NIOSH Resolution of W. R. Grace Site Profile Findings 2 and 7

White Paper

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INTRODUCTION

The S. Cohen & Associates (SC&A) review of the *Technical Basis Document: An Exposure Matrix for W.R. Grace and Company in Erwin, Tennessee, W.R. Grace, Erwin, TN* (TBD) (ORAUT 2011), resulted in seven findings (SC&A 2013).

This white paper provides resolutions to Findings 2 and 7. Finding 2 concerns intakes of uranium during the Atomic Weapons Employer (AWE) operational period. Finding 7 concerns environmental dose and intakes in the AWE operational and residual periods. This paper also provides a resolution to Secondary Finding D.

References to the TBD in this paper refer to Revision 02 of ORAUT-TKBS-0043 (ORAUT 2011). The National Institute for Occupational Safety and Health (NIOSH) plans to revise the TBD after agreement is reached on resolutions to these and the other findings. Responses to other findings are addressed separately.

The environmental intake estimates in this paper are based on environmental monitoring data in the later years. Occupation intake estimates of uranium and plutonium are used to supplement the environmental monitoring data in the early years when environmental data are not available. This document also provides an intake summary section of the methods to reconstruct occupational and environmental intakes for all years.

FINDING 2: URANIUM INTAKES

SC&A Finding 2 (SCA 2013, PDF pp. 9, 22-23) concerned the default uranium intakes the TBD provides for unmonitored workers.

Finding 2. Insufficient uranium bioassay/intake data.

> *"If a worker's uranium bioassay data are not available, the TBD recommends on page 25 that the intake values in Table 3-15 be used to assign unmonitored dose during the operational period 1958–1970. There has been no documentation or substantiation of the appropriateness of using a 1961 air concentration data point for operating conditions at WRG during the entire operational period. Additional investigation of the use of the 1961 data for 1958–1970 is needed."*

Finding 2 was discussed during the Advisory Board Work Group on Uranium Refining AWEs (Work Group) meeting on August 3, 2015. NIOSH provided the rationale for the default uranium intake in Table 3-15 for the Operator exposure category but indicated an assessment will be made for workers not routinely exposed to the highest levels of airborne radioactivity. SC&A agreed, in principle, with that approach to resolve Finding 2. This paper provides intake rates for those other categories of workers.

The default operational period intake rates are provided for periods when there were no bioassay data or to fill in gaps in individual monitoring data. Additionally, updated residual contamination period intakes are provided.

AWE Operational Period Intakes (1958 through 1970)

Table 3-15 of the TBD provides a total uranium (alpha) inhalation intake rate of 1.71×10^3 pCi per calendar day and an ingestion rate of 3.56×10^1 pCi per calendar day. These inhalation and ingestion rates are applicable for the AWE operational period from 1958 through 1970. The intake rates are applicable to Operators, a category defined for those considered to be the most highly exposed workers.

NIOSH derived intake rates for other worker categories in the AWE operational period based on the exposure model used in Battelle-TBD-6000 (NIOSH 2011). Battelle-TBD-6000 uses four uranium intake categories, which this white paper refers to as *Operator, Labor, Supervisor and Clerical*. The three lower levels of intakes are assigned as a function of the Operator intake. For the operational period, the default inhalation rate for the Operator job category provided in TBD Table 3-15 is retained (as discussed in the August 3, 2015 Work Group meeting). The Labor category of worker exposure is assigned 50% of the Operator intake rates. The Supervisor exposure category is assigned 25% of the Operator intake rate. The Clerical exposure category is assigned 10% of the Supervisor intake rate. These assumptions result in the intake rates provided in Table 1.

Table 1: Operational period uranium intake rates (dpm/day)

Intake Mode	Operator	General Labor	Supervisor	Clerical
Inhalation	3.80E+03	1.90E+03	9.50E+02	9.50E+01
Ingestion	7.92E+01	3.96E+01	1.98E+01	1.98E+00

Note: All intake rates are in units of dpm per calendar day for exposures from 1958 through 1970.
Note: Intakes represent total uranium alpha and are to be assigned as intakes of U-234 using the most favorable solubility type. Ingestion f1 values are assigned to match the inhalation type chosen.
Note: A worker's bioassay data should be considered.
Note: Intakes of other radionuclides are assigned according to ratios provided in TBD Table 3-12.

Residual Contamination Period Intakes (1971 to March 1, 2011)

The inhalation and ingestion intake rates in TBD Tables 5-2 and 5-3, respectively, from residual uranium contamination need to be updated to be consistent with current program assumptions and the updated operational period intakes. The residual period intakes were not part of Finding 2 but are related.

Based on guidance in Battelle-TBD 6000, the air concentration used for default uranium intakes for the operational period (578 dpm/m^3) was assumed to deposit on the surface for 30 days with a deposition rate of 0.00075 m/s, resulting in a surface contamination level of 1.124×10^6 dpm/m^2. A resuspension factor of 1×10^{-5}/m was applied, resulting in an initial residual period air concentration of 11.236 dpm/m^3. Assuming 2,000 hours of exposure and a breathing rate of

1.2 m^3/hour, the inhalation intake rate in the contaminated areas at the beginning of the residual period is 73.883 dpm/d (calendar day basis). This is an update from the current TBD version (Revision 2), which did not incorporate the settling and resuspension methods to derive residual period inhalation intake rates.

The ingestion rate in the operational period in TBD Table 3-15 was derived from methods described in OCAS-TIB-009 (NIOSH 2004). The initial residual period ingestion rate is assumed to be equal to the operational period ingestion rate (the same as the current TBD version).

The residual contamination levels are assumed to deplete at a rate of 0.00067/d, so the inhalation and ingestion intake rates were adjusted for subsequent years using the factors specified in ORAUT-OTIB-0070, Table 4-2 (ORAUT 2012).

During the residual period, the relative intakes for the four exposure categories are the same as specified for the operational period except that the Labor category is doubled to be equal to the Operator category because both categories of workers may have worked full time in contaminated areas. These assumptions result in the residual period uranium intake rates in Table 2.

