NIOSH Evaluation of Carborundum Company

Response to Site Profile Issues and Comments

National Institute for Occupational Safety and Health

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Introduction

NIOSH received a Special Exposure Cohort (SEC) Petition for the Carborundum Company on November 19, 2014. NIOSH issued an Evaluation Report (ER) on June 3, 2015, which was presented to the Advisory Board on Radiation Work and Health (Board) on July 23, 2015. In its evaluation report NIOSH concluded that dose reconstructions were feasible for both internal and external exposures. Subsequent reviews, discussion documents, and meetings were held. A complete chronological list of those meetings and documents is provided in Appendix B of this report.

This report was written to address comments on the use of surrogate data. This report also addresses other identified *Dose Reconstruction Issues and Observations* and provides recommendations for updated doses and intakes for use in dose reconstructions (DRs), which is presented following the discussion of *Surrogate Data Issues*.

Surrogate Date Issues

NIOSH issued a memorandum on the use of surrogate data in Carborundum dose estimates (Tomes, 2016b). SC&A reviewed the NIOSH memorandum against the Board's surrogate data criteria and commented that the dose rates NIOSH used in some estimates are implausibly high (Anigstein and Mauro, 2016).

NIOSH reviewed the SC&A comments and suggestions on the surrogate data, and provided updated dose estimates below. In this report the issues are referred to as Surrogate Data Issue 1 and Surrogate Data Issue 2, for the first AWE Operational Period and second AWE Operational Period, respectively.

Surrogate Data Issue 1: External Dose from Centerless Grinding in 1943

> Issue: Comment received from SC&A in memorandum of November 10, 2016, on use of surrogate data. SC&A commented that the external dose rates provided by DCAS in example dose reconstructions for the 1943 centerless grinding work are implausibly high using the default dose rate for machining in Battelle-TBD-6000 (TBD-6000). More appropriate dose rates should be selected.
>
> Discussion: As noted by SC&A, the DR methodology used the default dose for machining from Table 6.4 in TBD-6000. The 2.5 rem annual doses from exposure to uranium metal in TBD-6000 is based on a one foot dose rate of 2.08 mrem/hr, the highest of the various shapes (rectangular ingot) provided in Table 6.1. SC&A suggested NIOSH consider more appropriate dose rates from TBD-6000, recommending use of the dose

rates from the "slug" provided in Table 6.1 of TBD-6000. DCAS concurs with the SC&A recommendation, but proposes slightly higher doses from a more favorable application of the dose rate specific to Carborundum. Revised penetrating and non-penetrating doses for 1943 are explained and provided below. The "Clerk" or "Administrative" dose category identified in the previous DR methods for being applicable to workers in a building separate from the radiological work, is being omitted in the current recommendations because the location of the 1943 work is unknown.

Photon Dose

TBD-6000 Table 6.1 provides a one foot dose rate of 0.0524 mrem/hr from a slug of natural uranium. The slugs modeled in that evaluation were only slightly larger than the slugs handled at Carborundum and should represent a favorable dose rate from a single slug. The dose rate is multiplied by 10 to account for an array of ten slugs that were used at Carborundum, resulting in a dose rate of 0.524 mrem/hr.

Using the default assumptions and 48 hour work-week specified in TBD-6000 results in a dose rate of 0.00172 rem/calendar-day or 0.205 rem for an Operator for the entire 119 days that the slugs were present at Carborundum in 1943. The General Laborer category was calculated using the one meter rate for slugs from Table 6.1, resulting in 0.000171 rem/calendar-day or 0.0203 rem for the 119 days in 1943. The Supervisor dose is 50% of the General Laborer dose.

Photon dose from air submersion and contaminated floors are calculated as presented in TBD-6000, Table 6-4, based on the air concentration assumed for Carborundum in 1943.

Beta Dose

Whole body beta dose for an Operator was calculated based on an assumption of ten times the photon dose at one foot, resulting in a rate of 0.0172 rad/calendar-day or 2.05 rad for the 119 days in 1943. General Laborer dose is one half of the Operator dose. Supervisor beta dose is 10% of General Laborer Dose.

The beta dose to the hands and forearms are the same as specified in TBD-6000, Table 6.4.

Table 1 shows the total doses for 1943 for the 119 days in which the slugs were on site.

Table 1: Carborundum 1943 External Doses[a,b]

	Air Submersion & Contamination, photon	Contamination, beta	Metal Whole Body, photon	Hands & Forearms, beta	Other Skin, beta
	Roentgen	**rad**	**rem**	**rad**	**rad**
Operator	0.003	0.319	0.205	89.984	2.050
General Laborer	0.002	0.159	0.020	44.992	1.025
Supervisor	0.001	0.080	0.010	4.499	0.103

a. Doses in table assume full employment June – September 27, 1943.
b. Doses assigned as a lognormal distribution with a GSD of 5.

Surrogate Data Issue 2: External Dose from Uranium Work in 1959 Through 1967.

Issue: Comment received from SC&A in memorandum of November 10, 2016, on use of surrogate data. SC&A commented that the external dose rates provided by DCAS in example dose calculations for work with uranium from 1959 through 1967 are implausibly high using the default dose rate in TBD-6000. More appropriate dose rates should be selected.

Discussion: As noted by SC&A, the DR methodology used the default dose for machining from Table 6.4 in TBD-6000. The 2.080 rem annual doses from exposure to uranium metal for "1956 on" in Table 6-4 of TBD-6000 is based on a one foot dose rate of 2.08 mrem/hr, the highest of the various shapes (rectangular ingot) provided in Table 6.1. SC&A suggested NIOSH consider more appropriate dose rates from TBD-6000, and recommended the dose rates from the "flat plate" provided in Table 6.1 of TBD-6000. NIOSH concurs with the SC&A recommendation. Revised penetrating and non-penetrating doses for 1959-1967 are explained and provided below.

Photon Dose from Uranium

TBD-6000 Table 6.1 provides a one foot dose rate of 0.231 mrem/hr from a flat plate, which is assumed to be a favorable rate for the uranium materials handled at Carborundum from 1959-1967. Using the TBD-6000 assumptions for an Operator results in a dose from exposure to the uranium materials of 0.231 rem per year. The General Laborer dose category was calculated using the one meter dose rate, 0.0278 mrem/hr, and TBD-600 assumptions, resulting in a dose of 0.028 rem per year. The Supervisor dose is 50% of the General Laborer dose, and the Clerical dose is 10% of the Supervisor dose.

