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ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

A REVIEW OF NIOSH'S PROGRAM EVALUATION REPORT DCAS-PER-073, "BIRDSBORO STEEL AND FOUNDRY COMPANY"

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Prepared by

Robert Anigstein, PhD

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

Saliant, Inc.
5579 Catholic Church Road
Jefferson, Maryland 21755

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TASK MANAGER	Robert Anigstein, PhD [signature on file]
PROJECT MANAGER:	John Stiver, MS, CHP [signature on file]
DOCUMENT REVIEWER(S):	John Mauro, PhD, CHP [signature on file] Kathleen Behling [signature on file]

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ABBREVIATIONS AND ACRONYMS

Board or ABRWH	Advisory Board on Radiation and Worker Health
Co	cobalt
DCAS	NIOSH Division of Compensation Analysis and Support
DOL	U.S. Department of Labor
dpm	disintegrations per minute
DR	dose reconstruction
DWA	daily weighted average
EE	energy employee
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FMPC	Feed Material Production Center
GSI	General Steel Industries, Inc.
H*(10)	ambient dose equivalent
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
kVp	kilovolts peak
LOOW	Lake Ontario Ordinance Works
mCi	millicurie
MCNPX	Monte Carlo N-Particle eXtended
mR	milliroentgen
mrem	millirem
MV	megavolt
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH OCAS Claims Tracking System
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
PA	postero-anterior
pCi	picocurie
PER	program evaluation report

PIC	pocket ionization chamber
POC	probability of causation
R	roentgen
Ra	radium
RF	resuspension factor
SEC	Special Exposure Cohort
TBD	technical basis document
TIB	technical information bulletin
U	uranium

1 STATEMENT OF PURPOSE

To support dose reconstruction (DR), the National Institute for Occupational Safety and Health (NIOSH) and the Oak Ridge Associated Universities Team (ORAUT) have assembled a large body of guidance documents, workbooks, computer codes, and tools. In recognition of the fact that all of these supporting elements in DR may be subject to revisions, provisions exist for evaluating the effect of such programmatic revisions on the outcome of previously completed DRs. Such revisions may be prompted by document revisions due to new information, misinterpretation of guidance, changes in policy, and/or programmatic improvements.

The process for evaluating potential impacts of programmatic changes on previously completed DRs has been proceduralized in OCAS-PR-008, Revision 2, “Preparation of Program Evaluation Reports and Program Evaluation Plans” (NIOSH 2006), dated December 6, 2006. This procedure describes the format and methodology to be employed in preparing a program evaluation report (PER).

A PER provides a critical evaluation of the effects that a given issue or programmatic change may have on previously completed DRs. This includes a qualitative and quantitative assessment of potential impacts. Most important in this assessment is the potential effect on the probability of causation (POC) of previously completed DRs with POCs of <50%.

During a meeting of the Advisory Board on Radiation and Worker Health (ABRWH) on December 14, 2017, in Albuquerque, New Mexico, SC&A was tasked by the Board to conduct reviews of two PERs, one of which is a Subtask 1–3 review of DCAS-PER-073, “Birdsboro Steel and Foundry Company” (NIOSH 2016). In conducting this PER review, SC&A is committed to perform the following three subtasks, each of which is discussed in this report:

- Subtask 1: Assess NIOSH’s evaluation and characterization of the issues and their potential impacts on DR. Our assessment intends to ensure that the issues were fully understood and characterized in the PER.

- Subtask 2: Assess NIOSH’s specific methods for corrective action. In instances where the PER involves a technical issue that is supported by documents (e.g., white papers, technical information bulletins [TIBs], and procedures) that have not yet been subjected to a formal SC&A review, Subtask 2 will include a review of the scientific basis and/or sources of information to ensure the credibility of the corrective action and its consistency with current/consensus science. Conversely, if such technical documentation has been formalized and previously subjected to a review by SC&A, Subtask 2 will simply provide a brief summary of this review process.

- Subtask 3: Evaluate the PER’s stated **approach** for identifying the universe of potentially affected DRs, and assess the **criteria** by which a subset of potentially affected DRs was selected for reevaluation. The second step may have important implications in instances where the universe of previously denied DRs is very large and, for reasons of practicality, NIOSH’s reevaluation is confined to a subset of DRs that, based on their scientific judgment, have the potential to be significantly affected by the PER. In behalf of Subtask 3, SC&A will also evaluate the timeliness of the completion of the PER.

- Subtask 4: Conduct audits of DRs affected by the PER under review.

The present review will encompass Subtasks 1–3, which have been authorized by the ABRWH. This review will also recommend criteria for selecting cases for future Subtask 4 audits.

2 SUBTASK 1: ASSESS NIOSH'S EVALUATION AND CHARACTERIZATION OF THE ISSUES THAT NECESSITATED DCAS-PER-073 AND ITS POTENTIAL IMPACTS ON DR

2.1 BACKGROUND

On December 13, 2006, Battelle (2006) issued TBD-6000, Rev. 0, a technical basis document (TBD) for use in reconstructing doses to workers at Atomic Weapons Employers that worked uranium and thorium metals. This was a generic document to be used in the absence of case-specific or site-specific data. Prior to that time, DRs for such workers utilized more generic documents and methods, such as ORAUT-OTIB-0004 (ORAUT 2003).

To facilitate DRs for work sites for which more detailed information was required, NIOSH prepared or commissioned a series of appendices to TBD-6000. These appendices constituted site profiles, which supplemented or replaced the generic data and guidance provided by TBD-6000. One such document was Appendix B, Rev. 0, a site profile of the Birdsboro Steel Foundry and Machine Company (Battelle 2007).

