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National Institute for Occupational Safety and Health

Review of Electro Metallurgical Company Technical Basis Document, Revision 01

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SC&A, Inc. technical support for the Advisory Board on Radiation and Worker Health's review of NIOSH dose reconstruction program

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Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
AEC	U.S. Atomic Energy Commission
AWE	Atomic Weapons Employer
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
dpm	disintegrations per minute
dpm/m^3	disintegrations per minute per cubic meter
DR	dose reconstruction
ER	evaluation report
GM	geometric mean
GSD	geometric standard deviation
HASL	AEC's New York Operations Office Health and Safety Laboratory
ICD	International Classification of Diseases
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron volt
MDA	minimum detectable activity
MED	Manhattan Engineer District
mrad	millirad
mrem	millirem
N/A	not applicable
NIOSH	National Institute for Occupational Safety and Health
Pa	protactinium
PA	posterior-anterior
PER	program evaluation report
R	roentgen
R&D	research and development
SEC	Special Exposure Cohort
SPR	Subcommittee for Procedure Reviews
SRDB	Site Research Database
TBD	technical basis document
Th	thorium

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tons/mo	tons per month
TWA	time-weighted average
UC	Union Carbide
UF_4	uranium tetrafluoride
WG	Work Group
Zr	zirconium

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1 Introduction and Background

The Advisory Board on Radiation and Worker Health (ABRWH, "Board") Subcommittee for Procedure Reviews (SPR), at its June 21, 2023, teleconference, tasked SC&A to review DCAS-PER-068, revision 0 (NIOSH, 2016), which the National Institute for Occupational Safety and Health (NIOSH) had initiated to determine how the Electro Metallurgical ("Electro Met") technical basis document (TBD), DCAS-TKBS-0007, revision 01 (NIOSH, 2015), affected previously completed dose reconstructions (DRs). SC&A subsequently produced its program evaluation report (PER) review, SCA-TR-2023-PER068, revision 0 (SC&A, 2024a), and presented it at the SPR's November 8, 2024, teleconference meeting (SC&A, 2024b). At that meeting, the SPR tasked SC&A to perform a more detailed review of revision 01 of the TBD beyond the partial evaluation done in the PER review; this document is a report on the revision 01 review.

In addition to its PER review, SC&A had previously reviewed revision 1 of the NIOSH petition evaluation report (ER) for Electro Met Special Exposure Cohort (SEC) Petition SEC-00136 (NIOSH, 2012). In its 2012 revision to its 2009 ER (NIOSH, 2009), NIOSH reevaluated the available information and concluded that it is not feasible to estimate internal doses with sufficient accuracy for the designated period due to inadequate bioassay, work area monitoring, and source term data. The SEC-approved class includes all workers at the plant from August 13, 1942, through December 31, 1947 (NIOSH, 2012).

This TBD review, which relies in part on and consolidates information from SC&A's previous work evaluating both the ERs (revisions 0 and 1) and DCAS-PER-068, has one finding and four observations.

1.1 TBD chronology of events

The following summarizes the chronology of events, including relevant reports and meetings, that led to the creation of revision 01 of the TBD, and continues to the present. Note that although Electro Met was discussed separately from other uranium refining facilities as early as 2007 (NIOSH, 2007), the plant did not have a standalone TBD until 2011 when DCAS-TKBS-0007, revision 00 (NIOSH, 2011a), was issued.

- **Battelle-TBD-6001 ("TBD-6001"), revision F0 (Battelle, 2006):** The U.S. Atomic Energy Commission (AEC) employed Electro Met to refine and process uranium from ore to a desired final state. TBD-6001 describes the typical processes and provides guidance applicable to DR for these types of facilities.

- **Battelle-TBD-6001, Appendix C, revision 0 (NIOSH, 2007):** This is the original Electro Met TBD, included as Appendix C to the general TBD for uranium processing facilities (Battelle, 2006). NIOSH later extracted Appendix C from the general TBD as a standalone Electro Met TBD, revision 00 (NIOSH, 2011a).

- **ER revision 0 (NIOSH, 2009):** NIOSH evaluated the SEC-00136 SEC 83.13-type petition for all workers in any area of Electro Met from April 1, 1943, through June 30, 1953 (note that petition SEC-00132 was merged into the SEC-00136 petition), and concluded that DR is feasible for the designated period.

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- **SC&A's first review of ER revision 0 (SC&A, 2010):** SC&A reviewed revision 0 of the ER (NIOSH, 2009), as tasked by the ABRWH at its October 20–22, 2009, meeting.

- **ABRWH TBD-6001 Work Group (WG) meeting, July 7, 2010 (ABRWH, 2010a):** The meeting included a review of TBD-6001 issues and SC&A's findings and observations. The Electro Met-specific portion of the meeting (transcript pages 158–249) was concerned with ER revision 0 (NIOSH, 2009) and SC&A's findings.

- **ABRWH TBD-6001 WG meeting, November 4, 2010 (ABRWH, 2010b):** The Electro Met portion of this meeting appears on transcript pages 158–207. The discussion primarily continued that of the July 7, 2010, meeting (ABRWH, 2010a).

- **Electro Met TBD, DCAS-TKBS-0007, revision 00 (NIOSH, 2011a):** The Record of Issues/Revisions section of the TBD states the following: "Changes Battelle-TBD-6001 Appendix [C] to a standalone document. Change is primarily format only. Does not incorporate review comments" (p. 2). This is basically a reformatting that did not change the technical material.

