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National Institute for Occupational Safety and Health

SC&A Commentary on NIOSH's Approach to Quantifying Outdoor and Indoor Airborne Dust Loadings

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Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
g/m^3	gram per cubic meter
hr	hour
M&C	Metals and Controls Corporation
mg/m^3	milligram per cubic meter
$\mu g/m^3$	microgram per cubic meter
µm	micrometer
NAPCA	National Air Pollution Control Administration
NIOSH	National Institute for Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
ORAUT	Oak Ridge Associated Universities Team
pCi/g	picocurie per gram
pCi/m^2	picocurie per square meter
pCi/m^3	picocurie per cubic meter
PM 10	particulate matter <10 µm
PM 2.5	particulate matter <2.5 µm
SEC	Special Exposure Cohort
SME	subject-matter expert
SRDB	Site Research Database
TBD	technical basis document
WG	Work Group

1 Introduction

Adequately characterizing the amount of airborne radioactive dust available for inhalation and ingestion is an integral factor in modeling potential exposures based on contamination survey data. In its January 21, 2021, response paper, the National Institute for Occupational Safety and Health (NIOSH, 2021, p. 12) discusses NIOSH's approach for deriving a "Dust Load Factor for Inside and Outside Subsurface Work" for use in support of the Metals and Controls Corp. (M&C) Special Exposure Cohort (SEC) investigations underway by the Advisory Board on Radiation and Worker Health (Board). That section states the following:

> NIOSH examined an excavation at the Mound site and determined it to be a useful general model for dust loading during excavations of soils and plans to include it in the next ORAUT-OTIB-0070 revision [[NIOSH,] 2012]. This model is directly applicable to M&C's Outside Area excavations and conservatively bounds M&C's Inside Building 10 work.

This statement indicates that NIOSH plans to use 212 micrograms per cubic meter (µg/m^3) (2.12E-4 grams per cubic meter (g/m^3)) as a default value for outdoor and indoor dust loads associated with excavations at M&C. NIOSH further indicates that this general model will be included in a future revision of ORAUT-OTIB-0070 ("OTIB-0070"). During the March 18, 2021, M&C Work Group (WG) meeting, the WG asked SC&A to evaluate the representativeness of NIOSH's dust loading values for dust loadings from M&C indoor and outdoor excavations (M&C WG, 2021a). Additionally, the WG asked SC&A to evaluate the appropriateness of using the data as a generic default value for incorporation into OTIB-0070.

2 Background

NIOSH originally proposed a dust loading value of 220 µg/m^3 in its October 24, 2018, white paper, "Metals and Controls Corp. Maintenance Worker Exposure Model." In this paper, NIOSH compared the use of the Mound site air monitoring data against the surrogate data criteria from OCAS-IG-004. SC&A notes that the criteria listed in OCAS-IG-004, revision 0 (NIOSH, 2008), are not the same surrogate data criteria that the Board adheres to. The use of 220 µg/m^3 was supported by email correspondence cited by NIOSH (2018) that documented a study conducted for the Mound Plant Canal Cleanup Project (hereafter referred to as "the Mound data" or "the Mound study").

During the September 2, 2020, M&C WG meeting, Board members indicated that there was not enough information available to interpret the Mound data (M&C WG, 2020). NIOSH volunteered to interview the subject-matter expert (SME) on the study to provide additional information on the air sampling work that was completed at Mound. This interview was conducted on October 15, 2020, with only representatives from NIOSH present. The purpose of this interview was to collect and document the SME's experience in measuring the airborne dust loadings that occurred outdoor at the Mound facility while excavating soil and sediment in a contaminated drainage canal at Mound. The original interview is documented in NIOSH (2020) and includes data, photographs, and discussions between the SME and NIOSH representatives.

On January 21, 2021, NIOSH issued a response paper that modified the original 2018 dust loading study. The paper discussed additional data that modified the original dust loading calculations (NIOSH, 2021, p. 12):

> There were three areas monitored at Mound: the excavation itself, the staging area, and the support area. The excavation area had the highest concentrations at 213 µg/m^3, followed by the staging area (where a front-end loader dumped soils into railroad cars) at 212 µg/m^3, and the support area, which had the lowest concentrations at 137 µg/m^3. NIOSH did not use the data from the support area because it was described as a non-working, background type of area. Using this more complete data set, NIOSH calculated an empirical 95th percentile value of 212 µg/m^3 and can use this value in conjunction with the 95th percentile uranium and thorium concentrations to bound exposures during subsurface work.

At the subsequent April 2021 WG meeting, NIOSH presented the results of this interview and the January 21, 2021, white paper to the WG. During the meeting, the WG judged that it would be prudent to repeat and perhaps expand upon the interview with the active participation of the M&C WG and representatives of SC&A (M&C WG, 2021b). The WG believed that additional information might be helpful in understanding the applicability of these airborne dust-loading measurements to modeling both outdoor and indoor dust loadings during excavations at M&C during the residual period. An additional consideration was the possible use of the Mound data as the basis for developing generic models that can be incorporated into OTIB-0070 for use at other sites.

On May 20, 2021, SC&A representatives participated in a re-interview of the SME conducted by representatives of NIOSH and the M&C WG. The re-interview followed the same structure as the original interview; however, Board members and SC&A representatives were given an opportunity to raise questions to help gain a better understanding of the Mound excavation and the data obtained from it. During that interview, SC&A requested the digitized data obtained from the Mound study; NIOSH provided this information to SC&A as an Excel file on May 26, 2021.