Table 2: Residual period uranium intake rates (dpm/day)

Year	Operator/Labor Inhalation	Operator/Labor Ingestion	Supervisor Inhalation	Supervisor Ingestion	Clerical Inhalation	Clerical Ingestion
1971	7.39E+01	7.92E+01	1.85E+01	1.98E+01	1.85E+00	1.98E+00
1972	5.79E+01	6.20E+01	1.45E+01	1.55E+01	1.45E+00	1.55E+00
1973	4.53E+01	4.85E+01	1.13E+01	1.21E+01	1.13E+00	1.21E+00
1974	3.55E+01	3.80E+01	8.87E+00	9.50E+00	8.87E-01	9.50E-01
1975	2.78E+01	2.98E+01	6.94E+00	7.44E+00	6.94E-01	7.44E-01
1976	2.17E+01	2.33E+01	5.43E+00	5.82E+00	5.43E-01	5.82E-01
1977	1.71E+01	1.83E+01	4.27E+00	4.57E+00	4.27E-01	4.57E-01
1978	1.34E+01	1.43E+01	3.34E+00	3.58E+00	3.34E-01	3.58E-01
1979	1.04E+01	1.12E+01	2.60E+00	2.79E+00	2.60E-01	2.79E-01
1980	8.20E+00	8.79E+00	2.05E+00	2.20E+00	2.05E-01	2.20E-01
1981	6.41E+00	6.86E+00	1.60E+00	1.72E+00	1.60E-01	1.72E-01
1982	5.02E+00	5.38E+00	1.25E+00	1.34E+00	1.25E-01	1.34E-01
1983	3.93E+00	4.21E+00	9.83E-01	1.05E+00	9.83E-02	1.05E-01
1984	3.07E+00	3.29E+00	7.68E-01	8.23E-01	7.68E-02	8.23E-02
1985	2.41E+00	2.58E+00	6.02E-01	6.45E-01	6.02E-02	6.45E-02
1986	1.88E+00	2.02E+00	4.71E-01	5.05E-01	4.71E-02	5.05E-02
1987	1.48E+00	1.58E+00	3.69E-01	3.96E-01	3.69E-02	3.96E-02
1988	1.15E+00	1.24E+00	2.88E-01	3.09E-01	2.88E-02	3.09E-02
1989	9.09E-01	9.74E-01	2.27E-01	2.43E-01	2.27E-02	2.43E-02

Year	Operator/Labor Inhalation	Operator/Labor Ingestion	Supervisor Inhalation	Supervisor Ingestion	Clerical Inhalation	Clerical Ingestion
1990	7.09E-01	7.60E-01	1.77E-01	1.90E-01	1.77E-02	1.90E-02
1991	5.55E-01	5.95E-01	1.39E-01	1.49E-01	1.39E-02	1.49E-02
1992	4.34E-01	4.66E-01	1.09E-01	1.16E-01	1.09E-02	1.16E-02
1993	3.41E-01	3.65E-01	8.51E-02	9.13E-02	8.51E-03	9.13E-03
1994	2.67E-01	2.86E-01	6.67E-02	7.15E-02	6.67E-03	7.15E-03
1995	2.09E-01	2.24E-01	5.23E-02	5.60E-02	5.23E-03	5.60E-03
1996	1.63E-01	1.75E-01	4.08E-02	4.37E-02	4.08E-03	4.37E-03
1997	1.28E-01	1.37E-01	3.20E-02	3.42E-02	3.20E-03	3.42E-03
1998	1.00E-01	1.08E-01	2.51E-02	2.69E-02	2.51E-03	2.69E-03
1999	7.83E-02	8.39E-02	1.96E-02	2.10E-02	1.96E-03	2.10E-03
2000 3/1/2011	6.15E-02	6.59E-02	1.54E-02	1.65E-02	1.54E-03	1.65E-03

Note: All intake rates are in units of dpm per calendar day for the period of 1971 through March 1, 2011.
Note: Intakes represent total uranium alpha and are to be assigned as intakes of U-234 using the most favorable solubility type. Ingestion f1 values are assigned to match the inhalation type chosen.
Note: A worker's bioassay data should be considered if it provides a *lower* intake rate.
Note: Intakes of other radionuclides are assigned according to ratios provided in TBD Table 3-12.

FINDING 7: ENVIRONMENTAL DOSE

This section provides an assessment of environmental exposures at the W.R. Grace site in response to Finding 7 of the SC&A TBD review. The SC&A report concluded the TBD does not provide an adequate assessment of internal and external environmental exposures. NIOSH identified the following issues from Finding 7 (SCA 2013, PDF pp. 10-11, 31-32).

Finding 7, Issue 1:

The TBD "*methods do not account for airborne uranium materials that were generated by the cleanup and processing of waste from the ponds and burial grounds during the residual period to which monitored, as well as unmonitored, workers may have been exposed; although, these workers may not be considered to have been directly involved with the cleanup activities.*"

NIOSH Response: The default uranium intakes and the environmental intakes in the sections below, in conjunction with worker monitoring data, provide a means to assess intakes for all workers.

Finding 7, Issue 2:

"*The methods recommended do not account for intakes of plutonium for unmonitored workers during the operational period, or plutonium during the residual period for both monitored and unmonitored workers.*"

NIOSH Response: NIOSH issued a white paper on March 1, 2019, that provides intakes of plutonium for unmonitored exposures in the plutonium facilities. This paper provides additional calculations of those intakes as applicable to the various exposure categories. This paper also provides environmental plutonium intakes.

Finding 7, Issue 3:

TBD statements indicate that at some later times "*office workers were not assigned dosimeters. These statements indicate that some workers may not have been monitored for external exposure during the operational and residual periods; hence, requiring coworker or environmental external dose assignments*."

NIOSH Response: This paper provides environmental external doses.

Finding 7, Issue 4:

"*The internal and external environmental exposures throughout the site during both the AEC period (1958-1970) and from the cleanup of the AEC legacy materials during the period 1971-present are not adequately addressed*."

Issue 4 is a general comment that the TBD does not adequately address environmental exposures, while Issues 1, 2, and 3 are specific comments on certain aspects of dose. NIOSH has performed additional data capture efforts and reviewed the available environmental monitoring data for the W. R. Grace site. Analyses of the available environmental internal dose monitoring data and external dose monitoring data are provided below.

ENVIRONMENTAL INTAKES

Site Information

The Nuclear Fuel Services (NFS) site, formerly the W.R. Grace site, in Erwin, Tennessee, comprises approximately 70 acres. The site is shown in Figure 1.