- **Revision 1 of SC&A's review of ER revision 0 (SC&A, 2011):** SC&A revised its earlier evaluation (SC&A, 2010) of the SEC-00136 ER, revision 0 (NIOSH, 2009), and produced 17 findings.

- **ABRWH Uranium Refining Atomic Weapons Employers (AWEs) WG meeting, May 16, 2011 (ABRWH, 2011a):** The Electro Met-specific discussion is included on pages 210–239 of the transcript. That discussion included all of SC&A's 17 findings (SC&A, 2011) on ER revision 0 (NIOSH, 2009).

- **ABRWH Uranium Refining AWEs WG meeting, August 16, 2011 (ABRWH, 2011b):** The WG received a brief update from NIOSH on its data-gathering efforts and progress on responding to SC&A's findings on ER revision 0 (NIOSH, 2009).

- **ABRWH Uranium Refining AWEs WG meeting, November 21, 2011 (ABRWH, 2011c):** NIOSH stated that it had reassessed its ER revision 0 (NIOSH, 2009) and concluded that it could not adequately reconstruct doses from 1942 through 1947 using back-extrapolation from the post-1947 period (due primarily to process improvements in the latter period). NIOSH proposed adding an SEC class from 1942 through 1947. NIOSH maintained that they could reconstruct doses from 1948 through 1952.

- **ER revision 01 (NIOSH, 2012):** In this revision to NIOSH (2009), NIOSH reevaluated the available information and concluded that it is not feasible to estimate internal doses with sufficient accuracy for the designated SEC period due to inadequate bioassay, work area monitoring, and source term data.

- **ABRWH Uranium Refining AWEs WG meeting, February 14, 2012 (ABRWH, 2012):** The WG continued to discuss the ER. Based on a preliminary analysis, SC&A believed that NIOSH might be able to adequately reconstruct internal doses for the 1942-

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to-1947 time period, which is at odds with NIOSH's conclusion. The WG decided to wait until this issue was resolved before making recommendations to the Board.

- **SCA-TR-SEC2012-0010, revision 0 (SC&A, 2012):** SC&A produced an addendum to its previous review (SC&A, 2011) of ER revision 0 (NIOSH, 2009) in response to NIOSH's revised ER (revision 1; NIOSH, 2012). This SC&A report can be characterized as a partial review, reflecting the limited amount of time SC&A had to review the new material to support a request by the AWEs WG.

- **Electro Met TBD, DCAS-TKBS-0007, revision 01 (NIOSH, 2015):** This was a major revision of the original Electro Met TBD, including greatly expanded sections on DR guidance and incorporation of the SEC designation for the early days of the plant. This revision prompted NIOSH to investigate the effect on prior DRs and to issue DCAS-PER-068 (NIOSH, 2016).

- **DCAS-PER-068, revision 0 (NIOSH, 2016):** NIOSH issued this PER to evaluate the effect of TBD revision 01 (NIOSH, 2015) on the previously completed DRs and to present a plan for corrective actions.

- **SC&A PER-068 review report, SCA-TR-2023-PER068, revision 0 (SC&A, 2024a):** SC&A issued its DCAS-PER-068 review report (SC&A, 2024a), followed by a PowerPoint presentation to the SPR (SC&A, 2024b).

1.2 Electro Met background

The following background information is based primarily on Electro Met TBD revision 01 (NIOSH, 2015). Electro Met, a Union Carbide (UC) subsidiary located in Niagara Falls, NY, was an existing ferro-alloy manufacturing plant when it was selected to participate in the nuclear weapons program. The nuclear weapons program portion of the plant ("Area Plant") became operational in March 1943 under contract to the Manhattan Engineer District (MED), a predecessor of the AEC, that began during World War II in support of the Manhattan Project; subsequent contracts were with the AEC. The uranium operations facility occupied a single purpose-built, fenced-off, 50-foot by 219-foot, one-story building on the larger UC site. The Area Plant converted uranium tetrafluoride (UF_4; "green salt") into uranium metal. It received the UF_4 from the UC Linde Air Products Division Plant in Tonawanda, NY, and sent the finished product and residues to several other nuclear weapons program sites. The final contract terminated on June 30, 1953, when Electro Met purchased the facility from the AEC. Electro Met decontaminated the site, and, after the final cleanup survey on August 14, 1953, the site was released.

The conversion process from UF_4 to uranium metal was accomplished by mixing the UF_4 with magnesium, putting the mixture into a metal "bomb" lined with dolomite (a refractory material), and heating the bomb in a furnace to initiate a vigorous exothermic ("thermite") reduction reaction.[1] When finished, the bomb was opened, the uranium metal separated from the

[1] This uranium refining process, developed for the Manhattan Project and used at Electro Met, is explained in detail on the U.S. Department of Energy's (DOE's) *Uranium Milling and Refining* web page (DOE, n.d.).

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magnesium fluoride slag, and both components removed. The uranium was then cast into 110- to 135-kilogram ingots, which were later recast in a vacuum reduction furnace into billets that were shipped off site for further processing. Electro Met also received uranium scraps from other facilities and remelted the scraps into ingots (DOE, 1986).

Figure 1 of TBD revision 01 shows the layout of the facility as it appeared in 1949; the text mentions that the figure "helps show the level of intermixing of process and non-process areas" (NIOSH, 2015, p. 5).