Beta Dose from Uranium

Whole body beta dose for an Operator was calculated based on an assumption of ten times the photon dose at one foot, resulting in dose 2.310 rad per year. General Laborer

dose is one half of the Operator dose. Supervisor beta dose is 10% of General Laborer Dose. The Clerical dose category is assumed to have no beta dose from direct exposure to the uranium materials.

The beta dose to the hands and forearms are the same as specified in TBD-6000, Table 6.4.

Photon and Beta Dose from Contamination

Photon and beta doses from air submersion and contaminated floors also need to be recalculated due to a small change in the air sample analysis (discussed below). The dose estimate methods presented in TBD-6000 were used in conjunction with the Carborundum air sampling data. The 95th percentile uranium area air concentration is 7.384 dpm/m^3, which is assumed for the General Laborer category. The Operators' air concentration is assumed to be twice that value, or 14.768 dpm/m^3. Dose from contaminated surfaces for Operators are estimated from this air concentration using the methods specified in TBD-6000, section 6.1.2, the conversion factors in Table 3.10, and 2,000 hours per year exposure. This results in an annual dose of 0.000023 R from photons and 0.0022 rad from beta particles.

Table 2 below shows the annualized dose rates.

Table 2: Carborundum External Doses from Uranium 1959-1967[a,b,c]

	Air Submersion & Contamination, photon	**Contamination, beta**	**Uranium Whole Body, photon**	**Hands & Forearms, beta**	**Other Skin, beta**
	R/yr	rad/yr	rem/yr	dose (rad/yr)	dose (rad/yr)
Operator	0.000	0.002	0.231	230	2.310
General Laborer	0.000	0.001	0.028	115	1.155
Supervisor	0.000	0.001	0.014	11.5	0.116
Clerical	0.000	0.000	0.001	0	0

a. Doses listed as 0.000 are rounded values.
b. Clerical dose is for personnel known to have not worked in Building 1.
c. Doses assigned as a lognormal distribution with a GSD of 5.

Dose Reconstruction Issues and Observations

This report responds to: (1) issues, or findings, identified as being significant by SC&A, and (2) SC&A comments and observations on NIOSH dose calculations. All the issues/findings have recommended solutions. However, two observations on dose calculations are not addressed in this document. SC&A recommended adjustments to the MCNP-model for external dose from plutonium, and they also commented on the need for NIOSH to reevaluate the appropriate fraction of individual radionuclides used to partition total plutonium alpha measurements. The comments on plutonium are still under review by NIOSH and will be addressed separately; NIOSH is currently using the plutonium values as presented in the July 23, 2015, methodology documents, although resolution of those issues could result in some changes in final dose estimates. Otherwise, this document provides responses to all open issues and observations that impact dose calculations and performance of dose reconstructions. This report lists and summarizes all the findings, including those that have been closed by the Work Group.

Previous Review of Dose Methodology Issues

As noted above NIOSH presented an SEC ER overview to the Board on July 23, 2015. At that time NIOSH also transferred the following supporting files to the Board's document review folder on the NIOSH shared drive.

DR Methodology Carborundum 2015-07-23 FINAL.doc
Carborundum Methodology 2015-07-23 FINAL.xlsx
Carborundum Example DR Report 2015-07-23 final.docx

The first file contained dose and intake tables and a description of the dose estimation methods. The second file contained associated spreadsheets with the dose calculations and derivation of intakes. And the last file was a summary report of Example DRs based on the information in the other two files. At the time those were newly drafted dose estimates based on additional site information gathered during the SEC petition review. The Departments of Energy (DOE) and Labor were also in the process of modifying the dates and scope of work provided for Carborundum in the DOE EEOICPA Covered Facility List Database, which was done soon thereafter.

After NIOSH presented the ER, the Board created the Carborundum Work Group (Work Group) and tasked SC&A to review the SEC petition and the NIOSH Evaluation Report. SC&A reviewed the ER, the three supporting files listed above, and requested, and received, supporting files from NIOSH on the MCNP work to model plutonium exposures.

SC&A issued a report of their review in January 2016 (Anigstein, 2016); that report is referred to as the *ER Review* in this document. Seven findings, "Issues" 1 through 7, were identified in the *ER Review*. The chronology of the various reviews and discussions is provided in Appendix B.

Summary of Issues and Resolutions

The issues deemed to be most significant to the ability to reconstruct doses were specifically listed as findings or issues by SC&A and have been specifically addressed. Additionally, SC&A made numerous comments on the Carborundum ER and on the supporting files containing the dose methods and calculations. NIOSH reviewed the SC&A ER Review and compiled a list of those comments deemed applicable to dose reconstructions, which is in Appendix A.

A summary of each of the seven Issues identified by SC&A are listed below along with the resolution. Updated dose calculations and additional explanations are provided in subsequent sections.

Issue 1

This issue concerns dose estimates for X-ray Diffraction (XRD) work at Carborundum. This issue was closed by the Work Group after NIOSH performed an additional assessment of dose, noting the dose for support workers in the uranium laboratory area is higher from an XRD technician would receive, and thus the higher dose estimates for support workers would be used under the assumption definitive information on exact work location is not available for individual claims. However, it should be noted that, in response to comments on surrogate data, NIOSH is now proposing to lower the external dose from uranium. The dose assumed for XRD work provides a higher dose for some workers in 1959 and 1960, as shown in Tables 5 and 6 below.

Issue 2

In this comment, SC&A opined that NIOSH should consider dose from thorium, based on the assumption that dose from residual contamination from thorium work in 1955, which is not covered under EEOICPA, could have contributed to internal dose during the second AWE Operational Period in 1959 through 1967. The issue is essentially whether NIOSH should consider the gross alpha air samples collected during the AEC work starting in 1959 to be part thorium from some unknown thorium work in 1955. This issue was discussed during the August 18, 2016, Work Group meeting. NIOSH did not agree that the available information supported an assumption of a significant level of thorium contamination; however, NIOSH agreed to review this issue again. Upon further review, the available information indicates that Carborundum had a contract with GE in which it performed experimental work with uranium compounds in the 1950s; that work ended in 1958. There was an indication that some thorium work may have been done in the research laboratory in 1955. Based on available information NIOSH concludes that the radioactive material work in the 1950s was primarily uranium, and that the available information does not support an assumption of significant thorium contamination in the uranium work areas in 1959.