3 Dust Loading Data

In the January 21, 2021, response paper, NIOSH indicated that its analysis resulted in the following dust loadings from each area:

- Excavation area: 213 µg/m^3
- Support area: 212 µg/m^3
- Staging area: 137 µg/m^3

However, the paper is silent as to what these values actually represent. SC&A reviewed the data and found there were 338 lines of data available in the dataset that contained relevant information on each sampling event, including start and stop time/date stamps, sampling location information, and initial and final filter weights. SC&A was able to verify that the values presented in the NIOSH response represented the empirical 95th percentile values of each area.

Without omitting negative values, SC&A was able to replicate the combined support and excavation empirical 95th percentile value of 212 µg/m^3 presented in the response paper.

When independently analyzing the data, SC&A identified one row with no masses reported; this data point was omitted because of the missing data. Additionally, 13 rows from the staging area were identified where the final mass was less than the initial mass. SC&A assumed there was an error with the data collection or reporting of these samples and omitted them from the analysis. This left 324 samples for analysis.

SC&A plotted the data as faceted histograms by sampling area in figure 1. From the histograms, it is readily apparent the support area in general had a lower dust loading than the excavation and staging areas. This is further supported by the summary statistics SC&A generated on the Mound dust loading samples in table 1. The support area was described by NIOSH as a "background" area where no excavation or dust creating actives occurred. SC&A agrees it is reasonable to remove these data from the dust-loading assessment.