Observation 1: Site description inadequate

Although section 2.0 of the TBD describes the site layout, it is lacking in detail. Figure 1 shows the general location of the equipment, but the figure is not clear whether there were internal walls (and if present, describes their physical details, such as whether rooms were airtight or had ventilation resulting in negative pressure) separating the process equipment areas from each other and from general non-process areas. Lack of such separation and ventilation could have led to all personnel being exposed to uranium dust.

Table 2 of TBD revision 01 (NIOSH, 2015) shows the operational history of the plant, divided into three operations periods and three standby periods, with start and stop dates and associated average monthly uranium metal production rates. Although the design capacity of the plant was 50 tons of uranium metal per month, the actual production rate was consistently less. The TBD notes that other nonradiological processes might have occurred during the standby periods. Table 2 of the TBD is adapted here as table 1.

Table 1. Electro Metallurgical operating history

Description	Non-uranium-related standby operations	Start date	Stop date	Approximate uranium metal production rates, tons/mo [a]
Operations 1	N/A	8/13/1942	8/31/1946	44
Standby 1	Calcium metal production	9/1/1946	9/30/1947	N/A
Operations 2	N/A	10/1/1947	9/30/1949	26 (10/1947–6/1948) 35 (6/1948–6/1949)
Standby 2 – [overall period]	N/A	10/1/1949	1/1/1951	N/A
Standby 2 – [Zr period]	Zr production during standby	4/1950	9/1950	N/A
Operations 3	N/A	1/1/1951	6/30/1951	Not provided (research quantities)
Standby [3]	N/A	6/30/1951	6/30/1953	N/A

Source: Adapted from NIOSH (2015), table 2.

[a] Production average from AEC (1951), p. 38.

Observation 2: Process descriptions inadequate

The TBD describes the uranium refining process in section 3.0 and elsewhere, and its table 1 lists job titles and their associated duties and locations. However, it would be beneficial to provide more detail of the processing equipment and the flow of uranium through the plant from reception, through the various processes, to production of the final product to better appreciate the potential for radiation exposures along the way.

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Note that the approved SEC period runs from August 13, 1942, through December 31, 1947, for all workers at the site, which encompasses the entire operations 1 and standby 1 periods and the beginning of the operations 2 period.

NIOSH (2015) comments on the size of the workforce: "Contemporaneous reports provide that some 50-70 persons operated the Area Plant, others also mention that others from the plant provided support as needed with an estimated 30 additional persons who are not recorded including electricians and pipe fitters" (p. 21). Also, when in an operational period, the Area Plant ran three shifts of workers to support production. NIOSH notes it is "unaware of any complete list of personnel for the Area Plant at Electro met during its operational history. As previously mentioned, construction workers from other companies completed work in the Area Plant during active operations (MED [1943])" (p. 22).

SC&A notes that overall TBD revision 01 (NIOSH, 2015) contains much more detailed information in its section 2, "Site Description and Operational History," than the corresponding section in TBD revision 00 (NIOSH, 2011a).

2 Radiation Sources and Dosimetry

Electro Met exclusively processed uranium. Therefore, uranium isotopes and members of their decay chains (also referred to as "progeny" or "daughter products") were the only radioisotopes of concern. For example, uranium-238, with a 4.3-billion-year half-life, has 13 radionuclides in its decay chain, with half-lives ranging from short to very long, eventually ending in stable lead-208. The decays result in the emission of alpha and beta particles as well as gamma radiation. TBD revision 01 states the following:

> No documentation was found indicating there were other sources of radiation beyond what has been described at Electro Metallurgical during the covered period between 1942 and 1953. Processes used in the Area Plant caused uranium progeny to be non-uniformly distributed and/or concentrated in the materials and equipment causing documented high beta doses to some workers. [NIOSH, 2015, p. 11]

SC&A, likewise, did not see any indication of other radiation sources at Electro Met, which just processed uranium.

2.1 Internal dosimetry

The NIOSH SEC-00136 ER, revision 1 (NIOSH, 2012), defines a class of Electro Met employees to be included in the SEC class based on internal dose considerations:

> NIOSH finds it is not feasible to estimate internal exposures with sufficient accuracy for all workers at the site from August 13, 1942 through December 31, 1947. Internal monitoring data, work area radiological monitoring data, and source term data are not sufficient to provide a sufficiently accurate estimate of the bounding internal dose during this early period at Electro Metallurgical. [p. 3]

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Section 4.0 of TBD revision 01 (NIOSH, 2015), discusses internal dosimetry for the different operations and standby time periods (refer to table 1 of this report). TBD revision 01 notes the following for the SEC period:

> A small group of employees at the Area Plant have bioassay data available to NIOSH during this period [1942–1947]. These values should be used with standard dose reconstruction methods to assess intake rates of uranium during the period. [p. 16]

After the SEC period, two large air sampling campaigns were conducted by the AEC's New York Operations Office Health and Safety Laboratory (HASL) in November 1948 (AEC, 1949a) and in August 1949 (AEC, 1949b). UC's Linde plant health physics personnel conducted some measurements at Electro Met as well (AEC, 1948), but "they appear to be ad hoc and without further write-up" (NIOSH, 2015, p. 16). TBD revision 01 reports the following:

> The time weighted average (TWA) [exposure] values determined from these [August 1949] measurements was lower than reported from the November 1948 samples and this was attributed to some changes that occurred to the practices and ventilation as well as the fact that the facilities doors [and windows] were open in August [providing outside air ventilation to the facilities] unlike during the November measurements. [p. 16]

