the piping because usually it is dealt with in some way that it is a sealed entity. In many cases when there was piping or ductwork, the idea was not to take material out of it and clean it. The idea was to get rid of it. On the other hand, the maintenance worker's job is to clean the pipe. So, I think the difference is the proximity to the source term, the handling of the source term, and their physical presence near the source term was probably a little different. [NIOSH, 2017d, p. 6]

While this particular health physicist had overseen D&D activities at M&C in the 1990s, there is no record or account of actual health physics coverage or radiological monitoring during the residual period for maintenance workers in terms of overseeing their activities for purposes of identifying, monitoring, and controlling radioactive contaminant intakes and exposures[6] (NIOSH, 2017a, pp. 4–5, 15; NIOSH, 2017c, pp. 3, 6, 11; NIOSH, 2017d, pp. 15–16).

In terms of contrasting controlled D&D activities with the typical maintenance work performed at M&C, a former health physicist observed that D&D is a "controlled environment where the workers were very aware of what [they] were doing," whereas the latter was "uncontrolled, unconfined, aggressive as hell, using mechanical processes that cause aggravation and clouds of dust" (NIOSH, 2017d, pp. 4–5). Moreover, maintenance worker "environments were rarely cleaned because they are not part of the normal process areas. Nooks, crannies, ductwork, ventilation, submerged piping, confined spaces, sumps; this is where they live. It's not on the workforce shop floor" (NIOSH, 2017d, p. 5).

[6] Two individuals, at separate times, were identified as having responsibilities for M&C health physics, but former workers who were interviewed do not recall those individuals actually performing monitoring or overseeing maintenance activities for radiation protection purposes (NIOSH, 2017c, pp. 3, 6, 11).

With M&C workers regularly performing such intrusive activities, as described, they could have been potentially exposed to elevated sources of radiological contamination. For example, maintenance workers dismantling, servicing, moving, or cleaning internally contaminated equipment may have been exposed to uranium or thorium at elevated activity levels, but these contamination levels were not surveyed.[7] Workers excavating, cutting, clearing, and removing radioactive sediment from drain lines may have been likewise exposed to uranium and thorium at elevated levels, sometimes exceeding 50,000 picocuries per gram (pCi/g) (NIOSH, 2017e, p. 8), but the historic scope, frequency, and maximum level of that exposure prior to 1995 is not documented. Workers excavating pits and trenches in elevated subsurface contaminated soils, including former waste burial sites (as established by later D&D surveys), may have been exposed to resuspended aerosols and particulates not only from the elevated uranium and thorium soil levels but also from higher airborne concentrations due to the confined spaces within which they were working.[8]

While NIOSH has injected conservatism in its OTIB-0070 and related bounding analyses, using a 95th percentile distribution and other conservative assumptions to accommodate such uncertainties, the presence of residual radionuclide concentrations substantially in excess of those found in routine operational era surveys and later D&D characterization studies cannot be ruled out.

The active and intrusive nature of the described maintenance work at M&C during the residual period clearly exceeded the residual period conditions and activities at other AWEs, as described in their corresponding evaluation reports and site profiles, and what would be assumed under OTIB-0070 for application of its resuspension and volumetric soil values. It falls within the continuum of post-operational intrusive activities ranging from Norton and Vitro (very active, D&D-like activities) to that of Linde (renovation activities), with M&C being closer to the latter, but without the radiological protection controls, protective equipment, and personnel monitoring that were typical of formal D&D programs. Table 1 provides an intercomparison of 15 AWEs,

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[7] Routine maintenance on equipment is cited by former workers (NIOSH, 2017a, p. 5; NIOSH, 2017c, p. 3; NIOSH, 2017h, p. 4), and was performed by the M&C Repair and Maintenance group. It was also identified by NIOSH as not being addressed by the ER resuspension models (OTIB-0070) and involved “repurposing M&C equipment (e.g., removing and replacing mill units)” (DCAS, 2017, p. 1). A former worker noted that relocating equipment in Building 10 was a regular activity that typically took place on weekends (NIOSH, 2017a, p. 12). The status of equipment carried over from the pre-1968 AWE operational period is not addressed explicitly in the ER. It should be assumed that any equipment used in the operational period, prior to D&D, may have had internal contamination, as well as contamination under it, to which maintenance workers would have been later exposed when servicing that equipment or moving it. This issue was raised during Board discussions about the Linde SEC by a Board member with firsthand experience, who found that when workers “were actually moving, removing production processes . . . we always found the most contamination was in the footprint of these processes” (ABRWH, 2011, pp. 267–268). For M&C, it is reported that compressed air was typically used to clean mechanical equipment (Elliott & Lorenzen, 2017), which could have resuspended internal contaminants. The concentration of this contamination may be higher than that of surface contamination surveys conducted in 1967–1968 and could have included uranium and thorium particulates.

[8] The Occupational Safety and Health Administration (OSHA) defines confined spaces and gives examples including pits, tanks, silos, sewers, underground utility vaults, and manholes (U.S. Department of Labor, 2015, p. 25519). OSHA notes that pits, although typically open on top, can be completely underground or below grade and can still be a confined space (OSHA, 2015). The uncertainties posed by particulate and aerosol resuspension within confined spaces are discussed further in section 3.3.1 of this report.

including M&C, for their respective sources of exposure potential during residual periods and whether intrusive work activities took place that would have brought workers in close proximity with elevated exposure sources.

Table 1. Comparison of AWE sites: Sources of exposure potential and intrusive work activity during residual period

AWE site	Source of exposure potential	Intrusive work activity? (covered)	SEC class designated?	Reference
Carborundum	Resuspended U and Pu	No	No	NIOSH (2015a), pp. 50, 52
Baker Brothers	Resuspended U	No	No	NIOSH (2012b), pp. 33, 35–36
Hooker Electrochemical	Resuspended U	No	No	NIOSH (2010a), pp. 24–26
Chapman Valve	Resuspended U	No	No	NIOSH (2008b), pp. 17–18, 29–30
Bliss & Laughlin	Resuspended U	No	No	NIOSH (2009), pp. 17, 21–22
Simonds Saw	Resuspended U, Th	No	No	NIOSH (2010b), pp. 54–55
Blockson	Resuspended U, Th, Rn-222 exhalation	No	No	NIOSH (2015b), pp. 15–16, 24–29
Dow Chemical (Madison)	Resuspended U and Th, Th daughters	Yes (scrap handling)	No	NIOSH (2008c), pp. 8, 25–30
General Steel	Resuspended U	No	No	NIOSH (2008d), pp. 19, 24
Wah Chang	Residual DU	No	No	NIOSH (2010c), p. 20
United Nuclear	Resuspended U	No	No	NIOSH (2010d), pp. 41–42
Norton	Dismantlement activities, resuspended U, Th	**Yes** (tear-down, cleanup, disposal)	**Yes**	NIOSH (2011a), p. 16
Linde	Renovation activities, resuspended U	**Yes** (details lacking, D&D source terms applied)	**Yes**	NIOSH (2011b), pp. 22–23
Vitro	Remediation activities, resuspended U	**Yes** (removal/burial of contaminated material)	**Yes**	NIOSH (2011c), pp. 12–13
M&C	Intrusive maintenance activities, resuspended U and Th	**Yes** (details lacking; D&D source terms applied). 6 exposure pathways modelled.	Petition pending	NIOSH 2018, NIOSH 2017j

A judgment about the intrusiveness or disruptiveness of work activities during the residual period should be based on whether, as described by NIOSH, such activities would have “altered the materials present and placed employees close to the disturbed materials” (NIOSH, 2020a, slide 7). Based on worker interviews, affidavits, and presentations, backed up by available site documentation, M&C meets these subjective criteria. On that basis, the standard exposure model, as founded in OTIB-0070 and TBD-6000 and complemented by exposure pathway bounding, may not be sufficiently accurate for at least one or more of these pathways, as there could be a potential for higher potential exposure than would be bounded by that approach. At the very least, there is insufficient information available to rule out this possibility.

3.2 Line of inquiry 2

Are the exposure bounding methods prescribed by the ER and subsequent NIOSH reviews appropriate and consistent with how other AWE sites have been addressed?

In its September 2, 2020, presentation before the work group, NIOSH concluded from its review of 16 petitions for 15 sites that handled uranium and thorium that the “types of radioactive material, the crafts personnel who worked with the material, and the tasks performed at M&C are found across all of the AWE sites” (NIOSH, 2020a, slide 12). NIOSH also found that the dose reconstruction methods proposed for M&C and these other sites are “similar and consistent with those previously approved by the Board” (NIOSH, 2020a, slide 12).

This question originated with a concern expressed by work group members over “source data,” with the “missing piece [being] the work that was actually done.” It was also observed by a work group member that “this residual period is unusual compared to the other residual periods we’ve covered at other sites” (ABRWH, 2020a, p. 77). NIOSH’s subsequent review provided a “summary of bounding methods used for sites with residual radiation periods added to the SEC to compare to M&C” (NIOSH, 2020a, slide 3).