Issue 3
Possible use of Sr-90 sources in a production process. NIOSH evaluated the use of those sources and concluded they were used at another Carborundum location that is not covered. Issue 3 was closed by the Work Group.

Issue 4 and Issue 5
Issues 4 and 5 were comments that medical X-ray doses should be included in dose reconstructions in the first and second AWE Operational Periods, respectively. NIOSH concurred. An annual X-ray dose will be included in DRs. ORAUT-OTIB-006 will be used as a guide for the dose estimates.

Issue 6
SC&A commented that dose calculations from air submersion and surface contamination should be done with factors provided in TBD-6000, rather that the factors NIOSH derived from Federal Guidance Report No. 12 used in the Example DRs. NIOSH concurred with the SC&A recommendation. The new dose estimates provided in this document have been updated to include the TBD-6000 factors. See additional discussion of Issue 6 below.

Issue 7
SC&A commented on the inability to duplicate doses in previous Example DR calculations provided by NIOSH. The reasons for those differences was discussed during the Work Group meeting on August 18, 2016. NIOSH said they would provide updated Example DR calculations after updating dose methods in response to other SC&A comments/observations. The other comments were not part of the Issues identified by SC&A, but were comments made throughout the *ER Review* on various aspects of dose estimates. NIOSH has compiled responses to those comments in Appendix A. The dose tables below have been updated consistent with the responses. New Example DRs will be provided to the Work Group in conjunction with this report.

Additional Discussion of Open Issues

Issue 6 warrants additional discussion to describe how the issue was resolved and to present the calculations.

Issue 6 (ER Finding 6)

> Issue: Comment received from SC&A in their *ER Review* on *Inappropriate and Incorrect Use of FGR 12*. The issue concerns the dose conversion factors NIOSH used in example dose reconstructions for calculation of external dose rates from air submersion and surface contamination. The issue was discussed during the August 18, 2016, meeting of the Carborundum Work Group.

Discussion: The first residual period starts at the end of September 1943. In the example dose reconstructions provided by NIOSH in July 2015, surface contamination at the start of the first residual period was calculated using the methods described in TBD-6000, section 6.1.2, combined with the 5480 dpm/m^3 air concentration assumed for centerless grinding at Carborundum in 1943. NIOSH then used dose conversion factors derived from Federal Guidance Report (FGR) No. 12 to estimate resulting external dose rates from residual contamination. SC&A did not agree with the use of the factors from the FGR, noting more appropriate factors are available in TBD-6000. Those factors are provided in TBD-6000, Tables 3.9 and 3.10, for dose from air submersion and surface contamination, respectively. NIOSH concurred with the SC&A recommendation during the August 18, 2016 Work Group meeting.

Updated Dose Calculations:
The dose from air submersion was calculated and is insignificant. Dose from surface contamination was recalculated using the dose factors from TBD-6000. The initial residual air concentration is 106.5 dpm/m^3 and the derived surface contamination value is 1.07×10^7 dpm/m^2, both the same as previously calculated and provided by NIOSH. The dose factors for both photon and beta dose rates from TBD-6000 Table 3.10 were applied and are included with the annual residual external doses from centerless grinding shown below in Table 3.

The second residual period dose from air submersion and surface contamination was also reassessed. The initial residual surface contamination value is 2.87×10^4 m^2. The resulting external doses from photons and beta particles are all <0.001 rem.

Response to Comments on Job Category and Work Area Assumptions

SC&A provided a few comments on interpretation of job categories, assumptions of work locations, and instructions for dose reconstruction. The descriptions below have been updated to resolve those comments. Some additional language has been added to these definitions, including specification of a default dose category.

Job Categories
For the purposes of performing dose reconstructions for Carborundum, four job categories have been established.

- *Operators – Individuals who operated the process equipment and/or routinely handled radiological materials. This is the default dose category for dose reconstructions when there is insufficient information to place a worker in a lower dose category.*

- *General Labor/Radiological Work Support Personnel – Individuals who were in close contact with the radiological materials product for a portion of the working day. This category would include maintenance workers, laboratory workers, health physics monitors, etc., who may have occasionally been in contact with radioactive material in the performance of duties. If information in a claim is insufficient to determine whether or not a worker fits this description, then the Operator category should be used.*

- *Supervisor/Non-Radiological Work Production Personnel – Individuals who routinely worked in the production areas and may have been periodically in the vicinity of where processing was occurring. This includes supervisory staff, engineers, and individuals who were not in contact with the radiological materials but who worked routinely in the production areas. If information in a claim is insufficient to determine that the worker did not handle radioactive material in the performance of their duties, then a higher dose category is assumed.*

- *Clerk/Other – Individuals who worked in the environment outside of the production areas where radiological work was being performed. This includes office workers and non-radiological production workers who are clearly documented to be at a physically different location than the radiological work (e.g., a different building). If work location cannot be determined for a claim, then one of the other categories of exposure is to be used.*

The job titles above are the same as previously provided. They are the job titles used in TBD-6000, with added descriptive titles for clarity. However, for simplicity only the TBD-6000 titles are used in the dose tables below.

The location (building) for the 1943 AEC work has not been determined; therefore updated dose estimates below do not include *Clerk* dose for 1943.

Previously, NIOSH provided residual dose and intake values for Radiological Work Areas and Non-Radiological Work Areas. The updated dose tables for the Residual Radiation Periods provided below are for all workers. Thus job category determinations are only applicable for the AWE Operational Period dose estimates.

Updated Annual External Dose Estimates

This section provides dose and intake tables that have been updated from the July 23, 2015, draft DR Methodology provided to the Board, to include resolutions to the above listed Issues, as well as changes made in response to other comments and observations, as listed in Appendix A. A brief explanation is provided for each of the dose tables that have been updated.