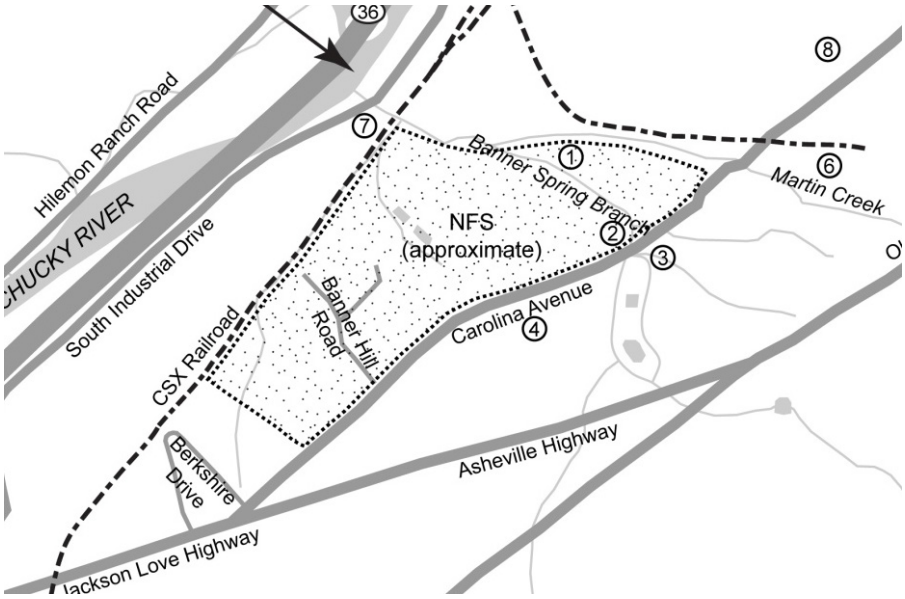

Figure 1: NFS Erwin, Tennessee site
(NRC 2011, PDF p. 23)

Figure 2 shows the general layout of the site from a 1978 environmental assessment report. It shows the security fence (protected area) around the production facilities. It also shows the fence around the Burial Grounds.

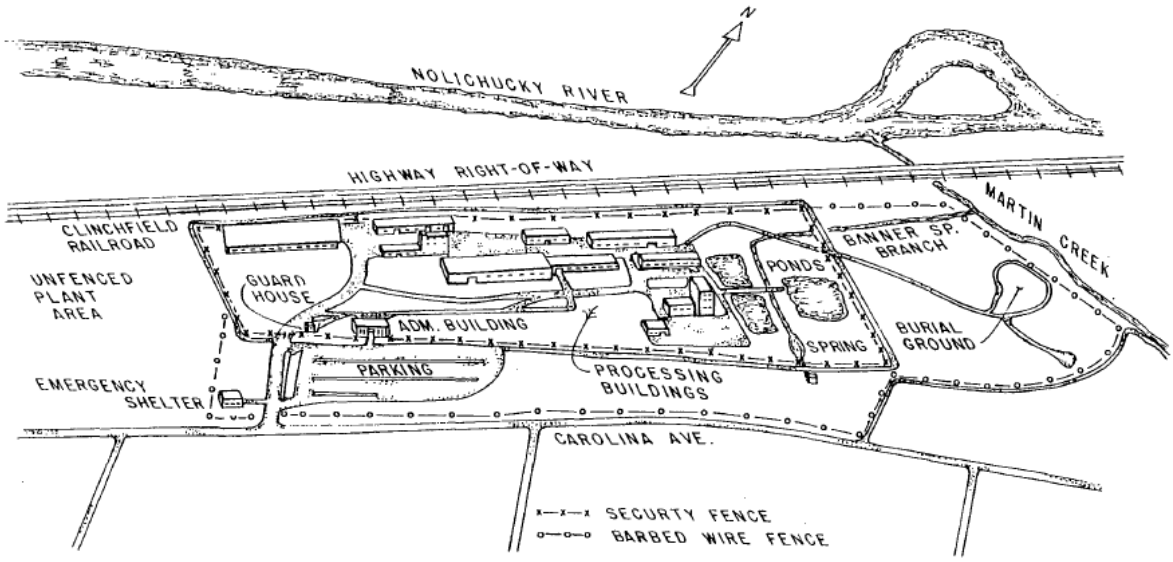

Figure 2: Layout of the NFS site
(NRC 1978, PDF p. 10)

In 1991, the U.S. Nuclear Regulatory Commission (NRC) reported that more than half of the then reported 57.8 acre site was occupied by buildings and associated grounds, parking lots, settling ponds, and waste burial grounds. A security fence surrounded the plant facilities, which comprised approximately 21 acres and included the various buildings as well as the settling ponds. The layout of the protected area fence, as shown in Figure 2, took that shape in 1969, when the security area was expanded. The fenced area was much smaller prior to 1969 (AEC, 1969a; AEC, 1970). The general layout and fenced areas in 1978, as seen in Figure 2, are very similar to the site layout shown in 2002 (NFS 2002, PDF p. 93).

Environmental Air Monitoring Data

Records indicate a routine independent environmental surveillance program began in 1968; some airborne concentration data are available for 1968 through 1970. Those data were from off-site locations (AEC 1969a, AEC 1969b, AEC 1970). Although the concentrations were very low, the data does not include on-site measurements.

The NRC described rigorous environmental monitoring in 1978 (NRC 1978). Continuous sampling was performed at fixed on-site and off-site locations. Alpha and beta airborne radioactivity concentrations are available starting in 1979. The general locations of the on-site air sample locations are shown in Figure 3, which is from a report written in 1991. The 1978 NRC report shows on-site sampling locations in relation to the security fences and process buildings and settling ponds (NRC, 1978, PDF. p. 75).

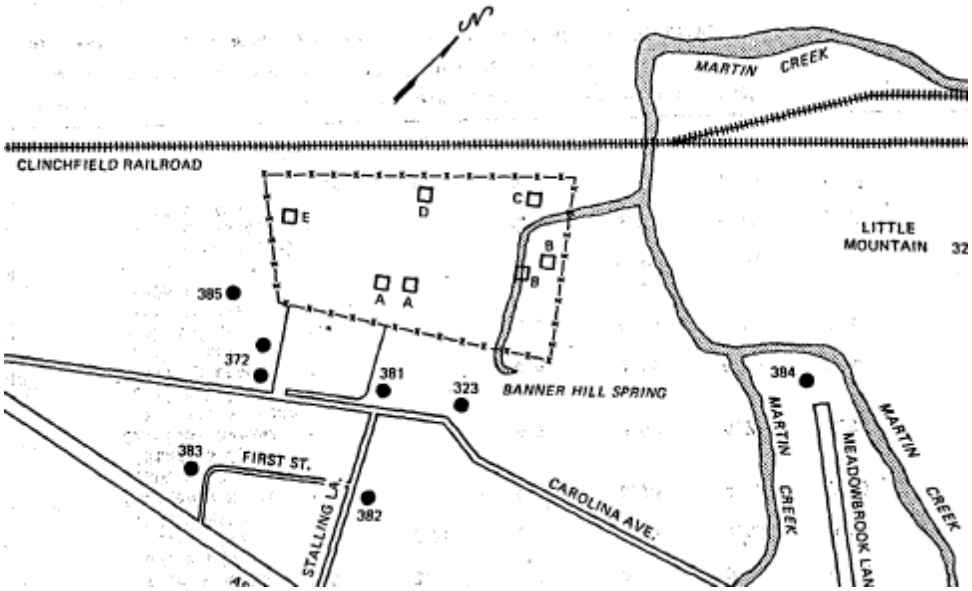

Figure 3: Location of on-site air sampling stations (NRC 1991, PDF p. 101)

Annual alpha air concentrations from the on-site monitoring stations are available from 1979 through 1995 (NRC 1991, PDF pp. 102-103; NFS 1996, PDF p. 5). The more recent environmental reports include only the off-site monitoring locations.