Figure 1. Histograms faceted by monitoring area

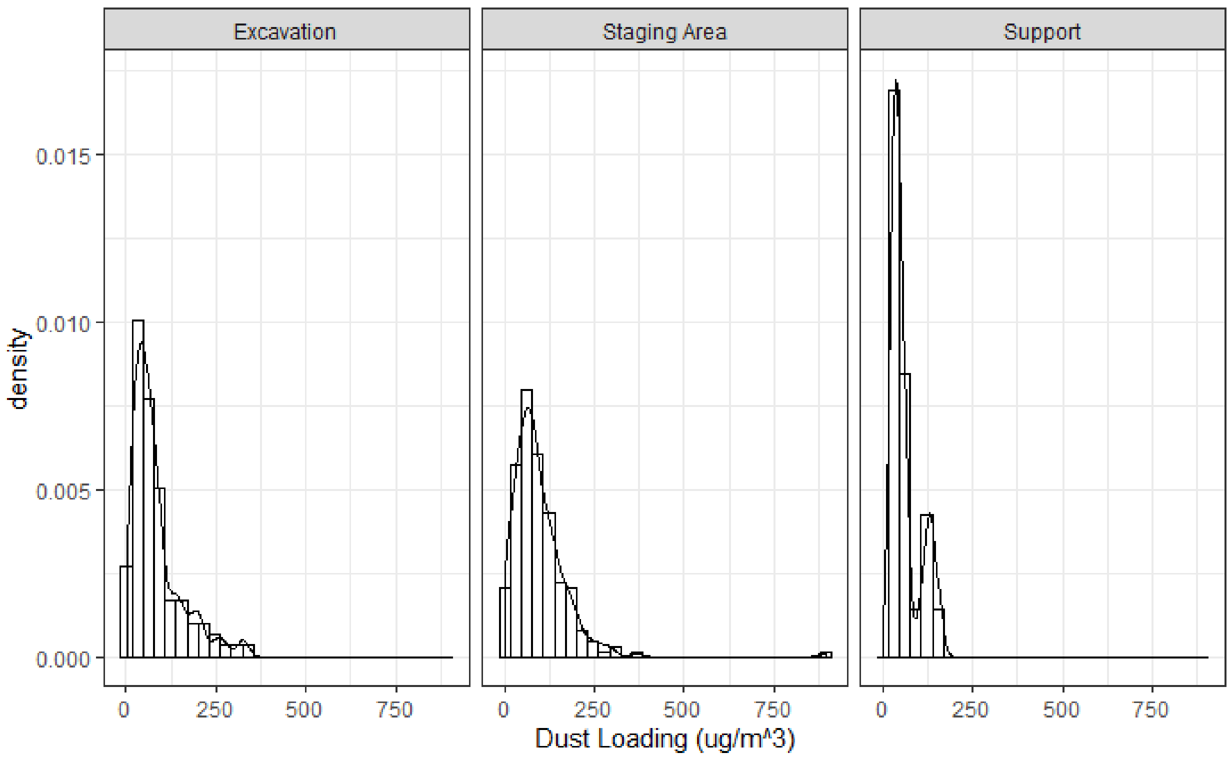


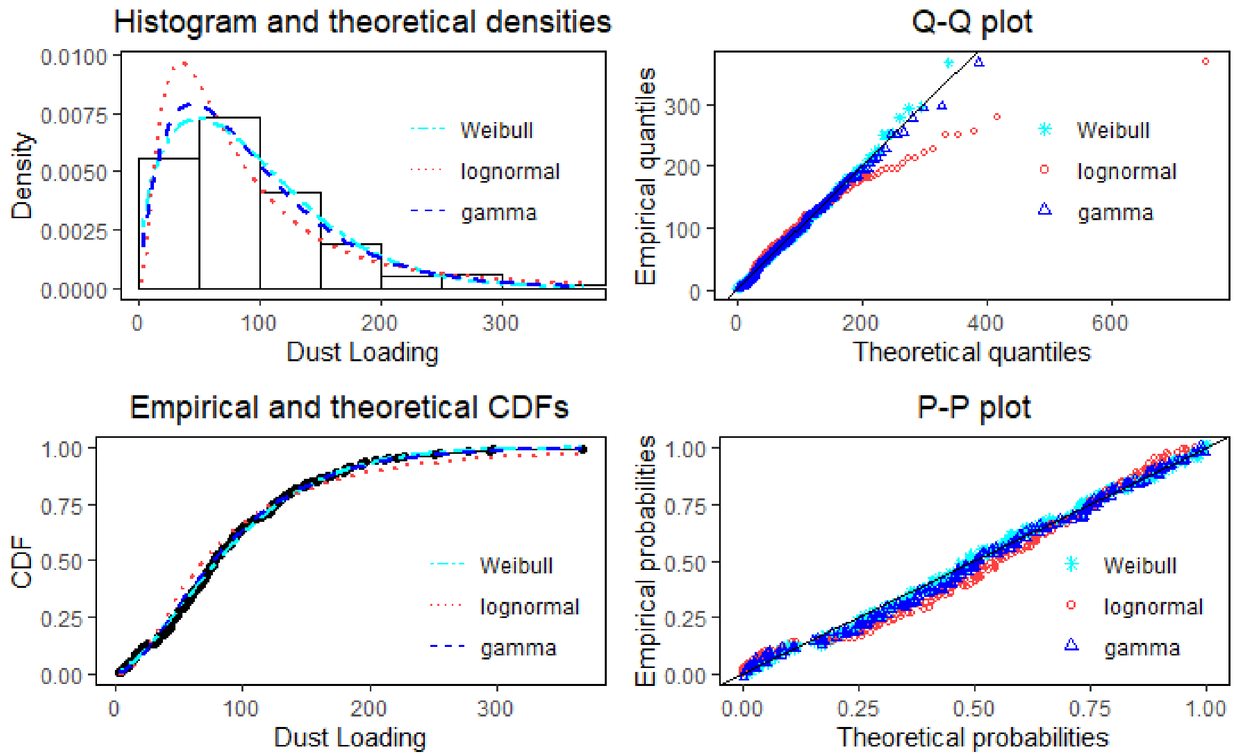
Table 1. Summary statistics of dust loading

Location of samples	No. samples included	No. samples omitted	Minimum (μg/m^3)	Maximum (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
Excavation area	97	1	0.38	327.93	80.81	59.50
Staging area	204	13	3.42	893.23	96.35	78.42
Support area	23	0	19.81	157.40	60.57	46.18
All locations	324	14	0.38	893.23	89.16	71.00
Staging and excavation areas	301	14	0.38	893.23	91.34	72.68

Further looking at the data, SC&A noted a single data point in the staging area that was significantly larger than all other dust loading values calculated: 893.23 μg/m^3. SC&A looked at the other dust loadings obtained from the same day and same location and found that the next closest dust loading value was approximately 6 times smaller than this sample. This is unexpected because samplers were placed around the dust-generating activities and were sampling simultaneously; however, since it is possible that an excavation could produce an extreme value, the sample was left in the data.

SC&A additionally assessed the fit of the data. From figure 1, Weibull, lognormal and gamma distributions were identified as possible distributions based on the shape of the data. In figure 2, SC&A plotted the data against theoretical distributions. While all three distributions in figure 2 visually have reasonable fits to the data distribution, from the QQ plot in figure 2, it can be inferred that the lognormal deviates from the theoretical tail at the upper end of the distribution.

Figure 2. Analysis of possible distributions



Because differences in fit were not visibly apparent in figure 2, SC&A tabulated various goodness-of-fit statistics and criteria (Kolmogorov-Smirnov statistic, Cramer-von Mises statistic, Anderson-Darling statistic, Akaike's information criterion, Bayesian information criterion) for both Weibull and gamma distributions. For all goodness-of-fit values tested, the gamma distribution was a stronger fit to the Mound dust loading data.

SC&A calculated the 95th percentile of a gamma distribution from the Mound data to be 222 µg/m^3. This is modestly larger though reasonably similar to the empirical 95th percentile value of 212 µg/m^3 that NIOSH calculated. SC&A notes that this dust loading when applied at M&C makes no adjustment for background (ambient) levels of dust in the air, which adds an additional degree of conservatism to the calculation.

4 Surrogate Data Issues

The Mound data and the data for indoor and outdoor excavation dust loadings described in section 3 can be considered a type of surrogate data, the use of which is governed by the Board's surrogate data criteria(ABRWH, 2010).[1] The Board's surrogate data criteria were developed primarily for radiological data characterizing external and internal doses and a facility's radiological characteristics. In this case, the following Board criteria apply:

1. **Hierarchy of Data:** The hierarchy of data stipulates the preference that should be placed on various types of data. There are no covered individual bioassays or air monitoring from M&C during the residual period; therefore, there are no data that should take precedence over the Mound data.