On June 17, 2011, the NIOSH Division of Compensation Analysis and Support (DCAS) issued TBD-6000, Rev. 1 (NIOSH 2011). Subsequent to this revision, NIOSH revised some of the previously issued appendices to ensure consistency with the revised TBD. One such revision was Appendix B, Rev. 1 (NIOSH 2015). On August 1, 2016, NIOSH (2016) issued a program evaluation report (DCAS-PER-073) that examined the effects of the revised appendix on all previously completed claims.

In order to assess the PER, we needed to review the changes implemented by Appendix B, Rev. 1. That, in turn, required an understanding of Appendix B, Rev. 0. Since neither document was previously reviewed by SC&A, we examined these reports in the course of our PER review.

2.2 APPENDIX B, REV. 0

We began our review with Appendix B, Rev. 0 (Battelle 2007). Appendix B, Rev. 0 (Battelle 2007), described the shipment of 346 pounds of uranium waste from Birdsboro to the Lake Ontario Ordinance Works (LOOW) (mistakenly identified as "Lake Ontario Ordinance Waste") in 1951, and the receipt by Birdsboro of four wafers cut from uranium rods, with a combined weight of 11.5 lb.[1] Appendix B specified four job categories—"Plant Floor High," "Plant Floor Low," "Supervisor," and "Clerk"—that corresponded to the four worker categories in TBD-6000: "Operator," "General Laborer," "Supervisor," and "Clerical." Appendix B also specified that occupational medical dose be assigned according to ORAUT (2005), the same guidance that was provided by TBD-6000.

2.2.1 Name of Facility

In reviewing contemporary and historical documents, we noted a change in the name used to refer to this facility. Historical documents contemporaneous with the operational period refer to

[1] This was actually the weight of five wafers received by Birdsboro (Smith 1952).

the facility as "Birdsboro Steel Foundry & Machine Company" (Smith 1952) or "Birdsboro Steel Foundry and Machine Company." Young (1987) appears to be the earliest reference to call the site "Birdsboro Steel & Foundry," while correctly referring to the owner as the "Birdsboro Steel Foundry & Machine Company." This mistaken appellation of the site was perpetuated in later Department of Energy documents and was adopted by NIOSH in the titles of Appendix B, Rev. 0 and Rev. 1.

Observation 1
We suggest that NIOSH refer to the site as the "Birdsboro Steel Foundry and Machine Company."

2.2.2 Occupational Internal Dose

To assess internal dose, Appendix B, Rev. 0 (Battelle 2007), assigned intakes of ^{234}U per calendar day for each year of the operational period, assuming that operator exposures in 1951 corresponded to those of a rolling operator and lasted 40 hours, while the 1952 exposures corresponded to those of a machining operator and lasted 8 hours. The inhaled intakes were calculated from the daily weighted average (DWA) air concentrations for rolling and machining operators listed in TBD-6000 (Battelle 2006, Tables 7.3 and 7.5). Intakes for the other job categories were based on the fractions of the exposure durations for these jobs:

- Plant Floor High: 100%
- Plant Floor Low: 50%
- Supervisor: 25%
- Clerk: 2.5%

SC&A confirmed that the inhaled intakes tabulated in Appendix B, Rev. 0 (Battelle 2007, Table B.2), were derived according to the methodology described in that document.

In Appendix B, Rev. 0, Battelle (2007, Table B.3) stated that it assigned daily ingested intakes of ^{234}U based on the "Generic Metal TBD" (i.e., TBD-6000, Battelle 2006). An explanatory note cited a conversion factor listed in TBD-6000, section 7.1.6. The latter document presented a formula for daily ingested intake to be entered into the Integrated Modules for Bioassay Analysis (IMBA). We applied this formula to derive the intakes of a rolling operator:

$$I_{IMBA} = 3.062 \times 10^{-5} \, Ah$$

where

I_{IMBA} = ingested intake
= 4.33 pCi/calendar day (1951)
= 1.34 pCi/calendar day (1952)

A = air concentration
= 3,533 dpm/m^3 (rolling)
= 5,480 dpm/m^3 (machining)

h = annual work hours
= 40 h (1951)
= 8 h (1952)

Comparing our values with the ingested intakes of ^{234}U listed in Appendix B, Rev. 0 (Battelle 2007, Table B.3)—1.95 pCi/d in 1951 and 0.605 pCi/d in 1952—we find that both values were lower than the corresponding values derived above by a factor of 2.22, which is the factor for converting activities in disintegrations per minute (dpm) to picocuries (pCi). It would appear that Battelle (2007) mistakenly divided the derived results by 2.22 to convert to pCi, despite the fact that, as stated by Battelle (2006, section 7.1.6), the formula in TBD-6000 already incorporated that conversion factor to yield a result in pCi. Thus, the ingested intakes listed in Appendix B are less than one-half the values that would have been obtained by correctly applying the methodology in TBD-6000.

2.2.3 Occupational External Dose

According to Appendix B, Rev. 0 (Battelle 2007), external doses were calculated on the basis of the "Generic Metal TBD" (i.e., TBD-6000, Battelle 2006). Table B.4 of the former document listed external whole-body exposures to an operator as 0.0312 and 0.00625 mR per calendar day in 1951 and 1952, respectively. We attempted to confirm these values by using the value of 6.27 mrem/d listed in TBD-6000 (Battelle 2006, Table 6.4) as the whole-body dose to an operator for 1951–1955. (The table listed the same value for all operations. The other contributions, from air submersion and exposure to a contaminated floor, are insignificant by comparison.) Since the listed value corresponds to a 2,200-h work year, we prorated the exposures to account for 40 h of work in 1951 and 8 h in 1952. We obtained values of 0.114 and 0.0228 mrem per calendar day, almost 4 times higher than those in Appendix B, Rev. 0 (Battelle 2007, Table B.4). We cannot explain this discrepancy.

