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ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF SEC PETITION EVALUATON REPORT SEC-00236 METALS AND CONTROLS CORPORATION

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TABLE OF CONTENTS

Abbreviations and Acronyms 5
Executive Summary 7
1 Introduction and Background 10
2 Review of Internal Dosimetry Methodology and Data 14
2.1 Internal Exposure Explicitly Addressed in the ER 14
2.1.1 Inhalation Initial Conditions during the ER Period 15
2.1.2 Source Term Depletion during the Residual Period 17
2.1.3 Inadvertent Ingestion 19
2.2 Exposure Associated with Maintenance and Repurposing Activities 20
2.2.1 Subsurface Exposure Scenarios 21
2.2.2 HVAC Scenarios 22
2.3 Assessment of Potential Internal Doses Associated with Maintenance and Repurposing Scenarios 24
2.3.1 Subsurface Excavation of Building 10 24
2.3.2 Subsurface Excavation in the Vicinity of the Waste Burial Pit 25
2.3.3 Internal Exposures Associated with HVAC Maintenance 26
2.3.4 Other Potential Exposure Scenarios 28
2.4 NIOSH Rationale for Not Explicitly Addressing the Potential Exposures Associated with Maintenance and Repurposing Activities 29
2.5 Concerns Expressed by Workers 31
2.6 Exposures Experienced by D&D Workers 32
3 Review of External Exposure Methodology and Data 35
3.1 NIOSH Methodology for Assigning Penetrating Doses to Workers during the Residual Period 35
3.1.1 Use of Landauer Film Badge Dosimetry Reports 35
3.1.2 Review of NIOSH Analyses 36
3.1.3 Reanalysis of Whole-Body Film Badge Dosimetry Data 37
3.2 NIOSH Methodology for Assigning Beta Skin Doses to Workers during the Residual Period 38
3.3 Applicability of Film Badge Dosimetry Results from the AWE Period to Doses during the Residual Period 39
3.3.1 Worker Exposures to Drain Pipe Residues 39
3.3.2 Worker Exposures to Contaminated Floors 40
3.3.3 External Exposures of HVAC Workers 40

3.4 Summary and Conclusions ... 40
4 References ... 42
Appendix A: Overview of SEC Petitions for AWE Sites During the Residual Period Previously Evaluated by the Advisory Board ... 46
Appendix B: M&C's Health and Safety Program ... 48
Appendix C: Independent Verification of Skin Dose from Uranium Dust ... 53
Appendix D: Summary of Literature on Indoor Airborne Dust Loadings ... 55
Appendix E: [Redacted in Full] ... 61

ABBREVIATIONS AND ACRONYMS

Board or ABRWH	Advisory Board on Radiation and Worker Health
ACGIH	American Conference of Governmental Industrial Hygienists
AMAD	activity median aerodynamic diameter
AWE	Atomic Weapons Employer
Bq	becquerel
CFR	*Code of Federal Regulations*
BZ	breathing zone
CPS	Creative Pollution Solutions
D&D	decontamination and decommissioning
DAC	derived air concentration
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ER	evaluation report
FMA	fuel manufacturing area
FUSRAP	Formerly Utilized Sites Remedial Action Program
GSI	General Steel Industries
H&S	health and safety
HEW	U.S. Department of Health, Education, and Welfare
HFIR	High Flux Isotope Reactor
HVAC	heating, ventilation, and air conditioning
ICRU	International Commission on Radiation Units & Measurements
LOD	limit of detection
M&C	Metals and Controls Corporation
MDA	minimum detectable activity
µCi	microcurie
µg	microgram
µm	micrometer
MPC-h	maximum permissible concentration hours
mR	milliroentgen

mrem	millirem
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
OTIB	ORAUT technical information bulletin
Pa	protactinium
pCi	picocurie
R&M	repair and maintenance
Ra	radium
RF	resuspension factor
RSAP	Radiological Site Assessment Program
SEC	Special Exposure Cohort
SRDB	Site Research Database
Sv	sievert
TBD	technical basis document
TEDE	total effective dose equivalent
Th	thorium
TI	Texas Instruments Incorporated
TLD	thermoluminescent dosimeter
TLV	threshold limit value
TSP	total suspended particulates
TWA	time-weighted average
U	uranium

EXECUTIVE SUMMARY

On September 1, 2016, Special Exposure Cohort (SEC) Petition 236, dealing with the residual period of the Metals and Controls Corporation (M&C), was submitted to the National Institute for Occupational Safety and Health (NIOSH), and on April 5, 2017, NIOSH completed the SEC petition evaluation report (ER) (NIOSH 2017a). On August 24, 2017, the Advisory Board on Radiation and Worker Health (the Board) requested that SC&A review the ER. This report is provided to the Board in response to that request.

The ER concludes that doses experienced by the workers covered by SEC Petition 236 can be reconstructed with sufficient accuracy and recommends denial of the SEC petition. This recommendation is based on data, methods, assumptions, M&C worker interviews, and other sources of information described in the ER and available on the Site Research Database (SRDB).

Upon authorization by the Board, SC&A began its review of the ER with two objectives:

1. Provide information for use by the Board in determining whether doses can be reconstructed with sufficient accuracy, as defined in 42 CFR Part 83.
2. Provide a technical evaluation of the scenarios, data, assumptions, models, and other information provided or referenced in the ER for reconstructing doses.

With respect to the first objective, SC&A concludes that doses to workers covered by the SEC petition can be reconstructed in a scientifically sound and claimant-favorable manner. The Board will use this information, in part, as the basis for determining whether dose can be reconstructed with sufficient accuracy. With respect to the latter, SC&A found many errors and deficiencies in the scenarios, data, assumptions, and models described in the ER for reconstructing doses, which will require substantial revisions and amendments to the ER.

The following is a summary of SC&A's findings and observations:

Finding 1: Internal exposures associated with subsurface maintenance and repurposing activities in Building 10 during the residual period should be explicitly included in the ER. NIOSH should not assume that there is sufficient conservatism inherent in the internal dose reconstruction methods employed in the ER to account for these exposures.

It is SC&A's understanding that, at the time of the preparation of the ER, NIOSH was aware that there were a number of maintenance and repurposing activities that took place during the residual period but believed that the potential exposures associated with these exposure scenarios were small and can be accounted for by the conservatism inherent in the internal dose reconstruction methods presented in the ER. The petitioners expressed concern that NIOSH did not have a full appreciation of the nature and extent of the maintenance and repurposing activities that took place during the residual period, and, in order to better evaluate this concern, worker interviews were conducted on October 26–28, 2017, to obtain additional information about the nature and extent of these activities. Following the meeting, all participants, which included representatives from NIOSH, Oak Ridge Associated Universities Team (ORAUT), and SC&A, appeared to agree that the potential exposures associated with these activities were potentially significant and required explicit consideration in the ER. This review of the ER presents an in-depth analysis of this matter.

Finding 2: NIOSH incorrectly transcribed some of the Landauer film badge dosimetry reports and incorrectly calculated annual 95th percentile external penetrating doses to workers in the residual period.

Finding 3: NIOSH incorrectly calculated annual 95th percentile beta skin doses to workers in the residual period.

Observation 1: SC&A suggests that a more appropriate approach to deriving the chronic airborne concentration of uranium from resuspension during the residual period would be to use the average value for the swipe data (i.e., 12.3 dpm/100 cm^2) and a resuspension factor of 1E-5/m. This would result in chronic uranium inhalation rates that are about 2 times higher, but well within a reasonable range for these types of exposures, given the available data.

Observation 2: The distinction between production and non-production workers should be better defined in the ER. After discussions with NIOSH, it was determined that the production worker group is intended to refer to workers who may have entered production areas. This includes construction trade workers, including but not limited to those listed in the ER. Additional text adding clarity to this point would ensure this distinction is consistently applied to workers.

Observation 3: NIOSH should consider adopting the approach used in the ER for Carborundum and the ER and technical basis document for General Steel Industries (GSI) for deriving ingestion doses during the residual period.

Observation 4: Exposures experienced by High Flux Isotope Reactor (HFIR) workers cannot be used *"as supporting evidence to validate the bounding method used in Section 7 of this report"* as stated on page 24 of the ER.

Observation 5: SC&A is concerned that it may be inappropriate to use external dosimetry data collected during the last year of Atomic Weapons Employer (AWE) operations as the basis for bounding the external doses during the residual period.

The method adopted in the ER for reconstructing external doses applicable to M&C workers during the residual period makes extensive use of external dosimetry data collected during the last year of AWE operations. Though we acknowledge and explicitly demonstrate that such a strategy results in external exposures during the residual period that are bounding, including external exposures associated with maintenance and repurposing activities, we are concerned that such a strategy is not appropriate. During the last year of AWE operations, there were large quantities of uranium and thorium on site, which were handled by M&C (and perhaps non-M&C) workers and which were likely to have been responsible for the majority of the external exposures experienced by workers in that year. At the end of operations and before the beginning of the residual period, all fuel assembly operations associated with AWE operations ceased, uranium and thorium associated with these activities were removed from the site, and there was considerable cleanup. As such, the only external exposures experienced by M&C workers during the residual period were from residual activity. Hence, it is questionable whether it is appropriate to use external dosimetry data applicable to AWE (or perhaps HFIR) operations to assign external doses to workers during the residual period. In many respects, this concern is comparable to the types of concerns that are often discussed with respect to the use of surrogate data.

1 INTRODUCTION AND BACKGROUND

During a meeting of the Advisory Board on Radiation and Worker Health held in Santa Fe, New Mexico, on August 24, 2017, the Board requested that SC&A, Inc. perform a review of *SEC Petition Evaluation Report Petition SEC-00236* (April 5, 2017; NIOSH 2017a), prepared by NIOSH and dealing with the Metals and Controls Corporation. This report is provided to the Board in response to that request.

The class evaluated by NIOSH in its SEC ER is as follows:

> *Based on its preliminary research, NIOSH accepted the petitioner-requested class. NIOSH evaluated the following class: All atomic weapons employees who worked as facilities construction and maintenance workers, including lubricators/oilers, industrial pipefitters, engineering technicians (mechanical, electrical, structural), maintenance supervisors, electricians, plumbers, millwrights, carpenters, instrumentation technicians, chemical handlers, waste treatment operators, and all production workers, including machine operators/helpers and repair & maintenance (commonly called R&M) workers, who worked in Buildings 4, 5, 10 interior areas, and Buildings 5, 10, 11, 12, 17 exterior areas at Metals and Controls Corp. in Attleboro, Massachusetts, from January 1, 1968 through March 21, 1997.* [NIOSH 2017a, page 3]

NIOSH's investigations and findings with respect to this matter are summarized in the ER as follows:

> *NIOSH has obtained personal and area monitoring records from the end of the operational period and prior to the beginning of the residual radiation period being evaluated in this report, and when coupled with radiological data in the residual period, the data can be used by NIOSH to develop bounding dose assessments for the entire residual radiation period. Based on its analysis of these available resources, NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy.* [page 3]

This SEC petition and ER deal specifically with the residual period at an AWE facility. Over the many years that SC&A has provided technical support to the Board with respect to AWE facilities, it has been our experience that few AWE facilities were granted an SEC that covered the residual period. In light of this experience, and as a means to help inform our review of this ER, SC&A reviewed the 50 ERs that were published as of the date of preparation of this report to determine which AWE facilities were granted an SEC covering the residual period and the technical reasons for granting the SECs at these facilities. Appendix A provides the results of this investigation. In summary, we found that, of the 50 facilities, only 3 extend coverage into the sites' residual periods. Those three facilities include Ames Laboratory SEC Petition 75, Norton Company SEC Petition 173, and Vitro Manufacturing SEC Petition 177. In all cases, the SECs were granted because unusual sources of radioactive material were present at the facilities during the residual period, and workers taking part in maintenance, decommissioning, and/or renovations of the sites during the residual period were found to have potential for exposure but that exposure could not be bounded due to the lack of source term information or lack of environmental and personnel monitoring data. In addition, because of the unique sources of exposures and the nature of the worker activities with and in the vicinity of these sources during the residual period, the Board determined that the standard default assumptions, as adopted and approved by the Board in Battelle-TBD-6000, *Site Profile for Atomic Weapons Employers that Worked Uranium Metals* (NIOSH 2011a; hereafter "TBD-6000"), and ORAUT-OTIB-0070, Revision 01, *Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities* (NIOSH 2012b; hereafter "OTIB-0070"), were not sufficient for reconstructing doses during the residual period. This review of the M&C ER addresses the degree to which these types of issues are also of concern at M&C.

As indicated in Section 4.0 of the ER, NIOSH reviewed many source documents and claimant affidavits that are now available on the Site Research Database (SRDB). NIOSH's review included air sampling data, alpha/beta/gamma survey data, and external and internal dosimetry data. It appears that some of these types of data are available, but NIOSH also made use of TBD-6000 (NIOSH 2011a) and OTIB-0070 (NIOSH 2012b) as a means to take advantage of the vast body of literature and guidance available for reconstructing doses at AWE facilities and, in particular, during the residual period. ORAUT-OTIB-0020, Revision 03, *Use of Coworker Dosimetry Data for External Dose Assignment* (NIOSH 2011b; hereafter "OTIB-0020"), was used as guidance for building an external dose coworker model, and ORAUT-OTIB-0024, Revision 00, *Estimation of Neutron Dose Rates from Alpha-Neutron Reactions in Uranium and Thorium* (NIOSH 2005; hereafter "OTIB-0024"), was used to estimate neutron doses from alpha-neutron reactions in uranium and thorium. NIOSH also made use of worker and expert interview notes (additional interviews were performed on October 24–26, 2017, and are explicitly considered in this ER review). Hence, this review focuses on (1) the adequacy of the site-specific survey and dosimetry data, and (2) petitioner affidavits and interview notes, and how they are used, along with TBD-6000, OTIB-0070, OTIB-0020, and OTIB-0024, to reconstruct external and internal doses during the residual period at M&C.

Section 5.0 of the ER explains that the SEC is concerned with exposure to workers during the residual period (i.e., from January 1, 1968, through March 21, 1997) associated with AWE operations. These AWE operations at the facility took place under the management of M&C from 1952 through 1965, at which time they continued under the management of Texas Instruments Incorporated (TI) (from 1966 through 1967). Section 5.0 (beginning on page 15 of the ER) explains that AWE operations included primarily fuel manufacturing operations that initially took place in Buildings 3 and 4, and subsequently in Building 10, where the major AWE operations took place.