2. **Exclusivity Requirements:** SC&A is aware of limited air sampling that occurred during remediation (1992 and July 1995–September 1996). These air sampling results were deemed not applicable to the M&C workforce by the M&C WG and petitioners because the work done while sampling was done with awareness of radiological hazards. Since there are no applicable air monitoring data from the site, surrogate data must be used to establish dust loading. However, site-specific data are still being used to quantify the radiological contamination on site.

3. **Site and Process Similarities:** The surrogate data criteria regarding outdoor and indoor dust loading during excavation activities certainly apply to these same activities as those at M&C and can also be considered generically applicable to outdoor and indoor excavation activities. However, for both indoor and outdoor excavation activities, there are likely many site-specific characteristics that can uniquely affect dust loadings, including the characteristics of the soil and the proximity of workers to the excavation activities. There is very little that can be done to accommodate these types of site-specific characteristics, except to use a degree of professional judgement that would tend to place an upper bound on the dust loading.

   For example, as applied to M&C, many interviews indicated that there was a high water table on site and that rains would cause backups and flooding. One worker indicated that when they dug in Building 4 (next to Building 10), they used sump pumps to remove water (NIOSH, 2017a, p. 3). Another worker recalled that when they would dig outdoors, they would hit water at around 6 to 8 feet deep (Worker 8, p. 9). When it rained heavily, the areas around Building 10 flooded due to poor drainage (NIOSH, 2017b, p. 9), and sometimes the water coming off the roof would back up (NIOSH, 2017b, p. 4). A worker recalled that when water would back up from the roof, "Some of the water would have to come out on the floor" (NIOSH, 2017a, p. 3).

   Digging in moist soil generates less dust than dry soil. SC&A believes that the presence of water likely results in an overestimate of the average dust loading over the time

[1] The Board's surrogate criteria are somewhat different than the surrogate criteria in OCAS-IG-004 (NIOSH, 2008), which NIOSH (2018) used to assess the applicability of the data to M&C.

periods during which outdoor and indoor repurposing and maintenance activities were performed at M&C, as compared to the Mound data and the literature review data summarized in this report. However, this cannot be said for the use of the 212 μg/m^3 for use as a generic value for outdoor and indoor excavations at some unknown facility or site. Hence, its use as a generic dust loading in OTIB-0070 should be uniquely evaluated at each site of proposed use.

4. **Temporal Considerations:** The Mound excavations occurred in 1996, while M&C excavations occurred from 1968 through 1996. The passage of time has not significantly altered backhoe operations, hand digging, or their ability to generate airborne dust. SC&A notes that the Mound study did have only minimal hand shoveling, while the M&C excavation work, especially indoors, had more significant hand shoveling.

5. **Plausibility:** SC&A deems the dust loading results of the Mound study to be scientifically plausible. This determination was made by analysis of the data obtained from the Mound study, which had a range consistent with values expected from excavation activities.

5 Literature Review

The term "dust load factor" (or "dust loading") is defined as the short-term or long-term average mass of airborne dry dust of respirable size particles per cubic meter of air. As used in the context of outdoor resuspension of soil (as opposed to outdoor airborne dust resulting from the release of emissions to the atmosphere from commercial and industrial operations), airborne dust is produced by disturbing the soil, such as by wind erosion, walking on the soil, vehicular traffic, soil-excavation activities, etc. In addition, the degree to which these disturbances create airborne dust is very much dependent on the characteristics of the soil; e.g., wet vs. dry soil, clay vs. loam vs. sand, vegetative cover, etc. (Anspaugh et al., 1975). SC&A identified several publications that address outdoor and indoor dust loadings, as summarized in sections 5.1 and 5.2.

5.1 Outdoor dust loadings

Anspaugh (1974) and Anspaugh et al. (1975) proposed the use of a mass-loading model to address the resuspension of material from a stabilized source of radioactive materials within a soil matrix. For this model, it was assumed that the concentration of a radionuclide in an atmospheric aerosol would be the same as the concentration of that radionuclide in soil. Thus, the additional parameter of mass loading in air is required for the model. Anspaugh (1974) examined data from the National Air Surveillance Network for the year 1966 (NAPCA, 1968); 217 urban and 30 non-urban stations were reporting data. The annual arithmetic mean for the urban stations ranged from 33 μg/m^3 (St. Petersburg, FL) to 254 μg/m^3 (Steubenville, OH), with a mean for all 217 stations of 102 μg/m^3. For the non-urban stations, the range was from 9 μg/m^3 (White Pine County, NV) to 79 μg/m^3 (Curry County, OR), with a mean for all 30 stations of 38 μg/m^3. Considering the range of the data, Anspaugh et al. (1975) proposed that a value of 100 μg/m^3 be used for a predictive value and presented several examples of data where that value appeared to be reasonable. It is important to note that measurements of mass loadings being made in 1966 were not based on specific particle sizes other than the standard housing in use, which was thought to sample all particles of aerodynamic diameter less than 100 micrometers (μm).