The threshold questions are whether the bounding approach for nonroutine exposure pathways applied to M&C is consistent with past practice and precedent for AWE residual periods, and whether dose reconstruction methods prescribed for these pathways can be considered plausible and sufficiently accurate.

3.2.1 Similarity of M&C to other AWEs

Like other AWEs, M&C had residual contamination resulting from various earlier uranium (and, in some cases, thorium) operations, for which some degree of surface area surveying or air monitoring had been conducted during the prior operational period. The crafts personnel making up the M&C maintenance crew were similar to those at the other AWE sites, including laborers, pipefitters, mechanics, and carpenters. Many of the work activities were similar as well and included welding, excavating, and general facility maintenance. Up to this point, there is agreement with NIOSH’s conclusion that “M&C operations were similar to operations at these other sites” (NIOSH, 2020b, p. 13).

However, the nature of much of the M&C maintenance work differed by the degree of its intrusiveness, which placed workers in close proximity to elevated contamination sources in normally inaccessible locations. As summarized in table 1, the 11 AWE sites listed by NIOSH in its response paper (NIOSH, 2020b), with the addition of the three SEC sites, were compared with M&C in terms of worker activities and exposure pathways for their respective residual periods.[9] Unlike these other AWE sites, M&C workers were faced with frequent blockages in drain lines that required subsurface excavations through concrete and contaminated soils and the close-in cleaning out of contaminated sediments and residues. Unlike other sites, M&C workers conducted much of their maintenance activities, for extended periods of time, in confined spaces, which included pits, trenches, and manholes. Unlike other sites, M&C maintenance excavations included former burial ground areas containing elevated subsurface contamination.

M&C's residual phase included maintenance activities that conform more to the "building renovation" scenario in NUREG/CR-5512 (NRC, 1992) than it does the "building occupancy" scenario that more typifies OTIB-0070 resuspension assumptions for other AWEs. The building renovation scenario assumes that following initial D&D, "surface and volume sources will be disturbed, creating loose contamination," and that "this loose contamination can produce higher concentrations of radionuclides in the air or on surfaces than the levels in an undisturbed building" (NRC, 1992, p. 3.1). Under this scenario, primary internal exposure pathways include inhalation of airborne radioactive dust and inadvertent ingestion of loose surface contamination (NRC, 1992, p. 3.1). Conversely, the building occupancy scenario assumes that workers "occupy a commercial facility in a passive manner without deliberately disturbing surface sources of residual contamination" (NRC, 1992, p. 3.9). Under this scenario, potential pathways of internal exposure include inhalation of resuspended surface contamination and inadvertent ingestion of surface contamination (NRC, 1992, p. 3.9). For convenience, attachment 1 reproduces figures 3.3 and 3.1 from NUREG/CR-5512 that illustrate the contrast between these two scenarios.

The precedent for addressing a building renovation scenario can be found in the Linde Ceramics Plant SEC ER. As noted previously, NIOSH found in the Linde Ceramics SEC-00107 ER that it is "reasonable to assume that [Linde's] renovation work could have resulted in elevated airborne radioactivity" (NIOSH, 2011b, p. 22), and that the internal dose for workers at the facility could be bounded with the highest air-monitoring data captured during jackhammering from earlier renovations, which could be assumed to be the maximum intake potential (NIOSH, 2020a, slide 6).

During its final review of the Linde SEC ER, the Board questioned this bounding approach. While jackhammering may have represented the highest measured contamination level (2.3 times the maximum allowable concentration air) for workers conducting that renovation activity (ABRWH, 2011, p. 263), members of the Board questioned whether it was appropriate to apply it as a bounding internal dose to non-D&D workers throughout the entire site for an extended time period, in the absence of information about these other work activities and related exposures. As noted by the Board Chair at that time, "we may have a bounding dose, but is it a plausible bounding dose, given how little information we have and the fact that most of these

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[9] For this review, the sections of these ERs and site profiles that addressed exposure sources and activities during the residual period were compared with M&C. With a few exceptions (e.g., the three SEC sites, radon at Blockson, thoron at Dow Chemical), exposures during the residual period for the other AWEs were attributed to routine resuspension of uranium and thorium from previous operations.

people probably weren't engaged in the activity [jackhammering] that we have done the dose reconstruction for?" (ABRWH, 2011, p. 124).

As given further elaboration in Board deliberations, the issue raised is where to "draw the line" for how expansively a maximized[10] exposure estimate is applied facility-wide or site-wide as a bounding dose (ABRWH, 2011, p. 129). Another consideration raised was that while such a conservatively constructed exposure estimate (or source term activity level) may be bounding, can it be considered "sufficiently accurate" if applied too broadly, for too long a time frame (ABRWH, 2011, p. 135)? The Board ultimately voted to recommend an SEC class for the Linde renovation period.

Assuming an extended renovation-like period during M&C's residual phase, during which disruptive maintenance activities were conducted, the question for the work group is whether the proposed dose-bounding approaches would be appropriate in the same context. For Linde, while exposure bounding was proposed based on a high airborne level taken for jackhammering, the extension of that assumed bounding air concentration value to the balance of the site for an extended time period was deemed not appropriate by the Board in the absence of information for non-D&D worker activities and their exposures (NIOSH, 2020b).

3.2.2 Bounding approaches for M&C

As with Linde, NIOSH determined that the OTIB-0070 resuspension model did not adequately address and bound all of the M&C worker activities during the residual period. As acknowledged by NIOSH, "The ER models resuspension (OTIB-0070) and does not specifically address potential exposures from digging, snaking/replacing clogged drain lines, or repurposing M&C equipment (e.g., removing and replacing mill units)" (DCAS, 2017, p. 1). These activities—which also included performing utility installations in contaminated roof areas and rafters, HVAC maintenance, and welding preparation—involved workers typically performing intrusive work with elevated dust loading. Following interviews with M&C former workers of that period, NIOSH developed exposure-bounding models for each of these nonroutine pathways to identify maximum soil or air concentrations values, amplified by a conservative 95th percentile distribution in determining the bounding value. Extensive reviews have already taken place regarding these models between NIOSH and SC&A and before the work group.

Putting aside the apparent health physics technical validity of the modeling calculations and their obvious conservatism, the questions before the work group should be the same as those debated for the Linde residual period: (1) Are such bounding formulations sufficiently accurate (i.e., do they adequately represent the exposure potential involved)? and (2) Is it plausible to back-apply

[10] The term *maximized* is used here to connote an exposure pathway bounding approach wherein NIOSH has estimated "the maximum radiation dose that could have been incurred under plausible circumstances" (NIOSH, 2020a, slide 17) applying conservative assumptions. Conservative assumptions applied at M&C include 95th percentile (subsurface, HVAC, roof and ceiling), 10^{-3} resuspension, 200 milligrams per cubic meter dust load (HVAC), the same person doing the job, and the most claimant-favorable solubility type (NIOSH, 2020a, slide 17).

them to a broad M&C maintenance worker population for a long period of time when actual information about their work activities or conditions may be limited?[11]

As noted in the Board's deliberations on the Linde residual period, the question of where to draw the line is a subjective one, weighing the precision (or accuracy) of the bounding assumption and data, and the plausibility of their application to the target worker population. Precision should be considered in the context of the relative dose levels involved (this is addressed in response to question 3 in section 3.3). For plausibility, its appropriateness should be corroborated by information available about the workers, the actual work performed, and their exposure potential.

On this basis, the bounding exposure pathway models for M&C can be reviewed, as described in sections 3.2.2.1–3.2.2.6.

3.2.2.1 Subsurface inside

NIOSH selected the highest Building 10 subsurface drain line sediment concentration of total uranium (measured from 20 samples taken in 1995 as part of 1996 remediation characterization[12]) and calculated a 95th percentile concentration of 6,887.84 pCi/g for bounding uranium in subsurface maintenance activities (NIOSH, 2018, p. 7). The use of this 95th percentile concentration acknowledges that "maintenance could have potentially removed sediments with the highest uranium concentration" in prior residual years (NIOSH, 2018, p. 7). NIOSH concludes that "the Priority-1 drain lines, worked on by M&C employees and removed by Weston, contained the highest subsurface radioactive material concentrations to which workers were exposed" (NIOSH, 2018, p. 6). This exposure pathway model assumes dust loading equal to the 95th percentile of the Mound project air sampling and a worker occupancy of 2 months conducting this work. Subsurface activities included (SC&A, 2021a):

- 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

The appropriateness of this bounding assumption can be judged on whether it is sufficiently accurate and plausible to select a high sediment reading in 1995, amplified by a 95th percentile concentration value, to characterize all inside subsurface exposures to maintenance workers for the residual period timeframe (1968–1997). While the stated purpose of the remediation survey was to "assess the potential for inadvertent exposures to non-radiological workers performing routine drainage system maintenance" (Weston, 1996, p. 2), there are no additional data for M&C drain pipe sediment readings for residual years prior to 1995.