The annual average gross alpha air concentration results for the on-site perimeter air samplers from 1979 through 1995 are shown in Table 3. The location with the overall highest annual average concentration was the east perimeter location in 1979 at 1.58×10^{-13} µCi/ml. The annual averages generally declined over time. The second highest of the average annual concentrations was the northwest location in 1980 with a result of 6.0×10^{-14} µCi/ml.

Table 3: Annual average perimeter gross alpha air concentrations by location (µCi/ml)

Year	E (A, #174, #218)	NE (B, #173, #217)	NW (C, #170)	W (D, #171)	S (E, #172)	ENE (#555)	W (#668)
1979	**1.58E-13**	4.20E-14	4.00E-14	4.00E-14	3.00E-14	NA	NA
1980	5.40E-14	5.25E-14	**6.00E-14**	5.25E-14	3.00E-14	NA	NA
1981	**4.00E-14**	2.30E-14	**4.00E-14**	3.25E-14	1.40E-14	NA	NA
1982	1.50E-15	1.40E-14	2.15E-14	**2.40E-14**	7.00E-15	NA	NA
1983	1.42E-14	1.07E-14	1.76E-14	**2.32E-14**	8.70E-15	NA	NA
1984	5.40E-15	3.80E-15	7.20E-15	**1.19E-14**	4.10E-15	NA	NA
1985	8.90E-15	8.80E-15	8.80E-15	**1.22E-14**	7.70E-15	NA	NA
1986	8.90E-15	8.40E-15	9.40E-15	**1.14E-14**	7.90E-15	NA	NA
1987	**4.70E-15**	4.60E-15	3.20E-15	4.20E-15	3.20E-15	NA	NA
1988	3.30E-15	3.40E-15	3.20E-15	**4.10E-15**	2.50E-15	3.20E-15	NA
1989	4.20E-15	2.60E-15	2.40E-15	3.60E-15	**4.60E-15**	4.20E-15	NA
1990	**4.60E-15**	2.90E-15	1.70E-15	4.50E-15	2.20E-15	3.90E-15	NA
1991	3.00E-15	3.00E-15	1.50E-15	2.60E-15	1.60E-15	3.00E-15	NA
1992	2.10E-15	1.90E-15	1.60E-15	2.20E-15	1.70E-15	**1.17E-14**	NA
1993	2.20E-15	3.20E-15	1.30E-15	2.30E-15	2.00E-15	**1.31E-14**	NA
1994	2.30E-15	2.60E-15	1.30E-15	2.40E-15	1.90E-15	**7.90E-15**	NA
1995	2.30E-15	2.40E-15	2.50E-15	2.70E-15	2.30E-15	1.80E-15	**1.10E-14**

Note: Values in bold type designate the highest result for the year.
Note: Location descriptions are listed as provided in the records.

NFS reported environmental alpha air concentrations for 1996 through 2000 for only one on-site location. It was in the northeast area of the Burial Grounds. The annual average for those years ranged from 3.2 x 10^{-15} µCi/ml to 4.3 x 10^{-15} µCi/ml (NFS 2001, PDF, p. 37). On-site total alpha airborne radioactivity concentrations from several on-site and off-site locations are also available for 2007 and 2008, with results ranging from 1.3 x 10^{-15} µCi/ml to 3.9 x 10^{-15} µCi/ml, both of which were from on-site locations (NRC 2009, PDF p, 139). The Burial Grounds remediation was reported completed in 2009 (MACTEC 2009).

All available results from 1996 through 2009 are relatively low, thus the maximum reported concentration of 3.9 x 10^{-15} µCi/ml will be used to bound environmental alpha intakes in those years. The intakes are extended through the March 1, 2011, end date of the covered residual contamination period, as shown in Table 4.

Table 4 provides the highest result for each year from 1979 through 2011 and the associated intake rates based on an assumption of 2,000 hours of exposure per year.

Table 4: Environmental alpha radioactivity intake rates 1979 - 2011

Year	Yearly maximum air, µCi/ml	Inhalation intake, dpm/day
1979	1.6E-13	2.31E+00
1980	6.0E-14	8.76E-01
1981	4.0E-14	5.84E-01
1982	2.4E-14	3.50E-01
1983	2.3E-14	3.39E-01
1984	1.2E-14	1.74E-01
1985	1.2E-14	1.78E-01
1986	1.1E-14	1.66E-01
1987	4.7E-15	6.86E-02
1988	4.1E-15	5.98E-02
1989	4.6E-15	6.71E-02
1990	4.6E-15	6.71E-02
1991	3.0E-15	4.38E-02
1992	1.2E-14	1.71E-01
1993	1.3E-14	1.91E-01
1994	7.9E-15	1.15E-01
1995	1.1E-14	1.61E-01
1996-3/1/2011	3.9E-15	5.69E-02

Note: Intake rates are in units of dpm per calendar day.

Environmental Intakes Before 1979

Table 4 provides alpha intake estimates from environmental monitoring data for 1979 through 2011. On-site environmental data is not available before 1979. However, workers may been exposed to environmental airborne uranium radioactivity from Atomic Energy Commission (AEC) contract work starting in 1958. Additionally, environmental exposures from plutonium work could have occurred starting sometime in 1965. The paragraphs that follow provide intake estimates in lieu of environmental measurements for those years.

Environmental Uranium

Occupational intakes of uranium are discussed above and provide intake rates based on exposure categories, the lowest of which are the Clerical intakes. The Clerical inhalation intake estimates are used in place of environmental intakes prior to 1979. Table 1 provides a Clerical inhalation intake rate of 95 dpm/day (calendar day basis), which will be used for environmental uranium intakes for 1958 through 1970.

Table 2 provides residual uranium intakes starting in 1971; however, the Clerical inhalation intake rates for 1971 – 1978 are lower than the environmental alpha intakes in Table 4 for 1979, the first year in which environmental alpha intakes are available. To ensure environmental intakes are not underestimated prior to 1979, environmental uranium intakes will be assumed equal to the Clerical intake rate in 1970, then exponentially decline to the environmental alpha intake rate in 1979, as described below.

The Clerical inhalation intake rate in Table 1 for 1970 is 95 dpm/day. That rate is assumed for the start of the residual contamination period in 1971. The environmental alpha intake rate in Table 4 for 1979 is 2.31 dpm/day. An exponential curve was fit between the two values and a daily intake rate for each year was calculated as shown in Table 5. These values overestimate the residual intakes estimate in Table 2 in some years for all the categories of workers because a favorable method was used account for years with no environmental data. Therefore, all workers with exposure to residual uranium will be assigned the higher of the residual or environmental intakes.