In a claimant-favorable approach, NIOSH decided to use the higher November 1948 sampling data (facility windows and doors closed) for DR. TBD table 3 lists TWA multiples of the preferred ("maximum permissible") level of 70 disintegrations per minute per cubic meter (dpm/m^3) for 21 different employee job titles. In contrast, the original version of the TBD differentiates the workforce into only three job titles:

1. Operators: employees routinely working directly with uranium
2. Supervisors/laborers: those in the vicinity of uranium operations but not directly involved in those activities
3. Others: personnel usually outside of uranium operations areas

Most of the titles in TBD revision 01 had associated TWA multiples greater than 1.0, ranging up to 577.0 for a green salt room operator. In a claimant-favorable decision, NIOSH chose to use the green salt room operator TWA with an uncertainty of geometric standard deviation (GSD) of 3 as the assumed air concentration data for all personnel and all operations periods (it is especially favorable for operations period 3, where TBD table 2 lists the metal production rate as only research quantities). NIOSH then used those values to determine ingestion intakes, following the guidance of OCAS-TIB-009 (NIOSH, 2004) during both the operational and standby periods.

TBD table 4 summarizes the assumed uranium air concentrations and ingestion rates for the individual operations and standby periods following the SEC. SC&A notes that this table does not actually contain radiation doses as the title erroneously indicates. Air concentrations are 40,390 dpm/m^3 during operations period 2 (for the portion not in the SEC) and period 3, and 210 dpm/m^3 for standby periods 2 and 3. The standby periods' value is 3 times the maximum

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permissible level, which is the high end on the HASL TWA range of 2–3 times the maximum permissible level for non-operator job categories. For all non-SEC periods, the ingestion rates are 5,691 disintegrations per minute (dpm)/calendar day; all values have a GSD of 3. This is a claimant-favorable approach in that NIOSH assumes that no cleanup occurred during the standby periods.

Observation 3: TBD table 4 title is misleading

Table 4 is labeled "Summary of Internal Dose at Electro Metallurgical Plant," which is incorrect since the information provided is air concentrations and ingestion rates, not doses.

Ingestion rates were calculated according to OCAS-TIB-009 methodology based on the air concentration data. The TBD states that "substantial floor contamination was clearly present as sweeping up of residues generated airborne concentrations up to 97,000 dpm/m^3" (NIOSH, 2015, p. 17). During the standby periods, when the uranium inventory in the plant would have been reduced, the TBD assigns intake rates based on the TWA for the highest nonoperational job title rate (3.0 for a repairman) to account for internal dose from uranium contamination. SC&A judges this assumption to be claimant favorable.

Figure 3 of TBD revision 01 shows a graph of the lognormal distribution of air sampling data at the Area Plant, plotting air concentration data (dpm/m^3) taken from "the limited uranium bioassay campaigns that were conducted at the Area Plant" (NIOSH, 2015, p. 17) as a function of Z-score. The graph displays horizontal lines corresponding to the green salt room operator's 577 TWA multiple of the maximum permissible level of 70 dpm/m^3, corresponding to 40,390 dpm/m^3, and the standby periods' 3 TWA, corresponding to 210 dpm/m^3.

Figure 4 shows a graph of the limited uranium bioassay data (milligrams uranium per liter urine) as a function of time and operations period. TBD revision 01 observes, "The very high uranium concentration data determined in the urine provides further support for the high intake rates determined by HASL and used for dose reconstruction by NIOSH beginning January 1, 1948" (NIOSH 2015, p. 17). Finally, internal doses were calculated using either type M or type S solubility, and, in a claimant-favorable approach, the highest of the two was used for dose determinations.

SC&A recognizes that revision 01 of the TBD uses several claimant-favorable assumptions in assigning internal doses to employees. Prominent among them are as follows:

- using the higher 1948 HASL air sampling data rather than the lower 1949 data
- applying the green salt room operator TWA air concentration level (the highest of any job category) to all employees for all operational periods
- assuming no cleanup occurred during the standby periods
- assigning intake rates during standby periods based on the highest TWA for a nonoperational job title to account for internal dose from contamination
- assigning highest internal doses assuming either type M or type S solubility

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2.2 External dosimetry

Electro Met's mission was to receive green salt, process it into uranium metal, and then to ship that metal out to other facilities for further processing. As described in TBD revision 01, section 5.0 (NIOSH, 2015, p. 22), external radiation exposures to workers arose from beta and gamma radiation (not from very short range, nonpenetrating alpha radiation) from uranium isotopes and their progeny as they decay. As mentioned previously, NIOSH did not find evidence of any other sources of radiation at Electro Met.

External exposures were not uniform for all job titles. Some of the processing steps exposed workers to particularly high beta fields as they "concentrated uranium progeny on the surfaces of the metal and also surfaces and residues of the production process (e.g., molds and slag)" (NIOSH, 2015, p. 22). For example, the data in the readings and sample sheets in AEC (1948–1953) indicate that in 1949 furnace operators had film badge readings of approximately 500–700 millirem (mrem)/week and some nonpenetrating dose levels measured up to 1,900 millirad (mrad)/week; these are far above the recommended maximum levels at that time.

Wearing of contaminated gloves (measured exposures of up to 2 roentgen (R)/8-hour day in 1944 and continuing afterwards) also contributed to the beta dose to workers. Laundry washed at Linde (Linde, as was Electro Met, was a UC plant and supplied UF_4 to Electro Met) was contaminated as well (measurements up to 15 mrad/hour beta on coveralls). TBD revision 01 notes, "However, since doses are being based on measured photon doses [rather than on beta doses], the issue of the contaminated laundry will not affect the assignment of dose at Electro Met" (NIOSH, 2015, p. 22).