2.3 APPENDIX B, REV. 1

Appendix B, Rev. 1 (NIOSH 2015) was issued on June 2, 2015. The new document was a complete rewrite of the original appendix and reflected a reappraisal of the site history and operations. We will briefly examine the differences between Appendix B, Rev. 0 and Rev. 1. A more detailed analysis of Rev. 1 was performed under Subtask 2 of the present review and reported in section 3.

Table 1 presents a comparison of the exposure pathways in the two documents. For the purpose of this comparison, the intakes in Appendix B, Rev. 1, which were stated in terms of dpm per calendar day, but limited to the actual period of operations during 1951, are scaled to the entire year and displayed in pCi/d. As shown in the table, both the inhaled intakes and the external exposures are higher in Rev. 0 than in Rev. 1. However, the ingested intakes in Rev. 1 are higher by one to two orders of magnitude.

Table 1. Comparison of Exposure Pathways in Appendix B, Rev. 0 and Rev. 1

Year	Inhaled intake (pCi/d)		Ingested intake (pCi/d)		External exposure (mrem/y)	
	Rev. 0	Rev. 1	Rev. 0	Rev. 1	Rev. 0	Rev. 1
1951	209	42.93	1.95	30.68	11.42	10.4
1952	64.92	45.72	0.605	154.50	2.28	1.28

2.4 DCAS-PER-073

It was not possible to determine ab initio whether the doses to a particular organ or tissue in a particular DR would go up or down as a result of the revision to Appendix B (NIOSH 2015). For cancers involving the respiratory tract, the time-dependent dose coefficients for inhaled particulates of ^{234}U are three or more orders of magnitude higher than for the ingestion pathway (ICRP 2001). In such cases, the higher inhaled intakes prescribed by Appendix B, Rev. 0 (Battelle 2007), would outweigh the effect of the lower ingested intakes, and the use of the earlier document would be more claimant favorable. However, this is not true for other tissues. Therefore, given the very large discrepancy between the ingested intake rates of Appendix B, Rev. 0 and Rev. 1, NIOSH needed to review any DRs that had been performed using the earlier methodology that had been denied because the POC was less than 50%. On August 1, 2016, NIOSH (2016) issued PER-073.

2.5 Reviewer's Comments

The operational period at Birdsboro spanned only two years: 1951 and 1952. In both years, the ingested intakes prescribed by Appendix B, Rev. 1 (NIOSH 2015), were significantly higher than those listed in Rev. 0 (Battelle 2007). Consequently, it was not possible to exclude any cases by period of employment. Given that DRs had been performed for only four former Birdsboro employees, NIOSH made the expedient decision to perform new DRs for all four cases under the PER.

3 SUBTASK 2: ASSESS NIOSH'S SPECIFIC METHODS FOR CORRECTIVE ACTION

The reason stated by NIOSH (2015) for revising Appendix B was to conform to the revision to TBD-6000 (NIOSH 2011). A comparison of the revised TBD to the original version (Battelle 2006) shows that there were no significant changes in the exposure pathways for organs other than skin that would affect the Birdsboro site profile. However, NIOSH did perform a fundamental revision of the exposure scenarios, based on a reassessment of the handling and working of uranium metal at Birdsboro, resulting in major changes in the exposure scenarios. Another fundamental change was in the methodology used to assess the ingestion pathway.

3.1 Site Activities

Both Appendix B, Rev. 0 (Battelle 2007), and Appendix B, Rev. 1 (NIOSH 2015), cited the role of Birdsboro in designing a uranium rolling mill for use at the Feed Materials Production Center (FMPC) in Fernald, Ohio. As discussed in section 2.2 of the present review, Battelle cited the shipment of eight assorted pieces of uranium billets, weighing 346 lb, from Birdsboro to LOOW in 1951 and assumed that these uranium pieces had been rolled at Birdsboro. Battelle assumed that the work took one week (40 h). Battelle noted that, in a telephone interview, a claimant said that Birdsboro "built a press to crush and press uranium" (NIOSH 2003a). Battelle concluded that the 11.5 lb of uranium wafers received by Birdsboro in 1952 were used in the development of uranium slug design, and that the work took one day (8 h).

In Appendix B, Rev. 1, NIOSH (2015) postulated that Birdsboro had received the uranium metal in order to perform microscopic analyses of the metal surfaces. NIOSH assumed that Birdsboro cut the pieces to prepare samples for the analyses, and that the work took one-fifth of the 44-h workweek assumed for this time period (NIOSH 2011). NIOSH (2015) postulated that Birdsboro received the billets on April 17, 1951, the earliest date that billets were produced at Simonds Saw and Steel Co. in support of the design of the FMPC rolling mill. The machining of the billets at Birdsboro was assumed to take place on the same day. The machining of the five wafers was assumed to take place on February 1, 1952, the day the pieces were shipped to Birdsboro.