Additionally, since multiple work areas and corresponding doses are provided, a summary table (Table 6) has been complied that contains the most favorable dose by year to be used in dose reconstructions.

First AWE Operational Period

In response to comments on surrogate data, NIOSH made changes to the external doses for centerless grinding in 1943, as described and shown above in Table 1.

First Residual Period

Annual external doses from residual contamination from the 1943 AEC work are provided in Table 3 below. The doses have been updated to incorporate resolution of comments from SC&A on external dose factors, as noted above in the Issue 6 discussion.

Table 3: Residual External Dose from 1943 Centerless Grinding[a]

Year	Photon, R/yr	Beta, rad/yr	OTIB-70 Depletion Rate
9/28/43-12/31/43	0.003	0.265	1.00E+00
1944	0.010	1.017	1.00E+00
1945	0.008	0.797	7.83E-01
1946	0.006	0.624	6.13E-01
1947	0.005	0.488	4.80E-01
1948	0.004	0.383	3.76E-01
1949	0.003	0.299	2.94E-01
1950	0.002	0.235	2.31E-01
1951	0.002	0.184	1.81E-01
1952	0.001	0.143	1.41E-01
1953	0.001	0.113	1.11E-01
1954	0.001	0.088	8.67E-02
1955	0.001	0.069	6.79E-02
1956	0.001	0.054	5.32E-02
1957	0.000	0.042	4.16E-02
1958	0.000	0.033	3.26E-02
1959	0.000	0.026	2.55E-02
1960	0.000	0.020	2.00E-02
1961	0.000	0.016	1.56E-02
1962	0.000	0.012	1.23E-02
1963	0.000	0.010	9.60E-03
1964	0.000	0.008	7.51E-03
1965	0.000	0.006	5.88E-03
1966	0.000	0.005	4.61E-03
1967	0.000	0.004	3.61E-03
1968	0.000	0.003	2.83E-03
1969	0.000	0.002	2.21E-03
1970	0.000	0.002	1.73E-03
1971	0.000	0.001	1.36E-03
1972	0.000	0.001	1.06E-03
1973-1992	0.000	0.001	8.32E-04

a. Doses assigned as a lognormal distribution with a GSD of 5.

Second AWE Operational Period

The 1959-1967 AEC contract period involved work with uranium and plutonium in Building 1, which was a new Research and Development building that opened in 1953. Uranium work started in 1959; however, the plutonium laboratory did not start operations until 1961. The plutonium work involved a mixture of uranium and plutonium. Both the

uranium laboratory and the plutonium laboratory were located on the fourth floor; however, the plutonium laboratory was isolated. X-ray Diffraction (XRD) work occurred on the second floor.

Uranium: Annual external doses for the 1959-1967 uranium work is provided in Table 2 above, which were updated based on comments from SC&A on surrogate data.

Plutonium: Annual external doses for the 1961-1967 plutonium work is provided below in Table 4 below. The Table 4 dose estimates are the same as provided to the Board on July 23, 2015 with the Example DRs; however, the doses are now listed being applicable starting in 1961.

Table 4: Carborundum External Doses from Plutonium 1961-1967[a]

Photon Dose,[b] rem/yr			
	<30 keV	30-250 keV	>250 keV
Operator	1.074	2.166	1.258
Laborer	0.127	0.256	0.149
Supervisor	0.063	0.128	0.074
Clerical	0.006	0.013	0.007
Neutron Dose,[c] rem/yr			
	10-100 keV	0.1-2 MeV	2-20 MeV
Operator	0.001	0.109	0.183
Laborer	0.000	0.013	0.022
Supervisor	0.000	0.007	0.011
Clerical	0.000	0.001	0.001

a. Doses assigned as a constant distribution.
b. Photon doses to organs are calculated using the personal dose equivalent, $H_p(10)$, organ dose conversion factors. From the NIOSH External Dose Reconstruction Implementation Guideline.
c. Neutron dose to organs are calculated using the deep dose equivalent, $H_{p,\,slab}(10)$, organ dose conversion factors from NIOSH External Dose Reconstruction Implementation Guideline.

XRD: NIOSH provided dose estimates to the Work Group for the Carborundum XRD work (Thomas, 2016). The annual dose was estimated to be 0.167 R/year, as shown in Table 5. Based on descriptions of job dose categories provided with this paper and the NIOSH XRD evaluation, an XRD technician is assigned to the Laborer category. Dose estimates for the Supervisor and Clerk category are also provided in Table 5. Dose for the Operator dose category was not provided for XRD work because the higher dose for an Operator would come from work in the uranium or plutonium areas of Building 1.

Table 5: External Photon Dose from XRD, R/yr[a]

Year	Operator	XRD Technician	Supervisor	Clerk
1959-1967	N/A	0.167	0.084	0.008

a. Doses assigned as a constant distribution.

Second Residual Period

External doses from residual contamination from the 1959 - 1967 work were estimated. All photon doses were less than 0.001 R/yr and all beta doses were less than 0.001 rad/yr.

Annual External Doses for Dose Reconstructions

The annual doses provided in Tables 1 through 5 were used to determine the most favorable dose for each category of worker for each year. Those doses are provided in Tables 6 and 7 for photon doses and electron doses, respectively. Those values are to be used for dose reconstructions.