Table 5: Clerical/environmental uranium intakes 1958 - 1978

Year	Inhalation, dpm/day
1958-1970[2]	9.50E+01 (from Table 1)
1971	9.50E+01
1972	5.97E+01
1973	3.75E+01
1974	2.36E+01
1975	1.48E+01
1976	9.31E+00
1977	5.85E+00
1978	3.67E+00
1979	2.31E+00 (from Table 4)

Note: All intake rates are in units of dpm per calendar day.

Environmental Plutonium

NIOSH previously provided plutonium intake rate estimates in a March 1, 2019, white paper (NIOSH 2019). That paper provides coworker intake rates during the 1965-1973 years of plutonium production (Tables 5 and 6); intake rates based on air sampling data from 1976 - 2011 (Table 7); and intakes for 1974 and 1975 based on an exponential curve fit between the 1973 and 1976 intake rates (Tables 8 and 9). That paper says workers who did not work in the plutonium facility will be assigned environmental intakes; however, as seen in Table 4 of this document, environmental alpha intake data is not available until 1979.

Environmental plutonium intakes from 1965 through 1973 (period of plutonium production) will be assumed to be equal to the Clerical intakes according to information provided in the March 1,

2019, NIOSH white paper. The Clerical rate is not listed in that paper but it is described as a ratio equivalent to 5% of the Labor intake. Table 6 provides those Clerical intake rates.

Environmental plutonium intakes for 1974 through 1978 (a period in which the plutonium facilities were idle) was derived from intake estimates for that period provided in Tables 8 and 9 of the March 1, 2019 white paper. Those tables have intake rates for any worker who entered the plutonium facility. Outdoor environmental plutonium intakes for those years was calculated assuming intakes outside the facilities were 5% of the indoor intakes. Those values are provided in Table 6.

Table 6: Annual environmental intakes of plutonium 1965-1978

Year	Type M, dpm/d	Type S, dpm/d	Distribution
1965-1968	2.50 (GSD=4.65)	84.6 (GSD=5.07)	Lognormal
1969-1971	0.548 (GSD=3.39)	14.6 (GSD=3.3)	Lognormal
1972-1973	0.128 (GSD=6.59)	5.36 (GSD=6.59)	Lognormal
1974	1.53	18.4	Constant
1975	0.82	2.84	Constant
1976	0.437	0.437	Constant
1977	0.437	0.437	Constant
1978	0.437	0.437	Constant

1. All intakes are in dpm per calendar day.
2. Intakes are to be assigned as either Type M or Type S, whichever provides the higher dose.
3. Intakes are assigned as total plutonium alpha.

Intake Summary

The site performed uranium work that is covered under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) and uranium work that is not covered under EEOICPA. All exposures to plutonium are presumed covered exposures. This section explains when intakes are to be assigned from workers' individual bioassay data and when intakes are assigned from the default intake estimates provided in this paper (occupational and residual, and/or environmental intake estimates). For any time period that intakes of uranium or plutonium are assigned using an individual's bioassay data, the default intake estimates do not apply.

Uranium Worker Intakes

A review of claims in the NIOSH OCAS Claims Tracking System (NOCTS) indicates the W. R. Grace site started a routine uranium monitoring program for all exposed workers in 1964. This paper provides uranium intake rates to supplement worker monitoring data for intakes during the AWE operational period and provides applicable intakes during the residual contamination period. In all cases workers bioassay should be used in the AWE operational period; workers bioassay should also be used if it provides a lower intake that the default intakes in the residual contamination period.

Uranium intakes for the AWE operational years are provided in Table 1, and intakes during the AWE residual contamination period is provided in Table 2. However, as discussed above, the environmental intakes in Table 5 (for 1971 through 1978) exceed some of the residual intakes in Table 2. Therefore, Table 7 was generated to specify intakes for all years choosing the more favorable of the environmental or residual intakes. Note the values in boldface type in Table 7 are the values in which the uranium intakes are based on the higher environmental intake data.

Table 7. Uranium intake values for all years

Year	**Operator Inhalation**	**Operator Ingestion**	**Labor Inhalation**	**Labor Ingestion**	**Supervisor Inhalation**	**Supervisor Ingestion**	**Clerical Inhalation**	**Clerical Ingestion**
1958-1970	3.80E+03	7.92E+01	1.90E+03	3.96E+01	9.50E+02	1.98E+01	9.50E+01	1.98E+00
1971	**9.50E+01**	7.92E+01	**9.50E+01**	7.92E+01	**9.50E+01**	1.98E+01	**9.50E+01**	1.98E+00
1972	**5.97E+01**	6.20E+01	**5.97E+01**	6.20E+01	**5.97E+01**	1.55E+01	**5.97E+01**	1.55E+00
1973	4.53E+01	4.85E+01	4.53E+01	4.85E+01	**3.75E+01**	1.21E+01	**3.75E+01**	1.21E+00
1974	3.55E+01	3.80E+01	3.55E+01	3.80E+01	**2.36E+01**	9.50E+00	**2.36E+01**	9.50E-01
1975	2.78E+01	2.98E+01	2.78E+01	2.98E+01	**1.48E+01**	7.44E+00	**1.48E+01**	7.44E-01
1976	2.17E+01	2.33E+01	2.17E+01	2.33E+01	**9.31E+00**	5.82E+00	**9.31E+00**	5.82E-01
1977	1.71E+01	1.83E+01	1.71E+01	1.83E+01	**5.85E+00**	4.57E+00	**5.85E+00**	4.57E-01
1978	1.34E+01	1.43E+01	1.34E+01	1.43E+01	**3.67E+00**	3.58E+00	**3.67E+00**	3.58E-01
1979	1.04E+01	1.12E+01	1.04E+01	1.12E+01	2.60E+00	2.79E+00	**2.31E+00**	2.79E-01
1980	8.20E+00	8.79E+00	8.20E+00	8.79E+00	2.05E+00	2.20E+00	**8.76E-01**	2.20E-01
1981	6.41E+00	6.86E+00	6.41E+00	6.86E+00	1.60E+00	1.72E+00	**5.84E-01**	1.72E-01
1982	5.02E+00	5.38E+00	5.02E+00	5.38E+00	1.25E+00	1.34E+00	**3.50E-01**	1.34E-01
1983	3.93E+00	4.21E+00	3.93E+00	4.21E+00	9.83E-01	1.05E+00	**3.39E-01**	1.05E-01
1984	3.07E+00	3.29E+00	3.07E+00	3.29E+00	7.68E-01	8.23E-01	**1.74E-01**	8.23E-02
1985	2.41E+00	2.58E+00	2.41E+00	2.58E+00	6.02E-01	6.45E-01	**1.78E-01**	6.45E-02
1986	1.88E+00	2.02E+00	1.88E+00	2.02E+00	4.71E-01	5.05E-01	**1.66E-01**	5.05E-02
1987	1.48E+00	1.58E+00	1.48E+00	1.58E+00	3.69E-01	3.96E-01	**6.86E-02**	3.96E-02
1988	1.15E+00	1.24E+00	1.15E+00	1.24E+00	2.88E-01	3.09E-01	**5.98E-02**	3.09E-02
1989	9.09E-01	9.74E-01	9.09E-01	9.74E-01	2.27E-01	2.43E-01	**6.71E-02**	2.43E-02
1990	7.09E-01	7.60E-01	7.09E-01	7.60E-01	1.77E-01	1.90E-01	**6.71E-02**	1.90E-02
1991	5.55E-01	5.95E-01	5.55E-01	5.95E-01	1.39E-01	1.49E-01	**4.38E-02**	1.49E-02
1992	4.34E-01	4.66E-01	4.34E-01	4.66E-01	**1.71E-01**	1.16E-01	**1.71E-01**	1.16E-02
1993	3.41E-01	3.65E-01	3.41E-01	3.65E-01	**1.91E-01**	9.13E-02	**1.91E-01**	9.13E-03
1994	2.67E-01	2.86E-01	2.67E-01	2.86E-01	**1.15E-01**	7.15E-02	**1.15E-01**	7.15E-03
1995	2.09E-01	2.24E-01	2.09E-01	2.24E-01	**1.61E-01**	5.60E-02	**1.61E-01**	5.60E-03
1996	1.63E-01	1.75E-01	1.63E-01	1.75E-01	**5.69E-02**	4.37E-02	**5.69E-02**	4.37E-03
1997	1.28E-01	1.37E-01	1.28E-01	1.37E-01	**5.69E-02**	3.42E-02	**5.69E-02**	3.42E-03
1998	1.00E-01	1.08E-01	1.00E-01	1.08E-01	**5.69E-02**	2.69E-02	**5.69E-02**	2.69E-03
1999	7.83E-02	8.39E-02	7.83E-02	8.39E-02	**5.69E-02**	2.10E-02	**5.69E-02**	2.10E-03
2000 - 3/1/2011	6.15E-02	6.59E-02	6.15E-02	6.59E-02	**5.69E-02**	1.65E-02	**5.69E-02**	1.65E-03