Table 1 presents a timeline of activities that took place at M&C as described in the ER (NIOSH 2017a). The timeline serves as a platform for understanding the activities and personnel at M&C that are covered and are not covered by the SEC petition, and the sources of the data that are useful in reconstructing doses that may have been experienced by M&C workers covered by the petition during the residual period. The activities and data sources identified in Table 1 are discussed throughout this report.

Table 1. Timeline of Major Activities and Events at Metals and Controls Corp.

Date	M&C activity
1952–1967	AWE operations (covered by a previously granted SEC).
1964	Disposal and decontamination throughout the operational period. Contaminated material and machinery were collected in 55-gallon drums and were disposed of through authorized agencies or buried on site.
1968–1981	Fuel fabrication for the HFIR at Oak Ridge National Laboratory and other government-owned research reactors (not covered by the SEC).
1967	Burial site closed.
1978	U.S. Nuclear Regulatory Commission (NRC) approved the TI general decontamination and decommissioning (D&D) plan for HFIR area in Building 10.
1981	End of non-weapons-related fuel fabrication operations for HFIR, and TI initiated D&D of HFIR area of Building 10.
1983	NRC released Buildings 3, 4, and 10 for unrestricted use but withheld license termination pending investigation into the former radioactive waste burial site between Buildings 11 and 12.
April–May 1984	The Radiological Site Assessment Program (RSAP) of the Oak Ridge Associated Universities (ORAU) conducted a radiological survey of portions of the facility's outdoor areas during April and May 1984. Several outdoor areas had surface and/or subsurface uranium concentrations that exceeded NRC release guidelines. (These and subsequent activities and associated data are useful in helping to reconstruct the doses to workers covered under the petition and in understanding the types and magnitudes of the exposures.)
1992	TI hired Creative Pollution Solutions (CPS) for remediation. During remediation of former burial site, 63,000 ft^3 of soil and debris were removed.
November 1992	TI submitted post-excavation radiation survey report for burial area to the NRC. Data in CPS 1993. (These activities are not covered by the petition, but the exposures to the D&D workers are helpful in understanding the types of exposures that might have been experienced by M&C workers covered by the SEC.)
January 1993	TI revised final survey.
June 1993	Final walkover survey.
December 1993	Confirmatory survey by Oak Ridge Institute for Science and Education (Ansari 1994, page 13).
April–November 1994	Remediation of the Metals Recovery Area (located near Building 5 and to the northwest of Building 11).
May 1994	TI received new guidelines from NRC and incorporated them into D&D.
July 1994	TI performed radiation survey of the open land areas and found contamination in the Metals Recovery Area.
1994–1995	NRC asked for comprehensive radiation survey, which included discussion with long-term employees. Residual contamination found in Stockade and Building 12 south lawn, also Buildings 4, 5, and 10 where unclad uranium operations were, including the areas that were previously decommissioned.
1995–1996	Decontamination of Buildings 4, 5, and 10 and radioactive waste shipped for disposal.
February 1997	After additional areas were decontaminated, NRC did confirmatory radiological measurements.
March 21, 1997	Released for unrestricted use by NRC.

Source: NIOSH 2017a.

SC&A's review of the ER is divided into three parts. Following this introductory and background material, Sections 2 and 3 present a review of the methods adopted in the ER to reconstruct internal and external doses, respectively, to help determine if the doses to all AWE workers during the residual period can be reconstructed in a scientifically sound and claimant-favorable manner. SC&A does not provide any conclusions or recommendations regarding whether doses can be reconstructed with sufficient accuracy, as defined in 42 CFR Part 83. This determination is made by the Board as a recommendation to the Secretary of the Department of Health and Human Services. However, this review of the ER does assess the degree to which doses to workers at M&C during the residual period can be reconstructed in a scientifically sound and claimant-favorable manner.

2 REVIEW OF INTERNAL DOSIMETRY METHODOLOGY AND DATA

There are two categories of internal exposure experienced by covered M&C workers during the residual period. One category deals with exposure that were explicitly evaluated in the ER to reconstruct doses to workers from the standard resuspension pathway. The other category addresses exposures applicable to covered M&C workers involved in maintenance and repurposing activities, which are not explicitly addressed in the ER but became apparent as potentially important exposure pathways during the worker interview process that took place in October 2017. Our review is therefore divided into these two broad categories.

2.1 INTERNAL EXPOSURE EXPLICITLY ADDRESSED IN THE ER

The approach used in the ER to reconstruct internal doses during the residual period takes advantage of the abundant data characterizing alpha surface contamination at the end of AWE operations in the late 1960s and also in 1982, when a special survey of surface alpha contamination was performed. The ER uses these data to reconstruct the airborne activity due to resuspension and associated inhalation doses. This section summarizes this part of the ER and reviews the data and approach to reconstruct the inhalation doses and also the ingestion doses during the residual period.

Section 5.2.1 of the ER describes the sources of internal exposure during the residual period, explaining that the primary sources of internal exposure were due to residual uranium associated with a range of uranium-handling operations, including natural, depleted, and enriched uranium in the form of uranium metal, UO_2, and U_3O_8. The uranium-handling activities included fuel fabrication with enrichments up to 93% and combining the enriched uranium with natural and depleted uranium to produce special-order fuel enrichments. The uranium handled was in a powdered UO_2 and in metallic form, which was rolled and machined into various geometries, such as plates.

Section 5.2.1.2 explains that M&C also handled thorium metal in the form of reactor fuel, metallic alloys, and metallic foils, some of which were melted and cast into ingots. The ER explains that the total quantity of thorium handled at M&C was relatively small, 244 kg, as compared to tens of thousands of kg of uranium, most of which was depleted uranium.

Section 5.2.1.3 of the ER explains that, for a short time period, 1965 to 1967, Texas Instruments performed commercial work (unrelated to AWE activities) producing electrical breakers for the U.S. Navy, where radium was used in the form of luminous glass beads so that the electrical breakers could be seen in the dark. The ER explains that this work was performed in a completely separate building at M&C, away from AWE activities, and that worker exposures due to radium residues can be excluded from exposures associated with AWE activities. SC&A accepts this position because the exposures under consideration in the ER are limited to the residual period, and it is NIOSH's policy that such exposures are appropriately excluded from worker dose reconstruction <u>during the residual period</u> (e.g., see the Dow Madison ER, NIOSH 2007a).

Section 7.1.1 of the ER addresses the pedigree of data used to reconstruct internal doses during the residual period, stating that 7,765 swipe survey data entries are available for review and were used in the ER as the basis for deriving the airborne concentration of gross alpha emitters at the beginning of the residual period at locations where AWE operations took place. In support of this statement, the footnote at the bottom of page 24 of the ER states, "*The Health and Safety Contamination and Radiation surveys that were analyzed are located in the following SRDB Ref ID numbers: 69181, 69314, 69231, 69239, 69289, 69283, 69210, 69228, 69233, 69287, 69295, 69300, 69305, 69269, 69271, 69276, 69293, 69185, and 69167*."

The ER explains that the methods used to reconstruct doses drew from site-specific data and also generic guidance from TBD-6000, OTIB-0070, and NUREG/CR-5512, Volume 3, *Residual Radioactive Contamination from Decommissioning* (NRC 1999). These generic protocols have been previously reviewed and approved by the Board. Consequently, this part of our review focuses on (1) the nature and extent of site-specific data used to reconstruct doses during the residual period, (2) the degree to which the dose reconstruction methods make use of and are in accord with the cited generic protocols, and (3) the degree to which the nature of the exposures at the facility fall within the envelop prescribed in the generic protocols.

2.1.1 Inhalation Initial Conditions during the ER Period

Section 7.2.2 of the ER explains that, near the end of AWE operations in 1966 and 1968, 7,765 surface swipe data were collected, and that NIOSH used these data to derive the upper 95th percentile removable surface contamination of gross alpha activity, which was determined to be 54.8 disintegrations per minute (dpm)/100 cm^2. Given this value, a resuspension factor (RF) of 1E-6/m was used to derive an airborne concentration of resuspended alpha emitters of 0.00548 dpm/m^3 (i.e., 54.8 dpm/100 cm^2 × 1E-6/m × 1E4 cm^2/m^2 = 5.48E-3 dpm/m^3).

SC&A reviewed the cited SRDB documents (SRDB Ref. IDs 69181, 69314, 69231, 69239, 69289, 69283, 69210, 69228, 69233, 69287, 69295, 69300, 69305, 69269, 69271, 69276, 69293, 69185, and 69167). Swipe samples were collected between 1964 and 1969 and analyzed for gross alpha contamination. NIOSH limited the swipe samples included in the analysis primarily to those taken during 1966 and 1967, because they represent the alpha surface contamination at the end of AWE operations. In addition, the samples included in the analysis were limited to those locations that can be verified as not part of the HFIR.

SC&A spot-checked the sample results and found that, when results were questionable, NIOSH selected the most claimant-favorable interpretation of values. SC&A confirmed that 54.8 dpm/100 cm^2 is the upper 95th percentile of the swipe data and represents a reasonable upper bound of the removable surface alpha contamination at the end of AWE operations in 1967. However, there is some question regarding the use of an RF of 1E-6/m. To further investigate this issue, SC&A consulted other ERs where the residual period was investigated. Baker Brothers Petition 204 (NIOSH 2012a) and Bliss and Laughlin Steel Co. Plant Petition 131 (NIOSH 2009) are most similar to the conditions surrounding M&C. Both sites also selected an RF of 1E-6/m. However, at two other sites recently reviewed by SC&A—Carborundum and GSI—NIOSH used an RF of 10^{-5} m^{-1} for the residual periods.

OTIB-0070, Revision 01 (NIOSH 2012b), which is cited as the source for the RF, states (page 7), "*Generally, early conclusions of a value of 10^{-6} m^{-1} under quiescent conditions and a factor of 10 higher (10^{-5} m^{-1}) under conditions of moderate activity (Stewart 1964) have been* *supported by later analysis (Brodsky 1980).*" An RF is the ratio of the airborne radionuclide concentration per unit air volume divided by the surface concentration per unit area and is generally reported in units of m^{-1} (e.g., pCi/m^3 per pCi/m^2). SC&A questions if an RF of 10^{-6} m^{-1} is appropriate given that the site conditions are not accurately described as quiescent. According to the ER and worker interviews, heavy non-radiological commercial work continued during the residual period. The concept of an RF has been studied extensively, with RF values ranging from 10^{-10} m^{-1} to 10^{-2} m^{-1} reported. NUREG-1720, *Re-evaluation of the Indoor Resuspension Factor for the Screening Analysis of the Building Occupancy Scenario for NRC's License Termination Rule* (NRC 2002; still in draft), found a 90th percentile RF of 8.7×10^{-7} m^{-1} for a normal fit and 9.6×10^{-7} m^{-1} for a lognormal fit. However, the data cited apply to decommissioned facilities where all contaminated surfaces had been cleaned and washed.

Our review of the health and safety manual for M&C (see Appendix B) reveals that a comprehensive radiation protection program was employed during and following AWE operations, and that the program included cleanup of surface contamination throughout operations. Under these circumstances, a resuspension factor of 1E-6/m would seem reasonable. However, since we are dealing with swipe samples (i.e., readily removable contamination, as opposed to alpha surveys), and a wide range of operations continued at the facility, including in Building 10, there is some question about whether it would be more appropriate to use an RF of 1E-5/m. Offsetting this concern is the fact that the upper 95th percentile of the surface swipe data was employed. This is a conservative assumption because the average airborne activity of removable contamination on surfaces associated with resuspension was found to be 12.3 dpm/100 cm^2, significantly lower than the 95th percentile contamination level employed in the ER for the beginning of the residual period.

<u>Observation 1</u>: SC&A suggests that a more appropriate approach to deriving the chronic airborne concentration of uranium from resuspension during the residual period would be to use the average value for the swipe data (i.e., 12.3 dpm/100 cm^2) and an RF of 1E-5/m. This would result in chronic uranium inhalation rates that are about 2 times higher, but well within a reasonable range for these types of exposures, given the available data.

As a reference point, assuming a uranium surface contamination of 54.8 dpm/100 cm^2 at the beginning of the residual period and a resuspension factor of 1E-6/m, the annual dose commitment to the lung from the inhalation of resuspended uranium is less than 1 millirem per year (mrem/y). Hence, it appears that we are dealing with potential internal exposures from this pathway that are extremely small, even at the beginning of the residual period. The big question is what is the potential magnitude of the potential exposures associated with maintenance and repurposing activities, which are evaluated below.

2.1.2 Source Term Depletion during the Residual Period

NIOSH also compiled gross alpha survey data that were collected in 1982 prior to the Formerly Utilized Sites Remedial Action Program (FUSRAP) cleanup operations at Buildings 3, 4, and 10 (i.e., the buildings where AWE operations took place). Of a total of 207 average direct alpha survey measurements, the upper 95th percentile was 144.85 dpm/100 cm^2. SC&A confirmed this value by a review of TI 1982. The alpha results were generated as part of the TI effort to terminate NRC License No. SNM-23. Survey measurements were taken by gridding off Buildings 3, 4 and 10. The average survey readings from within each gridded location were documented, as well as the highest reading within the area. NIOSH selected the average value from each reported result and computed the 95th percentile value among the collection of average values. NIOSH assumed that 10% of the gross alpha activity was removable (this is an often-used assumption, see NUREG-1720[1]). Hence, the assumed removable surface contamination used in the ER is 14.5 dpm/100 cm^2. Again, applying an RF of 1E-6/m, NIOSH derived an airborne gross alpha dust loading of 0.00145 dpm/m^3, as compared to 0.00548 dpm/m^3 using the swipe data collected in the late 1960s.

The gross alpha survey data were collected in 1982, which is 14 years after the termination of AWE operations and reflects surface contamination that has undergone natural depletion for about 14 years and any additional contamination associated with non-covered activities, such as HFIR operation, maintenance, and repurposing activities, and any off-normal conditions. As with the swipe data, the use of the upper 95th percentile alpha survey data is conservative, at least as applied to the 1982 time frame. Hence, we have two estimates of removable surface contamination of gross alpha activity: 54.8 dpm/100 cm^2 for 1968 and 14.5 dpm/100 cm^2 for 1982 (NIOSH 2017a).