3.1.1 Reviewer's Comments

The assumption in Appendix B, Rev. 0 (Battelle 2007), regarding the rolling of uranium billets, is reasonable, since Birdsboro was responsible for designing a uranium rolling mill for use at the FMPC. According to the Steel Founders' Society of America (1961), Birdsboro operated a roll foundry in 1961. Detailed information for earlier years is not readily available, but it is reasonable to assume that the roll foundry was present during the covered period, which was why Birdsboro was selected to design the rolling mill at Fernald. The assumption that the rolling took one week is a claimant-favorable, high-end estimate. To cite a randomly selected example, Taussig (1948) stated that the Joslyn Manufacturing and Supply Co., then under contract to the Atomic Energy Commission, could roll 35 tons of uranium rods in 5 d. However, this was the capability of an experienced facility operating in production mode. The work at Birdsboro was developmental, so the throughput would likely have been much lower. Battelle (2007) described the shipment to LOOW as waste, although this designation does not appear in either Malone (1951a) or Malone (1951b), the only available references for this shipment. This description most likely originated with the mistaken identification of the acronym as "Lake Ontario Ordinance Waste" rather than Lake Ontario Ordinance Works. Since eight billets could have been easily rolled in one day, the duration of work assumed in Appendix B, Rev. 1 (NIOSH 2015), is also reasonable and more likely than a 1-week duration.

Observation 2

The statement that TBD-6000 assumed that the standard workday was 8.8 hours is based on a misinterpretation. In fact, TBD-6000 assumed a 44-h week, which was based on working 8 h/d Monday–Friday and working half a day (4 h) on Saturday (Sopher 2014).

It is more plausible and, as will be shown, claimant favorable, to assume that Birdsboro used the 346 lb of billets for rolling than to assume it acquired these pieces, with an average weight of 43 lb, for microscopic examination. However, that is a likely assumption for the wafers that were received in 1952. Smith (1952) stated that these samples, which were 1–2 inches thick and weighed between 1.9 and 2.6 lb, were cut from a rolling at the Bethlehem Steel plant in Lackawanna, New York. Such uranium pieces would have been between 1.3 and 2.2 inches in diameter, which is consistent with the reported diameter of 1.41 inches of rods rolled at Lackawanna (Kattner and Riches 1951).

Although it would have a trivial effect on the estimated doses, we observe that the assumed dates of operations are implausible. If the billets were rolled at Simonds Saw and Steel in Lockport, New York, on April 17, 1951, it is implausible that they could have been machined on the same day at Birdsboro, which is over 300 miles away, especially since the machining was assumed to take an entire workday. A more likely date would be April 19, 1951, allowing one day for shipment after the rolling. Likewise, the wafers were shipped by Railway Express, a commercial carrier, from Model City, New York, also over 300 miles from Birdsboro, on February 1, 1952, which fell on a Friday. It is implausible that they could have been machined at Birdsboro on the same day. The earliest plausible date would be February 4, the following Monday.

Observation 3

We recommend that NIOSH adopt April 19, 1951, as the date for processing the 346 lb of billets and April 19, 1951, for working on the five wafers.

3.2 Revised Occupational Internal Dose

3.2.1 Inhaled Intakes

In Appendix B, Rev. 1, NIOSH (2015) assumed an air concentration with a geometric mean of 3,160 dpm/m^3 during operations in both 1951 and 1952. This concentration was based on a review of the air sampling data tabulated in TBD-6000 (NIOSH 2011, section 7.1.2). Having dismissed both rolling and centerless grinding as operations that did not take place at Birdsboro, NIOSH (2015) selected the DWA for the surface grinder listed in TBD-6000, Table 7.5, the next highest DWA concentration listed in Tables 7.2–7.7. The inhaled intakes were based on exposure to this concentration for 8.8 h in each year. NIOSH (2015) also assumed that this airborne activity settled to the floor during this period of operations at a rate of 0.00075 m/s, resulting in a surface contamination of 75,082 dpm/m^2. This activity then became resuspended. Using a resuspension factor (RF) of 1×10^{-5} m/s, NIOSH derived an airborne activity of 0.751 dpm/m^3, which it used to calculate intakes during the working hours following the first operation in 1951 until the second operation in 1952. The second surface grinding operation, assumed to have taken place on February 1, 1952, again generated airborne activity that settled to the floor, doubling the previous level of surface contamination, which in turn doubled the airborne activity due to resuspension during the remainder of the operational period (i.e., until the end of 1952).

Reviewer's Comments

NIOSH (2015, Table B.1) listed "other work hours," the hours of exposure to resuspended airborne activities. According to Allen (2018), this value for 1951 was calculated by multiplying 2,200, the work hours in the full year, by the fraction of the year the uranium was on site—from the time it was assumed to arrive until the end of the year. The "other work hours" in 1952 were calculated by using the ratios of the months—1 month before the wafers arrived and 11 months after they arrived—to 12 months in a year. This resulted in a slight double accounting: the workers were exposed to intakes of resuspended activities during the same time that the activities generated by the metal work were settling.

We performed a revised analysis of the inhaled intakes, assuming an airborne concentration of 3,533 dpm/m^3, which is the DWA of a rolling operator that was used in Appendix B, Rev. 0, during an 8-h workday on April 19, 1951. We assumed that this activity settled out during an 8-h period, resulting in a surface contamination of 76,313 dpm/m^2, which in turn resulted in a resuspended airborne concentration of 0.761 dpm/m^3. The rest of the intake calculations paralleled those performed by NIOSH, except that we assumed that the surface grinding of the wafers took place on February 4, 1952, and that the workdays were 8 h on weekdays and 4 h on Saturdays. We calculated the actual workweeks following the rolling or machining of the uranium, based on the calendar, for assessing intakes of resuspended activities. The net result of this revision is an increase in the total intake in 1951 but a decrease in 1952, for a decrease of ~3.4% in the total inhaled intakes for both years.

Observation 4
The methodology used by NIOSH had the net effect of slightly overestimating the inhaled intakes of uranium.