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[11] The only definitive information available for the actual maintenance work involved are the recollections of former workers that, while helpful to describe the general nature of their work, do not substitute for the lack of actual job and task records, exposure monitoring records, contamination surveys, and incident reports.

[12] Performed by Roy F. Weston, Inc., as a part of a characterization of Building 10 drain lines for remediation. (Weston, 1996).

Former remediation workers involved with excavation and extraction at that time noted that extracted drain line residues included “metal chips and fines, and sludge” (NIOSH, 2017c, p. 10) and a “five-inch piece of an encapsulated fuel rod” (NIOSH, 2017c, p. 10), but they could not account for the “degree of blockage” over time[13] (NIOSH, 2017e, p. 7) or actual history of sediment (or residue) activity levels. Elevated sediment concentrations were found in remediation surveys conducted on Priority-1 drain lines, with a “worst-case subsurface contamination” level of 53,000 pCi/g being measured in 1995 (NIOSH, 2018, p. 11).

Given the likelihood of such “hot spots” being present in historic pipeline sediments, NIOSH sought to corroborate the conservatism of its bounding source term by comparing M&C’s experience with six other AWE sites with documented drain line sediment sampling.[14] That survey showed that “the maximum specific activity was at least an order of magnitude larger than the majority of other samples” which, in NIOSH’s belief, indicates that sporadic hot spots would not be unexpected at M&C and that there would not be a significant difference in the “mechanism of deposition and accumulation of sediment and pipe scale at M&C when compared to other sites” (NIOSH, 2021a, p. 6). NIOSH further believes this pattern shows that while there is a potential for such hot spots, “there is no indication of systemic conditions at these hot spot levels” (NIOSH, 2021b, slide 10).

The absence of actual records of historic drain pipe sediment activity levels at M&C before 1995, coupled with accounts of frequent blockages involving contaminated sediments, rags, artifacts, and even a discarded fuel rod piece[15] during the 27 years prior to D&D sampling, raises questions about the appropriateness of NIOSH’s bounding assumptions. While the presence of uranium and thorium in effluents are common attributes of the AWEs surveyed, these AWEs (and, notably, M&C) each had its own unique operations, equipment, and facility engineering; radiological, chemical, and mechanical processes; drain pipe composition, layout, and configurations; and effluent handling practices. Likewise, the comparative measurements taken at the six AWEs would have been influenced by the specific sampling method used at each site, location of the sampling, and the type of sample taken (e.g., dirt samples from floor drains, sediment samples from piping, average of aliquot samples taken from drains). All of these variables would have influenced the systemic amount of, and contamination levels in, residues, sediments, and sludge.

Would it be possible, if not likely, that the unique combination of covered and uncovered operations, conditions, configuration, and practices at M&C would have led to the generation and discharge of similarly unique radiologically contaminated effluents to its drain system? For example, the M&C Wire Department in Building 10 commonly used a vegetable-based mineral oil for drawing wire, which was known to coagulate upon discharge to the drainage system and

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[13] The 1995 remedial characterization surveys of the Priority-1 lines reported that 50–90 percent blockage from sediment and residue was found (Weston, 1996, p. 5).

[14] NIOSH reviewed Vitro, Bridgeport, Horizons, Peek Street, Mallinckrodt, and DeSoto (NIOSH, 2020a).

[15] The accumulation of various artifacts in the M&C drain lines can be attributed to missing grates on the drains, which allowed production residues and items to go down them, contributing to blockages that were apparently aggravated by the presence of vegetable-based oils used in production that coagulated in the drain lines (NIOSH, 2017i, pp. 6–8).

would frequently "plug up the drains" (NIOSH, 2017i, p. 6). Would it not be as likely that the regular release of a coagulant to the drain line system during active Building 10 operations (through 1981) would have led to more frequent and substantial blockages, perhaps involving higher concentrations of uranium and thorium as a function of the binding properties of the coagulant oil and other residues? While most of the drain line sediment samples taken at the surveyed AWEs were less than the 95th percentile (6,887 pCi/g) of the M&C sampling in 1995, would this necessarily be so with earlier M&C sediment hot spots?[16]

Another historical aspect of M&C drain lines is the accumulation of contaminant scale that has plated out inside the piping. This scaling was found in at least one instance at M&C to exceed 1,000,000 dpm/100 cm^2 in a 4-inch mainline drain that was being cut and removed (NIOSH, 2021a, p. 7). While such pipe scale has been identified at other AWE sites, M&C maintenance workers frequently cut, repaired, replaced, and cleaned out such piping during the residual years using power tools such as saws, drills, grinders, and powered snakes, as well as cutting torches. As noted by DOE in its hazard assessment of the Bridgeport Brass AWE, "the residual uranium could eventually be released . . . through intrusive work activities such as pipe cutting and removal" (DOE, 1996, PDF p. 11), and that "it is possible that under certain conditions (such as cutting through a steel pipe with a cutting torch) surface activity attached to the steel could be released with the steel particles" (DOE, 1996, PDF p. 48). Such work procedures would have generated fine airborne aerosols, including airborne contamination from the plated material, which would have been concentrated by the confined space (i.e., trenches, pits) atmosphere within which they were working. While the million-count reading represents a high activity level, contaminated scale elsewhere in M&C's extensive drain line network could have had similar, if not higher, levels over the residual years. There is no available information to address this question at M&C. This exposure pathway is not addressed by the current models.

Beyond these unique considerations, M&C maintenance workers regularly performed construction-like excavations, involving sawing, drilling, and jackhammering concrete floor slabs and subsurface digging, in order to install or modify equipment, and to access power conduits, airlines, and gas lines, as well as drain lines, all of which then required the aforementioned cutting, sawing, and drilling. While the 1995 drain line sediment reading is a high concentration level, can it be applied as a bounding exposure for unrelated inside subsurface work (i.e., non-drain line cleaning) for which little, if any, information is available and for which confined space atmospheres were involved? Does the Linde SEC precedent apply here?

NIOSH acknowledges that M&C subsurface work has been described as "very intrusive and included accessing contaminated materials that had accumulated for decades without work controls to mitigate the hazard" (NIOSH, 2018, p. 8). Accordingly, NIOSH found that the default dust-loading value of 100 $\mu g/m^3$ from OTIB-0070 and NUREG/CR-5512 was not appropriate for M&C subsurface work where "workers actively disturbed the contaminated material during

[16] Regarding work group questions raised related to possible material dilution and extraction inside drain pipes over time, 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" (SC&A, 2021a, p. 14). This conclusion, while reasonable, cannot be confirmed by available survey data and does not obviate the need to address the broader concern over the accuracy and plausibility of such bounding formulations in general, a concern that is addressed in section 3.3.

episodic responses throughout a given year" (NIOSH, 2018, p. 8). An increase in the dust loading factor for M&C subsurface activities was proposed based on dust-loading data from the Mound Plant Canal Clean-up Project (hereafter, the "Mound project"). The use of these additional (called "surrogate" by NIOSH (2018), p. 9) data is reviewed in section 3.3.1, with the concern being that it apparently lacks treatment of confined space considerations, which directly impacts resuspension and dust loading, and its applicability to M&C.

The former worker cited by NIOSH in its maintenance worker exposure model (NIOSH, 2018, p. 5), who stated that Exhibit 1 of the Weston 1996 characterization survey represented conditions prior to D&D activities, and therefore, offered "good insight into site conditions during the Residual Period and to which members of the class of employees subject to this SEC Petition were exposed" (Affidavit, 2016, p. 3), did not (and could not) account for whether higher activity sediments could have been handled at some earlier time by M&C maintenance workers performing cleanouts for the previous 27 years.

The former 1990s worker quoted by NIOSH (2018, p. 6) as referring to the drains in Building 10 as containing the "mother lode" of radioactive contamination (NIOSH, 2017e, p. 8) was likely correct about the significance of the contamination level involved in 1995. However, this worker would not have been able to distinguish which sediments and which jobs over time would have had the highest contamination and exposure potential for workers cleaning out or replacing earlier drain lines. Given the active radiological operations in Building 10 through 1981, it is just as likely that more frequent drain line blockages occurred in the earlier years involving higher activity sediment due to increased effluent volume related to operations, compounded by frequent discharge of the vegetable-based mineral oil that was implicated in the pipe clogging, as well as ongoing maintenance and cleanup of equipment.

