Draft

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

A FOCUSED REVIEW OF THE HOOKER ELECTROCHEMICAL COMPANY PETITION EVALUATION REPORT FOR SEC-00141

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ABBREVIATIONS AND ACRONYMS

Advisory Board or ABRWH	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AWE	Atomic Weapons Employer
BZ	breathing zone
CFR or C.F.R.	*Code of Federal Regulations*
dpm/m^3	disintegrations per minute per cubic meter
DWA	daily weighted average
DWE	daily weighted exposure
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ElectroMet	Electro Metallurgical Company
EPA	Environmental Protection Agency
FGR	Federal Guidance Report
g/cm^3	grams per cubic meter
GM	geometric mean
GSD	geometric standard deviation
HCl	hydrochloric acid
Hooker	Hooker Electrochemical Company
kg	kilogram
LOOW	Lake Ontario Ordnance Works
MAC	maximum allowable concentration
MCNP	Monte Carlo Neutron and Photon (transport code)
MCW	Mallinckrodt Chemical Works
MED	Manhattan Engineer District
mg	milligram
mR/hr	milliRoentgen per hour
mrad/hr	milliradian per hour
mrem	millirem
mrep/hr	millirep per hour
m/s	meters per second
NIOSH	National Institute for Occupational Safety and Health

ORAUT	Oak Ridge Associated Universities Team
ORNL	Oak Ridge National Laboratory
PER	(NIOSH) Petition Evaluation Report
pCi/day	picocuries per day
pH	phosphate (pg. 7)
R or r	roentgen
Rem	Roentgen equivalent man
rep	roentgen-equivalent-physical
SC&A	S. Cohen and Associates (SC&A, Inc.)
SEC	Special Exposure Cohort
TBD	Technical Basis Document
U	uranium
w/w	weight per unit weight

EXECUTIVE SUMMARY

SC&A was tasked by the TBD-6001 Work Group to conduct a focused review of the Petition Evaluation Report (PER) for the Special Exposure Cohort (SEC) Petition SEC-00141, Hooker Electrochemical Company, prepared by the National Institute for Occupational Safety and Health (NIOSH). This report summarizes SC&A's review, which includes the seven findings and one observation listed below:

Finding A: *NIOSH should re-examine its assumption that the slag contains 0.2% U; the assumption of 1% U is more favorable to claimants and, given the information presented here, it is bounding.*

Finding B: *NIOSH should review its estimate of the monthly slag throughput at Hooker to insure that all relevant data have been considered.*

Finding C: *NIOSH should consider revising Appendix AA to base internal exposures on surrogate slag handling data, rather than on surrogate data from TBD-6001 scrap recovery operations.*

Finding D: *NIOSH should clarify whether 1.6 mrep/hr for gamma and 11.5 mrep/hr for beta or the values contained in Tables AA.3 and AA.4 of Appendix AA should be used for a bounding calculation.*

Finding E: *While clearly bounding, the measured gamma dose from the St. Louis Airport Site slag pile may not be representative of C-2 clag.*

Finding F: *The PER should recognize that slag was present during the residual period, at least through 1958, and ensure that this information is incorporated into the bounding external exposure calculation for the residual period.*

Finding G: *Depending on employment history, use of a resuspension factor of 1E-06/m for the residual period may not be bounding when calculating inhalation doses. If NIOSH believes that use of this resuspension factor is appropriate, they should provide justification describing, for example, clean-up procedures conducted after the cessation of operations.*

Observation A: *NIOSH should explain why they accepted the petitioners' assumptions regarding the duration of the operating period, since we are not aware of any evidence to support the extended operating period.*

SC&A also revisited the findings previously made during the review of Appendix AA of TBD-6001 to determine if any of the open issues could have SEC implications. All of these findings were judged to be site profile issues, rather than SEC issues. SC&A believes that when the findings listed above are satisfactorily resolved, NIOSH should be able to demonstrate that they can "estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class."

1.0 INTRODUCTION

At the TBD-6001 Work Group Meeting held in Cincinnati, Ohio, on November 4, 2010, SC&A was tasked by the Work Group to prepare a focused review of the NIOSH Petition Evaluation Report (PER) for the Hooker Electrochemical Atomic Weapons Employer (AWE) site (NIOSH 2010). SC&A had previously prepared a review of the Hooker Site Profile (SC&A 2010), which was included by NIOSH as Appendix AA to TBD-6001 (Battelle 2007). Since the PER contained new information developed since Appendix AA was issued in 2007, the Work Group felt that a focused review of this new information was needed. This report documents SC&A's findings based on its review of the PER and supporting documents.

The SEC-00141 petition was received by NIOSH on March 6, 2009, and qualified on October 16, 2009. The proposed Special Exposure Cohort (SEC) class evaluated by NIOSH consisted of:

> *All employees who worked in any location at the Hooker Electrochemical Corporation during the operational period from January 1, 1943 through December 31, 1948, and during the residual period from January 1, 1949 to December 31, 1976.*

The basis for the petition was the claim that internal and external monitoring data were not available for dose reconstruction. A petitioner also expressed concerns about the use of surrogate data in bounding exposures (Personal Communication 2010). NIOSH researched the basis for the petition and agreed with the petitioner regarding the lack of monitoring data, thereby qualifying the petition for evaluation.