Section 3.6 of Yu et al. (2015) is a relatively recent compendium of literature on outdoor dust loading by Argonne National Laboratory. The emphasis is on the average outdoor dust loading, but also includes references to reports addressing outdoor dust loading associated with excavation activities. According to Section 3.6.2 (pp. 111–112) of that report:

> The 24-hr weighted air concentrations of PM-2.5 particles for FY 2011–2014 from the EPA's Air Data web site were reviewed for more than 1000 counties in the U.S. The ambient average PM-2.5 air concentration ranged from 1×10^{-6} to 4.5×10^{-5} g/m^3, and the 98th percentile PM-2.5 air concentrations ranged from 5×10^{-6} to 1.7×10^{-4} g/m^3 . . . . Healy and Rodgers (1979) used 1×10^{-4} g/m^3 for predictive purposes and found that the predicted results and the real cases were comparable. The value of mass loading, 1×10^{-4} g/m^3, used for predictive purposes is more conservative compared to the average ambient concentrations observed and takes into account the enhanced activity concentration in resuspended particulates compared to the activity concentration in soil. The EPA (EPA 1977) has used the same value to screen calculations.
>
> The mass loading value will fluctuate above its ambient level depending on human activities such as plowing and cultivating dry soil or driving on an unpaved road. The estimated mass loading for construction activities is about 6.0×10^{-4} g/m^3; for exposure to construction traffic on unpaved roads, it is 4.0×10^{-4} g/m^3; and for agriculture-generated dust, it is about 3.0×10^{-4} g/m^3 ([NRC] 1981). The maximum respirable dust loading inside the cab of heavy construction equipment during a surface coal mining operation was found to be 1.8×10^{-3} g/m^3 ([NRC] 1981). Estimates of mass loadings have been as high as 1.3 g/m^3 for instantaneous mass loadings during tilling.

The U.S. Environmental Protection Agency (EPA) data mentioned in the first paragraph of this quoted passage are based on criteria related to specific particle sizes—in this case, only mass associated with particles with aerodynamic diameters of <2.5 µm. This reflects concern that particles of this size may represent health impacts due to the particles alone and not associated with any radioactivity. Radionuclides can be attached to particles much larger than 2.5 µm; it is generally considered that particles up to 100 µm or even larger can be inhaled. SC&A examined data from the same EPA source (http://www.epa.gov/airdata); tables 2–5 summarize these data for 2011 to 2020. The data for particulate matter <10 µm (PM 10) are more relevant for our considerations. Values for PM 10 are about twice those for PM <2.5 µm (PM 2.5), but single maximum values as high as 3,400 µg/m^3 are noted. Data reported in tables 2–5 are for the number of counties reporting as indicated under "Count." All values are in µg/m^3. Mono County, CA, and Pinal County, AZ, compete for the highest values of PM 10.

Table 2. 98th percentile values (PM 2.5) of mass loading extracted from http://www.epa.gov/airdata for 2011 through 2020

Year	Mean	Count	Max	Min
2011	25	459	76	8
2012	23	457	160	7
2013	23	488	97	8
2014	22	484	82	7
2015	23	535	110	7
2016	21	327	150	8
2017	24	328	150	9
2018	25	333	170	8
2019	20	328	71	5
2020	29	330	520	7

Table 3. Weighted average values (PM 2.5) of mass loading extracted from http://www.epa.gov/airdata for 2011 through 2020.

Year	Mean	Count	Max	Min
2011	9.8	459	20	3.4
2012	9.3	457	22	1
2013	9.0	488	23	3.1
2014	8.7	484	19	1.6
2015	8.5	535	21	2.2
2016	7.9	327	16	2.3
2017	8.3	328	18	2.6
2018	8.3	333	19	2.5
2019	7.8	328	16	0.9
2020	8.4	330	23	2.3

Table 4. Second maximum values (PM 10) of mass loading extracted from http://www.epa.gov/airdata for 2011 through 2020

Year	Mean	Count	Max	Min
2011	82	320	3400	20
2012	81	327	2200	17
2013	72	315	1900	17
2014	76	301	1900	13
2015	74	288	980	18
2016	72	200	460	20
2017	87	195	1000	18
2018	90	193	830	20
2019	74	191	530	14
2020	110	192	620	16

Table 5. Mean 24-hour values (PM 10) of mass loading extracted from http://www.epa.gov/airdata for 2011 through 2020

Year	Mean	Count	Max	Min
2011	21	320	140	7
2012	21	327	100	6
2013	20	315	96	6
2014	20	301	98	6
2015	20	288	65	6
2016	21	200	83	7
2017	21	195	87	6
2018	22	193	79	6
2019	19	191	59	5
2020	23	192	88	5

With respect to M&C, and excavation in general, the Yu et al. (2015) estimated mass loading for construction activities, 6.0×10^{-4} g/m^3 (600 µg/m^3), appears somewhat applicable to the scenario of concern to this report, considering factors such as soil moisture and time averaging over the duration of the soil disturbance activities. Although Yu et al. (2015) do not specifically state it, SC&A presumes that this value of 600 µg/m^3 is not limited to particles of size <2.5 µm.

NUREG/CR-1759, volume 3 (U.S. Nuclear Regulatory Commission (NRC), 1981, pp. A-5–A-9), estimates a mass loading of 0.565 milligram per cubic meter (mg/m^3) (565 µg/m^3) during construction-related excavation activities. It also identifies 1980 experimental findings of "respirable dust loading ranging from 0.56 mg/m^3 (for a bulldozer) to 6.7 mg/m^3 (for a front end loader) within a few feet of the equipment" (NRC, 1981, pp. A-8–A-9). However, the characteristics of the soil (dry vs. wet) between scenarios might differ, as no information on the soil makeup is provided. Notwithstanding these issues, SC&A believes the dust loading values reported in NUREG/CR-1759, volume 3, tend to support the 212 µg/m^3 NIOSH is using for the outdoor excavation scenario, but the NIOSH value does not appear to be necessarily bounding. The fact that the M&C soil was likely moist tends to provide a degree of assurance that the 212 µg/m^3 is reasonable.