Adding to the inherent uncertainty of the back application of D&D era data is the disparity between the radiological control program that was administered for the remedial contractors compared with that of M&C maintenance workers. For D&D activities, a comprehensive radiation safety program was in place, defined by detailed procedures, facilitated by worker knowledge and training, overseen by experienced health physicists, and regulated by the NRC. For M&C maintenance activities, workers were unaware of the radiological contamination, with no radiological control program implemented, no apparent health physicist presence, and no radiological control oversight.[17] Under such circumstances, M&C maintenance workers would have been more likely to have been exposed to elevated radioactive contamination during the course of their routine and nonroutine work, and no record of that exposure (e.g., source, contamination level, and exposure) would be available.

Relevant to this question, NIOSH did point out that while the 53,000 pCi/g uranium sediment measurement in the Priority-1 drain line was the "worst-case subsurface contamination," workers conducting the remedial work on these and other drain lines in 1995–1996 were not required to

[17] The only relevant safety document was the M&C Health and Safety Manual, which former workers were not familiar with and apparently did not follow (refer to section 3.3.2). A fellow worker was identified by some interviewees as having radiological control responsibilities, but there is no evidence of radiological surveillance, worker monitoring, or oversight of work activities during the residual period (outside of D&D), other than one or two isolated instances (e.g., when a portable Geiger-Muller counter was borrowed to conduct a spot survey).

wear respiratory protection (NIOSH, 2018, p.11). However, as emphasized by one former D&D worker, remedial work on drain pipes differed markedly from the corresponding work M&C maintenance workers performed; the former removed and disposed of the pipe, while the latter also repaired and cleaned out the pipe (NIOSH, 2017d, p. 6), with the degree of intrusiveness and potential exposure much greater for M&C maintenance workers. The D&D work was performed under strict monitoring and control procedures, overseen by a health physicist; the M&C maintenance work was conducted with none of that.

While there are precedents for back-applying conservative D&D measurements for AWE residual periods (e.g., particulates in Linde utility tunnels and intakes at Chapman Valve), that modeling did not assume intrusive activities occurred or that those activities could involve higher exposures due to elevated exposure conditions, uncertain facility activities, or unknown contamination sources. The sediment readings taken in 1995 from a Priority-1 pipe obviously had a high uranium concentration, but is it the bounding case for all inside subsurface activities for the previous 27 years of the residual period?

Finding 1. The back application of a high 1995 sediment survey result to bound inside subsurface activities is not adequately supported by information for M&C worker activities from the earlier residual time period.

3.2.2.2 Subsurface areas outside

NIOSH used characterization data for outside subsurface areas "surrounding Building 10, in the former Burial Area, the Metals Recovery Area, the Building 11 Stockade Area, the Building 11 Railroad Spur Area, and the Building 12 West and South Lawn Areas" (NIOSH, 2018, p. 7), with 2,391 soil samples collected in 1984 by Oak Ridge Associated Universities (ORAU) (Sowell, 1985) and in 1992 by Creative Pollution Solutions, Inc. (CPS, 1992) before remediation (including 1994 remedial survey samples for areas outside of the Burial Area). Of these samples, 1,629 were analyzed for gross alpha, and the remaining 762 were analyzed for isotopic uranium and thorium (NIOSH, 2018). To develop this model, NIOSH selected "594 lines of burial-site data" from the 1985 ORAU report (Sowell, 1985) and "blended them with data from other outside areas" to develop a 2,391-line spreadsheet that forms the basis of the exposure determination (NIOSH, 2021c, p. 2).

NIOSH calculated the 95th percentile uranium soil concentrations for uranium and thorium and arrived at 118 pCi/g and 88 pCi/g, respectively, for the bounding subsurface soil concentrations. NIOSH acknowledges that outside maintenance work performed during the residual period (notably the air-line installation in 1980) could have removed radioactive sediments, thereby diminishing these later source term estimates. The calculated 95th percentile concentrations address this potential discrepancy (NIOSH, 2021a, p. 12).

The appropriateness of this bounding assumption can be judged on whether (1) the outside maintenance excavations that took place at the M&C site prior to 1984 served to substantially spread, dilute, and otherwise alter the levels and contours of elevated subsurface contamination, and (2) whether, in the absence of actual measurements made of M&C site subsurface contamination prior to the 1984 ORAU and 1992 CPS surveys, whether these bounding values are sufficiently accurate, whether the 95th percentile value is sufficiently conservative, and whether it is plausible to back-apply these values to the many and diverse maintenance worker excavation activities during the earlier years of the residual period for which records are lacking.

There are accounts of artifacts, residues, and soils with elevated contamination that were encountered at the radioactive burial ground during installation of an air-line in 1980 and, according to former worker interviews, by other maintenance activities.[18] This installation required a trench to be dug through a portion of the burial ground. NIOSH believes the exposure of involved maintenance workers would not have been significant because, if they were, "the NRC would have directed M&C to use radiological controls, and reports of this work would be available similarly as they are for the other remediation tasks" (NIOSH, 2021c, p. 4). However, in 1980, information was limited to the types of contaminated waste material disposed of and the location, area, and depth of the burial site. It would seem that neither M&C nor NRC could have known about the configuration of subsurface uranium and thorium contaminants and their activity levels within the burial site and the attendant potential exposure, information that would not become available until the 1984 ORAU and 1992 CPS surveys.[19] NIOSH construes the lack of NRC regulatory direction to signify that the reported "elevated levels" were merely "above background, but less than release criteria (30 pCi/g)," and that "information related to this task supports NIOSH's outside subsurface model, in that the 95th percentile contamination level NIOSH applied (118 pCi/g) is approximately four times higher than the contamination level these workers experienced" (i.e., 30 pCi/g) (NIOSH, 2021c, p. 4), but without giving any apparent substantiation beyond inferring how NRC staff would have perceived the risk and what action they would or would not have taken.

In fact, these later D&D characterization surveys would show the following:

- The ORAU (Sowell, 1985) survey results for several bore holes within the burial area found elevated concentrations of uranium (U)-235 ranging from 6.03 pCi/g to 20.6 pCi/g, and elevated concentrations of U-238 ranging from 5.48 pCi/g to 680 pCi/g (CPS, 1993, p. 5).

- Survey results from the CPS (1992) pilot study, involving four trenches dug in the burial area, found that the concentration of total uranium in soil samples ranged from 8.22 to 3,349 pCi/g total uranium (CPS, 1993, p. 6).

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[18] The M&C burial ground is located between Buildings 11 and 12, with burials taking place in 1958–1961 (and possibly earlier in the 1950s). As described in site documents, "uranium - and thorium - contaminated noncombustible scrap material and machinery were collected in 55-gallon steel drums and disposed of through authorized agencies, or were buried on-site in compliance with 10CFR20.304" (Sowell, 1985, p. 1; NIOSH, 2017j, pp. 16-17).

[19] Following the 1984 survey, the NRC noted that "residual radioactive contamination remained in the burial area east of Building 11 and west of the recently constructed Building 12" (NRC, 1997a, p. 3). In 1990, the NRC listed the M&C site on the NRC's nationwide Site Decommissioning Management Plan (SDMP) because "on-site disposals [of radioactive material] had been made but the location and extent of the disposals were not well-known," and the extent and location of soil contamination on the site was also not well-known (NRC, 1997b, p. 2). The site was not removed from the SDMP until 1997, when a confirmatory survey showed no accessible contamination above the NRC criterion for unrestricted release (NRC, 1997a, pp. 4–5).

Upon initial remedial excavation by CPS at the burial site location where the most elevated subsurface sample had been previously identified:

> a large pocket of debris [was identified] at a depth of approximately 4 - 6 feet. Some of the debris indicated surface readings with a pancake [Geiger-Muller] detector of greater than 20,000 counts per minute (cpm). The surrounding soil had concentrations from 100 pCi/g to > 5000 pCi/g total uranium based on gross alpha screening results.
>
> The debris consisted of laboratory bottles, graphite crucibles, extruded uranium/ zirconium tubes, mounted uranium samples, 55 gallon drums, partial mock fuel elements, metal fines, uranium ingots, ductwork, uranium/aluminum plates, etc. [CPS, 1993, p. 12]

Texas Instruments, Inc. (TI) concluded that, "since the levels of soil contamination and debris were higher than expected, an adjustment in the remediation approach was implemented" (CPS, 1993, p. 13).

The 1992 CPS radiological characterization survey found that "contaminants may have been disturbed and distributed over an unspecified area" (CPS 1992, p. 3). This survey concluded:

> This process or processes have left some areas with isolated elevated concentrations of Uranium and a distribution of other areas with less, if any, contamination. This phenomenon also helps explain the presence of contaminants, at nonuniform distributed concentrations, at varying depths. [CPS 1992, p. 3]

Following completion of the 1992 remediation and survey of the burial area, TI identified soil contamination in three locations within the Metals Recovery Area (NRC, 1997a), adjacent to Building 5. This area was formerly involved with waste handling and included an open-air incinerator and liquid waste evaporator. The highest concentration of uranium identified in subsurface soil characterization and remediation sampling at that location was found to be 17,000 pCi/g. Remediation activities in this area were conducted in April–November 1994.