Given these data and assumptions, NIOSH elected to use an airborne concentration of 0.00548 dpm/m^3 at the start of the residual period in 1968 and 0.00145 dpm/m^3 in 1982, which reflects a rate of depletion (i.e., natural attenuation rate) of 2.45E-4/day. This is as compared to the depletion rate of 6.7E-4/day recommended in OTIB-0070. SC&A considers this a reasonable and claimant favorable approach for reconstructing internal exposures from 1968 to 1982 from the resuspension pathway.

Taken in its entirety, SC&A believes that the approach used by NIOSH to derive the surface and airborne contamination of gross alpha emitters during the residual period due to and following AWE operations is reasonable, but it could be improved by using surface contamination levels that represent overall average contamination levels and a higher RF, perhaps 1E-4/m to 1E-5/m. Note that we underlined "due to and following AWE operations." We emphasized this because there might have been additional surface contamination due to decontamination operations in Buildings 3, 4, and 10, which appear to have taken place in 1994 and could have added to the exposures experienced by non-D&D contract workers during the residual period from 1994 to

[1] NUREG-1720 states that, to calculate the RF for decommissioned sites, the fraction of total contamination that is loose (removable) must be addressed. In this respect, the NRC staff has assumed that a reasonable value for screening purposes is 0.1. This removable fraction value has been used to develop a decontamination and decommissioning (DandD) default parameter value of 1.42×10^{-5} m^{-1} applicable for all surface contamination types (e.g., removable and nonremovable) of decommissioned sites.

1996. This is a relatively short period of time and might not have contributed substantively to indoor exposures to AWE covered workers. This issue is discussed below.

Note that the above discussion refers to gross alpha contamination. This contamination is likely due to primarily uranium but might also have included some thorium. To address which isotope to use in reconstructing doses (i.e., uranium versus thorium), Section 7.5.1 of the ER explains that, in determining internal dose for M&C workers, "*NIOSH can choose the most claimant-favorable isotope of thorium or uranium when estimating worker doses*" (page 32). SC&A believes that this is a reasonable and claimant-favorable method for reconstructing doses when there is some uncertainty about which of these radionuclides might be responsible for internal dose.

A potentially confounding factor that could have some effect on the above-described approach for deriving internal exposures during the residual period is the operations described on page 14 of the ER that took place from 1965 through 1981:

> *Texas Instruments performed fuel fabrication for the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory and other government-owned research reactors. While this information is necessary for the site description and related topics, this HFIR work is considered non-weapons related work and therefore the radiological exposures associated with this work are not covered under the Energy Employee*[s] *Occupational Illness Compensation Program Act (EEOICPA) radiological dose reconstruction process during the AWE Facility residual radiation period (DOE, 2001).*

In theory, these activities could have contributed to surface contamination in Building 10 during the residual period, which should not be included in the doses experienced by AWE workers during the residual period. In our review of the swipe data, we believe that all or the majority of those data appropriately do not reflect very much of the surface contamination that might have been associated with HFIR operations. If some of the surface contamination did originate from HFIR activities, the approach used in the ER would have an added level of claimant favorability.

In many AWE site profiles and ERs for AWE facilities, NIOSH elected to use the default assumptions in TBD-6000 to derive internal doses during the residual period when site-specific data were limited. In light of this, it is instructive to reconstruct the internal doses using default assumptions adopted in TBD-6000 (Revision 03; NIOSH 2011a), which was reviewed and approved by the Board.

As described in Section 7.1.2 of TBD-6000, air sampling data for a number of different uranium handling operations were obtained from Harris and Kingsley (1959) for facilities where there was minimal cleanup and ventilation, resulting in default values that would tend to represent the high end of the potential airborne and surface contamination during operations at uranium-handling facilities. Section 7.1.5 of TBD-6000 assumes that the airborne uranium concentration from resuspension <u>during periods with no active uranium operations</u> is 147 picocuries (pCi)/m^3 (326 dpm/m^3). In theory, this value could be used as a surrogate for the airborne uranium concentration at the beginning of the M&C residual period, as compared to 0.00548 dpm/m^3 that was used in the ER using site-specific data—a difference of over 4 orders of magnitude. The reason for this large difference is that the surface contamination level used in TBD-6000 is 1.47E8 pCi/m^2 or 3.26E8 dpm/m^2, as compared to the upper 95th percentile removable surface contamination of 54.8 dpm/100 cm^2 or 5480 dpm/m^2 used in the ER.

Note that the M&C-specific value is 6E4 times smaller than the level of surface contamination used as the default value in TBD-6000, thereby accounting for this large difference in the airborne concentration during non-operations time periods. In light of this important difference, SC&A performed a detailed review of the M&C SRDB reports containing the gross alpha swipe and survey data in order to ensure the completeness and reliability of those data. That review revealed that the residual gross alpha activity on surfaces in the buildings where AWE activities took place is based on comprehensive and scientifically sound data. We believe that the default residual radioactivity levels adopted in TBD-6000 do not apply to M&C and should not be used as default values for M&C. The M&C values are low as compared to default TBD-6000 values because of the nature of the uranium work performed at M&C and the fact that good housekeeping practices were employed at M&C (see Appendix B), which helped to reduce the level of surface alpha contamination at the start of the residual period.

<u>Observation 2</u>: The distinction between production and non-production workers should be better defined in the ER. After discussions with NIOSH, it was determined that the production worker group is <u>intended to refer to</u> workers who may have entered production areas. This includes construction trade workers, including but not limited to those listed in the ER. Additional text adding clarity to this point would ensure this distinction is consistently applied to workers.

2.1.3 Inadvertent Ingestion

The ER explains (page 29) that NIOSH used the methods described by NUREG/CR-5512, Volume 3 (NRC 1999), to derive the intake rates of residual radioactivity and associated doses from inadvertent ingestion of contaminated residue on surfaces. SC&A used NUREG/CR-5512, Volume 1 (NRC 1992), for its calculations. This approach is based on an assumed inadvertent ingestion rate of 1E-4 m^2 per hour of the removable surface contamination. Hence, at the beginning of the residual period in 1968, the inadvertent ingestion rate (I) is derived as follows:

$$I = 54.8 \text{ dpm/100 cm}^2 \times 1\text{E-4 m}^2\text{/h} \times 1\text{E4 cm}^2\text{/m}^2 = 0.0548 \text{ dpm/h or } 1096 \text{ dpm/y}$$

This is the ingestion rate for production employees in 1968, as provided in Table 7-1 of the ER.

For uranium-234 (U-234), this ingestion rate corresponds to an initial annual dose commitment of 1.42 mrem/y to the bone surface (i.e., the limiting organ) at the beginning of the residual period, if we were to assume an acute intake equal to the annual rate, which will decline at a rate of 2.54E-4/day due to natural attenuation. This rate of decline is based on the same approach used to derive the rate at which inhalation of radionuclides declines, as described above. For other organs, the dose rate would be smaller.

For non-production employees, the inadvertent ingestion rate is assumed to be a factor of 10 lower, as indicated in Table 7-2 of the ER. On first inspection, this assumption appears to be inappropriate because the residual radioactivity on surfaces would seem to be more or less uniform on surfaces throughout the facility because of processes that would tend to redistribute deposited activity over time. However, since the starting point for this calculation is the upper 95th percentile value for deposited radioactivity, it is not unreasonable to assume that the residual radioactivity in non-production areas would be about a factor of 10 lower than in production areas.

However, SC&A does have a concern with the assumption that the inadvertent ingestion rate is 1E-4 m^2/h at the beginning of the residual period. Though SC&A had previously reviewed and approved this approach in other technical basis document (TBD) reviews, we note that this approach was not adopted in the ER for Carborundum (NIOSH 2015) and the ER and TBD for GSI (NIOSH 2008, 2017c). For those facilities, the approach used by NIOSH was to derive the inadvertent ingestion rate at the end of operations (using the methods described in OCAS-TIB-009) and then assume that this was the ingestion rate at the beginning of the residual period, which, in turn, declined according to an appropriately derived natural attenuation rate (in this case that would be 2.54E-4/day). This approach was implicitly accepted by the Board, which denied the SEC petition for Carborundum and accepted the final revision of Appendix BB to TBD-6000 (the TBD for GSI), as recommended by the respective work groups. NIOSH should explore using this strategy for deriving the inadvertent ingestion rate at M&C.

<u>Observation 3</u>: NIOSH should consider adopting the approach used in the ER for Carborundum and the ER and TBD for GSI for deriving ingestion doses during the residual period.

2.2 Exposure Associated with Maintenance and Repurposing Activities

As part of the ER review process, SC&A participated in worker interviews held in Mansfield, Massachusetts, near the M&C facility in Attleboro, Massachusetts. Representatives of NIOSH and ORAUT also participated. The interviews were held on October 24 through October 26 and consisted of individual interviews with 12 former M&C employees, petitioners, and claimants; each interview lasted about 60 to 90 minutes. Unredacted transcripts of nine of the interviews have now been made available to SC&A and to the Board; however, they were still in preparation at the time the present report was written (NIOSH 2017b). This section presents a brief summary of those interviews based on detailed notes taken during the interviews and how the information obtained from those interviews has been incorporated into this ER review process. The important point is that the interviews revealed the need to perform more detailed analyses of the potential exposures experienced by M&C workers who were involved in maintenance and repurposing activities during the residual period. The following summarizes the salient information obtained during those interviews, which supplements the information in the ER and the supporting SRDB reports.

The interviews with M&C workers revealed that many of the maintenance and refurbishment activities required digging into the subsurface, snaking clogged drain lines, and replacing drain lines. M&C workers were also involved in maintaining the heating, ventilation, and air conditioning (HVAC) systems, which required periodic cleaning of the HVAC ducts and replacing large dust filters. From the interviews, we have some information on how this work was done, how often it was done, who did the work, and the number of work hours each activity required. For example, during the interviews, workers indicated that drain line work occurred fairly frequently (every 6 to 8 weeks) and lasted as long as a week (most of the work took only a couple of days). Based on this information, some workers may have accumulated up to a month of exposure per year from this type of subsurface work.

The interviews also revealed that M&C workers performing these activities were not aware that there might be some uranium and thorium contamination on building surfaces and in the soil beneath the concrete floor, the sludge clogging drain lines, and the dust in the HVAC ductwork. The workers also stated that, because M&C was a non-union shop, workers from many departments were often involved in maintenance and repurposing activities. The following describes the exposure scenarios and pathways that were identified and described during the worker interviews.

2.2.1 Subsurface Exposure Scenarios

Several workers explained that, as part of maintenance and repurposing activities[2] during the residual period, M&C workers periodically bored out clogged drainage pipelines to remove blockages. In addition, it was often necessary to break through the concrete and excavate subsurface soil beneath buildings, including Building 10, and also areas outdoors in the immediate vicinity of the low-level waste disposal area, to gain access to drainage and other pipelines and conduits in order to repair or replace segments of these pipelines and conduits. Due to leakage of subsurface pipelines, seepage of water down through cracks and penetrations in the concrete floor of the buildings, and seepage of water through outdoor soil and waste disposal pits, the subsurface soil often contained deposits of residual uranium and possibly thorium. Subcontractors were used to cut the concrete, then M&C workers or subcontractors excavated the gravel and soil beneath the concrete and the rubble and soil outdoors. M&C maintenance workers entered the excavations to perform the necessary repair activities, which included removing dirt in the vicinity of pipelines and cutting and replacing pipelines and conduits.

These types of maintenance and repurposing activities put M&C workers in direct contact with subsurface soil and material inside pipelines that contained some residual uranium, and possibly some residual thorium, resulting in the potential for internal exposures from inhalation of suspended soil and inadvertent ingestion of contaminated soil. In addition, external exposure to penetrating radiation from these subsurface contaminants and skin exposure from the direct deposition of contaminated soil on clothing and skin were also likely. These represent exposure pathways unique to subsurface maintenance and refurbishing scenarios, and which require explicit dosimetric consideration.

The types of data and information required to place a plausible upper bound on the exposures that might have been associated with subsurface maintenance and repurposing activities during the residual period include the following:

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[2] Workers explained that repurposing activities involved moving or replacing old equipment with new equipment for use in new commercial contracts and other activities. These activities often required subsurface excavation to depths of up to about 8 feet below building surfaces to install new equipment, trenches, and underground tanks and conduits.

- The concentration distribution of radionuclides in the soil and in pipelines where these activities took place (pCi/g)
- The airborne dust concentration generated during these activities, taking into consideration the degree to which the soil and other solids were moist
- The number of hours per year workers might have been involved in these activities

The subsurface exposure scenario and associated pathways (inhalation, inadvertent ingestion, exposure to penetrating and non-penetrating radiation, and exposure of skin due to direct deposition of radionuclides on skin) are explicitly addressed later in this report.

2.2.2 HVAC Scenarios

Worker interviews revealed that, during the residual period, M&C maintenance workers routinely entered HVAC ductwork in the various buildings, including Building 10, to clean out the interior surfaces of the ductwork, maintain the air movers, and replace large dust filters. There was some uncertainty about how often this type of maintenance work was performed on the HVAC systems in each building. However, workers explained that quarterly maintenance on these systems was desirable, but these activities usually were performed less frequently. In theory, these maintenance activities could have resulted in periodic exposures to uranium dust because uranium dust was (1) chronically airborne within Building 10 due to chronic resuspension from surfaces and (2) episodically airborne due to various maintenance activities, such as cutting through concrete floors and maintenance work performed in the rafters of the building, where relatively large amounts of dust accumulated. In addition, workers stated that there were occasional off-normal incidents, such as fires and perhaps two explosions, that could have resulted in short-term elevated levels of dust and smoke that could also have contained some uranium particulates.

Such dust would have been largely ventilated through the HVAC systems, where the particulate material may have deposited on the interior surfaces of the HVAC ductwork and also onto the filters used to remove dust before the ventilated air was recycled back into the buildings. It is likely that HVAC workers involved in cleaning and maintaining the HVAC ducts and the air movers and in removing and replacing the filters were exposed to elevated levels of dust. One worker explained that the filters often crumbled and needed to be removed in the form of crumbled sections followed by vacuuming. It was explained by one worker, who performed these activities, that the airborne level of dust was high during filter replacement. These workers wore dust masks on occasion and likely inhaled considerable quantities of dust. In addition, it is likely that the workers' clothing and skin were contaminated with dust. Though these activities were periodic and perhaps not of a protracted duration, they appear to represent a potential source of internal and external exposure to uranium-contaminated dust.