Table 6: Carborundum External Photon Doses for Dose Reconstructions

Year	Operator	Laborer	Supervisor	Clerk	Units
1943[a,e]	0.210	0.023	0.011	N/A	rem, Hp(10)
1943	0.003[e]	N/A	N/A	N/A	R
1944	0.010[e]	N/A	N/A	N/A	R
1945	0.008[e]	N/A	N/A	N/A	R
1946	0.006[e]	N/A	N/A	N/A	R
1947	0.005[e]	N/A	N/A	N/A	R
1948	0.004[e]	N/A	N/A	N/A	R
1949	0.003[e]	N/A	N/A	N/A	R
1950	0.002[e]	N/A	N/A	N/A	R
1951	0.002[e]	N/A	N/A	N/A	R
1952	0.001[e]	N/A	N/A	N/A	R
1953	0.001[e]	N/A	N/A	N/A	R
1954	0.001[e]	N/A	N/A	N/A	R
1955	0.001[e]	N/A	N/A	N/A	R
1956	0.001[e]	N/A	N/A	N/A	R
1957	<0.001	N/A	N/A	N/A	R
1958	<0.001	N/A	N/A	N/A	R
1959[c]	0.231[e]	0.167[c,d]	0.084[c,d]	0.008[c,d]	rem, Hp(10); R
1960[c]	0.231[e]	0.167[c,d]	0.084[c,d]	0.008[c,d]	rem, Hp(10); R
1961	Pu dose[b]	Pu dose	Pu dose	Pu dose	
1962	Pu dose	Pu dose	Pu dose	Pu dose	
1963	Pu dose	Pu dose	Pu dose	Pu dose	
1964	Pu dose	Pu dose	Pu dose	Pu dose	
1965	Pu dose	Pu dose	Pu dose	Pu dose	
1966	Pu dose	Pu dose	Pu dose	Pu dose	
1967	Pu dose	Pu dose	Pu dose	Pu dose	
1968-end	<0.001	N/A	N/A	N/A	rem, Hp(10)

a. For efficiency purposes, the first row of 1943 dose, reported in rem, includes dose from uranium metal (in rem), as well as dose from air submersion and contamination (in R). The air submersion and contamination components have been adjusted to allow use of the Hp(10) organ factors.
b. For Pu dose, see Table 4 for photon and neutron doses.
c. 1959-1969 dose to Laborer, Supervisor, and Clerk is from XRD dose estimates in Roentgens.
d. Doses assigned as a constant distribution.
e. Doses assigned as a lognormal distribution with a GSD of 5.

Table 7: Carborundum External Beta Doses for Dose Reconstructions[a,b]

	Operator	Laborer	Supervisor	Clerk	Units
1943	2.369	1.184	0.182	N/A	rem
1943	0.265	N/A	N/A	N/A	rem
1944	1.017	N/A	N/A	N/A	rem
1945	0.797	N/A	N/A	N/A	rem
1946	0.624	N/A	N/A	N/A	rem
1947	0.488	N/A	N/A	N/A	rem
1948	0.383	N/A	N/A	N/A	rem
1949	0.299	N/A	N/A	N/A	rem
1950	0.235	N/A	N/A	N/A	rem
1951	0.184	N/A	N/A	N/A	rem
1952	0.143	N/A	N/A	N/A	rem
1953	0.113	N/A	N/A	N/A	rem
1954	0.088	N/A	N/A	N/A	rem
1955	0.069	N/A	N/A	N/A	rem
1956	0.054	N/A	N/A	N/A	rem
1957	0.042	N/A	N/A	N/A	rem
1958	0.033	N/A	N/A	N/A	rem
1959	2.312	1.156	0.117	<0.001	rem
1960	2.312	1.156	0.117	<0.001	rem
1961	Pu dose	1.156	Pu dose	Pu dose	
1962	Pu dose	1.156	Pu dose	Pu dose	
1963	Pu dose	1.156	Pu dose	Pu dose	
1964	Pu dose	1.156	Pu dose	Pu dose	
1965	Pu dose	1.156	Pu dose	Pu dose	
1966	Pu dose	1.156	Pu dose	Pu dose	
1967	Pu dose	1.156	Pu dose	Pu dose	
1968	0.003	N/A	N/A	N/A	rem
1969	0.002	N/A	N/A	N/A	rem
1970	0.002	N/A	N/A	N/A	rem
1971-end	0.001	N/A	N/A	N/A	rem

a. For dose to the hands and forearms (1943, 1959-1967 only), use dose from the appropriate year in Battelle-TBD-6000, Table 6.4.

b. Listed doses assigned as a lognormal distribution with a GSD of 5. Pu doses assigned as a constant distribution.

Updated Internal Dose Estimates

First AWE Operational Period

Intake rates of uranium (total alpha) during the 1943 centerless grinding work are provided in Table 8. The Table 8 intake estimates are the same as provided to the Board on July 23, 2015, with the Example DRs.

Table 8: Intakes from Centerless Grinding[a,b]

Uranium Alpha Intake Rates		
Job Category	**Inhalation (dpm/calendar day)**	**Ingestion (dpm/calendar day)**
Operator	43,632	895
Labor	21,816	446
Supervisor	10,909	224
Clerk	1,090	22

a. Assigned as a lognormal distribution with a GSD of 5.
b. No intakes are assigned prior to June 1, 1943, as no source material was on site.

First Residual Period Intakes

Intake rates of uranium (total alpha) from residual contamination from the 1943 work are provided below. The *inhalation* rate is the same as previously provided for *Production Areas*. Non-production area estimates have been omitted in the updated calculations. The *ingestion* rate has been revised upward by setting the ingestion rate at the beginning of the residual period equal to the ingestion rate during the operational period, then it gradually declines according to the depletion rate.

Table 9: Intakes from Residual Contamination from Centerless Grinding[a]

	Inhalation	Ingestion	
Year	**dpm/day**	**dpm/day**	**OTIB-70 Depletion Rate**
9/28/43-12/31/43	876	895	1.00E+00
1944	876	895	1.00E+00
1945	686	701	7.83E-01
1946	537	549	6.13E-01
1947	420	430	4.80E-01
1948	329	337	3.76E-01
1949	257	263	2.94E-01
1950	202	207	2.31E-01
1951	158	162	1.81E-01
1952	123	126	1.41E-01
1953	97	99	1.11E-01
1954	76	78	8.67E-02
1955	59	61	6.79E-02
1956	47	48	5.32E-02
1957	36	37.2	4.16E-02
1958	29	29.2	3.26E-02
1959	22	22.8	2.55E-02
1960	17	17.9	2.00E-02
1961	14	14.0	1.56E-02
1962	11	11.0	1.23E-02
1963	8.4	8.6	9.60E-03
1964	6.6	6.7	7.51E-03
1965	5.2	5.3	5.88E-03
1966	4.0	4.1	4.61E-03
1967	3.2	3.23	3.61E-03
1968	2.5	2.53	2.83E-03
1969	1.9	1.98	2.21E-03
1970	1.5	1.55	1.73E-03
1971	1.2	1.21	1.36E-03
1972	0.93	0.95	1.06E-03
1973-1992	0.73	0.74	8.32E-04

a. Doses assigned as a lognormal distribution with a GSD of 5.