Uranium inhalation material solubility type is chosen based on whichever type provides the highest dose. Ingestion f1 values are selected to match the inhalation type. Uranium is assumed to be recycled uranium that included other radionuclides according to the ratios specified in TBD Table 3-12. Uranium alphas are applied as U-234.

Uranium workers are also assigned the following intakes:

1965 – 1978: Environmental plutonium intakes from Table 6

1978 – 2011: Environmental alpha intakes from Table 4, interpreted as plutonium.

Plutonium Worker Intakes

Plutonium intakes for the various exposure categories are provided in Tables 8 through 12 and were calculated from the intakes and information provided in the March 1, 2019, NIOSH white paper. These are default intakes to use for assumed exposure to plutonium when plutonium bioassay data are not available. The plutonium isotopic constituents are determined from the information provided in Table 4 of the March 1, 2019, paper. Plutonium inhalation intakes in Tables 8 through 12 are assigned as either Type M or Type S, whichever type provides the higher dose. Ingestion intakes in should be assigned f1 values to match the inhalation type used.

Table 8. Plutonium Operator intakes

Year	Inhalation Type M, dpm/d	Distribution	Inhalation Type S, dpm/d	Distribution
1965-1968	6.27E+02	constant	2.44E+04	constant
1969-1971	8.15E+01	constant	2.08E+03	constant
1972-1973	5.71E+01	constant	2.38E+03	constant

Table 9. Plutonium Labor intakes

Year	Inhalation Type M, dpm/d	Lognormal distribution	Inhalation Type S, dpm/d	Lognormal distribution
1965-1968	4.99E+01	GSD=4.65	1.69E+03	GSD=5.07
1969-1971	1.10E+01	GSD=3.39	2.92E+02	GSD=3.30
1972-1973	2.57E+00	GSD=6.59	1.07E+02	GSD=6.59

Table 10. Plutonium Supervisor intakes

Year	Inhalation Type M, dpm/d	Lognormal distribution	Inhalation Type S, dpm/d	Lognormal distribution
1965-1968	2.50E+01	GSD=4.65	8.46E+02	GSD=5.07
1969-1971	5.48E+00	GSD=3.39	1.46E+02	GSD=3.30
1972-1973	1.28E+00	GSD=6.59	5.36E+01	GSD=6.59

Table 11. Plutonium Clerical intakes

Year	Inhalation Type M, dpm/d	Lognormal distribution	Inhalation Type S, dpm/d	Lognormal distribution
1965-1968	2.50E+00	GSD=4.65	8.46E+01	GSD=5.07
1969-1971	5.48E-01	GSD=3.39	1.46E+01	GSD=3.30
1972-1973	1.28E-01	GSD=6.59	5.36E+00	GSD=6.59

Table 12. Plutonium facility intakes 1974 - 2011

All Workers	Inhalation Type M, dpm/d	Inhalation Type S, dpm/d	Ingestion, dpm/d	Distribution
1974	3.06E+01	3.68E+02	6.11E+00	constant
1975	1.64E+01	5.69E+01	3.27E+00	constant
1976-1987	8.74E+00	8.74E+00	1.75E+00	constant
1988-3/1/2011	1.13E+00	1.13E+00	2.30E-01	constant

NOTE: Intakes in this table are for workers who may have entered the facility for miscellaneous landlord activities and inspections.

Workers who have plutonium bioassay data for work in the plutonium facilities or who are assessed default occupational intakes of plutonium are also assigned uranium intakes from their bioassay data.

Environmental Intakes

Workers assumed to have only environmental exposures are assigned the following intakes:

1958 – 1978: Uranium Clerical intakes from Table 7

1965 – 1978: Plutonium intakes from Table 6

1978 – 2011: Alpha intakes from Table 4, interpreted as either uranium or plutonium, whichever results in the higher dose.

The alpha intakes are considered to be either uranium (Types F, M, or S) or plutonium (Types M or S), whichever provides the higher dose. The plutonium and uranium intakes, and isotopic constituents are applied the same as specified for a uranium or plutonium worker.

Dose Reconstruction Notes

The various intakes estimates in the this paper, and from the March 1, 2019, white paper were used to compile the various uranium and plutonium intake tables. Additional considerations for dose reconstructions are listed below.

- All intakes and doses are reconstructed for exposures in the AWE operational period. The site performed work after 1970 that is not covered under EEOICPA.

- Uranium bioassay data should be used when available. Uranium bioassay data should not be used for intake estimates after 1970 (exceptions noted below) except when it provides a more limiting intake than the default residual intakes in this paper.