The types of data and information required to place a plausible upper bound on the exposures that might have been associated with these HVAC maintenance activities depend on the strategy adopted to derive these exposures. In one strategy, it can be assumed that the airborne concentration of uranium (as determined using the resuspension factor approach described in Section 2.1.1) is the source of the uranium drawn into the HVAC system. If the flow rate of the air mover is known, the rate at which uranium particulates entering the HVAC system can be derived, along with the total quantity of uranium deposited on the HVAC filters up to the time that the filters are replaced. We know, from discussions with workers, that a considerable amount of dust was generated during filter replacement operations. The concentration of the uranium in the dust can be estimated based on the total activity of uranium on the filters just prior to filter replacement divided by the mass of the filters (pCi/g), assuming that the filters often crumbled during the replacement process. The airborne uranium concentration experienced by workers during filter replacement can be estimated by assuming appropriately conservative estimates of the airborne dust loading (likely in the mg/m^3 range). Once this concentration is estimated, the internal dose to workers from inhaling the uranium particles can be estimated using reasonable estimates of the exposure duration, based on information provided by the workers.

An alternative strategy is to assume that the chronic concentration of dust in Building 10, for example, is perhaps 100 to 200 micrograms (µg)/m^3 of uranium oxide (see Appendix D.1). This value, in combination with the airborne uranium concentration, as derived using the resuspension factor approach, can be used as another method to derive the concentration of uranium associated with the soot deposited on the filter in units of pCi/g. During filter change-out, it is likely that the airborne dust loading would have been substantially higher than the chronic airborne dust loading in the air in the building, likely on the order of many milligrams per cubic meter. For example, we know from previous research (see Appendix D.2) that it is unlikely that workers could perform their work for extended periods of time in areas where the concentration of airborne dust was greater than perhaps 30 to 100 mg/m^3. This value, together with an estimate of the concentration of uranium associated with the dust in pCi/g, is another approach for determining the airborne concentration of the dust during filter replacement in pCi/m^3.

A third approach that can be used is to take advantage of the rate of depletion of uranium deposited on surfaces during the residual period, as described in Section 2.1.2. It can be assumed that the rate of depletion of the uranium on surfaces is also the rate of deposition of uranium on the filters. Given this information, the inhalation dose to workers during filter change-out can be estimated in the same manner as described in Section 2.1.2.

Hence, the types of information that would be useful in determining the uranium intakes maintenance workers might have experienced during filter replacement include the following:

- The HVAC ventilation rate in Building 10 (cfm)
- The floor surface area of the Building 10 (m^2)
- The mass dust loading of the air in Building 10 (µg/m^3)
- The concentration of uranium in the air drawn into the HVAC system and deposited in the ductwork and filter (pCi/m^3)
- The mass of the filter that contained the deposited dust (g)
- The frequency of filter replacement (number of times per year)
- The duration of each filter replacement activity (h/y)

This exposure scenario and associated pathways (inhalation, inadvertent ingestion, exposure to penetrating and non-penetrating radiation, and exposure of skin due to direct deposition of radionuclides on skin) are explicitly addressed in Section 2.3.

2.3 Assessment of Potential Internal Doses Associated with Maintenance and Repurposing Scenarios

This section presents an assessment of a number of different exposure scenarios associated with maintenance and repurposing activities. The intent of this section is three-fold. First, it demonstrates that strategies can be developed for reconstructing doses from these exposure scenarios. Second, the exposures, even using quite conservative assumptions, are small. Third, though the exposures are small, some of them need to be explicitly addressed in the ER because they are comparable to, if not somewhat greater than, the exposures explicitly addressed in the ER (i.e., the resuspension pathway).

2.3.1 Subsurface Excavation of Building 10

During the interviews, the petitioners brought to light that a substantial amount of digging occurred in Building 10 as part of ongoing commercial activities at the site. One interviewee described the cement floor of the building as appearing “patchworked” from all the subsurface modifications performed over the years. During the D&D of the facility in the 1990s, it was discovered there was a substantial amount of contamination in the pipes below the building. One drainage pipe was even found to contain a uranium rod, 5 inches long and ½ inch in diameter. Digging in these areas was performed without any protection from potential contamination. This exposure scenario is not explicitly addressed in the ER, and the resuspension factor model used in the ER cannot be considered representative of this subsurface exposure scenario. Therefore, it is appropriate to explicitly evaluate this exposure scenario.

In September 1995, a radiological survey of the subsurface drains in the affected areas of Buildings 4 and 10 was performed to determine the concentrations, distribution, and inventory of uranium present in the drainage system as a result of historical nuclear materials processing (Weston 1996a). This survey resulted in the recommendation to remove many of the subsurface pipes in Building 10. As part of this survey, pipes were sampled in 15 locations. In some of the sample locations, more than one type of pipe was found in the same location (vitreous clay, cast-iron, and PVC pipes ran throughout the building), and the contents of all pipes were sampled. During sampling, the length and percent blockage of the pipes were also estimated. Enrichment levels of the sediment within the pipes ranged from 0.43% to 35% U-235 by weight.

Using this information, SC&A created a distribution radionuclide concentration in pipes in Building 10, assuming that the sample activity was representative of the full pipe length. Total uranium concentrations in the pipes in Building 10 ranged from 9.75 pCi/g to 53,224.7 pCi/g. SC&A found the upper 95th percentile of total uranium in the pipes to be 5,878.1 pCi/g.

SC&A could not locate sampling results from the soils surrounding the pipes, but we assumed that the pipes contained the same radionuclide concentration distribution as the surrounding soils. This is likely a bounding assumption because we believe that the majority of contamination remained inside the pipes. This assumption is essentially the same as modeled by Abelquist (2013, page 100).

Given an understanding of the potential upper-end radionuclide concentration in the soil beneath Building 10, the next step in an evaluation of potential inhalation exposures to workers involved in subsurface maintenance and repurposing activities is to estimate the airborne dust loading in this environment. Appendix D.1, which includes an excerpt from NUREG/CR-5512, Volume 1 (NRC 1992, Section 6.3), presents a review of outdoor and indoor dust concentrations associated with a broad range of activities. Based on this review, SC&A assumed an upper-end chronic mass loading of 200 μg/m^3. We consider this a bounding value, given the information provided by the interviewees that the subsurface soil was almost always quite moist.

According to the interviews, much of the subsurface work was done by hand, indicating that the breathing rate may have been somewhat elevated, perhaps as high as 2.5 m^3/h, as compared to the standard breathing rate of 1.2 m^3 per hour used in most dose reconstructions. This is the breathing rate for adult males engaging in moderate activities, including "*heavy indoor cleanup* [and] *performance of major indoor repairs and alterations*" (EPA 1997). Interviewees also stated that the floor in the building was excavated for roughly 1 month over the duration of a given year, yielding a maximum exposure duration for a given worker of about 184 hours per year. Using these assumptions, SC&A estimates an upper-end total uranium inhaled intake rate of 540.8 pCi/y (20 becquerels [Bq]/y) (5,878.1 pCi/g × 2 × 10^{-4} g/m^3 × 2.5 m^3/h × 184 h/y × 0.037 Bq/pCi ≈ 20 Bq/y). This is 2 orders of magnitude higher than the inhaled intake of 13.15 dpm/y (0.219 Bq/y) that NIOSH assigned to production workers during the first year of the residual period (NIOSH 2017a, Table 7-1).

As a point of reference, an acute inhaled intake of 20 Bq of Type S U-234, 5 micrometers (μm) activity median aerodynamic diameter (AMAD), is associated with a committed equivalent dose to the extrathoracic airways of 144 mrem and an effective dose commitment of 15.6 mrem. This estimate of the annual inhalation dose, though relatively small, is substantially higher than the internal exposure rate assigned to workers in the ER (which is limited to the conventional resuspension factor pathway associated with surface contamination) and should be explicitly considered in the ER.

Finding 1: Internal exposures associated with subsurface maintenance and repurposing activities in Building 10 during the residual period should be explicitly included in the ER. NIOSH should not assume that there is sufficient conservatism inherent in the internal dose reconstruction methods employed in the ER to account for these exposures.

2.3.2 Subsurface Excavation in the Vicinity of the Waste Burial Pit

Several interviewees also indicated that a substantial amount of subsurface work occurred outside of buildings and sometimes included digging around and in the radioactive waste burial grounds. Records indicate one such excavation occurred in 1958, which included contaminated ductwork, and another occurred in 1961, which included 28.4 mCi of enriched uranium in noncombustible scrap. The burial site was closed in 1967 (Ansari 1994).

The site was estimated to cover 1.1 hectares and is described as being at least 1.2 meters deep. The waste burial site was covered with a soil cap of unknown thickness, and there is no indication that a liner of any kind was used. While Building 10 was under construction, the burial site was disturbed, and contaminated soil from the area may have been distributed over the construction site (Sowell 1985).

Prior to remediation of the site in the 1990s by subcontractor personnel, a series of surface and borehole samples were taken and analyzed for radiological content. Because the area was disturbed, an area of 6.1 hectares was surveyed by establishing a 10-meter grid system over the 6.1-hectare area. In addition, 5-meter sub-grid blocks were used in the 1.1-hectare suspected burial area. Soil samples were analyzed by gamma spectrometry for U-238, U-235, thorium-232 (Th-232), and radium-226 (Ra-226) (Sowell 1985).

Sowell (1985) reported results for 473 soil surface samples taken from the area. In the samples, 420 of the results were reported at levels below the minimum detectable activity (MDA) for U-235, and 95 were below the MDA for U-238. Assuming an individual spent 2,000 hours per year in subsurface work, a breathing rate of 1.2 m^3/h, and an aerosol mass loading of 200 $\mu g/m^3$, we calculated the inhalation intakes shown in Table 2 below. In performing the analyses, we assigned values of one-half the MDA to all samples that were reported to be below the MDA. We also assumed that if a worker inhaled aerosols with radionuclide concentrations corresponding to the average levels in surface soil, his total annual intake activity (the sum of the four radionuclides listed) would have been significantly smaller than the 13.15 dpm (5.92 pCi) that NIOSH assigned to production workers during the first year of the residual period (NIOSH 2017a, Table 7-1). Therefore, the internal exposure associated with subsurface excavation in the vicinity of the waste burial pit does not constitute a bounding pathway for M&C workers during the residual period.

Table 2. Annual Inhaled Intakes from Subsurface Work (pCi)

U-235	U-238	Th-232	Ra-226	Total
0.15	1.26	0.51	0.29	2.21

2.3.3 Internal Exposures Associated with HVAC Maintenance

Based on the interviews, SC&A determined that HVAC filters were periodically replaced, and that filter replacement was often a very dusty activity. In addition, it is reasonable to assume that the dust on the filters contained at least some uranium and thorium associated with chronic resuspension of dust on contaminated surfaces and periodic elevated dust loadings associated with repurposing activities and occasional off-normal occurrences. As such, filter replacement activities represent a potential exposure scenario for maintenance workers.

One approach SC&A explored as a means to estimate potential maximum activity levels on the filters and the internal exposures associated with periodic filter replacement is to take advantage of the information we have on the average removable surface contamination level in Building 10 at the beginning of the residual period (i.e., 12.3 dpm/100 cm^2) and knowledge of the rate at which that activity declined (i.e., 2.54E-4/day). Using this information, along with knowledge of the floor surface area of the clad fuel manufacturing area in Building 10, as cited in the ER

(14,000 square feet), we can estimate the total amount of gross alpha activity at the end of one year after the beginning of the residual period, as follows. We first calculate the total activity at the beginning of the residual period:

$$12.3 \text{ dpm}/100 \text{ cm}^2 \times 1\text{E}4 \text{ cm}^2/\text{m}^2 \times 14{,}000 \text{ ft}^2 \times 0.0929 \text{ m}^2/\text{ft}^2 = 1.600\text{E}6 \text{ dpm}$$

Next, we observe that the activity would have been depleted over the course of 1 year by the following fraction:

$$\text{EXP}(-0.000254 \times 365) = 0.9115$$

The amount remaining after 1 year = 1.600E6 × 0.9115 = 1.458E6 dpm. Therefore, the decline in total alpha activity on surfaces in Building 10 over the first year of the residual period is 1.600E6 dpm – 1.458E6 dpm = 141,600 dpm (2,360 Bq). In theory, this is the amount of activity that was resuspended, drawn into the HVAC system, and deposited onto the filters over the first year of the residual period.

Another approach that can be used to estimate the activity on the filters at the end of the first year of the residual period is to make use of the average airborne concentration of alpha emitters in Building 10 at the beginning of the residual period and the air flow rate drawn into the HVAC system, as follows:

$$12.3 \text{ dpm}/100 \text{ cm}^2 \times 1\text{E}4 \text{ cm}^2/\text{m}^2 \times 1.0\text{E-}5/\text{m} \times 4{,}000 \text{ ft}^3/\text{min} \times 0.0283 \text{ m}^3/\text{ft}^3 \times 60 \text{ min/h} \times 8{,}760 \text{ h/y} = 7.323\text{E}5 \text{ dpm} = 12{,}204 \text{ Bq}$$

This approach is based on the assumption that the contamination level on building surfaces remained constant over the course of the first year of the residual period. As mentioned earlier, the surface contamination level declined at a rate of about 2.54E-4/day. However, this depletion rate is very slow, such that, over the course of 1 year, the contamination level declines by only about 9% and can be ignored for the purposes of this estimate of activity level on the filter.

We originally performed this calculation as a type of “range finding” regarding the levels of potential internal exposures we are dealing with. The strategy that we used to place a plausible upper bound on the inhalation doses to workers involved in filter change-out is described as follows.

It can be assumed that the gross alpha activity on HVAC filters can become at least partially airborne during filter replacement. It is reasonable to assume that this activity would be associated with airborne dust in Building 10, that the chronic concentration of the dust in the building could have been on the order of 100 μg/m^3 (see Appendix D.1), and that the chronic airborne concentration of gross alpha activity in Building 10 was 0.0123 dpm/m^3, as discussed in Section 2.1.1 (12.3 ÷ 100 cm^2 × 1E4 cm^2/m^2 × 1E-5/m = 0.0123 dpm/m^3). Hence, the estimated specific activity of the airborne dust could have been 0.0123 dpm/m^3 ÷ 100 μg/m^3 = 1.23E-4 dpm/μg.