Based on its evaluation of the petition, NIOSH concluded that (NIOSH 2010, p. 3):

> *Per EEOICPA and 42 C.F.R. § 83.13(c)(1), NIOSH has established that it has access to sufficient information to: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class; or (2) estimate radiation doses of members of the class more precisely than an estimate of maximum dose. Information available from the site profile and additional resources is sufficient to document or estimate the maximum internal and external potential exposure to members of the evaluated class under plausible circumstances during the specified period.*

In subsequent sections of this focused review, we will describe the AWE operations at Hooker Electrochemical (Section 2), review the NIOSH approach to bounding doses presented in the Petition Evaluation Report (Section 3), and discuss whether SC&A's prior findings from its review of Appendix AA to TBD-6001 have any SEC implications, or whether they are strictly site profile issues (Section 4). Since the Findings related to Appendix AA were numbered, we have used capital letters to enumerate the Findings related to the PER.

SC&A plans to interview former employees and will amend this report when that process has been completed.

2.0 AWE OPERATIONS AT HOOKER ELECTROCHEMICAL

The Hooker Electrochemical Company (Hooker) in Niagara Falls, New York, processed uranium-bearing (C-2) slag from July 11, 1944, to January 15, 1946 (Appendix AA, Section AA.2). The operations at the Hooker facility involved treatment of C-2 slag from the nearby Electro Metallurgical Company (ElectroMet) with hydrochloric acid (HCl) to recover uranium. The C-2 slag from ElectroMet was a byproduct of the bomb reduction process, in which uranium tetrafluoride was reacted with magnesium to produce uranium metal. The HCl was excess acid produced at Hooker under an Atomic Energy Commission (AEC) contract as a byproduct from the non-radioactive P-45 chemical process.

Slag from ElectroMet was shipped in wooden barrels to Hooker by rail (DOE 1977, MED 1944). Each barrel was filled with 500 lbs of slag (reduction bomb liners) with the nominal composition of "90% MgF" (sic) and 10% CaO, plus 1% X (MED 1944, p. 29). We note that the correct chemical formula for magnesium fluoride is MgF_2 and that "X" was used as code for uranium. However, there is some uncertainty as to the uranium content of the slag. As noted above, the uranium content is stated on page 29 of MED 1944 as 1%. On page 30 of MED 1944, it is stated that, "slag is concentrated from about 1 lb to 5 or 10 lb by weight." If the barrel contained 1 lb of uranium in 500 lb of slag, then the initial composition would be 0.2% (as assumed in NIOSH 2010 and SC&A 2010), not 1%, as stated in MED 1944. It is possible that 1% X represented the nominal rather than the actual composition.

Finding A: *NIOSH should re-examine its assumption that the slag contains 0.2% U; the assumption of 1% U is more favorable to claimants and, given the information presented here, it is bounding.*

The barrels were opened and the contents were dumped onto a 20-mesh screen, with the undersize being conveyed by a bucket elevator to one of three wooden digestion tanks (MED 1944, although DOE 1985 says that 4 tanks were used). Oversize (+ 20 mesh) material from the screening operation was drummed and returned to Manhattan Engineer District (MED) control. After 40 barrels of slag were loaded into a 13-ft diameter by 11-ft high wooden digester tank (Dowling 1944, p. 112; MED 1944, p. 30), HCl was added and the pH was adjusted to 4.0 with water additions (MED 1944). Digestion of the agitated slurry continued for about 20 hours (MED 1944). Operators standing on platforms above the tanks then added lime from 100-lb bags to neutralize the slurry (MED 1944). The neutralized slurry was pumped to a plate and frame filter press, where the filtrate was collected and discharged into a sewer. The filter cake was then washed several times, and was re-drummed and shipped by rail to MED control (MED 1944). The turnover rate for a digester tank was stated to be once every 2 days (MED 1944). A detailed description of the process issued by Hooker is included as Exhibit 2. The Hooker description differs in some details from the description provided in the references cited above, but the differences are not believed to significantly affect this focused review.

The digester tanks, bucket elevator, and filter press were housed in a cinder block building specifically constructed for the process (Dowling 1944, p. 112). Other operations, such as handling of barrels, were conducted outdoors near the rail siding. One former employee stated that the wooden tanks for processing the slag were located outdoors (Personal Communication

2009b), but this statement does not agree with information in the Construction Completion Report (Dowling 1944).