"Limited external dosimetry data was collected over the operating history of the Area Plant" (NIOSH, 2015, p. 22), and NIOSH's examination of records that it could locate show that there were workers with urinalysis data that were not badged for external radiation (NIOSH, 2015, p. 21). In addition, the quality of the available data in the first operations period (August 13, 1942–August 31, 1946), during the SEC period, is questionable, as many of the dosimeter films were fogged. Furthermore, NIOSH claims that it is not aware of any complete list of personnel over time at Electro Met and that, in addition to the employees operating regularly at the Area Plant, another group of about 30 support employees worked there part time. These Electro Met employees were also supplemented by outside construction workers at various times (NIOSH, 2015, p. 22).

External dosimetry improved during the second operations period (October 1, 1947–September 30, 1949), transitioning into the post-SEC period, and NIOSH has data for 58 employees representing 21 job titles from June 1948 through September 1949. Accordingly, TBD revision 01 recommends using the data from the second operations period as the basis for estimating external doses for all the operation and standby periods. The TBD claims that "Analysis of this data set provides for a claimant favorable dose reconstruction method (all workers at the 95th percentile) as compared to [the] operator category of TBD-6000 [NIOSH, 2011b]" (NIOSH, 2015, p. 23).

Table 5 of TBD revision 01 (NIOSH, 2015, p. 25) shows all the external dosimetry data by job title for the 21 titles for a total of 1,978 film badge measurements taken for 58 employees between June 1948 and September 1949. NIOSH "preprocessed" the data before analyzing it by

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eliminating duplicates and using only records that included employee name and title. Table 1 of TBD revision 01 (NIOSH, 2015, p. 10) helpfully provides brief descriptions of the type of work and location associated with each job title. The columns of table 5 list for each title the number of measurements available, the number with gamma measurements less than the minimum detectable activity (MDA) at the time, the number with beta measurements <MDA, the percentage with gamma measurements >MDA, and the percentage with beta measurements >MDA:

- The MDA over the period was 50 mrem/week gamma and 50 mrad/week beta.
- The two categories with the greatest gamma percentages >MDA (discounting junior chemists, who had a total of only 3 measurements) were laboratory operators (24 percent) and bomb toppers (21 percent).
- The two categories with the highest beta exposure percentages >MDA (discounting junior chemists again) were furnace operators (96 percent) and head remelt operators (90 percent).

Beta radiation is nonpenetrating and usually produces exposures that are most significant to the hands and forearms of workers closely handling uranium metal. TBD revision 01 remarks that several hundred ring dosimeter measurements (used to register doses to hands and forearms) are also available but not useful, as "they were without worker titles and offer little information about how they were worn (with or without protective gear). Furthermore, the ring badges were worn by only a fraction of the employees and only for a limited time" (NIOSH, 2015, p. 26).

In the absence of reliable ring dosimeter data, NIOSH chose to use Battelle-TBD-6000, section 6.3 (NIOSH, 2011b), to estimate skin doses to hands and forearms of workers handling uranium metal and adopted a value of 10 times the photon dose "to determine 'other skin' dose during all periods value rather than rely on the measured beta doses because of bias regarding the badge location as previously discussed (that the badges may have been worn under the clothing)" (NIOSH, 2015, p. 26). TBD-6000 revision 1 states, "For dose to other skin on the worker's body that is not in direct contact with uranium metal, but is nearby (for example, a worker's neck and face when the hands are in contact with metal), a dose relation can be used that estimates this dose to be 10 times the photon dose rate at 1-foot" (NIOSH, 2011b, p. 36).

Finding 1: Ring dosimeter data not used

NIOSH discarded the available ring dosimeter data in favor of the Battelle-TBD-6000, revision 1 (NIOSH, 2011b, p. 36), general guidance for treating nonpenetrating radiation emitted from uranium metal surfaces at uranium metal processing facilities. Ring dosimeter records should indicate the names of the personnel who wore them, which likely could be cross-referenced with other information to establish the corresponding job titles of the personnel. Possibly a cohort approach could be used to determine doses and then compared to those using TBD-6000, which would give a scientific basis for assigning one set over the other. SC&A requests additional information as to why NIOSH decided to use the approach from TBD-6000, rather than attempting to use the available ring dosimeter data.

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TBD revision 01 presents external dosimetry guidance on page 29 (NIOSH, 2015). Some highlights follow:

- *Item 1:* "The external dose from Table 7 [adapted in table 2 in this report] shall be used to determine dose for all Electro Met employees."
- *Item 2:* "Photon and Beta dose during operations was determined using the 95th percentile of all badged worker data."
- *Item 3:* "Photon dose during standby was determined using the geometric mean of all badged worker data."
- *Item 4:* "Non-penetrating dose to other skin is assigned based on the recommended 10 times the photon dose to account for incorrectly worn badges."
- *Item 5:* "The non-penetrating dose to the hands and forearms is based on . . . TBD-6000 and is used during the operational period only. Beta doses to the hands and forearms during standby periods are determined using whole body skin doses (10 times the GM of photon dose)."
- *Item 6:* "The annual dose values shall be assigned as the geometric mean for that period with an uncertainty equal to a GSD of 3."