As discussed in Appendix D.2, a nuisance dust loading above 100 mg/m^3 would be barely breathable. For the purposes of this assessment, let us assume that the worker changing the filter was exposed to this dust loading for 1 hour during each change-out. Under these conditions, the upper-end concentration of gross alpha would be as follows:

$$1.23\text{E-4 dpm}/\mu\text{g} \times 100\text{ mg/m}^3 \times 1{,}000\ \mu\text{g/mg} = 12.3\text{ dpm/m}^3$$

The 1-hour dose commitment to the extrathoracic airways of such a worker would be as follows:

$$12.3\text{ dpm/m}^3 \times 1.2\text{ m}^3\text{/h} \times 7.2\text{E-5 Sv/Bq} \times 1/60\text{ Bq/dpm} \times 1\text{E5 mrem/Sv} = 1.77\text{ mrem/h}$$

Inherent in this calculation is the assumption that (1) the chronic airborne concentration of gross alpha activity was 0.0123 dpm/m^3 and (2) the chronic dust loading in Building 10 was 100 µg/m^3. Based on this calculation, it appears that the internal exposure resulting from this scenario can be considered of little concern.

In this analysis, it is assumed that buildup of particulates on the filter continues for 1 year before filter replacement, and, therefore, the worker is exposed to elevated dust concentrations for only 1 hour per year. If we assume that filter replacement is 2, 4, or 12 times per year, the amount of time a worker is exposed per year increases, but the quantity of uranium on the filter is corresponding lower. Hence, filter replacement frequency does not affect the annual internal doses associated with this exposure scenario.

2.3.4 Other Potential Exposure Scenarios

The workers interviewed in October 2017 also described several other exposure scenarios that are described here but that are likely to represent a substantially lower exposure potential than the subsurface scenario described in Section 2.2.1. Therefore, they are described here for information purposes only but are not quantitatively analyzed.

One worker described the wastewater management system employed at the facility. Many of the operations at M&C required acid washing of components, including fuel manufactured at the HFIR. This acid wash water was collected in trenches and subsurface drainage tanks and transported to a central waste water processing facility in the plant. Processing included primarily neutralization of the water and collecting the precipitate and other suspended solids in the water. These solids were sent to a filter press to remove the excess water, and the resulting moist solids were deposited in a roll-off. These moist solids were then sent for further treatment at other facilities.

It is likely that the solids included trace levels of uranium that, in theory, could have resulted in some internal and external exposures to the wastewater treatment personnel. However, we believe that any such exposures would be small compared to the potential exposures experienced by the personnel involved in subsurface maintenance and repurposing activities.

Another worker explained that he worked at a location where low-level radioactive waste was excavated and removed from the site during D&D operations in the 1990s. The worker explained that the waste was excavated with a backhoe and loaded into a dump truck, and the dump truck transported the solid waste to railroad cars located on site at a railroad spur. He explained that the dump trucks did not appear to have a cover, but the railroad cars did have a cover once they were filled. He also explained that, as the dump trucks passed by, he noticed quite a bit of dust that often resulted in dust depositing on cars at the nearby parking lot.

We have information on the concentration of uranium in the excavated waste, but it appears that any incidental exposures M&C workers might have experienced from exposure to this dust would be small compared to the exposures experienced by the maintenance and repurposing activities described in Sections 2.3.1, 2.3.2, and 2.3.3. For example, 34,000 ft^3 of waste containing 278 mCi of U-238 was shipped for disposal (CPS 1993). This corresponds to about 144 pCi/g, assuming the loose solid waste had a density of about 2 g/cm^3. Assuming a chronic outdoor dust loading from these activities of 200 $\mu g/m^3$ (see appendix D.1), the airborne concentration of uranium would be about 0.014 pCi/m^3. The dose rate to the limiting organ would be about 4.0E-3 mrem/h.[3]

2.4 NIOSH Rationale for Not Explicitly Addressing the Potential Exposures Associated with Maintenance and Repurposing Activities

On page 24 of the ER, NIOSH states the following:

> *NIOSH is aware of data from surface contamination surveys, air monitoring, urinalysis, and lung scans that were performed during the evaluated period for M&C employees performing commercial work (TI, 1973–82, PDF p. 34; Barletta, 1973, PDF p. 50; CPS, no date, PDF p. 11; Hopper, 1979 PDF p. 43). Since these data are representative of conditions that existed during commercial operations, NIOSH will not rely on them to bound doses during the evaluated period. However, NIOSH can consider these data as supporting evidence to validate the bounding method used in Section 7 of this report.*

The implications of this statement are that:

1. A review of these reports and the associated data will reveal that the exposures from these activities could be used to validate the exposures experienced by M&C workers involved in maintenance and repurposing activities during the residual period.

2. The methods used in the ER to bound internal doses that might have been experienced by covered M&C workers are sufficiently conservative to account for any internal exposures associated with maintenance and repurposing activities, which are not explicitly addressed in the ER and which NIOSH believes are represented by the actual exposures experienced by non-covered M&C workers during the residual period.

Therefore, one of the objectives of this review is to evaluate the sources of the data (and associated exposures) NIOSH mentioned in the ER quote above to the extent that they can be considered "*as supporting evidence to validate the bounding method used in Section 7*" of the

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[3] 278 $mCi/ft^3 \times 35.31\ ft^3/m^3 \times 1\ m^3/10^6\ cm^3 \times 1\ cm^3/2\ g = 1.44E\text{-}7$ mCi/g = 144 pCi/g

144 $pCi/g \times 100\ \mu g/m^3 \times 1\ g/106\ \mu g = 0.014\ pCi/m^3$

0.014 $pCi/m^3 \times 1\ Bq/27\ pCi \times 1.2\ m^3/h \times 6.67\ E\text{-}5\ Sv/Bq \times 1E5\ mrem/Sv = 4E\text{-}3$ mrem/h

ER and representative of the exposures that covered M&C workers might have experienced during the residual period.

Appendix E presents the personnel monitoring data collected in SRDB Ref. ID 24654 (TI 1979). It is our understanding that these are the exposures and data that are described in the ER passage quoted at the start of this section. During a technical conference call between NIOSH and SC&A on November 20, 2017, NIOSH confirmed that the discussion of "commercial work" in the SEC ER refers to the work done for HFIR.

TI 1979, as summarized in Appendix E, contains urinalysis bioassay results, breathing zone samples, and air monitoring data for [redacted] M&C employees performing HFIR activities in Building 10 during 1977 through 1979. All of the data are presented quarterly. Employees [redacted] worked in what was described as the fuel manufacturing area (FMA) (presumed to be the unclad fuel manufacturing area) during more than 50% of the work week, while [redacted] worked there less than 50% of the time. The largest breathing zone measurement of 1.39×10^{-10} microcurie (µCi)/ml was taken for [redacted] in the fourth quarter of 1977, while the highest measured concentration for [redacted] who spent <50% of their time in the FMA was 2.31×10^{-11} µCi/ml. The largest air concentration in the unfiltered exhaust was 0.54×10^{-12} µCi/ml. [redacted] The results were summarized in TI 1979 (PDF page 34) as follows:

> *The maximum single breathing zone air sample result for individuals with more than 50% of their work assignments within the FMA was less than 25% of the permitted air concentration for ^{235}U as specified in Title 10 CFR Part 20, Appendix B, Table l, and the maximum calendar quarterly average is less than 10% of the permitted air concentration as presented in Table l.*
>
> *The maximum single calendar quarter urinalysis result was 4 pCi/liter with typical results averaging approximately 0.8 pCi/liter.*
>
> *The maximum single annual in vivo body count result was 124 ± 52 µg ^{235}U (followed by 56 ± 40 µg ^{235}U within three months) with typical results fluctuating between 0 ± 40 and 70 ± 50 µg ^{235}U.*

Using the highest breathing zone measurement of 1.39×10^{-10} µCi/ml, measured for [redacted] in the fourth quarter of 1977, the dose rate to the extrathoracic airways, the highest-dose organ, assuming the activity is Type S U-234, 5µm AMAD, is derived as follows:

$$1.39\text{E-}10\ \mu\text{Ci/ml} \times 1\text{E}6\ \text{ml/m}^3 \times 1.2\ \text{m}^3/\text{h} \times 3.7\text{E}4\ \text{Bq}/\mu\text{Ci} \times 7.2\text{E-}5\ \text{Sv/Bq} \times 1\text{E}5\ \text{mrem/Sv} = 44.4\ \text{mrem/h}.$$

Clearly, [redacted] would not have been continuously exposed for a year to the maximum breathing zone concentration of U-234 measured among all workers, nor was he assigned full time to the FMA. However, this calculation provides some perspective on the potential magnitude of the internal exposures to HFIR workers, for at least some short periods of time.

Based on this review, we believe that the exposures experienced by HFIR workers (who are not covered by the SEC) were fundamentally different and likely much larger than the exposures experienced by covered M&C workers during the residual period. Specifically, the external and internal exposures as monitored under the M&C health and safety program for HFIR workers were due to uranium handling in support of fuel fabrication. These types of exposures were fundamentally different, and certainly higher than the exposures experienced by covered M&C workers involved in maintenance and repurposing activities. This is evidenced by the data summarized in Appendix E.

Observation 4: Exposures experienced by HFIR workers cannot be used "*as supporting evidence to validate the bounding method used in Section 7 of this report*" as stated on page 24 of the ER.

2.5 Concerns Expressed by Workers

Issues related to potential exposures to covered M&C workers during the residual period were addressed during worker interviews held on October 24–26, 2017. Those discussions explored the possibility that the exposures experienced by the D&D contractor personnel in the 1990s (who were thoroughly monitored) could be used as a point of reference for the internal exposures experienced by M&C workers involved in maintenance and repurposing activities during the 1970s and 1980s. However, during the interviews, the petitioners argued that the work done by the D&D contractors in the 1990s was done under a comprehensive radiation safety program, while the maintenance and repurposing work done by M&C workers during the residual period (primarily in the 1970s and 1980s) was done without the benefit of health physics oversight. Hence, the petitioners claim that the exposures experienced by the D&D contractors in the 1990s cannot be used as a point of reference for exposures experienced by M&C workers during the residual period.

In order to assess this issue, this review of the ER also includes the following:

1. An assessment of the doses experienced by D&D workers in the 1990s, as reported in primary documents available in the SRDB
2. A review of radiological data characterizing the nature and extent of contamination present at the site during the residual period, including contaminants present in the subsurface environment, especially beneath Building 10, in buried drain lines and conduits, in dusty rafters, and inside the HVAC system
3. An assessment of the potential exposures experienced by covered M&C workers during the residual period

The objective of this aspect of the review is to help determine if exposures to D&D workers in the 1990s can be used to represent exposures experienced by covered M&C workers during the residual period and, if so, are the exposures assigned to covered workers in the ER using the OTIB-0070 resuspension models sufficient to bound the actual total exposures that might have been experienced by covered M&C workers during the residual period?

Critical to this assessment is our ability to understand and bound the exposures that covered workers might have experienced during maintenance and repurposing activities during the residual period. Therefore, this review heavily emphasizes these exposure pathways. Though the emphasis of this aspect of our review is on internal exposures associated with the inhalation and inadvertent ingestion of uranium and thorium residue, we are also concerned with the potential external exposures that might have been experienced by workers involved in maintenance and repurposing activities. These analyses will help to assess the degree to which the resuspension models used in the ER to bound internal doses are sufficiently conservative to account for internal exposures that might have been experienced by covered M&C workers from maintenance and repurposing activities during the residual period.

2.6 Exposures Experienced by D&D Workers

In addition to the other scenarios, former M&C employees discussed the possibility that the exposures to D&D contractors could be used to inform dose reconstruction of M&C employees involved in the repurposing and maintenance activities during the residual period. Beginning in 1992, Creative Pollution Solutions, Inc. (later called CPS Environmental, Inc.), and later Roy F. Weston, Inc., were hired by TI to decontaminate and decommission various areas of the M&C facility to comply with NRC regulations for unrestricted use. In 1992 and 1993, residual contamination was identified at the former burial site and adjacent to Building 11, and remediation was performed. In 1994, outdoor surveys identified additional contamination in the Metals Recovery Area, which was near Building 5 and Building 11. Finally, in 1994 and 1995, a site-wide comprehensive radiological survey was performed, which revealed residual contamination in several areas, including areas of Buildings 10, 4, and 5, which had been previously decommissioned. During these remediations, CPS and Weston followed health and safety procedures, which included area and breathing zone monitoring and urinalysis bioassays. These data were published in various documents, including CPS 1993, Weston 1996b and 1996c, and CPS no date. NIOSH summarized the specific D&D activities that took place during indoor remediation during 1995 and 1996. These activities can be compared to those performed by M&C in support of maintenance and repurposing activities, particularly the removal of the drain lines.