While NIOSH's OTIB-0070 guidance provides a basis for mass-based assignments to calculate air concentrations, given the above sample data, when combined with appropriate dust loading factors, two issues present themselves:

1. uncertainties surrounding the exposure potential of maintenance workers performing excavations in these contaminated soils
2. the inapplicability of the surrogate dust loading factor, a concern highlighted in section 3.3.1 of this review

For the first issue, with the assumption of a geometric mean (GM) and geometric standard deviation (GSD) based on 2,391 sitewide soil samples, the question is whether these averaged values would adequately reflect the elevated subsurface soil concentrations to which a worker may be exposed if that worker had been excavating a hot spot, such as the waste burial site or Metals Recovery Area. Unlike the modeling approach taken for the subsurface inside, the outside bounding soil concentration is not based on the 95th percentile of the highest potential concentration (i.e., sampling of Priority-1 drain lines), but that of the GM and GSD of a "blended" sampling of affected locations (NIOSH, 2021c, p. 2). NIOSH indicates that it has "reviewed the entire outside subsurface model data to determine if the burial ground samples are significantly different from the rest of the samples" and "found all of the outside areas' data were consistent, making sense because the site grading . . . in 1980 was responsible for much of the contamination on the other parts of the site" (NIOSH, 2021c, p. 2). Of the two identified burial area disturbances (1968 and 1980), however, NIOSH indicates that the "site grading [in 1968] was the only major disturbance and was responsible for many contamination finds on other parts of the site"[20] (NIOSH, 2021c, p. 4).

However, for the burial site and Metals Recovery Area, uranium soil concentrations in excess of 5,000 pCi/g and 17,000 pCi/g, respectively, were measured in later remedial subsurface surveys (1992–1994). From its subsurface characterization survey, CPS found the "presence of contaminants, at **nonuniform** distributed concentrations, at **varying depths**" (CPS, 1992, p. 3; emphasis added), meaning that the contaminants were not homogenously distributed by depth or area location. CPS concluded that this phenomenon was due to earlier landscaping processes (e.g., grading) that "left some areas with isolated elevated concentrations of Uranium and a distribution of other areas with less, if any, contamination" (CPS, 1992, p. 3).

Trenching by a maintenance worker within one of these isolated hot spot locations could conceivably lead to exposure to uranium and thorium at levels higher than the 95th percentile concentration derived from the sitewide GM and GSD based on the blended 2,391 samples (notwithstanding that some samples from these locations were included). There are documented accounts by former maintenance workers of performing at least two excavations within the burial area, installing a compressed airline in one case (NIOSH, 2021c, p. 3) and an electrical conduit in another (ABRWH, 2018, pp. 124–126). There are accounts by workers that adjacent to Buildings 10, 11 and 12, they "worked well below grade on all manner of piping," including the former outdoor incinerator area where they encountered "a lot of burnt black plastic and metals mixed with soil, and even the soil was blackened" (NIOSH, 2017c, p. 8). However, there is no further information available to account for where and how workers conducted what were likely other excavations in the burial area during the residual period to perform routine maintenance on the various gas lines, water main, communication cables, and other airlines and electrical conduits that crisscrossed near or within that area (CPS, 1993, p. 3).

While the combined sampling data from the ORAU and CPS surveys can be said to be representative of the M&C site, can this "blended" model accommodate disparate concentrations of such elevated uranium concentrations at varying locations and depths? It is not apparent that the burial ground sample data would be "consistent" with other sampling locations at the M&C site (NIOSH 2021c, p. 2) in the face of the elevated subsurface concentrations identified by CPS. It is also not clear how the 95th percentile distribution of ORAU/CPS survey data can be applied as bounding for burial area excavations having such hot spot levels, when NIOSH acknowledges

[20] These two statements appear contradictory; based on other NIOSH and SC&A findings, the second cited statement (for 1968) is the correct one.

that the "Sowell burial data contributes a small amount of data to one of our six exposure models" (NIOSH, 2021c, p. 2).

For the second issue, the dust loading in an outside subsurface trench or pit would be likely magnified by the confined space atmosphere involved—an issue made more uncertain by the lack of site-specific data and the contribution of power tool-generated aerosols. The question of an appropriate and accurate dust loading factor remains an open issue.

Observation 1. The use of blended D&D characterization survey data from 1984 and 1992 to support a bounding dose for outside subsurface activities may not be necessarily bounding for work in nonuniform soil contamination, given the presence of hot spots that existed during the residual period at M&C.

3.2.2.3 Roof and overhead area

NIOSH used direct contamination survey measurements of the Building 10 roof and overhead environment based on 285 grid average alpha-contamination survey results taken in 1982. The 95th percentile of these results is 89.9 dpm/100 cm^2 with 10 percent of the results associated with removable activity per OTIB-0070, providing for a bounding removable contamination activity level of 8.99 dpm/100 cm^2 (NIOSH, 2021b, slides 21–22). Given the direct measurements involved and their scope (which included undisturbed locations) and fit to the exposure potential (removable contamination), location (rafters), and timeframe, this exposure model and bounding calculation appear appropriate for their intended purpose. They were further validated by SC&A (2021a, pp. 20–22) in terms of accuracy and plausible application.

3.2.2.4 Welding operations

For welding operations, NIOSH assumed 100 percent of the gross alpha contamination activity involved (89.9 dpm/100 cm^2) is resuspended and assigned a conservatism factor of 10^{-3} to this 95th percentile contamination level to account for the weld-preparation activity generating the highest airborne concentration during welding work. This results in a bounding air concentration activity level of 8.99 dpm/m^3 for 48 hours per year (NIOSH, 2021a, p. 13). The conservative air concentration level provided in this model does not appear to be founded on actual results or experience at M&C and does not address resuspension in a confined space atmosphere. Welding did take place in some trench and pit venues, although it appears the referenced welding operations more often took place in open areas, such as the roof and in the rafters. However, the specificity of this maximizing air concentration level's application to the welding operations employed at M&C supports its plausibility.

SC&A's review of the exposure pathway models noted that "SC&A raised a concern (finding 2) in its 2019 (SC&A, [2019]) and 2020 (SC&A, [2020]) 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" (SC&A, 2021a, pp. 23–24). The M&C work group members repeated this concern during their meeting on September 2, 2020 (ABRWH, 2020b). While this issue has not been resolved, SC&A agrees that this is a site profile issue rather than an SEC issue, as does NIOSH (NIOSH, 2022a, p. 4).

3.2.2.5 HVAC maintenance

NIOSH adapted portions of a model developed by SC&A, with a geometric mean of 12.3 dpm/100 cm^2 calculated from 7,765 gross alpha swipe data collected at the end of AWE operations in 1966 and 1968. Using this surface contamination data and OTIB-0070, the gross alpha airborne concentration in Building 10 was estimated to be 0.0123 dpm/m^3. With an assumed dust loading providing a specific activity of airborne dust of 1.23E-4 dpm/µg, a bounding gross alpha air concentration of 12.3 dpm/m^3 was calculated for the HVAC maintenance activity (NIOSH, 2021a, p. 13). In 1982–1983, the NRC made 938 direct alpha, beta-gamma, and gamma measurements in Building 10 outside of HFIR, which, when compared with the late operations (1966, 1968) swipe samples (assuming 10 percent of the direct measured activity was removable), showed comparability. This was found likewise with 81 swipe samples taken by the NRC at the time. Therefore, 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" (SC&A, 2021a, p. 25).

3.2.2.6 Remaining exposures

As clarified in SC&A's exposure pathway evaluation (SC&A, 2021a, p. 26):

> 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.

For remaining exposures, NIOSH applies a bounding gross alpha airborne concentration for Building 10 (0.0123 dpm/m^3) with OTIB-0070 source term depletion adjustments to determine non-maintenance worker exposure rates throughout the residual period (NIOSH, 2021b, slide 27). SC&A compared this bounding approach to the same 1982–1983 direct radiation surveys of floors inside of Building 10 taken by the NRC inspectors and determined that the resulting exposure to natural uranium was below background and would be considered de minimis for purposes of dose reconstruction (SC&A, 2021a, pp. 27–28).

3.3 Line of inquiry 3

Are the available source term, survey data, and other information applied by NIOSH to support its dose bounding methods sufficiently accurate and plausibly applied?