Second AWE Operational Period

Intake estimates for the 1959-1967 AWE Operational Period have been revised for both uranium and plutonium. Plutonium intake rates increased and uranium intake rates decreased. These changes were made after review of comments from SC&A on the statistical methods used to analyze and report the distribution of uranium and plutonium air sample data. The updated NIOSH evaluation of the air sample data is essentially identical to the values reported by SC&A in Appendix A of their ER Review.

Table 10: Uranium Intakes 1959-1967[a,b]

Job Category	Inhalation (dpm/calendar day)	Ingestion (dpm/calendar day)
Operator	97.10	1.94
Labor	48.55	0.971
Supervisor	24.28	0.486
Clerk	2.428	0.049

a. Intakes are assessed as 100% Uranium-234.
b. Doses assigned as a constant distribution.
c. See Table 11 for intake ratios of associated radionuclides.

In the case of uranium intakes, 100% recycled uranium is assumed based on guidance in TBD-6000. The relative intakes to uranium (applied as U-234) are provided in Table 11.

Table 11: Recycled Uranium Ratios Applied

U-234	**Pu-239**	**Np-237**	**Tc-99**	**Th-232**	**Th-228**
1.00E+00	2.46E-03	1.82E-03	3.79E-01	2.73E-06	2.73E-06

Table 12: Plutonium Intakes 1961-1967[a,b]

Plutonium Mixture Total Alpha Intake Rates		
Job Category	**Inhalation (dpm/calendar day)**	**Ingestion (dpm/calendar day)**
Operator	7.650	0.153
Labor	3.825	0.077
Supervisor	1.913	0.038
Clerk	0.191	0.004

a. Doses assigned as a constant distribution.
b. See Table 13 for partitioning of these total alpha values into individual radionuclides.

Intakes of individual plutonium radionuclides are assigned according to the ratios of individual radionuclides to the total plutonium alpha intakes shown in Table 13.

Table 13: Plutonium Ratios

Pu-239:Total Alpha	0.802
Pu-240:Total Alpha	0.185
Pu-241:Total Alpha	8.168
Am-241:Total Alpha	0.013

Second Residual Period Intakes

Intake rates of uranium (total alpha) from residual contamination from the 1959-167 work are provided below in Table 14. The *inhalation* rate is the slightly lower than previously provided for *Production Areas* due to updated statistical methods to estimate uranium air concentration. Non-production area estimates have been omitted in the updated calculations. The *ingestion* rate has been revised upward by setting the ingestion rate at the beginning of the residual period equal to the ingestion rate during the operational period, then it gradually declines according to the depletion rate.

Table 14: Intakes from Residual Contamination from 1959-1967 Uranium Work[a,b]

	Inhalation	Ingestion	
Year	**dpm/day**	**dpm/day**	**OTIB-70 Depletion Rate**
1968	0.94	1.012	1.00E+00
1969	0.74	0.792	7.83E-01
1970	0.58	0.620	6.13E-01
1971	0.45	0.486	4.80E-01
1972	0.35	0.380	3.76E-01
1973	0.28	0.297	2.94E-01
1974	0.22	0.234	2.31E-01
1975	0.17	0.183	1.81E-01
1976	0.13	0.143	1.41E-01
1977	0.10	0.112	1.11E-01
1978	0.082	0.088	8.67E-02
1979	0.064	0.069	6.79E-02
1980	0.050	0.054	5.32E-02
1981	0.039	0.042	4.16E-02
1982	0.031	0.033	3.26E-02
1983	0.024	0.026	2.55E-02
1984	0.019	0.020	2.00E-02
1985	0.015	0.016	1.56E-02
1986	0.012	0.012	1.23E-02
1987	0.0091	0.010	9.60E-03
1988	0.0071	0.0076	7.51E-03
1989	0.0056	0.0060	5.88E-03
1990	0.0043	0.0047	4.61E-03
1991	0.0034	0.0036	3.61E-03
1992	0.0027	0.0029	2.83E-03

a. See Table 11 for intake ratios of associated radionuclides.
b. Doses assigned as a constant distribution.

Updated intakes of plutonium from residual contamination are provided in Table 15. Intakes are higher than in the previous methodology due to updated statistical methods used to estimate plutonium air concentrations.

Table 15: Intakes from Residual Contamination from 1961-1967 Plutonium Work[a,b,c]

	Inhalation	Ingestion	
Year	**dpm/day, total alpha**	**dpm/day, total alpha**	**OTIB-70 Depletion Rate**
1968	0.15	0.159	1.00E+00
1969	0.12	0.125	7.83E-01
1970	0.091	0.098	6.13E-01
1971	0.071	0.077	4.80E-01
1972	0.056	0.060	3.76E-01
1973	0.044	0.047	2.94E-01
1974	0.034	0.037	2.31E-01
1975	0.027	0.029	1.81E-01
1976	0.021	0.022	1.41E-01
1977	0.017	0.018	1.11E-01
1978	0.013	0.014	8.67E-02
1979	0.0101	0.011	6.79E-02
1980	0.0079	0.0085	5.32E-02
1981	0.0062	0.0066	4.16E-02
1982	0.0048	0.0052	3.26E-02
1983	0.0038	0.0041	2.55E-02
1984	0.0030	0.0032	2.00E-02
1985	0.0023	0.0025	1.56E-02
1986	0.0018	0.0020	1.23E-02
1987	0.0014	0.0015	9.60E-03
1988	0.0011	0.0012	7.51E-03
1989	0.00088	0.00094	5.88E-03
1990	0.00069	0.00073	4.61E-03
1991	0.00054	0.00058	3.61E-03
1992	0.00042	0.00045	2.83E-03

a. Intake rates have been normalized to units of dpm/calendar day.
b. Doses assigned as a constant distribution.
c. See Table 13 for partitioning of these total alpha values into individual radionuclides.

Assignment of Intakes

For dose reconstruction purposes it is assumed that a worker was in either in a uranium area or a plutonium area. The residual uranium intakes from the 1943 centerless grinding work in Table 9 provide higher doses than the intakes from the later uranium work for Building 1 in Table 14. Therefore, Table 14 will not be used for dose reconstruction purposes. DRs will use either Table 9 or Table 15 for internal dose calculations, whichever provides the higher dose. The intake options are consolidated below in Table 16.