- Starting in 1991, worker uranium bioassay data and other intake data, e.g., personal air sampling data, should be considered for workers involved with Burial Grounds remediation.

- Plutonium work started in 1965. All dose from plutonium exposures are to be reconstructed. If a worker had plutonium exposure, plutonium bioassay data should be used or the default plutonium intakes should be used. Plutonium workers should also be assigned uranium intakes from bioassay data in the applicable years because the plutonium work involved production of mixed oxide fuel.

- Plutonium material is assumed to have the constituents specified in the March 1, 2019, white paper.

ENVIRONMENTAL EXTERNAL DOSE

Environmental TLDs

NIOSH analyzed on-site environmental thermoluminescent dosimeter (TLD) dose data and dose rate characterization data from the waste burial grounds.

Permanent environmental TLD monitoring locations were established by 1979. Figure 4 shows seven environmental TLD monitoring locations around the protected area and four other nearby locations on the property but outside the protected area fence. Another TLD monitoring station was located five miles from the site. The TLDs were read quarterly. Annual doses from these locations are available for 1979 through 1995. In 1990, an eighth monitoring location was added on the fence line near Building 234, which is between locations number 4 and number 10 in Figure 4 (NRC 1991, NFS 1996).

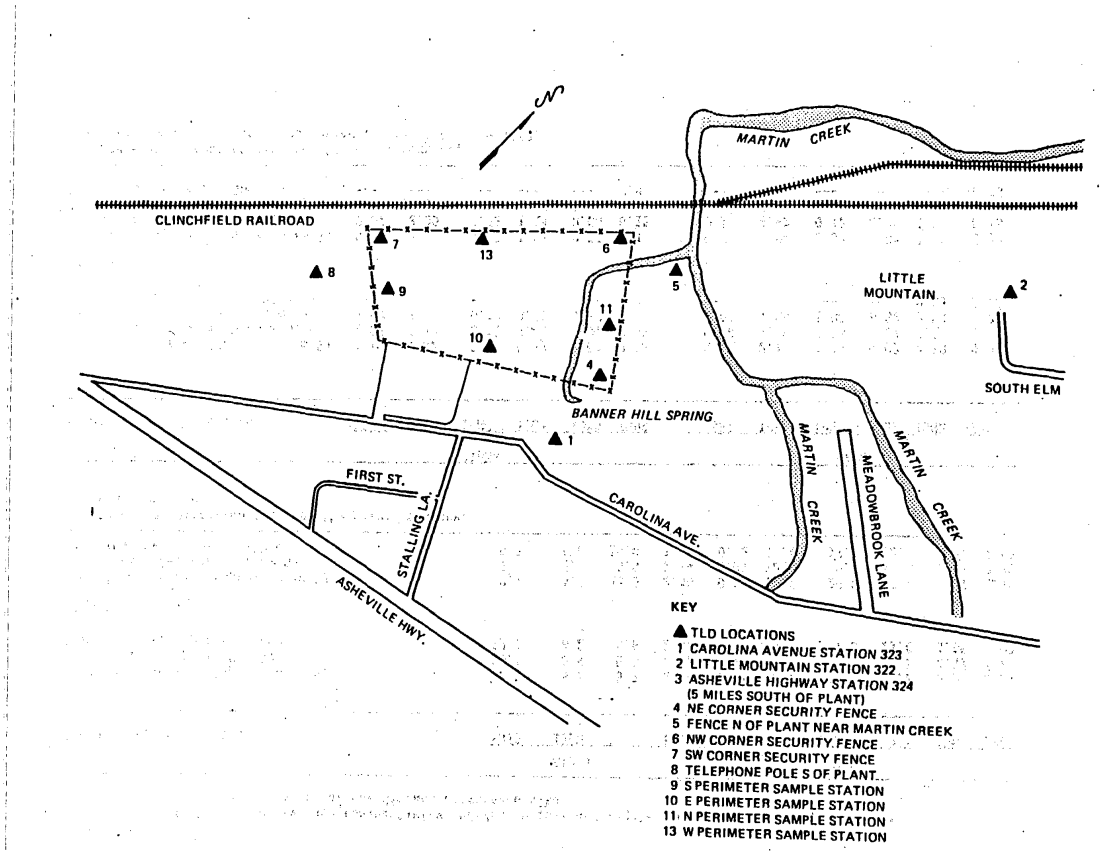

Figure 4: Location of environmental TLDs (NRC 1991, PDF p. 112)

Table 13 shows the annual dose from the location that provides the highest dose in each year. The dose data have been adjusted for a 2,000-hr work-year exposure.

Table 13: Annual doses based on environmental TLDs

Year	dose, mrem
1979	114
1980	100
1981	84
1982	99
1983	84
1984	67
1985	8
1986	22
1987	13
1988	50
1989	17
1990	123
1991	32
1992	21
1993	14
1994	27
1995	9

Dose Rates from Burial Grounds

The Burial Grounds contained waste pits that were used in the early years of the site. NFS ceased burying waste in the 1970s. Figure 5 shows the location of the Burial Grounds. There were two areas, both located outside the protected area fence: the Main Burial Grounds (Burial Grounds) and the Small Burial Area (Northwest Trenches). Most of the contaminated material was buried in the Burial Grounds; however, in 1969 contaminated metal was buried in the Northwest Trenches, which was later removed.