> *Prior to the full-scale remediation, a comprehensive characterization of the subsurface drainage system was performed. Characterization results were used to designate and prioritize three levels of drain line decontamination with respect to the volume and concentration of radioactive material. Priority 1 lines exhibited residue blockage greater than or equal to 10% and/or total uranium concentrations in excess of 1,000 picocuries per gram (pCi/g), and were identified for complete removal and disposal as radioactive waste…*
>
> *Further remediation activities in Buildings 4 and 5 primarily involved scabbling concrete floor surfaces. In a few cases, portions of the concrete slab and some underlying soil were removed. Building 10 required more extensive remediation work to remove contamination because unclad uranium operations had been conducted in portions of this building. Remediation activities included scabbling approximately 75 m^2 (800 ft^2) of the floor and lower wall surfaces. Approximately 1,400 m^2 (15,000 ft^2) of the concrete slab were removed to provide access to*

> *contaminated drain lines and soil. In most cases, the concrete was not contaminated or was only contaminated on the surface. Approximately 460 m (1,500 ft) of contaminated drain lines were removed from Building 10, and another 180 m (600 ft) were decontaminated using a high-pressure wash. Approximately 6 m^3 (200 ft^3) of sludge were collected and disposed (Callan, 1997, PDF p. 6). Approximately 10,000 ft^2 of Building 10's roof was subject to decontamination techniques including vacuuming gravel and dust, scraping roof tar layers, and removing section of the roof. Roofing material was transferred directly to shipping containers using a sealed hopper/chute system. Scraping and roof section removal were performed with roof cutters and hand tools. Decontamination and removal operations resulted in approximately 1,000 ft^3 of radioactive waste to be transported for disposal (Weston,* [1996c], *PDF p. 17).* [NIOSH 2017a, page 19]

SC&A reviewed the version of CPS 1993 provided by NIOSH in the SRDB, but Appendix A, which contained the health and safety monitoring data, had been removed. NIOSH indicated that the copy of this document that they have never contained that appendix or personnel monitoring data. Further discussion with NIOSH and TI staff indicated that these data may no longer be available. Therefore, the only D&D contractor information available is briefly summarized in Section 4.5.2 of Weston 1996b. The Weston and subcontractor employee monitoring data during work performed at the external areas of Buildings 11 and 12 are as follows:[4]

> *Weston and subcontractor dose summaries were prepared for the third and fourth quarters of 1995 and for the first quarter of 1996. Dose summaries included contributions from external and internal exposure sources, calculated based on thermoluminescent dosimeter badge results and area and personnel air sampling data. All worker total effective dose equivalent (TEDE) results were less than 20 milliroentgen equivalent in man (mrem) in each quarter. All worker TEDEs were considerably less than the acceptable federal limit of 1,250 mrem per calendar quarter. Personnel exposure records and data are maintained on file at the TI Attleboro Facility.* [Weston 1996b, PDF page 17]

The undated CPS document presents the radiological characterization performed on the former burial site between Buildings 11 and 12 on June 7, 1992. All general air samples were less than the MDA. Five identified TI and contractor employees were monitored with breathing zone samplers that were allowed to run during the entire work period. The breathing zone results were reported in terms of maximum permissible concentration hours (MPC-h); this is the same as the derived air concentration (DAC) specified in 10 CFR Part 20, Appendix B, Table l. We note that this table lists three different values of the DAC for U-235 and U-238, depending on the lung clearance class—day, week, or year. CPS did not specify which class was assumed. All the breathing zone results but one were below the minimum detectable limit, which was 0.025 MPC-h. The one positive result was 0.041 MPC-h. Urinalysis bioassays were also performed on all "principals" (presumably personnel involved in the remediation), but these results were not available at the time of the CPS publication. SC&A assumed that, since the air

[4] Weston employed more than 15 second-tier subcontractors, including CPS.

monitoring data were below the limits of detection, there would not likely be any positive bioassay results.

Notwithstanding issues related to whether or not exposures experienced by D&D workers are indicative of exposures that might have been experienced by M&C workers involved in subsurface maintenance and repurposing activities, it is interesting to note that the ER describes the worker D&D doses at less than 20 mrem in each quarter (TEDE), while SC&A, in Section 2.3.1 of this report, estimates internal doses of 15.6 mrem/y effective dose for subsurface maintenance and refurbishing activities (assuming about 1 month per year of subsurface activities). In addition, as will be shown in Section 3.3.1, SC&A estimates an upper-bound dose of 153 mrem/y external effective dose for subsurface maintenance and repurposing activities assuming 1 year of such activities. Assuming 1 month per year of such exposures, the upper-bound external doses would be about 13 mrem/y. Hence, based on SC&A models, exposures to M&C workers associated with subsurface maintenance and repurposing activities would be no more than about 30 mrem/y, while the upper-end dose, as estimated by CPS and Weston for D&D workers, is about 80 mrem/year, assuming 1 year of continual D&D work. Given the nature of these estimates, the doses as estimated for subsurface work by M&C workers compare favorably with the exposures actually experienced by D&D workers.

3 REVIEW OF EXTERNAL EXPOSURE METHODOLOGY AND DATA

The method used in the ER to reconstruct external doses during the residual period employed external dosimetry data collected in the last year of AWE operations. As will be shown in the sections that follow, such an approach is certainly bounding, notwithstanding certain findings and observations we have regarding the methodology used in the ER. However, we have concern that the data collected during AWE operations are not entirely applicable to the residual period. Specifically, during the AWE operations period, large quantities of uranium and thorium were on site and handled by AWE workers to manufacture fuel elements and fuel assemblies. All of this fuel, which would have been responsible for the majority of external exposures to AWE workers, was removed from the site at the end of AWE operations and would not have been present during the residual period.

<u>Observation 5</u>: SC&A is concerned that it may be inappropriate to use external dosimetry data collected during the last year of AWE operations as the basis for bounding the external doses during the residual period.

These concerns notwithstanding, this section evaluates the ER from two perspectives. The first is to evaluate the data and methods used in the ER to reconstruct external doses based on external dosimetry data collected during AWE operations. Second, we review the degree to which these data plausibly bound the external doses during the residual period, with specific consideration given to external exposures from residual contamination on building surfaces and also maintenance and repurposing activities that took place during the residual period, as described above in Section 2.

3.1 NIOSH Methodology for Assigning Penetrating Doses to Workers during the Residual Period

3.1.1 Use of Landauer Film Badge Dosimetry Reports

According to the ER, NIOSH assigned external doses to workers during the residual period on the basis of film badge dosimetry data recorded during 1967, the last year of the AWE operational period. Based on these data, NIOSH determined the 95th percentile penetrating dose as described below:

> *The data used was from the cumulative totals column of the Landauer dosimetry reports for "X" or "Gamma" exposure for the 162 monitored M&C employees. From this data, the 95th percentile value for the measured doses was determined to be 150 mrem/year.* [NIOSH 2017a, page 31]

The NIOSH data were tabulated in an Excel file, *MC AWE film badge data.xlsx* (Darnell 2017). These data included 162 year-to-date cumulative totals, in mrem, extracted from the R. S. Landauer JR & Co. reports for the third quarter of 1967—July 1 to September 30—collected in the SRDB PDF we reference as Landauer 1967. We reviewed these data, which were tabulated in the same sequence as in Landauer 1967, and were able to establish a correspondence between the source data and the Excel file. However, we found a number of issues with the NIOSH analyses.

3.1.2 Review of NIOSH Analyses

First, we found that NIOSH omitted a value of 80 mrem and 10 faint but decipherable "M" (minimal) values within the range of tabulated values. Such omissions skew the 95th percentile, which is based on the rank order of all values. The value of 80 mrem that was reported for participant number 699, although faintly visible on the scanned copy, was confirmed by noting that a clearly legible dose of 40 mrem for the current (third) quarter was reported for this worker; furthermore, a year-to-date dose of 40 mrem to the same worker was reported for the second quarter of 1967, thus confirming the cumulative dose of 80 mrem for the year. The omitted, faintly legible, M values can be likewise confirmed by noting that cumulative doses of M were reported for these workers for the end of the second quarter, and that the total exposure for the current quarter was listed as M or was left blank, indicating a cumulative value of M. We also noted that a value of 80 mrem, based on its sequential order in the NIOSH Excel file, corresponded to the cumulative dose to participant number 924 in the Landauer reports. However, Landauer 1967 listed the dose as 20 mrem, which can be confirmed by noting the listed value of 20 mrem for the current quarter and a cumulative value of M at the end of the second quarter. (Landauer 1967 does not include M values in the cumulative totals.)

All the participants whose doses were reported during the third quarter were issued "Type 1" badges, which Landauer 1967 described as "total body." Five of these workers were also issued "Type 2" badges, which Landauer described as "skin." The Landauer reports listed the readings for the Type 2 badges immediately below those for the Type 1 badges for the same workers. NIOSH erroneously entered the skin doses from the Type 2 badges under the whole-body doses to the same workers in its Excel file in the column headed "mrem/y X or gamma," as if these were doses to other workers, and included these badge reports in its count of 162 monitored M&C employees.

Ten of the doses in the NIOSH Excel file were to participants identified by the acronym "SR." In a letter to the Landauer company listing M&C's film requirements for its dosimetry program, Forcier (1965) identified the "Area Used" for these badges as the "Smidgen Room." This indicates that these badges were used as area monitors and that the recorded doses were not doses to individual workers. Finally, NIOSH included a badge with the participant number 000, identified as "Control." None of these badges should have been included in the NIOSH tabulation.

Eliminating the 10 SR badges, the five skin badges, and the control badge reduces the total number of participants to 146, while adding the 11 omitted readings brings it up to 157.

However, many of these participants were missing one or more badge reports for the year 1967. Furthermore, there were no reports in the available Landauer records for the last quarter of the year. NIOSH refers to these as "missed doses":

> *To account for missed doses, NIOSH will assume that the entire annual dose for each employee was delivered in the final quarter of 1967, and that the dose for the previous three quarters was below the LOD (10 mrem). NIOSH will then add in a missed dose component equivalent to the LOD/2 (5 mrem) for the other three previous quarters. This results in a missed dose component equivalent to*

> *3 x LOD/2 (15 mrem). Adding this to the measured dose, results in a 95th percentile total dose (missed and measures) value of 165 mrem/year.*
> [NIOSH 2017a, page 31]

NIOSH erroneously conflated missing film badges with missed doses. Missed doses occur when a dosimeter reading is recorded as zero because the actual dose was below the limit of detection (LOD). According to OCAS-IG-001, Revision 3, *External Dose Reconstruction Implementation Guideline* (NIOSH 2007b, page 16):

> *The method to be used for dose reconstruction related to EEOICPA is to assign a dose equal to the LOD divided by 2 for each dosimetry measurement (film badge, pocket ionization chamber or TLD) that is recorded as zero or if it is below the limit of detection divided by 2.*

In the case of the Landauer film badge dosimetry program, all film badges with doses below the LOD were reported as M. It would have been appropriate for NIOSH to tabulate such doses as LOD/2, which is 5 mrem in the case of photon exposures. NIOSH chose to tabulate these doses as equal to the LOD (10 mrem)—this does not change the 95th percentile, which is higher than the lowest recorded numerical dose. However, there is no basis for treating workers with *missing film badge reports* as having missed doses.

In summary, we do not agree that NIOSH employed a valid method of estimating the annual 95th percentile dose that could be used as a surrogate dose to other, unmonitored, workers. Calculating a rank-order statistic requires a consistent set of data, which precludes grouping workers with missing badge reports with those with complete sets of reports for the first three quarters. There is no basis for assuming that workers, some of whose badges were lost or otherwise unaccounted for, received doses of 5 mrem during those periods, and there is certainly no basis for assigning doses of 5 mrem to the last quarter of 1967, for which there are no available external dosimetry reports.

3.1.3 Reanalysis of Whole-Body Film Badge Dosimetry Data

To resolve this problem, we reviewed each film badge dosimetry report with an entry in the "Missing badges to date" column and eliminated those with missing badges for one or more quarters in 1967, which left 87 participants with reports for each of the first three quarters. We derived a 95th percentile cumulative dose of 180 mrem for these 87 participants. Prorating this dose to a full calendar year, we obtained an annual dose of 240 mrem (180 mrem/3 quarters × 4 quarters/y = 240 mrem/y). We believe that this represents a more valid assessment of the 95th percentile annual dose, based on the available film badge reports.

NIOSH compared its derived value of 165 mrem/y with a summary report of film badge results of doses to workers involved in the HFIR project in the mid- to late 1970s reported by Hopper (1979, Table 13.2.1) and reproduced as Table 3 of the present review. NIOSH observed that the annual dose, calculated as 4 times the mean quarterly dose, was 193.2 mrem. Because this was higher than the dose NIOSH derived from the 1967 film badge data, it rounded up the value extracted from Hopper's data to 200 mrem/y. The ER (NIOSH 2017a) stated that NIOSH intends to apply this value as a constant distribution in assigning external doses to M&C workers during the residual period.

Table 3. Whole Body Radiation Exposure History Uncorrected for Natural Background Exposures (mrem/qtr)

Low	High	Mean	Std. Dev.	No. of Badge Results
10	180	48.3	30.4	250 (5 qtrs) *

*Previous 4 yr. results yield lower results due to lesser product throughput.
Source: Hopper 1979, Table 13.2.1.

We disagree with this decision on several grounds. First, the value of 200 mrem/y is lower than the 95th percentile annual dose of 240 mrem/y derived from the 1967 film badge data. Second, NIOSH policy is to assign 95th percentile values as fixed distributions, reasoning that such a value in itself is at the high end of a probability distribution, so that no further uncertainty needs to be assigned. However, such an argument does not apply to the mean value of a distribution.

The data in Table 3 can, in fact, be used to derive the underlying distribution of film badge dosimetry results. Assuming that the distribution is approximately lognormal, we derived a median of 40.88 mrem/quarter and a geometric standard deviation of 1.78. We observe that the low value listed in Table 3 is approximately one-fourth the derived median, while the high value is roughly 4 times the median. Such ratios are consistent with the assumption of a lognormal distribution. Using these values of the median and the GSD, we derived a 95th percentile dose of 106 mrem/quarter, which yields an annual dose of 423 mrem.[5] Therefore, the dose rate of 200 mrem/y proposed by NIOSH is not bounding in the case of HFIR workers. However, because the external exposure of these workers was not limited to residual contamination from earlier AWE activities, their external doses do not represent the doses to the class of workers evaluated by NIOSH under the present petition.

Finding 2: NIOSH incorrectly transcribed some of the Landauer film badge dosimetry reports and incorrectly calculated annual 95th percentile external penetrating doses to workers in the residual period.

3.2 NIOSH Methodology for Assigning Beta Skin Doses to Workers during the Residual Period

NIOSH used a different approach to evaluate the beta dose to the skin. The ER (NIOSH 2017a, page 31) stated, "*Of the 162 monitored M&C employees in 1967, 12 were monitored for beta radiation*." In fact, only five workers were issued Type 2 film badges that were used to measure beta doses. There were a total of 12 quarterly skin dose reports for these five workers. NIOSH correctly determined the 95th percentile of the 12 quarterly beta doses as 112.5 mrem, but the ER incorrectly referred to it as 112.5 mrem/year, while it in fact represents mrem per quarter.

According to Landauer 1967, the LOD for beta doses was 40 mrem. As with the photon dose, NIOSH assumed a missed dose of one-half the LOD or 20 mrem for each of three quarters and

[5] The ratio is not exactly 1:4 due to round off.

added the resulting value of 60 mrem to the assumed annual beta dose of 112.5 mrem/year to obtain a beta skin dose of 172.5 mrem/year. We believe that a more valid assessment, based on the available film badge reports, is to use the 95th percentile dose of 112.5/quarter to estimate an annual beta dose to the skin of 450 mrem (112.5 mrem/quarter × 4 quarters/y = 450 mrem/y).

Finding 3: NIOSH incorrectly calculated annual 95th percentile beta skin doses to workers in the residual period.