Vehicles on unpaved roads are recognized as large dust generators. At Mound, this was mitigated by wetting the unpaved roads. It is not known the degree to which this technique was used at M&C, though SC&A believes it is reasonable to assume there was some dust generated from vehicles on unpaved roads at M&C. NUREG/CR-1759, volume 3 (NRC, 1981, pp. A-10 and A-12), estimates a mass loading factor of 0.334 g/m^3 (334,000 ug/m^3) from vehicular traffic on unpaved road and states:

> This value is considerably more than the value of 0.565 mg/ m^3 calculated for the construction case. A meaningful average may be obtained from this value, however, by assuming that exposure of the individual to this peak concentration lasts about 30 seconds. It is unreasonable to assume that the individual would remain in the vehicular dust cloud for more than a few seconds. Further assuming that during a period of 500 hours (comparable to the construction duration) he is exposed to the maximum concentration of dust from 70 vehicles (about one

> vehicle per working day), yields an average exposure mass loading of about 0.390 mg/m^3.

This illustrates an important consideration when evaluating dust loading measurements with significant variation based on the work activity: the time period used for averaging (occupancy time). Dust loadings have a wide range of values from a single exposure event. While the peak dust loading may be high and could be used to bound exposures, it is unreasonable to assume all exposures occurred at that level. The time period assumed in averaging has a profound impact on the dust loading assumed. In this example, averaging the peak mass loading over a more typical exposure period reduces the mass loading average by orders of magnitude.

NUREG/CR-1759, volume 3, also explores dust loadings during tillage activities (which may have some applicability to the M&C outdoor excavation scenario) as follows (NRC, 1981, p. A-14):

> The respirable particulate concentration calculated for tillage is about 6.7 times that for construction. Assuming that a construction event takes three months (about 500 working hours) and an agricultural season involves 3 soil tilling events (13.5 hours per tilling of the 100 acre site), exposure to construction-generated dust would be 12.35 times the duration of exposure to tillage dust. Averaging the agriculture-generated dust loading over 500 hours yields an airborne concentration of 0.304 mg/m^3, which corresponds closely to the 500 hour construction scenario average of 0.565 mg/m^3, and is smaller than that associated with the unpaved road scenario.

This further illustrates the effect that occupancy (i.e., scenario-specific) time averaging has on the evaluation of dust loading over a wide range of work activities. Perhaps more important to note, the 0.304 mg/m^3 (304 µg/m^3) dust loading value compares reasonably well to the 212 µg/m^3 value under consideration by NIOSH.

Section 6.4.4 of NUREG/CR-5512, volume 3 (NRC, 1999), discusses and characterizes the enormous variability in outdoor dust loadings. For example, section 6.4.4.1 (p. 6-68) states the following about outdoor and indoor dust loading factors:

> The dust-loading factors are used to calculate the average annual dose resulting from inhalation of airborne contaminants. The dust-loading factors, CDO and CDG, are used to calculate the inhalation dose due to activities occurring outdoors. CDO (g/m^3) represents the mass concentration of contaminated airborne particles in air outdoors, as defined in the exposure model, and corresponds to the long-term average quantity of respirable particulate material in outdoor air. CDG (g/m^3) represents the higher average mass loading of contaminated airborne particles in air while the individual is gardening. The default values for these parameters defined in Volume 1, are 1×10^{-4} g/m^3 for CDO and 5×10^{-4} g/m^3 for CDG. These values were defined based on the review of literature from outdoor air pollution studies from the National Air Sampling Network and studies on suspended particles in the atmosphere in communities across the United States.

SC&A believes that the gardening scenario, with a dust loading of 5E-4 g/m^3 (500 µg/m^3), is most applicable to the outdoor excavation scenario of concern for M&C. It is noteworthy that the dust loading associated with outdoor gardening is likely comparable to the type of exposures M&C workers might have experienced when up close to underground piping and conduits in both the indoor and outdoor settings. The 500 µg/m^3 value is surprisingly close to the value given in NUREG/CR-1759, volume 3 (NRC, 1981), and has the same type of limitations when applied to M&C. In SC&A's opinion, it tends to support the 212 µg/m^3 value under consideration by NIOSH as a reasonable but not necessarily bounding dust loading value on its own. However, other factors, such as occupancy time and contamination levels, impact the calculation of the intake value when evaluating whether it is a bounding exposure scenario overall.

Section 6.4.4.3 of NUREG/CR-5512, volume 3 (NRC, 1999, p. 6-69), also states the following:

> The outdoor air dust-loading factors range from 1×10^{-5} to 2.3×10^{-1} g/m^3 for all airborne particles. Under extreme conditions, air dust-loading can be as high as 5 g/m^3; however, these conditions persist for only very short periods of time. For particles less than 10 µm diameter (the respirable fraction), air dust-loading factors range from 1×10^{-5} to 7×10^{-4} g/m^3.

The range of values for respirable particles[2] of 1E-5 to 7E-4 g/m^3 (10 to 700 µg/m^3) bracket NIOSH's dust loading range of 212 µg/m^3.