Table 16: Intakes for Dose Reconstructions

Year	Intake Tables to use
1943	Tables 8 and 9
1944	Table 9
1945	Table 9
1946	Table 9
1947	Table 9
1948	Table 9
1949	Table 9
1950	Table 9
1951	Table 9
1952	Table 9
1953	Table 9
1954	Table 9
1955	Table 9
1956	Table 9
1957	Table 9
1958	Table 9
1959	Table 10[a]
1960	Table 10[a]
1961	Table 10[a] or Table 12
1962	Table 10[a] or Table 12
1963	Table 10[a] or Table 12
1964	Table 10[a] or Table 12
1965	Table 10[a] or Table 12
1966	Table 10[a] or Table 12
1967	Table 10[a] or Table 12
1968-1992	Table 9 or Table 15

a. Table 10 intakes also include associated radionuclides listed in Table 11.

References

Anigstein, R. A., 2016, *Review of the Carborundum Special Exposure Cohort (SEC) Petition-00223 and the NIOSH SEC Petition Evaluation Report*, SC&A-TR-SEC-2016-0001, Revision 1, January 27, 2016.

Anigstein, R. and Mauro, J, *Review of NIOSH Use of Surrogate Data in the SEC Evaluation Report for Carborundum*, memorandum to Advisory Board on Radiation and Worker Health, Work Group on Carborundum Company, November 10, 2016.

Battelle-TBD-6000, *Site Profiles for Atomic Weapons Employers that Worked Uranium Metals*, *Revision 1*, June 17, 2011.

NIOSH, 2015, *SEC Petition Evaluation Report, Petition SEC-00223*, Revision 1, June 3, 2015.

ORAUT-OTIB-070, *Technical Information Bulletin: Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities, Revision 1*, March 5, 2012.

ORAUT-OTIB-006, *Dose Reconstruction from Occupational Medical X-Ray Procedures*, Revision 4, June 20, 2011.

Thomas, E., 2016, *External Dose Assessment from X-ray Diffraction at Carborundum Company, Niagara Falls, NY*, June 13, 2016.

Tomes, T. P., 2016a, *NIOSH Response to SC&A Findings on SEC-00223, Carborundum Company, Niagara Falls*, NY, June 8, 2016.

Tomes, T. P., 2016b, *Use of Surrogate Data at the Carborundum Company*, memorandum to Carborundum Work Group, October 27, 2016.

Appendix A
SC&A Comments and Observations on NIOSH Dose Estimates

SC&A provided numerous observations and comments on the dose estimation methods NIOSH used in the Example DRs. NIOSH went through the SC&A report and listed all issues deemed to have significance to dose calculations or interpretations needed to perform dose reconstructions. Those comments are summarized by category below, and a NIOSH response to each is provided. The summaries of the SC&A Observations below have parenthetical references to sections in the SC&A's *ER Review*. Comments related to identified Issues/Findings are not listed because they have been addressed separately.

Comments on External Dose from Plutonium	
SC&A Observation	**NIOSH Response**
NIOSH should reevaluate the assumptions used for plutonium source material and the age of the material, based on references that two different sources of plutonium were used and noting the 1959-1967 duration of the project. They also commented that some of the glovebox and other model parameters should be changed. (sec. 4.7, 4.8, 5.1.2, Att. B)	The MCNP-modeled doses were under revision at the time the ER was written and approved. NIOSH revised the MCNP model in 2015 to address comments provided from SC&A on a DR review. The updated doses were provided in the Example DR and supporting files provided to the Board July 23, 2015. The additional comments received on the MCNP assumptions are currently under review by NIOSH.

Comment on Composition of Plutonium Intakes	
SC&A Observation	**NIOSH Response**
SC&A commented that the assumed activity fractions of plutonium may need to be changed to consider different plutonium material and age of material. (sec. 4.12, 5.2.2)	This comment affects how the total alpha intakes are divided into individual radionuclide components. The composition of the plutonium source material and age is under review in conjunction with the comments on the MCNP-modeled external dose.

Comments on Plutonium Air Concentration and Intake Estimates	
SC&A Observation	**NIOSH Response**
SC&A recommended NIOSH use a regression of order (ROS) statistical analysis to evaluate plutonium air sample results (total	NIOSH has re-evaluated the plutonium air sample results and agrees to use the results as interpreted by SC&A. The results of the

Comments on Plutonium Air Concentration and Intake Estimates	
SC&A Observation	**NIOSH Response**
alpha in air), and noted and assumed error in interpretation of a recorded result. SC&A provided an analysis of the plutonium air samples in Appendix A of their ER Review. SC&A commented that if the intake estimate changes, intakes in both the AWE Operational and Residual periods need to be updated accordingly. (sec. 4.10, 4.12, 4.13, 5.2.2, 5.2.3, App. A)	NIOSH ROS analysis was identical to the results reported by SC&A. Inhalation and ingestion intakes calculations for the AWE Operational and Residual periods have been updated accordingly.

Comments on Uranium Air Concentration and Intake Estimates	
SC&A Observation	**NIOSH Response**
SC&A recommended NIOSH use a regression of order (ROS) statistical analysis to evaluate uranium air sample results (total alpha in air). SC&A provided an analysis of the uranium air samples in Appendix A of their ER Review. SC&A commented that if the intake estimate changes, intakes in both the AWE Operational and Residual periods need to be updated accordingly. (sec. 4.13, 5.2.2, 5.2.3, App. A)	NIOSH has re-evaluated the uranium air sample results and agrees to use the results as interpreted by SC&A. The results of the NIOSH ROS analysis was nearly identical to the results reported by SC&A. Inhalation and ingestion intakes calculations for the AWE Operational and Residual periods have been updated accordingly.