3.2.2 Ingested Intakes

According to Appendix B, Rev. 1 (NIOSH 2015), OCAS-TIB-009 (NIOSH 2004) is not suitable for estimating ingested intakes because the uranium machining operations were of short duration, which did not allow the uranium airborne and surficial activities to achieve equilibrium. Instead, NIOSH estimated ingestion on the basis of the surface contamination levels cited in section 3.2.1 of the present review, assuming an ingestion rate of 1.1×10^{-4} m^2/h, citing NUREG/CR-5512 (Kennedy and Strenge 1992) as a reference. The resulting ingested intakes are listed in Table 1 in the present review.

Reviewer's Comments

NIOSH (2004) cited three pathways that contribute to the ingested intakes. The first (Mode 1)—the ingestion of material that is originally inhaled—is included in the inhalation pathway and needs not be considered further. The second (Mode 2) is the deposition of the airborne activity on a beverage cup, and the third (Mode 3) is the hand-to-mouth transfer from a contaminated surface. During a prolonged operational period, the latter two pathways make approximately equal contributions. During times when there are no uranium operations, the airborne uranium activity concentration is greatly reduced—0.751 vs. 3,160 dpm/m^3, according to the NIOSH model cited in section 3.2.1 of the present review—so that the contribution of Mode 2 can be neglected. However, the Mode 3 pathway can be applied in the present case.

NIOSH (2004) developed a method for calculating the Mode 3 contribution that assumed that each workday a worker ingested 10% of the activity on his hand, which was assumed to have an area of 4 × 6 inches, or 0.0155 m^2. The surficial activity on the hand was equal to that on the surface contaminated by uranium aerosol deposition. Applying this method to the surface contamination level of 75,082 dpm/m^2 derived by NIOSH, cited in section 3.2.1 of the present review, we obtained a daily ingestion rate of 116 dpm, or 14.5 dpm/h for an 8-h day during 1951, compared to 8.26 dpm/h listed by NIOSH (2015, Table B.2).

There are several reasons for adopting this alternative methodology:

- It is consistent with the model developed by NIOSH (2004), which has been reviewed by the ABRWH and cited in numerous site profiles.
- It is consistent with assessments of ingestion rates during residual periods at other worksites (e.g., General Steel Industries [GSI], Carborundum, Hooker Electrochemical), where the ingestion rate during the operational period was assigned to the start of the residual period. (This actually resulted in overestimates, since the Mode 2 pathway should not be carried over when the airborne activity is greatly attenuated.)
- It is claimant favorable, resulting in an intake rate that is 76% higher than the method employed by NIOSH (2015).

Observation 5

NIOSH used an ingestion rate that is inconsistent with rates used in exposure assessments for other worksites that were based on OCAS-TIB-009 and is not claimant favorable. This is an overarching issue that applies to other sites (e.g., the Evaluation Report on the Metals and Controls Special Exposure Cohort [SEC 236]) and should be addressed in a wider context.

Observation 6

NIOSH erroneously cited the source of the ingestion rate of 1.1 × 10^{-4} m^2/h as NUREG/CR-5512, Vol. 1 (Kennedy and Strenge 1992). Kennedy and Strenge cited an approximate value of 1 × 10^{-4} m^2/h, based on four published results: two cited sources listed a value of 1 × 10^{-3} m^2/h, while the other two cited 1 × 10^{-4} m^2/h. The value of 1.1 × 10^{-4} m^2/h used by NIOSH was based on Beyeler et al. (1996), who performed a detailed study of ingestion rates and found this to be the average value of a derived probability density function.

3.3 Revised Occupational External Dose

In Appendix B, Rev. 1, NIOSH (2015) assumed that an operator handled uranium metal for 1 week during 1951 and again in 1952—an exposure duration of 44 h, the assumed workweek during those years. The worker was assumed to be at a distance of 1 ft from the metal during one-half of this time. The external exposure of an operator handling uranium metal in 1951 was based on the dose rate from a short billet, as listed in TBD-6000 (NIOSH 2011, Table 6.1). The worker was thus assumed to receive this dose rate—0.469 mrem/h—during 22 h. During 1952, the dose rate was that from a slug—0.0524 mrem/h. NIOSH (2015, Table B.4) lists total photon doses of 10.3 and 1.15 mrem in 1951 and 1952, respectively.

3.3.1 Reviewer's Comments

We disagree with the choice of uranium shapes selected to assign doses to the operator. Since, as stated by NIOSH (2015), the billets were produced from 5-inch diameter ingots and were somewhere between the thickness of a rod and a 5-inch ingot, these billets are more properly represented by a long billet. The dose rates in TBD-6000 (NIOSH 2011, Table 6.1) are taken from Anderson and Hertel (2005). Table 1 of that paper describes the uranium metal shapes used in the dose rate calculations. The short billet has a radius of 7.62 cm, which is equal to a diameter of 6 inches, whereas the long billet has a radius of 6.35 cm, or a diameter of 5 inches. Furthermore, using the dimensions of the long billet listed by Anderson and Hertel, we calculate a mass of 170.7 kg (376 lb), close to the total reported weight of the uranium pieces: 346 lb. Thus, the long billet, for which Table 6.1 lists a dose rate of 0.703 mrem/h, is the more appropriate choice of the source of external exposure in 1951. The slug is described by Anderson and Hertel (2005, Table 1) as a hollow cylinder with an inner radius of 1.041 cm, an outer radius of 2.108 cm, and a length of 10.16 (4 inches). It is not a good representative of the wafers, which are described as cylindrical slices, 1–2 inches thick cut from rods. A better surrogate is the flat plate, which measured 3.1 × 18 × 0.18 inches. It had a dose rate at 1 ft of 0.231 mrem/h, more than 4 times higher than the slug. It weighs ~7 lb, which is consistent with the 11.5-lb weight of the five wafers. The operator might have been exposed to more than one wafer at the same time.