SC&A compared assigned annual external doses of TBD revision 01 (NIOSH, 2015) to those of TBD revision 00 (NIOSH, 2011a). Assigned annual external doses are given in table 3 of TBD revision 00 and table 7 of TBD revision 01. TBD revision 00 assigns doses to three job categories, operators, supervisors/laborers, and others, while TBD revision 01 assigns doses to all workers, in 21 job categories, based on the guidance contained therein. The resulting external doses are summarized here in table 2, illustrating that TBD revision 01 assigned doses are substantially greater than those for TBD revision 00 and hence are more claimant favorable.

Table 2. Comparison of TBD revision 01 and revision 00 external dose assignments

TBD revision, period	Photon whole-body dose, mrem/year	Nonpenetrating dose to other skin, mrad/year	Nonpenetrating dose to hands and forearms, mrad/year
Rev. 00, Operations	Operators: 3,934 Supervisors/Laborers: 1,003 Others: 256	Operators: 21,030 Supervisors/Laborers: 3,221 Others: 493	N/A
Rev. 01, Operations	All: 4,403	All: 44,030	All: 276,000
Rev. 00, Standby	All: 256	All: 493	N/A
Rev. 01, Standby	All: 1,356	All: 13,560	All: 13,560

Sources: TBD rev. 00 (NIOSH, 2011a), table 3; TBD rev. 01 (NIOSH, 2015), table 7.

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Overall, in comparing the TBD revision 01 assigned doses to the revision 00 assigned doses, SC&A found the following:

- The photon whole body dose during operations increased for all by a factor of 1.12 for operators, 4.39 for supervisors/laborers, and 17.2 for others; the dose during standby increased for all by a factor of 5.30.

- The nonpenetrating skin dose during operations increased for all by a factor of 2.09 for operators, 13.7 for supervisors/laborers, and 89.3 for others; the dose during standby increased for all by a factor of 27.5.

- The nonpenetrating skin dose to hands and forearms was not specified in TBD revision 00.

SC&A examined the methodologies and results pertaining to assignment of external dose in TBD revision 01 and find them valid and considerably more claimant favorable than those of revision 00. Examples include (1) expansion of job titles to 21 from the 3 in TBD revision 00 and (2) assuming nonpenetrating skin dose is 10 times the photon dose. The overall effect is to greatly increase the assigned external doses.

2.3 Occupational medical dose

Section 6.0 of the TBD provides guidance on assigning occupational medical dose; there is little difference between revision 00 and revision 01. The available information about the medical program at Electro Met is sparse, with a 1945 memo recommending pre-employment, annual, and termination x-rays, and a 1949 memo confirming that Electro Met was using x-ray equipment installed at the plant. Lacking more specific information, the TBD relies on the guidance of ORAUT-OTIB-0006, revision 04 (ORAUT, 2011). TBD revision 01 states the following:

> The assumed frequency in the document is PA chest X-ray for pre-employment, annual, and termination examinations between the years 1942 and 1953 (the covered period). Annual organ doses are entered into the NIOSH-IREP program as the annual dose due to an acute exposure to photons (E=30-250 keV). The distribution is assumed to be normal with a standard deviation of 30%. [NIOSH, 2015, p. 34]

The latest revision of the referenced OTIB is ORAUT-OTIB-0006, revision 06 (ORAUT, 2019), while the TBD, issued before that revision, cites revision 04 (ORAUT, 2011). The revision record for revision 06 states, “Revision initiated to incorporate ICD-10 codes. Additional clarification of citation for information to address SC&A comments. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document” (p. 3). SC&A did not find any changes in the OTIB to affect the TBD’s guidance.

3 Electro Met SEC-00136

Since the creation of TBD revision 01 (NIOSH, 2015) was largely motivated by the papers of NIOSH and SC&A and the discussions at WG meetings regarding SEC-00136 (section 1.1 of

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this report presents a chronology of those events), it would be useful to review the relevant issues raised. NIOSH issued its initial ER in 2009 for all workers in any area of Electro Met from April 1, 1943, through June 30, 1953 (NIOSH, 2009). SC&A evaluated this petition in April 2010 (SC&A, 2010), and potential issues were identified and discussed at subsequent WG meetings (ABRWH, 2010a, 2010b, 2011a). SC&A produced a revised evaluation in 2011 containing 17 findings, summarized in its executive summary (SC&A, 2011, pp. 6–8).

Following further WG discussions (ABRWH, 2011b, 2011c), NIOSH revised the ER (to revision 1) in January 2012 (NIOSH, 2012). Notably, revision 1 changed the SEC period for all plant workers to August 13, 1942, through December 31, 1947, and changed its determination of feasibility of internal DR during the SEC period from feasible to not feasible due to inadequate bioassay, work area monitoring, and source term data. The revision 1 ER was discussed at the February 2012 WG meeting (ABRWH, 2012). Also in February 2012, SC&A produced an addendum to its previous review report in response (SC&A, 2012). Attachment A to the 2012 SC&A addendum report contains an updated issues matrix of the 17 findings, including SC&A comments; SC&A (2011) contains a detailed discussion of the findings.

The SC&A addendum noted two overarching issues: (1) "the ability to identify and differentiate employees who worked in the Area Plant where . . . [AEC and MED] activities were conducted as compared to employees who worked in the commercial operations that constituted the majority of the activities at Electro-Met" and (2) "the ability to calculate bounding doses for the 'early operations' from August 13, 1942 through December 31, 1947" (p. 4).