A guiding principle NIOSH follows for addressing the "uncertainty around the work performed" or the "complete understanding of the work performed (e.g., one person doing all the maintenance work)" is that it is "NOT an issue when the bounding doses are very low, and specifically, during AWE residual periods such as at M&C" (NIOSH, 2020a, slide 14). To support the validity of its approach, NIOSH cites comments made by the former Board Chair:

> "with the residual period, we are going to have lots of situations — we have already had them — where we don't have very much information on the activities

> and the ability, usually very little sampling data. We are going to be using OTIB-70 a lot in these situations without knowing much about what individuals did on the site. [ABRWH, 2011, p. 144]
>
> If you look back at all of our decisions for a period of time — and I think it also goes to our evaluation of dose reconstruction. If the absolute value of the exposure is relatively low, then we're willing to accept more variability in the dose if it's being calculated for an individual. And if the exposure's absolute values are higher, then we're looking for a more accurate dose reconstruction method. [ABRWH, 2013, p. 19]

The first (2011) quote by the former Chair came from an extended discussion about the Linde Ceramics Plant residual period. It also included the discussion cited earlier in this report expressing concerns about the plausibility of applying a conservatively high air concentration to all of a site's workers based on a specific jackhammering activity. As the Chair stressed in that discussion, when information is lacking for affected worker populations, the application of generalized bounding doses, no matter how maximized, may not be appropriate (ABRWH, 2011, pp. 121–123). As the Chair explained:

> To me, the lack of information — and we have no sampling data during this renovation time period. We have very little information on what was done at the site during this time period and who was involved, and how many people were involved, that it seems to me that [it] is just as appropriate to be designated a Special Exposure Cohort.
>
> I think putting it into our terms, we may have a bounding dose, but is it a plausible bounding dose, given how little information we have and the fact that most of these people probably weren't engaged in the activity that we have done the dose reconstruction for? [ABRWH, 2011, pp. 123–124]

NIOSH's second cited (2013) quote was part of an extended discussion within the SEC work group about concepts and experience related to the issue of technical accuracy and the plausibility of applying upper bounds to the exposure of worker populations. As the former Chair noted in that discussion, "We all know we can upper-bound anything. So this always comes out with sort of what's the plausibility of that" (ABRWH, 2013, p. 24). He elaborated later on this point:

> I think it's sort of a Linde example that I was giving and it really maybe convoluted different concepts.
>
> But we saw two issues. One is . . . as long we can do it in upper bound and that's a plausible upper bound for the highest exposed individuals, then that method was okay, and we didn't really look at how that upper bound was — the population it was being used for. And so it may be a plausible upper bound for a certain group, but it really may not be a sufficiently accurate plausible upper bound for the others in that same population. [ABRWH, 2013, pp. 37–38]

The preceding suggests that while less precision or accuracy could be tolerated if the exposure of a worker cohort is relatively low, the use of a high exposure or concentration value based on a set of specific workplace data to bound or represent that of other workers in a facility or on a site, particularly over a lengthy time period, would not be appropriate if their exposure potential could be higher, work conditions were different, or if there is lack of information upon which to make that judgment.

Regarding conservatism, while any measurement can be made extremely conservative by the multiple layering of favorable assumptions and statistical 95th percentile values, the Board's original question remains: Where do we draw the line with the application of bounding values? As pointed out during the Board's Linde review, if "carried to an extreme, we could take any site . . . and we could come up with what we think is the highest possible exposure at that site that would occur, and that would be bounding, and apply that to everybody that ever worked at the site" (ABRWH, 2011, p. 129). However, the essential questions, as the former Board Chair put it, are "is that a plausible bound? And, then, who are we trying to characterize?" (ABRWH, 2011, p. 129).

Various means of supporting or corroborating the accuracy, validity, and representativeness of bounding analyses were presented by NIOSH during work group discussions. Sections 3.3.1 and 3.3.2 summarize and assess two of the key means.

3.3.1 Surrogate data (Mound Plant dust loading)

NIOSH acknowledged that the default dust-loading value of 100 $\mu g/m^3$ suggested in OTIB-0070 and NUREG/CR-5512, which was intended for a screening analysis for a long-term average, would not be appropriate for the intrusive subsurface work that former M&C workers described. Instead, a dust-loading factor determined during excavation at the Mound Plant was applied as a surrogate[21] value to provide a corroborating basis for increasing the resuspension factor at M&C (NIOSH, 2018, p. 8). As described by NIOSH in its 2018 white paper on the M&C maintenance worker exposure model, 294 hi-volume air samples were taken at backhoe excavation activities at Mound in 1997, with air-sample collection media weighed before and after taking each sample to determine their dust loading in grams (NIOSH, 2018, p. 8). NIOSH compared the Mound project with the five criteria listed in section 3 of OCAS-IG-004, "The Use of Data from Other Facilities in the Completion of Dose Reconstructions Under the Energy Employees Occupational Illness Compensation Program Act" (NIOSH, 2008a), to describe how that project satisfies these criteria for the use of dust loading values from Mound as surrogate data for use at M&C (NIOSH, 2018, pp. 9–10). NIOSH found that each of these criteria were satisfied.

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[21] The term *surrogate* is used here for consistency, given its use by NIOSH in earlier work group discussions. It is understood that NIOSH has since "determined the data should be classified as hierarchy #4 data in accordance with OCAS-IG-004" (NIOSH, 2020d, p. 8). That guide indicates the use of this categorization is appropriate if "source term and process information (hierarchy #4) for a particular facility need to be supplemented to adequately characterize the workplace exposure conditions, it may be necessary to rely on data from another facility to completely develop an exposure model" (NIOSH, 2008a, p. 4). However, the issues raised in this section remain the same in terms of the appropriateness of applying the Mound data to M&C in this manner.

SC&A reviewed NIOSH's surrogate use of the Mound data in its October 2021 report, "SC&A Commentary on NIOSH's Approach to Quantifying Outdoor and Indoor Airborne Dust Loadings" (SC&A, 2021b). That review found that "the Mound data and the data for indoor and outdoor excavation dust loadings described in section 3 can be considered a type of surrogate data, the use of which is governed by the Board's surrogate data criteria (ABRWH, 2010)" (SC&A, 2021b, p. 11). The review of this approach included its application of dust loading data, how it satisfies the Board's surrogate data policy, and supporting scientific literature. SC&A concluded that "NIOSH's adoption of 212 $\mu g/m^3$ for estimating respirable outdoor dust loading during excavation activities is reasonable but not necessarily bounding" (SC&A, 2021b, p. 20).

For four of the five Advisory Board surrogate data criteria[22]—hierarchy of data, exclusivity requirements, temporal considerations, and scientific plausibility—as applied to use of the Mound project data, it is clear that the criteria are satisfied, as noted by SC&A in its 2021 review (SC&A, 2021b). However, for site and process similarities, this reviewer shares the reservations expressed by SC&A's 2021 review.[23] For example, in terms of specific site characteristics for M&C, it is not apparent how the Mound project addressed considerations related to resuspension or dust loading in a confined space, such as the various manholes, trenches, pits, and vault spaces at M&C in which maintenance workers actively worked. "Confined space" is defined as "a space which, by design, has limited openings for entry and exit, unfavorable natural ventilation which could contain or produce dangerous air contaminants, and which is not intended for continuous worker occupancy" (NIOSH, 2022b). Because air may not move in or out of confined spaces freely, gases and particulates can concentrate to higher levels than in an unconfined environment.

For example, in addition to the initial excavation operations using backhoes, concrete saws, and jackhammers, M&C maintenance workers would have entered such subsurface excavations and other confined spaces to perform hand digging and scraping; to remove soil, concrete, and other debris; to operate hand saws, grinders, and drills to perform penetrations and to cut lines; to pull, cut, clean out, and repair drain and air lines; and to clean up afterwards. Beyond the resuspension of dust experienced from backhoe, jackhammering, or comparable excavation, the elevated dust loading is associated with not only intrusive work in a confined space but also the actual generation of fine aerosols and particulates through the sawing, grinding, drilling, and welding that were a part of the work being conducted. In essence, the contrast is between airborne dust levels during backhoe operations (Mound project), and those experienced inside of a tight and enclosed pit, hole, or ditch with related sawing, grinding, drilling, hand digging, and pipe cleaning (M&C). A confounding factor is the uncertainty and lack of site-specific information

[22] As noted by SC&A (2021b), the Board's surrogate criteria are somewhat different than the surrogate criteria in OCAS-IG-004 (NIOSH, 2008), which NIOSH (2018) used to assess the applicability of the data to M&C.

[23] SC&A found that "the surrogate data criteria regarding outdoor and indoor dust loading during excavation activities certainly apply to these same activities as those at M&C and can also be considered generically applicable to outdoor and indoor excavation activities. However, for both indoor and outdoor excavation activities, there are likely many site-specific characteristics that can uniquely affect dust loadings, including the characteristics of the soil and the proximity of workers to the excavation activities. There is very little that can be done to accommodate these types of site-specific characteristics, except to use a degree of professional judgement that would tend to place an upper bound on the dust loading" (SC&A, 2021b, p. 11).

about the configuration, condition, activity, location, and timeframe of indoor and outside subsurface work that M&C workers performed during the residual period.