A much more serious issue arises from the fact that NIOSH ignored other sources of external exposure that were present at Birdsboro at the time of the uranium work. According to records of telephone interviews with the survivors of one energy employee (EE) (NIOSH 2003b), the EE worked as an [redacted] who operated various [redacted], including a [redacted]. According to the interview report: "[redacted]." Furthermore, "[redacted] from a bucket lifting out a source with a pole from the bucket. There is a radioactive sign next to it. In another photograph, [redacted]." These accounts match the use of ^{226}Ra sources using the "fishpole" technique illustrated by Anigstein (2010, Figs. 3 and 4). A recent interview with a former Birdsboro employee, reported in Appendix A of the present review, confirms the information on radiographic sources.

Records obtained from the archives of the University of Illinois at Urbana–Champaign include a list of Allis-Chalmers betatrons dated December 26, 1952, which includes "Birdsboro Foundry" that had a 22-MV betatron installed in 1952. According to the Steel Founders' Society of

America (1961), Birdsboro had nondestructive test facilities comprising a 24-MV betatron, a 300-kVp x-ray machine, 200 mCi of ^{60}Co, and 500 mg of radium in 1961.[2] Detailed information for earlier years is not readily available; however, the cited data are consistent with the information cited previously.

The available information is entirely consistent with the information on radiographic operations at GSI. Since the greatest source of external photon exposure at GSI was the use of ^{226}Ra employing the fishpole technique, a strong case can be made for using the external exposure scenarios developed for GSI as surrogate data for Birdsboro. We recommend that NIOSH assign external exposures to operators as a triangular distribution, with a minimum, mode, and maximum of 6.279, 11.345, and 15 R/y, respectively, during 1951 and 1952, as listed by NIOSH (2017, Table 8). These are based on the use of 500-mCi ^{226}Ra sources, as reported at both Birdsboro and GSI. Because these are limiting values, there is no need to include the small external exposures from the handling of uranium metal, which were also omitted at GSI. Since the betatron was installed at Birdsboro in 1952, an additional exposure in 1952 should include 5.112 rad/y air kerma as a constant distribution, consisting of 30 keV photons in a postero-anterior (PA) geometry.

The operator should be assumed to also spend 50% of the time performing steel radiography using the betatron in addition to performing radiography with ^{226}Ra sources. (Unlike GSI, there is no evidence that Birdsboro performed radiography of uranium.) The operator would receive a neutron dose of 0.857 mrem ambient dose equivalent (H*[10]) per 8-h shift (Anigstein and Mauro 2014). Assuming a 2,200-h work year, his annual neutron dose would be 117.8 mrem (0.857 mrem/shift × 2,200 h/y ÷ 8 h/shift = 117.8 mrem).

Administrative personnel who are defined as anyone normally working in an office environment not routinely entering the production areas should be assigned external photon exposures of 571.5 mR/y. All other employees should be assigned the dose estimates for operators.

Finding 1: NIOSH neglected the external exposure to documented radiographic sources in assigning photon doses to Birdsboro workers.

Beta doses to the skin of operators from handling uranium metal should also be assigned for 1951 and 1952. We recommend that the beta dose rate to skin other than that of the hands and forearms in 1951 be based on the long billet, as described by TBD-6000 (NIOSH 2011, Table 6.1). Assigning a beta skin dose rate of 7.03 mrem/h, which is 10 times the photon dose rate from this shape, would be consistent with the results of an earlier SC&A analysis of the beta dose rate from a similar shape, using the Monte Carlo radiation transport code MCNPX. The beta dose rate to skin other than that of the hands and forearms in 1952, prescribed in Appendix B, Rev. 1 (NIOSH 2015), is consistent with the MCNPX analysis of a uranium wafer, using a model based on the description by Smith (1952), that was performed as part of the present review.

[2] Five hundred milligrams of ^{226}Ra is approximately equal to 500 mCi.

Observation 7

The beta dose rate to skin other than that of the hands and forearms in 1951 should be based on the long billet, as described by TBD-6000 (NIOSH 2011, Table 6.1). We make this an observation rather than a finding, since the change in the skin dose would be small compared to the much larger dose from radiographic sources cited in Finding 1.

4 SUBTASK 3: EVALUATE THE PER'S STATED APPROACH FOR IDENTIFYING THE NUMBER OF DOSE RECONSTRUCTIONS REQUIRING REEVALUATION OF DOSE

According to DCAS-PER-073 (NIOSH 2016),

> *In order to evaluate the effect of revision 1 of the Appendix on all previously completed claims, a search was conducted for all completed claims with verified employment at the Birdsboro site during the covered period and that had a probability of causation (POC) of less than 50%. This search identified 4 claims.*

4.1 Reviewer's Comments

We verified the results of the search conducted by NIOSH (2016) by viewing the Birdsboro web page of the U.S. Department of Labor (DOL 2018), which stated that five cases were referred to NIOSH for DR. In all five cases, the POC was less than 50% and the final decision was to deny compensation. We next searched for Birdsboro cases in the NIOSH OCAS Claims Tracking System (NOCTS) and found five cases. On reviewing these cases, we found that [redacted]

Therefore, NIOSH was correct in reporting that four claims were within the scope of PER-073. We also confirmed that all four claims had POCs of less than 50%, resulting in the claims being denied.

To determine the potential impacts of the changes discussed in section 3 of the present review, we examined the DR reports for these four cases. Given the small number of cases, it was simplest to perform a cursory inspection of the reports to determine the extent to which the DRs would be affected by the PER.