To facilitate further discussion, table 3 summarizes the findings and their status, taken from SC&A (2011) and discussions in the ABRWH Uranium Refining AWEs WG meeting (2011a); the accompanying page numbers denote the starts of the discussions on the findings from the meeting transcript. SC&A also examined transcripts of the later WG meetings (ABRWH, 2010b, 2011c, 2012) and noted that, although certain issues were discussed, there was no systematic review and no resolution of the 17 findings. Although there was frequent agreement on a finding, as far as SC&A could find in the transcripts, the WG did not classify any of them as either open, in progress, in abeyance, or closed: hence, they are all formally still open, or at least in progress. Note that these 17 findings are based on reviews and discussions of TBD revision 00 (NIOSH, 2011a), not the latest revision 01 (NIOSH, 2015), and were focused on the SEC review, so not all are relevant here.

Table 3. Summary of SEC-00136 ER findings based on Electro Met TBD revision 00

No. (page number [a])	SC&A finding	Status [b]
1 (p. 210)	NIOSH should discuss the issue of access controls explicitly in the ER to justify the basis for including all workers at Electro Met, rather than just those who worked in the Area Plant.	NIOSH requested worker location clarification from DOL.

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No. (page number [a])	SC&A finding	Status [b]
2 (p. 215)	R&D work with uranium ores was not mentioned in NIOSH (2009). While the information reviewed here does not indicate that significant quantities of uranium-bearing materials other than green salt were used by Electro Met, NIOSH should address the scope of work that might actually have been done at Electro Met (and in which facilities).	R&D was conducted for a short period using small quantities of low-grade African ore. SC&A is satisfied.
3 (p. 216)	NIOSH should review the start and end dates for the operational period to ensure that all relevant documentation has been evaluated.	Start and end dates should be revised to be consistent in the ER and the TBD to reflect those of the MED and AEC contracts.
4 (p. 217)	The NIOSH assumption that the uranium metal reduction process and associated industrial production and industrial hygiene conditions were unchanged from 1943 to 1949 may not be correct. The changes that appear to have been made in 1947 would need to be investigated before this assumption can be used to implicitly back-extrapolate post-October 1947 data to the 1943–1946 period. (Refer also to finding 17.)	Open.
5 (p. 222)	NIOSH should clarify the text to remove what appears to be an inconsistency regarding the availability of internal exposure data during standby periods.	NIOSH modified text in revised ER. Minor issue that was resolved between SC&A and NIOSH at the February 2012 WG meeting.
6 (p. 223)	NIOSH should take into account the difference between fixed head samplers, process samplers, and general area samplers and actual intake, and the uncertainties this creates for estimating bounding intakes.	Finding relates to how DRs are performed; not an SEC issue. Issue was resolved between SC&A and NIOSH at the February 2012 WG meeting.
7 (p. 224)	NIOSH needs to establish that job titles corresponded to the jobs actually done for the period of employment. NIOSH's job title consolidation scheme would not produce bounding estimates for all workers in the proposed class in the absence of such an analysis.	SC&A and NIOSH agreed at the February 2012 WG meeting that this finding relates to how DRs are performed; not an SEC issue.
8 (p. 225)	SC&A notes that the graphical method used by NIOSH in Appendix C of TBD-6001 (NIOSH, 2007) to calculate the inhalation intakes for operators results in the lowest estimate of the 95th percentile among possible alternative calculational approaches. Arguably, in this case, the graphical method is not claimant favorable.	SC&A and NIOSH agreed at the February 2012 WG meeting that this finding relates to how DRs are performed; not an SEC issue, but is a global issue.

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No. (page number [a])	SC&A finding	Status [b]
9 (p. 230)	The site-specific values for inhalation intakes for Electro Met from Appendix C are significantly more claimant favorable than the generic intakes proposed in table 8.29 of TBD-6001, rev. F0 (Battelle, 2006), which raises questions as to whether TBD-6001 is appropriately conservative for its intended purpose. This is noted for the record, but it is not an Electro Met finding.	SC&A and NIOSH agreed at the February 2012 WG meeting that this is moot since TBD-6001, rev. F0 (Battelle, 2006), is no longer applicable.
10 (p. 230)	Given the high frequency of blowouts at other facilities using the same equipment, NIOSH should reexamine the possibility that blowouts occurred at Electro Met.	Additional reviews have not uncovered evidence of blowouts.
11 (p. 232)	NIOSH should address residual exposures in the SEC-00136 ER.	Since the Area Plant was an AEC facility, evaluation of exposures during the residual period is not required.
12 (p. 232)	NIOSH should provide more detailed information to support their position stated in section 7.2.3 of NIOSH (2009) that, "Considering the intake scenarios established in Battelle-TBD-6001 Appendix C, the calculated urinary excretion of uranium from these intakes was compared to actual data and was found to be bounding in each case" (NIOSH, 2009, p. 26). Independent calculations by SC&A do not support this conclusion on the bounding nature of the intakes in Appendix C, table C.2.	The Electro Met TBD and the revised ER eliminated discussions about comparing actual and calculated excretion rates. NIOSH will investigate further.
13 (p. 234)	The approach taken to bound external photon exposure values in table C.4 of TBD-6001, Appendix C, appears to be reasonable for the operating period beginning June 1948. However, NIOSH must demonstrate that this approach is bounding for the earlier operating period, when essentially no film badge data are available. In addition, NIOSH should explicitly define in Appendix C how to proceed with DR when the job description is uncertain or unknown.	Not resolved.
14 (p. 235)	NIOSH should state in the SEC-00136 ER and in Appendix C of TBD-6001 that estimates of occupational medical exposure should be based on photofluorography, unless there is evidence that this technique was not used at AWE sites and only at DOE sites. This is a DR issue, not an SEC issue.	DR, not an SEC issue, and photofluorography was practiced only at larger AEC facilities. Not resolved.
15 (p. 236)	SC&A independently developed a database for annual beta doses and found that the 95th percentile value was in excellent agreement with that developed by NIOSH for table C.5. However, 50th and 95th percentiles were somewhat higher, based on the SC&A analysis. Consequently, it is possible that the dose to Supervisor/Laborers could be understated by about 40% and the dose to Others by about 80%.	DR, not an SEC issue, but should be investigated.