For M&C, it was not uncommon to be working in a trench doing routine utility repairs or pipe cleanouts for days and up to a week (DCAS, 2017, pp. 1–2), and for electrical, equipment, and tank installations, this could be longer. One installation project in Building 10 involved cutting out an existing drain line and installing new equipment, piping, and large tanks, necessitating a trench 100 feet long, with a depth of 8–10 feet in places, that was worked in for 6 months in 1983-1984 (NIOSH, 2017i, p. 12).

The lack of natural ventilation in a confined space is demonstrable and has a direct impact on resuspension and dust loading. To illustrate, while NIOSH applies a standard 10^{-6} m^{-1} resuspension factor in its OTIB-0070 evaluation, the International Atomic Energy Agency (IAEA) guidelines for “Radiological Aspects of Non-fixed Contamination of Packages and Conveyances” recommends a resuspension factor of 4×10^{-5} m^{-1} for dusty operations in confined spaces (IAEA, 2005, p. 11).[24] The U.S. Department of Energy (DOE) “User’s Manual for RESRAD-BUILD Version 3” gives a resuspension factor of 4.3×10^{-5} m^{-1} for “active work in confined, unventilated space” (Argonne National Laboratory, 2003, p. J-33). Dust loading calculations for confined spaces would be expected to be similarly influenced, with knowledge of site conditions and mechanical processes important to gauging the level of airborne dust generated.

For comparison, the 212 $\mu g/m^3$ dust loading factor, based on an empirical 95th percentile value from the highest monitored air concentration during the Mound excavation, is about double that of the 100 $\mu g/m^3$ value suggested in OTIB-0070 (NIOSH, 2012a) and NUREG/CR-5512 (NRC, 1992). However, the preceding scientific literature cites resuspension factors for confined spaces of about a factor of 40 times that of the recommended 10^{-6} m^{-1} resuspension factor in OTIB-0070. And these factors do not account for the level of intrusive activity within the confined spaces by M&C maintenance workers, or for the use of power equipment generating fine aerosols and particulates (e.g., drain line scale).

As background on this issue, OSHA published a new construction standard for confined spaces (29 CFR 1926, Subpart AA), effective on August 3, 2015, that promulgated safety requirements for workers in construction confined spaces. OSHA defines confined spaces and cites examples including pits, tanks, silos, maintenance holes, sewers, enclosed drains, and manholes (NIOSH, 2022b). OSHA notes that pits, although typically open on top, can be completely underground or below grade and can still be a confined space (OSHA, 2015). Supporting industry literature following promulgation of the Subpart AA standard noted that confined spaces “include tight work areas with reduced air flow” where work such as “welding, cutting, grinding, sanding or any high-energy activity can create . . . respirable particles and/or toxic aerosols” (Chase, 2019). The more deeply respirable particles are 4 microns or smaller and are typically generated from such high-energy work (Chase, 2021). The “potential of limited air movement and minimal

[24] IAEA-TECDOC-1449 references the Fairbairn model, which applies other parameters for modeling airborne contaminants. It is unclear how these parameters relate to similar OTIB-0070 considerations, although it does appear more conservative regarding confined spaces.

ambient air circulation in these spaces allows particulate concentrations to build quickly" (Chase, 2019).

SC&A has already conducted literature surveys of indoor airborne dust loadings (SC&A, 2018, pp. 55–60; SC&A, 2021b, pp. 12–18) and found a range of concentrations that may have applicability. However, the surrogate criterion question remains: Were dust loading concentrations within the trenches of the Mound excavation adequately characterized via air sampling such that these data can be applied to corresponding confined work spaces at M&C? NIOSH noted in a September 2, 2020, presentation that "during the Mound study the high-volume air samplers were positioned close to the excavation, which reduces the impact of the larger outside air volume" (NIOSH, 2020a, slide 25). From notes from an interview conducted with someone knowledgeable about the project, the samplers were apparently about "15-20 ft" from excavation activities (NIOSH, 2020c, p. 6). From this description, it appears that the samplers were near the excavation activities but were not sampling air at or within the trenches during any worker activities that may have taken place within those confined spaces.

Given the likelihood that generation and resuspension of radioactive particulates and aerosols were higher in these confined spaces, leading to higher dust loading factors, the location of the Mound project air monitors and their proximity to any actual work being conducted within the excavated trenches would be a key consideration for satisfying the Board's surrogate data policy. Given that the Mound project was conducted in an outdoor excavation site, another factor would be the presence of lateral air movement (wind), which would have diminished dust loading measurements taken there versus those applicable for confined space work areas, where it would not have been a factor.[25] At the same time, as pointed out by SC&A (2021b, p. 21), "it can also be stated with a degree of certainty that it would be highly implausible that workers could be exposed for extended periods of time to dust loading of any size distribution of about 100 mg/m^3 (100,000 μg/m^3) or greater because of the choking effect of such high levels."

For the application of the Mound project data to an indoor scenario at M&C, NIOSH assumes a conservative margin is provided by use of the 95th percentile case from that project, coupled with the "limited airborne-generating capacity of snakes and shovels . . . on wet soil inside" compared to operation of backhoes in an outside environment (NIOSH, 2020a, slide 25). However, the question of equivalency from the Board's surrogate policy remains the same: Are the Mound project measurements reflective of the same work conditions and environment as those at M&C?

Finding 2. The application of surrogate data from the Mound project to provide a dust-loading factor for M&C subsurface activities does not satisfy the Board's surrogate data policy.

[25] NIOSH notes that "windbreaks, tents, or ventilation were not used" during the Mound excavation nor during the M&C excavations (NIOSH, 2018, p. 9).

3.3.2 Building 10 routine alpha contamination surveys

NIOSH observed in a response to work group comments that, "although comprehensive sample data used to characterize earlier periods did not become available until 1983–1995, NIOSH is aware of the safety program that was in place during the residual period" (NIOSH, 2020b, p. 17). NIOSH proceeded in that response and others to "make the case that M&C's area monitoring assures that the 95th percentile soil-contamination value is conservative based on routine surveys of Building 10 during the first 14 years of the residual period (1968-1981)" (NIOSH, 2021a, pp. 7–8).

NIOSH's case is founded on citing area contamination survey requirements and procedures from the M&C health and safety manual from 1968 and noting that NRC inspections during the residual period for the regulated HFIR facility "provide NIOSH with independent assurance that radiological controls were monitored or maintained" (NIOSH, 2021a, p. 8). Actual routine contamination survey results are available for the first 2 years (1968–1969) of the residual period for the HFIR operation in Building 10, with an assumption that such surveys continued until 1981. NIOSH also references a summary of "typical" alpha contamination survey results for the HFIR facility work, provided from the environmental monitoring program, that it believes "clearly indicate[s] contamination was controlled within bldg.10 during the HFIR project" (NIOSH, 2021b, slide 17).

This reviewer respectfully disagrees with NIOSH's position and related assumptions in this case. Without corroborating testimony or evidence regarding the actual implementation of non-HFIR Building 10 workplace contamination surveillance procedures at M&C during the residual period, assurance cannot be placed solely on "typical" HFIR-specific survey results—although no actual routine contamination surveys were found[26]—or procedural requirements (e.g., a M&C safety manual or NRC inspection requirements). While "NIOSH believes [the M&C manual] adequately describes M&C's established concern for contamination control" (NIOSH, 2021b, slide 14), this has no bearing on whether M&C management's presumed concern translated into actual monitoring implementation and practice. NIOSH's awareness that NRC must have "enforced these contamination surveys" for licensed HFIR operations because "whenever M&C wanted to change administrative requirements (e.g., frequency of surveys), they send a request to the NRC" (NIOSH, 2021b, slide 15), is presumptive and not corroborated. Likewise, NIOSH's citing of NRC inspection results for HFIR operator knowledge, use of survey equipment, and licensee health physics training records does not corroborate that actual surveying took place and would have been carried over to non-HFIR spaces in Building 10 by virtue of the M&C health and safety manual.

As demonstrated by past site reviews under EEOICPA, there are notable instances where actual implementation of radiological monitoring fell considerably short of matching what was documented in site manuals and procedures.[27] Likewise, despite what undoubtedly was the

[26] Verified by NIOSH during the March 18, 2021, M&C work group meeting (ABRWH, 2021, p. 85).

[27] Most notably, the DOE enforcement program invoked a 120-day DOE-wide moratorium in 1998–1999 for enforcement actions against DOE operating contractors to enable them to self-assess and, as necessary, make corrective actions for their internal dose evaluation programs in the face of widespread deficiencies in implementing and enforcing those programs in accordance with site policies and procedures and DOE regulations (DOE, 1999).

expertise of M&C engineers in pioneering low-level alpha counting and quantitative gamma spectrometry technologies, this is not relevant to, nor makes the case that, M&C routine contamination surveys continued unchanged in the early residual period, or that the presumed rigor of the HFIR contamination survey program carried over to routine monitoring and cleaning up of contamination in non-HFIR spaces of Building 10 for the residual period.