The earliest DR was performed prior to the issuance of TBD-6000, Rev. 0, so it relied on generic guidance, such as that provided by OTIB-0004 (ORAUT 2003). That document specified the maximum plausible intakes of radioactive materials and external exposures, resulting in intakes and doses that were orders of magnitude greater than those in Appendix B, Rev. 1. A second DR report was issued after TBD-6000, Rev. 0, but prior to Appendix B, Rev. 0. That DR relied on TBD-6000 for data on external exposure while basing intakes on data from Simonds Saw and Steel, scaled to the ratio of the masses of uranium handled at Birdsboro and Simonds Saw. Another DR, although performed after the issuance of Appendix B, Rev. 0, also relied on TBD-6000 for data on external exposure while basing intakes on data from Simonds Saw and Steel. In these two cases, the intakes were orders of magnitude lower than either Appendix B, Rev. 0, or Rev. 1. Only one DR was based on the intakes and external exposures in Appendix B, Rev. 0. Therefore, except for the earliest of the four DRs discussed above, it was necessary for NIOSH to revise the DRs. Issuing DCAS-PER-073 provided a procedure and mechanism for performing these revisions. The earliest of the four DRs, [redacted], could have been excluded from the process due to the large overestimates of assigned doses and intakes, which nevertheless resulted in a denial of the claim. However, it was probably simpler to repeat the DR rather than justify excluding this one case from the PER. We therefore have no findings pertaining to the identification of claims that were impacted by DCAS-PER-043**.**

We observe that Appendix B, Rev. 1, was issued on June 2, 2015, while DCAS-PER-073 was issued August 1, 2016, 14 months later. SC&A does not have a basis for judging the timeliness of this PER.

5 SUBTASK 4: CONDUCT AUDITS OF A SAMPLE SET OF DOSE RECONSTRUCTIONS AFFECTED BY DCAS-PER-073

5.1 Selection of Dose Reconstructions

In order to complete our evaluation of DCAS-PER-073, we need to audit cases that represent a range of parameters that adequately characterize the cases evaluated by NIOSH for the present PER. In other PER reviews, SC&A typically cited case selection criteria, such as cancer type, job category, and period of employment. Following approval of the criteria by the ABRWH, NIOSH would select cases from a given site, based on these criteria. In the present circumstances, we had already performed a cursory examination of these reports to determine the extent to which they depended on earlier NIOSH guidance documents. Given that the cancer site and period of employment are listed on the cover page of each DR report, it was simplest to use the actual cases to determine the selection criteria that would enable us to perform an adequate review.

- [redacted]**.** Doses to the [redacted], which are part of the respiratory tract, represent a unique exposure pathway. The review should [redacted] to gauge the maximum effect of the additional sources of external exposure discussed in section 3.3.1 of the present review. The [redacted]; a substantial increase in the external dose from radiographic sources could have a significant impact on the outcome.

  We note that the POC is not necessarily part of the selection criteria. In the present instance, however, we need an opportunity to evaluate the impact of the increased external exposure that we have proposed under Finding 1. The impact would be greatest on the case that has the highest POC, as revised under the PER.

- [redacted]**.** A combined dose assessment of the [redacted] requires the analyst to select the correct [redacted] clearance type of uranium compounds to maximize doses to [redacted] simultaneously. The [redacted] is unusual in that, although it is a nonmetabolic organ, the presence of uranium in the urine following intake leads to a unique pathway. Reviewing such a combined assessment will also allow us to verify the calculation of the POC for [redacted].

- [redacted]**.** Because of the increased intake of ingested uranium, which was the primary motivation for this PER, organs that are part of the alimentary tract are of special interest. Furthermore, the additional sources of external exposure discussed in section 3.3.1 of the present review would represent a significant dose pathway for this organ, which has a higher dose conversion factor for external exposure than any other [redacted] site among the four cases evaluated by NIOSH, according to OCAS-IG-001 (NIOSH 2007).

- [redacted]**.** The [redacted] has a higher dose coefficient for intakes of ^{234}U via the ingestion pathway than any other cancer site among the four cases evaluated by NIOSH, according to the ICRP (2001).

6 REFERENCES

Allen, D. (NIOSH/DCAS). 2018. "RE: Appendix B, TBD-6000," personal email to Robert Anigstein, SC&A, Inc. May 24, 2018.

Anderson, J. L., and N. E. Hertel. 2005. "Bremsstrahlung doses from natural uranium ingots." *Radiation Protection Dosimetry, 115*(1–4), 298–301.

Anigstein, R. (SC&A, Inc.) 2010. "Review of NIOSH White Paper on Portable Radiography Sources at GSI." September 23, 2010.

Anigstein, R., and J. Mauro. 2014. "Review of 'Site Profiles for Atomic Weapons Employers that Worked Uranium Metals Appendix BB – General Steel Industries,' Revision 1," Memorandum to Advisory Board on Radiation and Worker Health, Work Group on TBD-6000. December 10, 2014.

Battelle. 2006. "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals," Battelle-TBD-6000, PNWD-3738 Rev. 0. Battelle Team, Dose Reconstruction Project for NIOSH. December 13, 2006.

Battelle. 2007. "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals, Appendix B: Birdsboro Steel & Foundry Company," Battelle-TBD-6000, Appendix B, Rev. 0. Battelle Team, Dose Reconstruction Project for NIOSH. September 14, 2007.

Beyeler, W. E., et al. 1996. "Residual Radioactive Contamination from Decommissioning: Parameter Analysis," NUREG/CR-5512. Vol. 3 (Draft for Review). Sandia National Laboratories.

Department of Labor (U.S.) (DOL) - Office of Workers' Compensation Programs (OWCP). 2018. "EEOICP Program Statistics: Birdsboro Steel + Foundry – Pennsylvania." Available at https://www.dol.gov/owcp/energy/regs/compliance/statistics/WebPages/BIRDSBORO_STEEL.htm. Accessed June 6, 2018.