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No. (page number [a])	SC&A finding	Status [b]
16 (p. 237)	Use of 95th percentile exposures, as proposed in tables C.4 and C.5 of TBD-6001, Appendix C, adequately accounts for enhanced exposures from high surface concentrations of Th-234 and Pa-234m produced during melting and casting of uranium ingots, except for exposures to the hands and arms. Table C.5 is specific to "Other Skin." Guidance should be added to Appendix C to specifically address exposure to the hands and arms.	DR, not an SEC issue.
17 (p. 238)	NIOSH needs to provide convincing arguments that 95th percentile values based on 1948–1949 data are bounding for the period prior to December 1947.	Not resolved.

[a] Page numbers refer to meeting minutes from the May 16, 2011, WG meeting (ABRWH, 2011a).

[b] As far as SC&A can determine, the WG has not assigned a status to any of the findings; hence, they are all considered in progress.

Of the 17 findings listed in table 3, SC&A believes that 1, 5, 9, and 11 are not applicable to the TBD review and 2, 3, 6, 7, 10, and 16 are related to the TBD review and resolved. The remaining 7 findings will be discussed in more detail.

- **Finding 4:** This finding pertains to the use of back-extrapolation of data gathered from the two HASL air sampling campaigns of 1948 (AEC, 1949a) and 1949 (AEC, 1949b) to the earlier SEC period. TBD revision 01 discusses that period in section 4.1 by recognizing that "it is not feasible to estimate internal exposures with sufficient accuracy for all workers at the site for the period August 13, 1942 through December 31, 1947 at . . . [Electro Met]. Any available personal monitoring data should be used to reconstruct an individual's internal exposure at Electro Metallurgical during this time period. However, unmonitored internal exposures during this time period cannot be reconstructed" (NIOSH, 2015, p. 16). SC&A believes that revision 01 of the TBD adequately addresses SC&A's finding.

- **Finding 8:** TBD revision 01 describes its approach to treat air concentration data in section 4.2: "NIOSH has chosen to use the highest TWA determined by HASL during the November 1948 sampling (i.e. the green salt room operator) along with an uncertainty of geometric standard deviation (GSD) of 3 as the air concentration data for use during all operational periods at Electromet beginning January 1, 1948" (NIOSH, 2015, p. 17). SC&A believes that this is a claimant-favorable approach.

- **Finding 12:** TBD revision 01 does not mention urinary excretion rates. The Status column in table 3 of this report notes, "The Electro Met TBD and the revised ER eliminated discussions about comparing actual and calculated excretion rates. NIOSH will investigate further." SC&A is not aware that NIOSH has done so.

- **Finding 13:** This finding appears to be moot since, as stated in the discussion of finding 4, it refers to the SEC period when any internal DR could only be done using a worker's own monitoring data.

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- **Finding 14:** TBD revision 01, section 6.0, on occupational medical dose, added the following statement: "A memo in 1949 from the AEC to Electro Met however, confirmed that they were using x-ray equipment installed at the plant to conduct examinations" (NIOSH, 2015, p. 34). SC&A considers the finding resolved.

- **Finding 15:** TBD revision 01 treats external dosimetry in section 5.0. As shown in table 5 (p. 25), the number of job titles considered increased to 21 from 3 in the previous revision. SC&A does not believe that the finding warrants further discussion.

- **Finding 17:** This finding refers to the SEC period and is no longer applicable.

Observation 4: Relevance of the SEC ER review findings to TBD revision assessment

SC&A's overall assessment related to the 17 findings of the SEC ER review that relied on information in TBD revision 00 is that none of them appear relevant to TBD revision 01 except for finding 12 on urinary excretion rates where NIOSH indicated that it would investigate. SC&A also notes that many of the findings have been discussed but not formally resolved at an ABRWH meeting.

4 Conclusions

In its review of Electro Met TBD revision 01, SC&A examined the two TBD revisions, material related to the ER, material related to DCAS-PER-068, and other related documents. SC&A's overall conclusion is that revision 01 represents a technically sound, considerable, claimant-favorable improvement over revision 00. Nonetheless, SC&A identified four observations and one finding:

- **Observation 1:** Site description is inadequate

- **Observation 2:** Process descriptions are inadequate

- **Observation 3:** TBD table 4 title is misleading

- **Observation 4:** Relevance of the SEC ER review findings to TBD revision assessment: one finding on urinary excretion rates might be relevant

- **Finding 1:** Further justification should be provided for discarding available ring dosimeter data in preference to the TBD-6000 approach

The observations on the adequacy of the site and process descriptions contain suggestions for improvement that could help clarify the details of what occurred in the plant and thereby increase the confidence of the work group in determining whether the TBD guidance is adequate for performing DRs. Resolution of finding 1 would provide more of a basis for the choice of methods to employ in assigning extremity doses.

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