Various Comments on DR Assumptions and Instructions	
SC&A Observation	**NIOSH Response**
(1) Comment that instructions should specify the Operator dose category for internal and external dose unless there is evidence to the contrary. Another comment said that more information and guidance is needed to determine job categories for assignment of dose. (sec. 4.14)	(1) NIOSH agrees that the Operator dose will be the default. When job title or other information is available, professional judgement will be used to determine the dose category. Additional instruction will be added to the updated site profile. Note: this comment only affects the AWE Operational periods. The updated dose methods for the residual periods have a single category of doses and intakes.
(2) Comment that residual periods' external doses should be based on radiological operational areas rather than an option for lower dose in other areas or buildings.	(2) NIOSH agrees. The updated dose tables provide only a single set of residual dose and intake rates for all residual years. Additionally, the non-operational area dose category (Clerk) has been omitted in the

Various Comments on DR Assumptions and Instructions	
SC&A Observation	**NIOSH Response**
	updated tables for the 1st AWE Operational Period because the 1943 work location is unknown.
(3) Comment that the work location providing the largest dose should be assigned for external dose and internal dose independently, such that a dose reconstructor should not determine the most favorable location based on a combination of external doses and internal doses. (sec. 5.1.2)	(3) NIOSH considered the options and discussion by SC&A. Consideration was also given to the difficulty in implementing a requirement to determine the most favorable work location for a given claim, a given organ, and for claims with multiple cancers. Therefore, updated tables are provided that list maximum external doses by year and maximum intake rates by year without linking the two, in agreement with the SC&A comment.
(4) Comment that SC&A concurs that external dose from uranium work or from plutonium work, not both, should be assigned to Operators and support dose categories. However, they argue that the non-radiological areas (Clerk dose category) should be assigned dose from both. (sec. 5.1.2)	(4) NIOSH disagrees. The dose for the Clerk category is defined as a function of the dose from the other worker categories. Regardless, the Clerk category has been removed from the 1943 dose estimates, and the updated external dose estimates for the Clerk category in 1959-1967 is 0.001 rem; it is insignificant compared to the estimate for Pu areas. This comment is not applicable to the updated dose estimates in the residual years.
(5) SC&A commented that the instructions on selection of appropriate category of DCFs for photon and neutron dose from plutonium work is not clear enough. (sec. 5.1.2)	(5) The updated site profile will use more clear descriptions of the DCF category. These are provided as footnotes to Table 4 in this document.
6) SC&A commented that in 1959-1967 workers should be assigned intakes from both plutonium and uranium because work was not performed in discreet areas. (sec. 5.2.2)	(6) NIOSH disagrees. Uranium work began in 1959 in the uranium lab. The first plutonium work began in 1961 in an isolated plutonium lab, so plutonium is not considered a source of exposure until 1961. Starting in 1961, workers may have worked in the uranium lab or in the plutonium lab, which involved a mixture of plutonium and uranium. However, NIOSH has no means to divide ones work hours into fractions of one area or another. Therefore, for 1961-1967 doses are to be assigned to whichever location provides the highest doses.

Comments on Calculations	
SC&A Observation	**NIOSH Response**
(1) SC&A had multiple comments on the use of the incorrect category of organ dose conversion factors (DCFs) in the Example DRs. (sec. 4.16, 5.1.1, 6.3)	The updated doses in this report explicitly state the correct dose units and appropriate conversion factors. NOTE: the previous Example DRs had combined multiple dose components, with different dose quantities reported, into a single annual dose, then applied the most favorable organ DCF. It was favorable, but resulted in some overestimates.
(2) SC&A commented that there was a large error in the NIOSH calculation for skin dose in the spreadsheet for 1943. (sec. 5.1.1)	NIOSH checked the calculation. There was no error; however, two components of the total skin dose were combined in the spreadsheet cell that was referred by SC&A. NOTE: the values have been updated based on other comments.
(3) SC&A commented that the methodology document cited TBD-6000 to support an assumption that non-operational area doses were 10% of operational area doses in the residual period. (sec. 4.17)	NIOSH has eliminated the non-operational dose category from residual period dose estimates; therefore, the comment is not applicable to the updated dose estimates.
(4) SC&A commented that factors applied for depletion of contamination should end after 30 years. (sec. 5.2.3)	(4) NIOSH agrees and has provided updated calculations.
(5) SC&A commented that dose from Pu should not be assigned in 1959 and 1960. (sec. 6.1)	(5) NIOSH agrees and has provided updated dose tables.

Appendix B

Chronological List of Previous Reports and Discussion Documents and Meetings with NIOSH, the Board, and SC&A on Review of Petition SEC-00223

SEC Petition 00223 received by NIOSH on November 19, 2014.

SEC Petition Evaluation Report, Petition SEC-00223, Revision 0, NIOSH, May 26, 2015.

SEC Petition Evaluation Report, Petition SEC-00223, Revision 1, NIOSH, June 3, 2015.
NOTE: Revision 1 was issued to correct a date and document number for an interview described in Section 4.3 and in the References section.

Review of the Carborundum Special Exposure Cohort (SEC) Petition-00223 and the NIOSH SEC Petition Evaluation Report, SC&A, Revision 0, January 25, 2016.

Review of the Carborundum Special Exposure Cohort (SEC) Petition-00223 and the NIOSH SEC Petition Evaluation Report, SC&A, Revision 1, January 27, 2016.
NOTE: In revision 1 SC&A revised the discussion of an issue and updated the References. All responses from NIOSH were based on revision 1.

NIOSH Response to SC&A Findings on SEC-00223, Carborundum Company, Niagara Falls, NY, NIOSH, June 8, 2016.

External Dose Assessment from X-ray Diffraction at Carborundum Company, Niagara Falls, NY, Response Paper, Rev. 01, NIOSH June 13, 2016.

Advisory Board on Radiation and Worker Health, Carborundum Work Group, Transcripts of August 18, 2016, teleconference.

Use of Surrogate Data at the Carborundum Company, NIOSH memorandum to Carborundum Work Group, October 27, 2016.

Review of NIOSH Use of Surrogate Data in the SEC Evaluation Report for Carborundum, SC&A memorandum to Carborundum Work Group, November 10, 2016.

Advisory Board on Radiation and Worker Health, Carborundum Work Group, Transcripts of November 17, 2016, teleconference.

Advisory Board on Radiation and Worker Health, Carborundum Work Group, Transcripts of November 30, 2016, meeting, discussion on Carborundum, pp. 74-113.