3.3 Applicability of Film Badge Dosimetry Results from the AWE Period to Doses during the Residual Period

The more overriding issue in applying the 1967 film badge dosimetry results to workers employed during the residual period stems from the difference in exposure conditions during the AWE period and the residual period, when no weapons-related work was being performed. It can be argued that the film badge data place an upper limit to the doses during the residual period: at the end of the AWE period, the monitored workers were exposed to the accumulated residual contamination that was similar to that present during the residual period, as well as to sources peculiar to the weapons-related activities. The exposures at the end of the AWE period thus represent an upper bound to the exposures during the residual period, assuming that the nature and extent of maintenance and repurposing activities performed during AWE operations were similar to those performed during the residual period.

3.3.1 Worker Exposures to Drain Pipe Residues

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

In performing the analyses, we assumed that the U-235 and U-238 in the soil were in full equilibrium with their short-lived progeny. We calculated the effective dose and skin dose, using the dose coefficients for exposure to soil contaminated to an infinite depth tabulated in Federal Guidance Report No. 12 (EPA 1993). We ranked the effective doses and skin doses corresponding to each of the 22 locations, along with the cumulative volumes of pipe scale or sediment in each pipe, and calculated the dose corresponding to 95% of the cumulative volume by linear interpolation. In this manner, we derived 95th percentile annual doses of 153 mrem effective dose and 390 mrem skin dose. The Weston (1996a) data are noteworthy in that they were collected in September 1995, prior to extensive remediation of the M&C site that commenced in 1996. They thus constitute one of the few data sets on radioactive contamination collected prior to the final remediation.

3.3.2 Worker Exposures to Contaminated Floors

At the low end of the contamination scale, we note the results of a survey of surface contamination performed by TI (1982) in support of a request for the termination of the NRC license for the facility. TI performed measurements at 207 locations, including the walls and ceiling of a structure described as a vault, part of the unclad fuel manufacturing area. However, according to Sherman and Schwensfeir (1982, PDF page 7), "*TI selected the floors of areas identified as processing unclad materials for these measurements because floors represent the worst condition for holding residual radioactivity*." The results of 40 sets of measurements performed on these areas were listed by TI (1982, Appendix A, 4.2.2). For each area, TI listed the maximum activity and the average of all measurements in the given area. We calculated the 95th percentile of these average readings to be 234.44 dpm/100 cm^2, or 23,444 dpm/m^2. Assuming the contamination to be due to natural uranium in equilibrium with its short-lived progeny, we applied the dose conversion factor of 3.94×10^{-10} milliroentgen (mR)/h per dpm(α)/m^2 listed in TBD-6000 (NIOSH 2011a, Table 3.10) to obtain an exposure rate of 9.24×10^{-6} mR/h, which is undetectable in the presence of natural background. Assuming an exposure duration of 2,000 h/y, we derived an annual exposure of 0.0185 mR, which is far below the minimum exposure that needs to be considered in a dose reconstruction. The corresponding beta skin dose rate, based on the dose conversion factor of 3.82×10^{-8} mrad/h per dpm(α)/m^2 listed by NIOSH (2011a, Table 3.10), is 1.79 mrad/y, which is just above the 1 mrem/y threshold for radiation doses that need to be addressed by a dose reconstruction.

3.3.3 External Exposures of HVAC Workers

Another potential external exposure pathway are the external doses to a worker changing HVAC filters. Such a worker could potentially receive a skin dose from airborne contaminated dust settling on his skin during this operation. Using conservative assumptions about the dust loading and specific activity, as discussed in Section 2.3.3 of the present review, the settling velocity recommended by TBD-6000 (NIOSH 2011a), and the skin dose rates discussed in Appendix C, we find that the annual skin dose from this pathway is much less than 1 mrem. Therefore, the contribution to the skin dose from this scenario does not need to be included in the assessment of worker doses.

3.4 Summary and Conclusions

We thus have four estimates of 95th percentile external effective doses during the residual period: 240 mrem/y, based on our reanalysis of the 1967 film badge reports: 423 mrem/y, based on our analysis of the HFIR film badge data; 153 mrem/y, from a worker's standing on soil with the same uranium isotope concentrations as the contaminated drain pipe residues or pipe scale; and 0.0185 mR/y, from standing on the floor of the unclad fuel manufacturing area (outside the HFIR project area). The highest dose rate is derived from the HFIR film badge data; however, these data cannot be used to estimate doses to M&C workers during the residual period because HFIR workers were exposed to radiation sources that were not related to the weapons program—such doses from such exposures are not included in dose reconstructions under EEOICPA. The next highest dose rate is based on film badge data from the AWE period. These doses resulted from exposure to materials related to production of fuel elements used in the weapons program, as well as from radioactive residues from such materials. These exposures, although they included sources that were presumably removed at the end of the AWE period, constitute a bounding scenario for the residual period: the external doses based on the 1967 film badge data are higher than, but comparable to, the doses derived from standing on contaminated soil (a bounding scenario), and far higher than the dose from the floor of the unclad fuel manufacturing area.

We have three corresponding beta skin dose rates: 450 mrem/y, based on our reanalysis of the 1967 film badge reports; 390 mrem/y, from standing on soil with uranium isotope concentrations equal to those in the contaminated drain pipe residues or pipe scale; and 1.79 mrad/y, from standing on the floor of the unclad fuel manufacturing area. The highest dose rate is derived from the 1967 film badge data (there are no beta skin dose film badge data for the HFIR project).

We therefore conclude that external dose rates of 240 mrem/y effective dose and 450 mrem/y beta skin dose are bounding external doses to M&C workers covered by EEOICPA during the residual period if one deems that it is appropriate to use dosimetry data obtained during AWE operations as appropriately applicable and bounding to exposures experienced by M&C workers during the residual period. Alternatively, using the bounding models for subsurface exposures evaluated above in Section 3.3.1, an annual penetrating dose of 153 mrem/y and a skin dose of 350 mrem/y would be appropriate, assuming that an M&C worker might have experienced such exposures for an entire year.

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APPENDIX A: OVERVIEW OF SEC PETITIONS FOR AWE SITES DURING THE RESIDUAL PERIOD PREVIOUSLY EVALUATED BY THE ADVISORY BOARD

Of the 50 approved SECs for AWE sites, only 3 of them extend coverage into the sites' residual periods. Those three facilities include Ames Laboratory SEC Petition 75, Norton Company SEC Petition 173, and Vitro Manufacturing SEC Petition 177. Below are excerpts from each of the SEC petition evaluation reports for these facilities that summarize why individuals who were employed during the residual periods were included in the SEC cohorts. In all cases, the SECs were granted because workers taking part in maintenance, decommissioning, and/or renovations of the sites during the residual period were found to have potential for exposure but that exposure could not be bounded due to the lack of source term information or lack of environmental and personnel monitoring data.

Ames Laboratory: SEC Petition 75 (NIOSH 2007, page 3):

> *The NIOSH-proposed class includes sheet metal workers, physical plant maintenance and associated support staff (includes all maintenance shop personnel of Ames Laboratory), and supervisory staff who were monitored, or should have been monitored for potential internal radiation exposures associated with the maintenance and renovation activities of the thorium production areas in Wilhelm Hall (a.k.a. the Metallurgy Building or "Old" Metallurgy Building) at the Ames Laboratory, for the time period from January 1, 1955 through December 31, 1970 and who were employed for a number of work days aggregating at least 250 work days, either solely under this employment or in combination with work days within the parameters (excluding aggregate work day parameters) established for other classes of employees included in the SEC. The class was accepted because data and documentation available to NIOSH show that the renovation and demolition activities described in the petition took place with little Health Physics or Industrial Hygiene oversight, presented radiological exposure potential, and the workers involved were not monitored.*

Norton Company: SEC Petition 173 (NIOSH 2011a, page 3):

> *Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all atomic weapons employees who worked in any building or area at the facility owned by the Norton Co. (or a subsequent owner) in Worcester, Massachusetts, during the period from January 1, 1958 through October 10, 1962, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort. NIOSH has determined that decontamination and decommissioning activities were conducted during the period from January 1, 1958 through October 10, 1962, for which NIOSH has insufficient source term and monitoring*

data to bound internal and external doses potentially received from exposures during that work.

Vitro Manufacturing (Canonsburg): SEC Petition 177:

NIOSH reserved the evaluation of residual radiation period exposures at Vitro Manufacturing starting in 1960. This report documents the evaluation of Vitro Manufacturing potential radiological exposures for the portion of the residual radiation period from January 1, 1960 through September 30, 1965. NIOSH ended its evaluation at the conclusion of significant remediation activities. The buildings were decommissioned and exposure due to the presence of the residue storage piles had been remediated through burial in 1965. [NIOSH 2011b, page 11]

- *The proposed class period from January 1, 1960 through September 30, 1965, follows immediately after the already-designated SEC period for Vitro Manufacturing (Canonsburg). During this period, 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 has documentation indicating that Vitro Manufacturing (Canonsburg) completed the transfer and burial of the residue storage piles onsite. The report describing the completed state of the burial work is dated September 30, 1965.*

- *NIOSH does not have access to personnel monitoring, workplace monitoring, or source term data to estimate unmonitored internal and external exposures for Vitro Manufacturing (Canonsburg) workers during the period of residue storage and site decommissioning and burial operations from January 1, 1960 through September 30, 1965.* [NIOSH 2011b, pages 4–5]

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APPENDIX B: M&C'S HEALTH AND SAFETY PROGRAM

SC&A's experience in reviewing health and safety programs at AWE facilities is that routine surveys or bioassay programs were rarely implemented during the residual period but were implemented many years later during cleanup operations under the FUSRAP program. To confirm that a comprehensive health and safety program was implemented during operations and also during the residual period, SC&A reviewed the various documents cited in the ER.

Section 6.1 of the ER states the following (NIOSH 2017, page 24):

> *Beginning in the 1950s, M&C's Instrument Engineering Section developed nondestructive testing methods for process control and to ensure in-process quality including radiography and radiation monitoring (TI, 1960, PDF p. 24). M&C's intensive cleaning program during the AWE Facility operational period required daily surface surveys to check for nuclear materials (TI, 1960, PDF p. 27).*
>
> *M&C performed routine contamination monitoring of employees and areas. Area surface-contamination survey data[4] (analyzed for gross-alpha content) from the end of the AWE Facility operational period indicate that removable alpha contamination was generally below 100 dpm/100 cm^2…*
>
> *[4] The Health and Safety Contamination and Radiation surveys that were analyzed are located in the following SRDB Ref ID numbers: 69181, 69314, 69231, 69239, 69289, 69283, 69210, 69228, 69233, 69287, 69295, 69300, 69305, 69269, 69271, 69276, 69293, 69185, and 69167.*

A review of TI 1956–1960 (SRDB Ref. ID 13634) reveals that this PDF collects information that appears to have been prepared by M&C for use as introductory information for new employees. The PDF also contains promotional material prepared by Texas Instrument Corporation, *Fuels of the Future* (PDF pages 21–37), which appears to be a marketing and public relations document intended to advertise the highly specialized experience and skills of M&C in the areas of metals and controls, including nuclear metals handling, machining, and fuel fabrication to very high tolerance specifications. The document is useful because it contains considerable information about M&C and its history, including its metal plating operation.

In 1952, M&C Nuclear, Inc. was formed as a subsidiary of M&C to support the manufacture of nuclear fuel. As stated in *Fuels of the Future*,

> *In cooperation with Research and Development, the Process Engineers provide engineering liaison for fuel production, machining, and fuel and core assembly. This group includes specialists in melting, forging, extrusion, rolling, chemical milling, machining, welding, and assembly.* [TI 1956–1960, PDF page 26]

With the exception of core assemblies, these activities are standard uranium metal-handling activities as covered in Battelle-TBD-6000 (NIOSH 2011). *Fuels of the Future* addresses health and safety at the facility, which, as cited in the ER, states the following:

> *The equipment and procedures employed for health protection enable us to maintain levels of uranium concentration which are lower by a factor of fifty than those permitted by the Code of Federal Regulations. To insure that these extremely low levels are maintained, constant checks are run on airborne impurities in the specially segregated area where bare uranium and thorium are handled, elsewhere in the plant and outside the building. An intensive cleaning program provides for daily surveys to check surfaces exposed to nuclear materials. It is also the responsibility of Health and Safety to assign safe limits for the handling of fissionable materials. These simple, yet accurate and complete monitoring systems enable us not only to protect our personnel, but also our products from Uranium surface activity*. [TI 1956–1960, PDF page 27]

The ER provides a large number of references that appear to address the health and safety program at M&C (e.g., M&C 1964, M&C 1966, Weiss 1968, and a couple of TI citations with no date, including SRDB Ref. ID 7092). SC&A reviewed these SRDB files with the objective of gaining an understanding of the types and extent of health physics monitoring programs and controls that were implemented during AWE operations (1952–1968) and during the residual period (post 1968).

M&C 1964, *General Safety Standards and Procedures at M&C Nuclear Products* (SRDB Ref. ID 13642), is cited in the ER as containing M&C health and safety (H&S) information. We assume that this document provides information that would be applicable to the AWE operations period, which extended from 1952 to 1968. It appears that the manual would apply to AWE activities because it refers to a broad range of uranium- and thorium-handling operations, but may also apply to HFIR operations, which began in 1965 after the date that the H&S manual was issued (1964).

M&C 1964 is a relatively large document (91 pages) describing all aspects of the H&S program. Part II of the plan addresses “Nuclear Health & Safety Policies and Practices,” and Part III addresses “M&C Health Physics Standard Procedures.” Notable, as applied to the review of the internal dosimetry section of the ER, are procedures titled “Internal Radiation Protection” and “Surface Contamination Control,” where particular reference is made to 10 CFR Part 20. Reference is also made to:

- Air sampling for radioactive aerosols, including routine general air, operational, and breathing zone samples
- Respiratory protection and protective clothing and equipment
- Bioassay programs
- Surface contamination control, including limits on fixed alpha emitters expressed in units of dpm/100 cm^2, the methods for measurement, and cleanup procedures and requirements

Clearly, a very comprehensive radiological H&S program was in place at M&C, at least beginning in 1964.