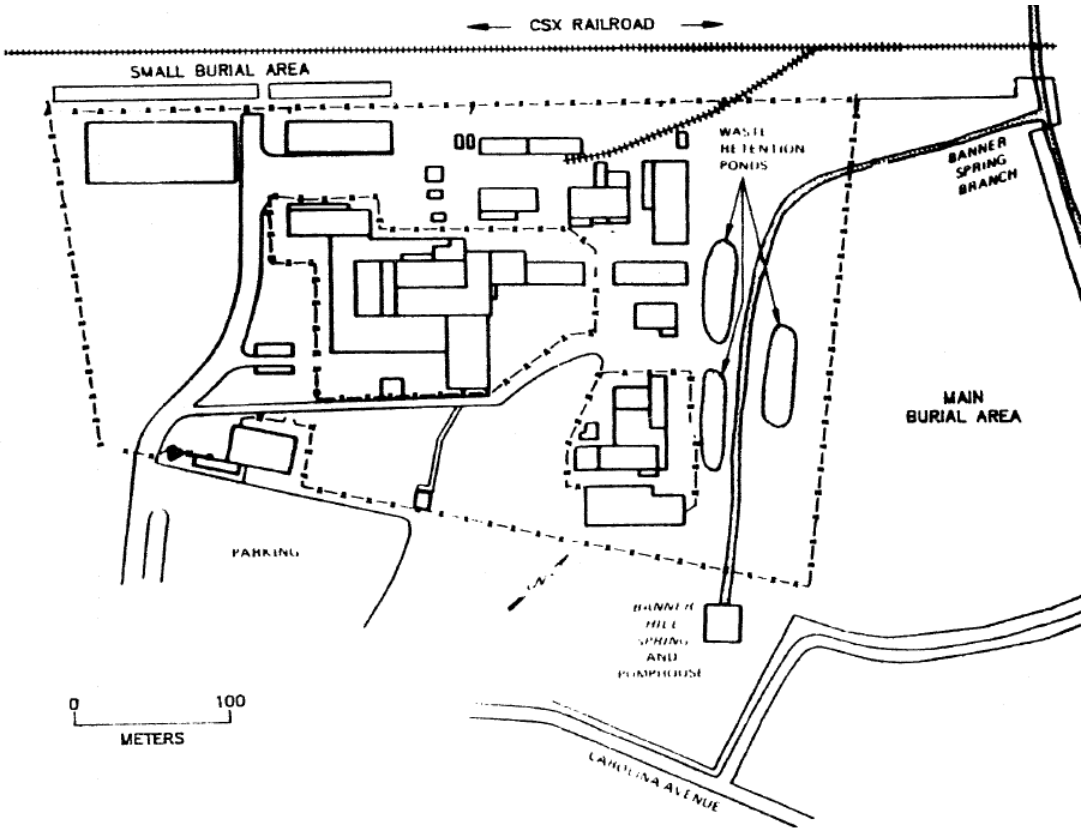

Figure 5: Layout of the NFS plant showing waste burial areas (ORAU, 1987, pdf p. 29)

As part of a radiological characterization in 1987, radiation surveys were performed of the Burial Grounds and the Northwest Trenches (ORAU 1987). The dose rate surveys consisted of walkover scans and a 20 m gridded survey pattern at contact and one meter above the surface. The results from the one meter walkover scans and the results from the 20 m grid surveys were combined, resulting in 97 dose rate results for the Burial Grounds and 62 results for the Northwest Trenches.

The combined 97 results from the Burial Grounds were fit to a lognormal distribution. The recorded results were adjusted for a natural background of 7 µR/hr, which is the mode value of dose rates taken at eight off-site locations. The resulting distribution had a net geometric mean dose rate of 8.56 µR/hr with a geometric standard deviation of 2.015. The 95th percentile is 27.1 µR/hr, or 0.0271 mR/hr. A 2,000 hr work-year of exposure at the 95th percentile rate results in an annual dose of 54 mR.

The 62 results from the northwest trenches were analyzed similarly and resulted in a geometric mean dose rate of 10.8 µR/hr with a geometric standard deviation of 1.225. The 95th percentile is 15.2 µR/hr, or 0.0152 mR/hr. A 2,000 hr work-year of exposure at the 95th percentile rate results in an annual dose of 30 mR. The higher of the 95th percentile doses from the two burial areas

will be used as a bounding dose for exposure to buried waste. The results are provided in Table 14. The doses derived from the Burial Grounds characterization data are assumed for all operational and residual years.

Table 14: Dose rates from the Burial Grounds

Burial Ground	dose, mR/yr
Median Dose	17
Geometric Standard Deviation	2.015
95th Percentile Dose	54

Bounding Environmental External Doses

The annual external environmental doses from TLD data from Table 13 and the annual doses from the Burial Grounds from Table 14 are both shown in Table 15 for the purpose of determining bounding environmental dose estimates.

Some workers were not exposed to these bounding environmental dose rates; therefore, dosimeter dose should be considered when it is lower than the doses provided in Table 15.

Table 15: Annual site environmental doses

Year	TLD data, mrem/yr	Burial Grounds, mR/yr
1958-1978	114[a]	54[a]
1979	114	54
1980	100	54
1981	84	54
1982	99	54
1983	84	54
1984	67	54
1985	8	54
1986	22	54
1987	13	54
1988	50	54
1989	17	54
1990	123	54
1991	32	54
1992	21	54
1993	14	54
1994	27	54
1995	9	54
1996-2011	-	54[b]

a. Dose rate from 1979 is assumed for earlier years.
b. Dose rate from 1995 is assumed through March 2011.
Note: The higher of the dose rates, TLD data or Burial Grounds data, is assumed to bound environmental external dose in each year.

SECONDARY FINDING D

SC&A commented that the methods used to derive the external doses in TBD Table 5-5 were not provided (SC&A 2013, PDF p. 31).

Table 5-5 of the TBD is a table of annual external doses in the residual period. The TBD provides a discussion of how the contamination levels were determined and references dose conversion factors from Federal Guidance Report 12 (EPA 1993). But the TBD did not provide the specific details on radionuclides and which factors from FGR 12 were used.

The updated methods to estimate residual contamination (discussed with Finding 2 above) requires an update to the external doses derived from the contamination levels. The updated initial residual contamination level was 1.124×10^6 dpm/m^2. Table 3.10 of Battelle-TBD-6000 provides dose conversion factors for photon and beta radiation from surface contamination. Those factors are for surfaces contaminated with natural uranium and should provide a favorable dose rate from contamination from enriched uranium recovery operations that was performed for the AEC during the AWE operational period.

The Battelle-TBD-6000 Table 3.10 dose conversion factor for photon dose, 3.94×10^{-10} mR/hr/dpm m^2, results in an annual exposure less than 1 mR, which is less than the bounding annual environmental dose provided in Table 15 of this document. Therefore, for purposes of external dose reconstruction from photons, workers will be assumed to have environmental exposure rather than be exposed to residual contamination in the residual uranium facilities.

The Battelle-TBD-6000 Table 3.10 dose conversion factor for beta dose, 3.82×10^{-8} mrad/hr/dpm m^2, was used to estimate the beta dose rate and annual dose from residual uranium contamination. The dose for a 2,000-hour work-year in 1971 (first year of the residual period) is 85.8 mrad. The dose in subsequent years is estimated by applying the contamination depletion factors from ORAUT-OTIB-070, Table 4-2 (ORAUT 2012). The annual beta doses are presented in Table 16, which is to replace the beta values in TBD Table 5-5.

Table 16: Annual beta dose from residual contamination

Year	Dose, rad
1971	8.58E-02
1972	6.72E-02
1973	5.26E-02
1974	4.12E-02
1975	3.23E-02
1976	2.52E-02
1977	1.98E-02
1978	1.55E-02
1979	1.21E-02
1980	9.53E-03
1981	7.44E-03
1982	5.83E-03
1983	4.57E-03
1984	3.57E-03
1985	2.80E-03
1986	2.19E-03
1987	1.72E-03
1988	1.34E-03
1989	1.06E-03
1990	8.24E-04
1991	6.45E-04
1992	5.05E-04
1993	3.96E-04
1994	3.10E-04
1995	2.43E-04
1996	1.90E-04
1997	1.49E-04
1998	1.17E-04
1999	9.10E-05
2000 on	7.14E-05

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