On the contrary, the only first-hand corroboration of the status of health physics monitoring and surveying practice in non-HFIR areas of Building 10 are the accounts of former M&C workers. That testimony attests to (1) health physics personnel generally not being present during the residual period (not including those supporting remedial contractors), (2) worker unfamiliarity with the M&C health and safety manual, and (3) workers having little recollection of any routine alpha contamination surveys being conducted in Building 10 during the residual period (e.g., NIOSH, 2017c, pp. 3–4, 6; NIOSH, 2017d, pp. 9–10, 13, 15–16; NIOSH, 2017f, p. 3; NIOSH, 2017b, p. 9; NIOSH, 2017e, p. 11; NIOSH, 2017g, p. 3; NIOSH, 2017i, p. 10; ABRWH, 2021, pp. 26–31; ABRWH, 2020b, p. 101). NIOSH's conclusion that, "if widespread removable alpha contamination existed at levels higher than the 95th percentile in the areas where maintenance was performed, then the routine surveys would have eventually identified tracking throughout the plant during this 14-year period" (NIOSH, 2020b, p. 18), is not corroborated by actual evidence of any routine monitoring performed after 1969 in non-HFIR areas of Building 10.

Observation 2. References to the M&C safety and health manual, NRC inspection results, operator training, and other programmatic considerations do not necessarily substantiate the conservatism of the 95th percentile soil contamination value being applied.

4 Conclusions

Precedent suggests that while less precision or technical accuracy can be tolerated if the exposure of a worker cohort is relatively low, the use of a high exposure or concentration values based on these data to bound or represent that of other workers in a facility or on a site for long time periods would not be appropriate if their exposure potential could be higher, conditions were different, or if there is lack of information upon which to make those judgments. As noted in the Board's deliberations on the Linde residual period, the question of where to draw the line for applying such bounding constructs is a subjective one, weighing the precision (or accuracy) of the bounding assumption and data, as well as the plausibility of their application to the target worker population.

The following findings and observations arise from this issue, as well as others addressed in this supplemental review.

1. **Finding 1. The back application of a high 1995 sediment survey result to bound inside subsurface activities is not adequately supported by information for M&C worker activities from the earlier residual time period.**

   For the inside subsurface exposure model, the issue for the work group is whether it is plausible for an elevated sediment reading from a D&D drain pipe sediment survey in 1995 to be assumed, in the absence of additional site-specific information, to be the bounding exposure for all M&C maintenance workers who may have conducted various (and diverse) subsurface activities inside Building 10 (and to a lesser extent, Building 4) for the earlier 27 years of the residual period. While the 1995 drain line reading is a high activity level, can it be applied as a bounding exposure for related and unrelated inside subsurface work for which little, if any, documented information is available and for which confined space atmospheres were involved? Given the active radiological operations in Building 10 through 1981, it is just as conceivable that more frequent drain line blockages occurred in the early years, involving higher activity sediment due to increased effluent volume related to operations, compounded by frequent discharge of vegetable-based mineral oil that was implicated in the pipe clogging, as well as routine maintenance of equipment. Unlike for D&D activities, for which the sediment sample was taken, M&C maintenance workers were unaware of the radiological contamination involved, and there was no radiological control program, no health physicists, and no oversight.

2. **Observation 1. The use of blended D&D characterization survey data from 1984 and 1992to support a bounding dose for outside subsurface activities may not be necessarily bounding for work in nonuniform soil contamination, given the presence of hot spots that existed during the residual period at M&C.**

   For the burial site and Metals Recovery Area, uranium soil concentrations in excess of 5,000 pCi/g and 17,000 pCi/g, respectively, were measured in later remedial subsurface surveys (1993–1994). Such hot spots were found at differing locations and depths, given the heterogeneity of contamination that originated with waste disposal (burial site) and waste incineration (Metals Recovery Area) and the non-uniform mixing that occurred in the 1968 site grading at M&C. The 95th percentile subsurface soil concentration derived from the sitewide GM and GSD based on the selected and blended 2,391 samples taken during D&D characterization surveys, while including sampling data from these locations, may not necessarily bound exposures from excavation work performed by individual workers exclusively within these elevated hot spot locations.

3. **Finding 2. The application of surrogate data from the Mound project to provide a dust-loading factor for M&C subsurface activities does not satisfy the Board's surrogate data policy.**

   The dust loading monitoring results for the Mound project excavation, being apparently derived from air samplers located near backhoe excavation, are not equivalent to and would not necessarily characterize dust loading within the confined spaces at M&C where subsurface maintenance activities were conducted.

4. **Observation 2. References to the M&C safety and health manual, NRC inspection results, operator training, and other programmatic considerations do not necessarily substantiate the conservatism of the 95th percentile soil contamination value being applied.**

   The claim "that M&C's area monitoring assures that the 95th percentile soil-contamination value is conservative based on routine surveys of Building 10 during the first 14 years of the residual period (1968-1981)" (NIOSH, 2021a, pp. 7–8) is not necessarily substantiated by the assumed strength of the M&C radiological surveillance program. Without corroborating accounts or evidence regarding the actual implementation of non-HFIR workplace contamination surveillance procedures at M&C, assurance cannot be placed solely on typical HFIR-specific survey results or the assumed implementation of procedural requirements such as the M&C safety manual or NRC inspection requirements.

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Attachment 1

This attachment reproduces images of building activity scenarios from NUREG/CR-5512, Vol. 1, "Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent" (NRC, 1992).

Figure A-1. Potential activities within the building occupancy scenario (NUREG/CR-5512, vol. 1, figure 3.1)

Building Scenarios

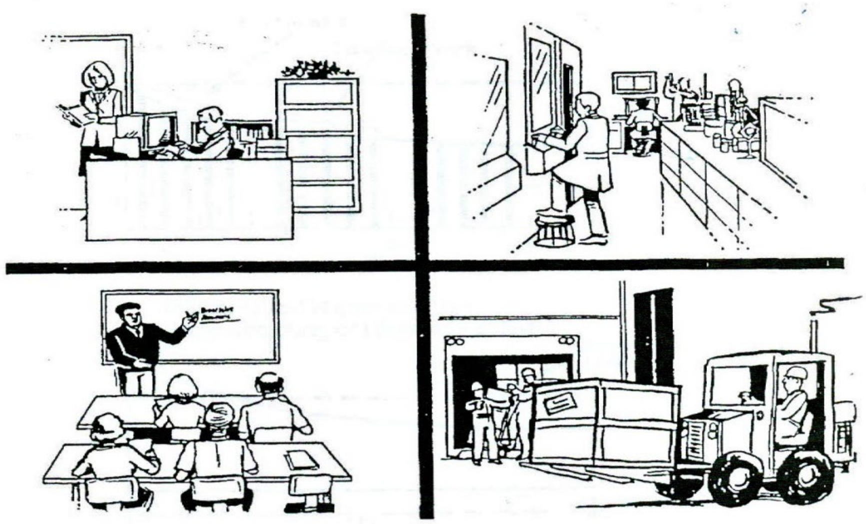

Figure 3.3 Potential activities within the building occupancy scenario

Source: NRC (1992).

Figure A-2. Potential activities within the building renovation scenario (NUREG/CR-5512, vol. 1, figure 3.1)

Building Scenarios

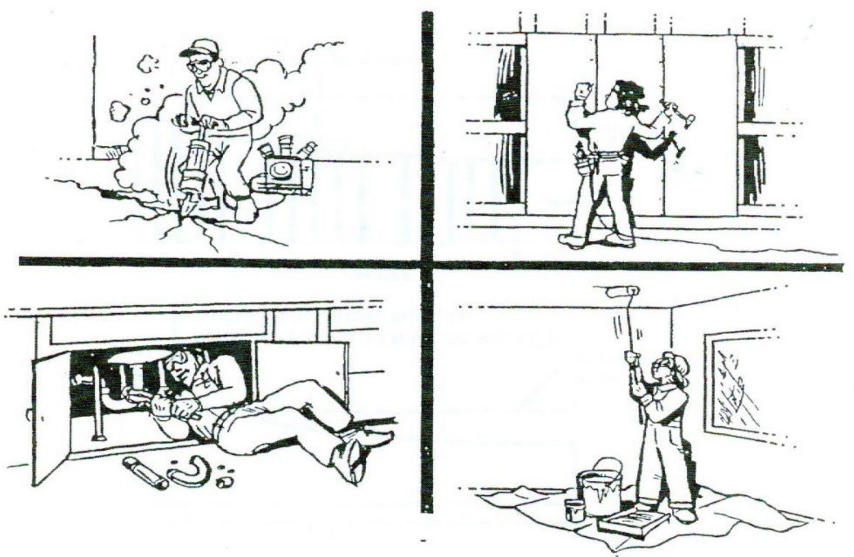

Figure 3.1 Potential activities within the building renovation scenario

Source: NRC (1992).