International Commission on Radiological Protection (ICRP). 2001. The ICRP Database of Dose Coefficients: Workers and Members of the Public, Version: 2.0.1. [Computer software]. Pergamon.

Kattner, W. T., and J. W. Riches. 1951. "Trip Report: Visits Pertaining to Metal Fabrication and Canning." October 17, 1951. SRDB Ref. ID: 16127, PDF pp. 2–7.

Kennedy, W. E., Jr., and D. L. Strenge. 1992. "Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent," NUREG/CR-5512. Vol. 1. Washington, DC: U.S. Nuclear Regulatory Commission.

Malone, F. W. 1951a. "Weekly Production Report November 15th 1951," excerpt from memo to R. J. Smith, Chief, Operations Branch, Production Division, NYOO, November 11, 1951. SRDB Ref. ID: 61144, PDF p. 3.

Malone, F. W. 1951b. "Monthly Progress Report for November," United States Government Office Memorandum to R. J. Smith, Chief, Operations Branch, Production Division, NYOO, November 26, 1951. SRDB Ref. ID: 9545, PDF pp. 13–19.

NIOSH. 2003a. "Energy Employees Occupational Illness Compensation Program Act (EEOICPA) Dose Reconstruction Telephone Interview, NIOSH Claimant ID: [redacted]." NIOSH OCAS Claims Tracking System: Online.

NIOSH. 2003b. "Energy Employees Occupational Illness Compensation Program Act (EEOICPA) Dose Reconstruction Telephone Interview, NIOSH Claimant ID: [redacted]." NIOSH OCAS Claims Tracking System: Online.

NIOSH. 2004. "Estimation of Ingestion Intakes," OCAS-TIB-009, Rev. 0. National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, OH. April 13, 2004.

NIOSH. 2006. "Preparation of Program Evaluation Reports and Program Evaluation Plans," OCAS-PR-008, Rev. 2. National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, OH. December 6, 2006.

NIOSH. 2007. "External Dose Reconstruction Implementation Guideline," OCAS-IG-001, Rev. 3. National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, OH. November 21, 2007.

NIOSH. 2011. "Site Profile for Atomic Weapons Employers that Worked Uranium Metals," Battelle-TBD-6000, Rev. 1. National Institute for Occupational Safety and Health, Division of Compensation Analysis and Support, Cincinnati, OH. June 17, 2011.

NIOSH. 2015. "Site Profiles for Atomic Weapons Employers that Worked Uranium Metals, Appendix B: Birdsboro Steel and Foundry Company," Battelle-TBD-6000, Appendix B, Rev. 1. National Institute for Occupational Safety and Health, Division of Compensation Analysis and Support, Cincinnati, OH. June 2, 2015.

NIOSH. 2016. "Program Evaluation Report: Birdsboro Steel and Foundry Company," DCAS-PER-073, Rev. 0. National Institute for Occupational Safety and Health, Division of Compensation Analysis and Support, Cincinnati, OH. August 1, 2016.

NIOSH. 2017. "Site Profiles for Atomic Weapons Employers that Worked Uranium Metals: Appendix BB – General Steel Industries," Battelle-TBD-6000, Appendix BB, Rev. 3. National Institute for Occupational Safety and Health, Division of Compensation Analysis and Support, Cincinnati, OH. February 9, 2017.

ORAU Team, Dose Reconstruction Project for NIOSH (ORAUT). 2003. Technical Information Bulletin: "Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities," ORAUT-OTIB-0004, Rev. 2. December 4, 2003.

ORAU Team, Dose Reconstruction Project for NIOSH (ORAUT). 2005. "Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures," ORAUT-OTIB-0006, Rev. 3 PC-1. December 21, 2005.

Smith, R. J., Jr. 1952. Letter to L. King, Birdsboro Steel & Foundry Company, February 1, 1952. SRDB Ref. ID: 009545, PDF p. 11.

Sopher, P. 2014. "Where the Five-Day Workweek Came From," *Atlantic*, August 21, 2014. Available at https://www.theatlantic.com/business/archive/2014/08/where-the-five-day-workweek-came-from/378870/. Accessed June 6, 2018.

Steel Founders' Society of America. 1961. *Directory of Steel Foundries in the United States, Canada, and Mexico: 1961–62.* Cleveland: Author. Available at https://babel.hathitrust.org/cgi/pt?id=coo.31924004418764;view=1up;seq=7. Accessed June 6, 2018.

Taussig, W. A. 1948. "Facilities for Rolling Uranium," memo to W. E. Kelley, Manager, New York Office of Directed Operations (February 26, 1948). SRDB Ref. ID: 011036, PDF p. 226.

Young, C. 1987. "Elimination Recommendation," memorandum to file, October 28, 1987. SRDB Ref. ID: 9545, PDF pp. 5–7.

APPENDIX A – INTERVIEW REPORT

REPORT OF INTERVIEW WITH [redacted], FORMER EMPLOYEE OF BIRDSBORO STEEL FOUNDRY AND MACHINE COMPANY

Robert Anigstein, SC&A task manager for the review of DCAS-PER-073, contacted former Birdsboro employee [redacted] by telephone at approximately 2 PM on May 9, 2018. [redacted] name and phone number had been furnished during the Dose Reconstruction Telephone Interviews by the [redacted] (NIOSH 2003b). [redacted] worked at Birdsboro for [redacted] years, starting in the [redacted]. [redacted] and also used ^{60}Co and radium sources. [redacted] the radium source had a strength of 500 mCi, while the ^{60}Co had decayed to 200 mCi. [redacted] that the workers performing this work wore film badges as well as pocket ionization chambers (PICs).