SC&A also reviewed Weiss 1968, *Health and Safety Manual* (SRDB Ref. ID 16985). This document is an H&S manual and was issued in August 1968, at about the time when AWE operations ceased. Hence, it might have applicability specifically to former AWE workers who are covered by EEOICPA during the residual period and, therefore, is particularly applicable to the ER. This manual is in many ways similar to the M&C H&S manual dated 1964 discussed above. However, the extent to which the program was actually implemented specifically to monitor and control exposures to workers other than HFIR workers is difficult to discern from reviewing the manual itself.

The ER describes decontamination and decommissioning operations that took place at M&C with the specific objective of cleaning up Buildings 3, 4, and 10, where AWE operations, and also non-AWE operations (e.g., HFIR), took place. Most importantly, page 17 of the ER states the following about the cleanup of facilities where AWE operations took place:

> *Texas Instruments reported to the NRC that the three areas used for AWE Facility operations (Buildings 3, 4, and 10) were decontaminated and decommissioned and that all radioactive materials were removed at the completion of D&D operations (occurring from 1955 to 1968). The largest Building 10 cleanup effort occurred at the end of 1958 (ASTRA, 1962, PDF p. 71). Texas Instruments also reported that all three areas were surveyed after each area's respective D&D efforts were completed (TI, Nov1982, PDF pp. 12–13; NRC, 1983, PDF p. 7). No other AWE-related radiological work was performed in Buildings 3, 4, or 10 again after 1968. From 1968 to 1981, the only radiological work that was performed at the Texas Instruments site was the non-weapons related fuel fabrication operations for HFIR and other government-owned research reactors.*

The implications are that substantial data should be available confirming the radiological conditions in Buildings 3, 4, and 10 at the end of AWE operations. However, the ER also states the following:

> *Although the three areas were previously surveyed, Texas Instruments could not locate the survey documentation from 1968 for Buildings 3, 4, and 10, so in 1982, Texas Instruments resurveyed the areas used for AWE Facility operations and documented that the three areas had remained decontaminated during the time since the end of AWE Facility operations (TI, Nov1982, PDF pp. 12–13; NRC, 1983, PDF p. 7). In 1983, the NRC was satisfied that the interiors of Buildings 3, 4, and 10 were sufficiently decontaminated and they released Buildings 3, 4, and 10 for unrestricted use, but the NRC withheld license termination pending further investigations into the former radioactive waste burial site between Buildings 11 and 12 (Ansari, 1994, PDF p. 12; TI, 1994, PDF p. 8).* [NIOSH 2017, pages 17–18]

These statements, and the supporting data provided in the SRDB, represent the most important data supporting the ER, because they establish the bases for reconstructing doses during the residual period, which began in 1968. These source documents are reviewed in depth in this report.

The ER also explains that the cleanup work performed in 1992 to the end of the covered period on March 21, 1997, involved contractor personnel, who are not considered AWE workers and are not covered under EEOICPA. The ER makes a point to distinguish between operations that are covered as AWE activities and those considered non-AWE or commercial activities during the AWE period and also during the residual period. This distinction is also important to the conclusions of the ER that doses can be reconstructed for both workers who are covered and those who are not covered by the SEC.

In addition to D&D of indoor areas, page 18 of the ER describes the cleanup of outdoor areas, including waste burial grounds. However, it appears that this work was performed by contractors, who are not covered under EEOICPA, and need not be evaluated as part of this review. In addition, the surveys performed in 1994 and 1995, which were implemented to confirm the completion of cleanup, also surveyed Buildings 3, 4, and 10 (i.e., the buildings where AWE activities formerly took place) and found some residual contamination. Additional cleanup of these facilities was then implemented by contractor personnel.

The ER explains that these survey data are useful in understanding how residual activity in the AWE areas declined from the beginning to the end of the residual period. The implications of these additional data are that there could have been sources of contamination in Buildings 3, 4, and 10 during the residual period that need to be explicitly considered in reconstructing doses during the residual period that were not necessarily captured by previous surveys or by the default assumptions used in Battelle-TBD-6000 (NIOSH 2011) and ORAUT-OTIB-0070 (NIOSH 2012). In addition, though contractor personnel who performed additional D&D activities in Buildings 3, 4, and 10 are not covered by EEOICPA, these activities could have resulted in some exposures to non-contractor workers in these buildings at the time of the D&D operations. This report reviews these circumstances and data with respect to their implications for data adequacy and the ability to reconstruct doses during the residual period.

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APPENDIX C: INDEPENDENT VERIFICATION OF SKIN DOSE FROM URANIUM DUST

Michael W. Mallett, PhD, CHP, MBA[6]

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

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

VARSKIN Method

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

MCNP Method

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

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

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

[6] Prepared by Michael W. Mallett, PhD, CHP, MBA, on September 15, 2013, as an SC&A associate under the direction of John Mauro, PhD, CHP. Dr. Mallett is currently as associate of SC&A, Inc.

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APPENDIX D: SUMMARY OF LITERATURE ON INDOOR AIRBORNE DUST LOADINGS

D.1 LITERATURE REVIEW

One of the challenges associated with reconstructing internal doses associated with maintenance and repurposing activities at M&C is placing a plausible upper bound on the airborne dust loading during these activities. Section 6.3 of NUREG/CR-5512, Volume 1 (1992), provides an overview of the applicable regulations and literature addressing indoor airborne dust loadings. The following is an excerpt from that report:

> *The concentration of respirable dust in the air will vary depending upon a variety of factors, including the physical condition (such as the particle size) of the material being handled, the quantity of the material present, and the building ventilation or wind conditions. For this study, concentrations of respirable dust in the air are estimated using mass-loading factors and resuspension factors.*
>
> *Perhaps the simplest method of estimating air concentrations is to use mass-loading factors. For this method, the average air concentration is defined in terms of g/m^3 of air. This concentration is converted to units of activity using the concentration of the source material. Although dust-loading in itself is not a topic that is widely studied or reported in the literature, topics related to dust-loading are reported, including concentrations of particles, aerosols, and total suspended particulates (TSP). The field of air pollution has the greatest amount of relevant literature, including representative entries in several leading reference books. (MaGill, Holden, and Ackley 1956; Stern 1968; U.S. Department of Health, Education, and Welfare [HEW] 1969; Lillie 1970; and Hinton et al., 1986). In addition, health hazard evaluation reports listed in the* Energy Research Abstracts *sometimes contain data for indoor or outdoor concentrations of particles for specific industrial settings. Additional information can be found in the* Air Pollution Control Association Journal *for specific situations.*
>
> *For indoor dust, 29 CFR 1910.1000 (1990) provides the regulatory limits authorized by the Occupational Safety and Health Administration (OSHA), Department of Labor. The 8-hour time-weighted-average (TWA) value allowed for dust ranges from 5 to 15 mg/m^3. The value for total dust is 15 mg/m^3, but is reduced to 10 mg/m^3 for certain compounds. The respirable fraction of dust is regulated at 5 mg/m^3. Other dusts have specific concentration limits based on their harmful characteristics. Cadmium and crystalline quartz silica are the most restrictive, with limits of 0.02 and 0.05 mg/m^3. Other dusts have limits up to 5 mg/m^3. The American Conference of Governmental Industrial Hygienists (ACGIH 1987) recommends threshold limit values (TLVs) of 10 mg/m^3 of total dust. This limit is for a "normal workday" and does not apply for short periods of exposure to high concentrations.*
>
> *For this analysis, the radioactive concentrations in indoor air for the building renovation and residual scenarios have been assumed to be 10^{-4} and 5 x 10^{-5}*

> *g/m^3, respectively. This range is a fraction of the maximum total dust limits, representing longer-term average concentrations and accounting for airborne dust from nonradioactive sources. This range provides a prudently conservative estimate of actual radioactive dust-loadings in the workplace or household, and serves as an adequate basis for the first-level generic screening analysis.* [pages 6.10–6.11]

K. Stewart (1964) also provides a review of airborne dust loadings and places an upper bound on the concentrations of airborne dust that is barely tolerable, as follows: "*high airborne dust loadings (110 mg/m^3 is barely tolerable)*" (page 67).

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D.2 SPECIAL STUDY ON MAXIMUM LIKELY DUST CLOUD PERFORMED BY W. VAN PELT

[Source: This appendix is a copy of work performed by Wesley Van Pelt, PhD, CHP, CIH, in January 2005 as an SC&A associate under the direction of John Mauro, PhD, CHP.]

30 January 2005

Dr. John Mauro
SC&A
209 Ueland Road
Red Bank, NJ 07701

Subject: Maximum Likely Dust Cloud

Dear John,

At your request I have considered the issue of how much airborne dust would be likely in an industrial setting. The question, as I understand it, is what is the largest reasonable dust concentration that one would expect before other issues intervened such as limited visibility, irritation, coughing, sneezing, eye irritation, etc. Other limitations on the maximum likely concentration of airborne dust include physical and environmental forces which tend to reduce or dissipate the dust cloud.

Physical Limits

There is a limit on the amount of dust in the air that can sustain itself beyond a very short time. The natural processes of sedimentation, attachment, coagulation, eddy diffusion, dilution, etc. will reduce the concentration of airborne dust. For aerosols, the upper bound for a stable cloud of inhalable dust has been estimated as 500 mg/m^3 (Craig, et. al.).

Occupational Limits and Standards for Dust Concentrations in Air

Non-toxic or nuisance dusts are now called Particulates (insoluble) Not Otherwise Classified (PNOC). The American Conference of Governmental Industrial Hygienists, Inc. (ACGIH) recommends a total dust, 8-hour TLV-TWA of 10 mg/m^3 for inhalable PNOCs containing no asbestos and <1% crystalline silica; and 3 mg/m^3 for respirable dust. Inhalable dust is airborne particulate that can deposit anywhere in the respiratory tract and includes particle sizes from the finest dust to very large particles (diameters up to 100 micrometers and larger).

PNOCs refer to airborne insoluble materials whose only known hazards are physical irritation, discomfort, impaired visibility and enhancement of accident potential, but not health impairment. Although these materials may not cause fibrosis or systemic effects, they are not necessarily biologically inert. They can inhibit the clearance of toxic particulates from the lung and, at high concentrations, cause alveolar proteinosis.

The TLV-TWA is defined by the ACGIH as the time-weighted average airborne concentration for a normal 8-hour workday and a 40-hour workweek to which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse health effects.

For substances, such as PNOC, without a Short Term Exposure Limit (a 15 minute TWA, which cannot be exceeded at any time during the workday), ACGIH recommends a concept called an *excursion limit* which is defined by the following:

- Excursions in worker exposure levels may exceed 3 times the TLV-TWA for no more than a total of 30 minutes during a workday.

- Under no circumstances should excursions in worker exposure levels exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded.

Thus, PNOCs in a reasonably well controlled industrial setting, where workers were not wearing respirators, would not be expected to exceed:

10 mg/m^3 (the TLV-TWA for an 8-hour day),

30 mg/m^3 (the excursion limit for not more than 30 minutes per day), and

50 mg/m^3 (the absolute excursion limit any time period).

Actual Industrial Dust Concentrations

Pertinent to the problem at hand would be exposure to airborne dusts consisting of metal oxides such as that produced when welding metals. A large compendium of actual metal fume[7] concentrations during welding operations can be found in reference 3, The Welding Environment. This document summarizes actual measurements of welding fume concentrations as published in the literature and those under test conditions where specific welding operations were conducted for the purposes of measuring airborne concentrations and assessing potential occupational exposures to fumes and toxic welding gas products. I summarized the measured dust concentrations in mg/m^3 from this document. Many entries specify the location of the sampler with respect to the source and receptor as well as the local ventilation conditions. Therefore, the airborne dust concentration data were extracted and listed in the following categories as shown in the attached Appendix 1 [not provided]:

- outside helmet
- inside helmet
- unventilated
- ventilated
- breathing zone
- other or general air

The data are reported in reference 3 in a variety of ways including the mean and the range of dust concentration. When the range was given, both the low and high values of the range were

[7]Fume: Finely divided airborne particles created when volatilized solids condense in cool air, such as a heated process like welding, smelting, furnace work and foundry operations.

recorded in Appendix 1 [not provided]. This was done to include the highest (and lowest) values of measured dust concentration rather than have them "buried" in a mean value.

For welding fume concentrations in each of the above six exposure categories, I calculated the mean, standard deviation ("sigma"), mean plus standard deviation, minimum, maximum and number of values. These summary data are shown in the table below.

[Parameter]	outside helmet mg/m3	Inside helmet mg/m3	Unventilated mg/m3	Ventilated mg/m3	Breathing zone mg/m3	Other or general air mg/m3
Mean	115	28	183	40	21	35
Sigma	164	34	235	42	27	89
Mean + Sigma	279	63	417	82	47	124
Minimum	5	1	4	3	0	1
Maximum	713	166	850	136	124	560
Number of Items	23	48	18	20	47	56

[Note: The original structure of this table has been modified to meet current CDC standards for compliance with Section 508 of the Rehabilitation Act.]

To gain a sense of the maximum likely dust concentration in an industrial setting we should look at both the Maximum and the (Mean + Sigma) entries in the table above. The Maximum value ranges from about 100 to 700 mg/m^3. This is in good agreement with the estimated upper bound for a stable cloud of inhalable dust of 500 mg/m^3 (Craig, et. al.)

A better predictor of the maximum likely dust concentration is the (Mean + Sigma) value. Assuming a normal distribution of values, this value represents a statistic such that only 16% of the individual values are greater than the (Mean + Sigma). The (Mean + Sigma) value ranges from about 50 to 400 mg/m^3.

Summary and Conclusion

While it is impossible to predict the maximum likely dust concentration to which a worker would be exposed in an industrial setting, it is possible to construct some likely bounds on the largest dust concentration likely to occur. Considering the physical forces, the occupational limits and standards on airborne dust concentrations, and the range of metal oxide (fume) dust concentrations found in welding operations, it is my opinion that the maximum likely dust concentration in the breathing zone of a worker without a respirator would be about 30 mg/m^3 for exposures lasting many hours per day and about 300 mg/m^3 for exposures lasting only 5 or 10 minutes or less.

Note that these maximum likely dust concentrations would exceed present industry standards and governmental limits covering occupational exposure to airborne Particles Not Otherwise Classified.

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Best regards.
Very truly yours,
WESLEY R. VAN PELT ASSOCIATES, Inc.
Wesley R. Van Pelt, Ph.D., CIH, CHP
President

APPENDIX E: [REDACTED IN FULL]

[Appendix E is withheld in its entirety to prevent the disclosure of Privacy Act-protected information.]