5.2 Indoor dust loadings

Under most circumstances, indoor dust loadings associated with suspension processes from contaminated surfaces are calculated through the use of a resuspension factor, expressed in units of picocuries per cubic meter (pCi/m^3) per picocuries per square meter (pCi/m^2), which reduces to units of m^{-1}. Resuspension factors are widely employed by NIOSH in dose reconstructions, site profiles, and SEC petition reviews. In addition, generic guidance addressing resuspension factors is provided in Battelle-TBD-6000 and OTIB-0070. However, M&C maintenance activities at times involved indoor excavation. In the case of excavation, the dust loading approach is generally more appropriate.

For M&C, NIOSH plans to use the same dust loading of 212 µg/m^3, based on outdoor dust loading data associated with excavations from Mound (NIOSH, 2020). It is difficult to judge whether outdoor dust loading data associated with excavations can be used as a surrogate for indoor excavation activities. SC&A found there is limited research on dust loadings comparable to the indoor digging done at M&C where indoor soil is aggressively disturbed. However, NUREG/CR-5512, volume 1 (NRC, 1992, p. 6.11), states the following:

> For this analysis, the radioactive concentrations in indoor air for the building renovation and residential scenarios have been assumed to be 10^{-4} and 5×10^{-5} g/m^3, respectively. This range is a fraction of the maximum total dust

[2] The respirable particulates are the airborne particulates that can penetrate beyond the bronchioles into the gas exchange regions of the lungs.

> 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.

The renovation indoor dust loading of 10^{-4} g/m^3 (100 µg/m^3) might include excavation and would seem to independently support NIOSH's use of 212 µg/m^3 as a reasonable estimate when applied to the M&C subsurface indoor excavation scenario and also to indoor excavation dust loading in general. Since this is an indoor dust loading value, SC&A suggests that NIOSH also refer to NUREG/CR-5512 (in addition to the Mound outdoor data) as a basis for the selected dust loading for both M&C and for use in OTIB-0070. SC&A also suggests that NIOSH address enrichment/enhancement issues, as discussed in section 6 of this report, for outdoor dust loadings.

6 Enrichment/Enhancement

The literature review in section 5 makes a distinction between total dust loading and dust loading of respirable particles. This distinction can be important because of a phenomenon referred to as enrichment or enhancement: not enrichment in terms of enriched uranium, but the enrichment or enhancement that often occurs when contaminants in soil or residue are suspended and tend to be enriched in smaller sized particles as compared to the soil from which the airborne dust originates.

Often, dust load factors that are used to derive inhalation doses from suspension processes are premised on the assumption that the concentration of a given residual radionuclide in soil or residue (for example, in units of picocuries per gram (pCi/g) dry weight) is the same as the concentration of a given radionuclide in suspended airborne dust (pCi/g dry weight). Tamura (1975) observed that plutonium in soil was preferentially attached to small to mid-size particles, which contained the majority of surface area. There is also evidence that the dust that is suspended is of a different particle size distribution than the soil from which it originates. The implications of this phenomenon are that the concentrations of many radionuclides in suspended dust are likely to be somewhat higher than in the soil or residue from which it originates. For example, Envirosphere (1984) cites Adams et al. (1980) enrichment factors of 1.5 for uranium and 3.2 for thorium. Enrichment/enhancement should be taken into consideration when the starting point for deriving inhalation doses is the concentration of a given radionuclide in soil followed by suspension.

The relevant equation for the concentration of radioactive materials in air via the pathway of resuspension is as follows:

$$\chi = ML \times C_{soil} \times EF$$

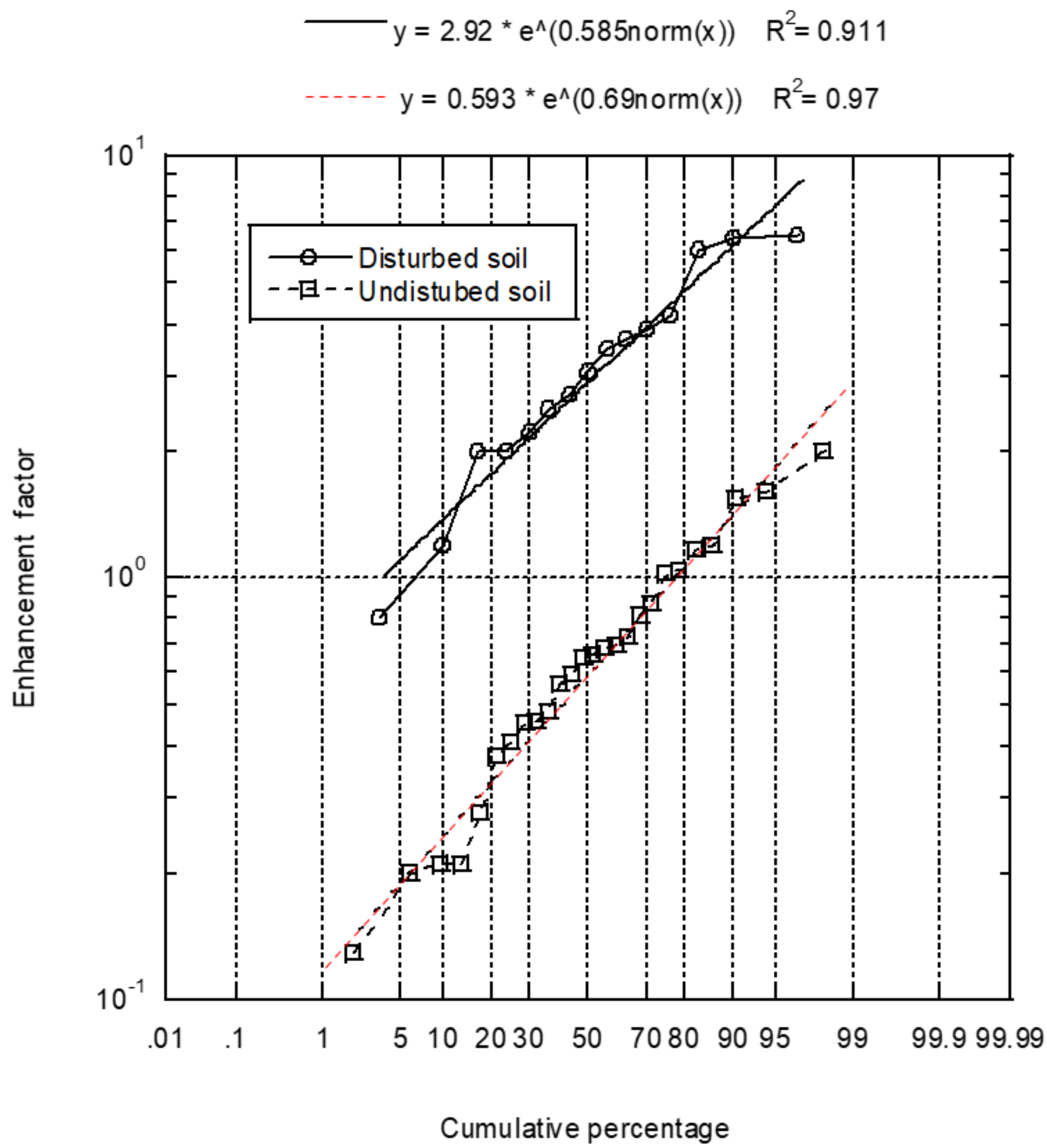
$$EF = \frac{C_{air}}{C_{soil}}$$

where

χ = Concentration of radionuclide in air (Ci/m^3);
ML = Mass loading in air (g/m^3);
C_{soil} = Concentration of radionuclide in soil (Ci/g);
EF = Enhancement factor
C_{air} = Concentration of radionuclide in airborne mass (Ci/g).

An analysis of enhancement factors was included in DOE (2006). These data are summarized in figure 3. There is a substantial difference in the values of enhancement factors depending upon whether soil is disturbed or not. For measurements of undisturbed soil, the geometric mean is 0.59 with a geometric standard deviation of 2.0; for disturbed soil the geometric mean is 2.9 with a geometric standard deviation of 1.8. NIOSH should consider incorporating enrichment/enhancement factors into the calculation of inhalation doses associated with suspension processes outdoors.

Figure 3. Plot of enhancement factors measured over undisturbed and disturbed soils



Source: Data are presented in DOE (2006).

7 Conclusions

Considering the totality of information compiled in this report, SC&A believes that the use of a dust loading of 212 µg/m^3 for subsurface work both indoors and outdoors at M&C is reasonably compatible with data and information summarized in this report, including the data reported from Mound by the interviewed SME. SC&A concludes that NIOSH's adoption of 212 µg/m^3 for estimating respirable outdoor dust loading during excavation activities is reasonable but not necessarily bounding. Additionally, SC&A believes that NIOSH should refer to the numerous dust loading studies cited in section 5 as the basis for the dust loading of 212 µg/m^3 in addition to the Mound data.

While SC&A's survey and interpretation of the data indicate that the suggested value of 212 µg/m^3 may not necessarily be sufficiently conservative for many excavation scenarios, a number of mitigating factors are also present at M&C that should be considered. First, the soil at M&C was likely moist. Second, the dust loading used for dose reconstruction at M&C covered the entire assumed time period of 2 months; i.e., the suggested exposure models are not trying to reconstruct short-term exposures, where dust loading might peak during active and aggressive excavation, but are making use of the dust loading for deriving inhalation exposures over a more protracted period of time.

With respect to using 212 µg/m^3 as a generic value in OTIB-0070 for dust loading associated with excavation at other Energy Employees Occupational Illness Compensation Program Act sites, SC&A believes that such a generic strategy may be problematic. As discussed in this report, dust loading, especially dust loading associated with excavation, is extremely dependent on many site-specific factors. Hence, it would be difficult to pick a default dust loading that would be universally applicable. The best that can be said is that it is unlikely that workers would be exposed for extended periods of time to respirable dust loadings above a few mg/m^3. It can also be stated with a degree of certainty that it would be highly implausible that workers could be exposed for extended periods of time to dust loading of any size distribution of about 100 mg/m^3 (100,000 µg/m^3) or greater because of the choking effect of such high levels. As Stewart (1967) notes, "The high degree of stirrup of dust produced by the experiments resulted in high airborne dust loadings 110 mg/m^3 is barely tolerable." Finally, NIOSH should discuss the potential effect of enrichment factors on dust loading in both the specific context of the M&C methodology and how it may apply to other sites if the suggested dose loading of 212 µg/m^3 is to be used as a generic methodology in the OTIB-0070 guidance.

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