Four operators handled the slag-leaching process that involved 200 manhours per week (MED 1944). The maximum throughput rate was 10 tons of slag per month (MED 1944), and a total of 152 tons of slag was processed from July 1944 through January 15, 1946 (Battelle 2007, Appendix AA; Mears 1946, p. 30).[1] Based on a slag throughput rate of 10 tons per month, 40 barrels would need to be processed monthly. In its review of Appendix AA, SC&A assumed that 10 tons per month was the **output** of treated (acid-leached) slag (SC&A 2010). However, NIOSH suggested at the November 4, 2010, TBD-6001 Work Group meeting that SC&A had misinterpreted the value of 10 tons per month (from MED 1944, p. 29) as product output, rather than slag input. The MED 1944 Data Sheet for Industrial Hazard Rating states, "ACTUAL QUANTITY (MONTHLY RATE – 10 tons)." The Data Sheet is ambiguous and the 10 tons could be either input or output. However, Mears (1946) states that "Approximately 152 tons of C-2 slag were processed …," suggesting that the 10 tons per month cited in MED 1944 was input.

Using the NIOSH interpretation for throughput, it would appear that the plant had significant excess capacity, since processing 10 tons of slag would require only a single digester batch each month. Given the 2-day turnover rate cited above, the slag treatment plant had the capacity to process about 45 batches per month. It is surprising that this much over capacity would have been designed into the plant, since MED and Hooker engineers presumably had reasonable knowledge as to the quantities of slag and HCl available. One worker involved in slag handling said that they initially dumped about 25 barrels per day, and that this was later increased to about 40 barrels per day (Personal Communication 2009a). This would set the monthly slag input at 195 to 300 tons, well above either the NIOSH or SC&A estimate.

Finding B: *NIOSH should review its estimate of the monthly slag throughput at Hooker to ensure that all relevant data have been considered.*

The start date for the operations period is based on the date that the cinder block building was completed and turned over to operations (Dowling 1944, p. 112). The end date was based on the termination date for Contract No. W-7405-eng-28, the P-45 production contract (Mears 1946, p. 29). Mears (1946, p. 29) cites the start date of July 1945, rather than July 11, 1944. We believe that the cited date of July 1945 is in error. The assumption made by NIOSH in Appendix AA is claimant favorable, since the operating period may have actually been shorter.

The residual period began on January 15, 1946, and continued through October 11, 1976. The end date was established based on a site survey by Oak Ridge National Laboratory (ORNL). The survey determined that residual radioactivity levels were below limits for unrestricted release of the site (DOE 1985, p. 100). A Hooker employee stated in 1979 that, "Acid handling, conveyor, and concrete pad for uranium ore handling have long since been removed. Disposition unknown" (Olotka 1979).

[1] Another source states that the plant was shut down in October 1945 (Young 1985). The NIOSH assumption that shutdown occurred on January 15, 1946, is claimant favorable.

It is possible that some slag remained at the Hooker Site for a considerable period after cessation of operations. AEC correspondence in 1958 discusses shipment of C-oxide slag located at Hooker Electrochemical to the Y-12 Plant in Oak Ridge, Tennessee (Keller 1958). In the PER, NIOSH states that this material was located at the Lake Ontario Ordnance Works (LOOW), not at Hooker (NIOSH 2010, p. 14). NIOSH does not explain why they assumed that the material was at the LOOW rather than at Hooker as stated by Keller (1958). Saprie (1957) confirms the presence of 18,132 kg of C-slag at Hooker, based on an April 30, 1957, inventory. (See *Finding D* below.)

It should also be noted that the dates for the operating period proposed in Appendix AA are less inclusive than the dates proposed by the petitioners and accepted by NIOSH for the class to be evaluated (see Introduction above). As discussed above, the basis of the dates for the operating and residual periods are reasonably well documented and consistent with Appendix AA.

Observation A*. NIOSH should explain why they accepted the petitioners' assumptions regarding the duration of the operating period, since we are not aware of any evidence to support the extended operating period.*

3.0 NIOSH APPROACH TO ESTIMATING BOUNDING DOSES IN THE PETITION EVALUATION REPORT

Although workers at Hooker were presumably subjected to thorough periodic medical monitoring and examinations, no documentation was uncovered by NIOSH in their data capture efforts. According to Mears (1946), medical examinations for employees included:

- Complete pre-employment physical examination
- Complete monthly urinalyses
- Complete monthly blood counts
- Pre-employment serology
- Pre-employment chest x-ray

NIOSH concluded that:

> *Based on its Hooker Electrochemical research and data capture efforts, NIOSH determined that it does not have access to any site-specific internal, external, or area monitoring for Hooker Electrochemical workers that were involved with radiological work or potentially exposed to residual radiation during the time period under evaluation.* (NIOSH 2010, Section 3.1)

To compensate for this lack of site-specific data, NIOSH, examined C-2 slag exposures at other facilities in the MED complex where similar material was processed/handled. This approach for the use of surrogate data provides a better focus on process similarities than the approach adopted in Appendix AA. In Appendix AA, NIOSH selected data for a different type of scrap recovery process than was implemented at Hooker. The revised approach is more compatible with the surrogate data criteria recently approved by the Advisory Board on Radiation and Worker Health (ABRWH).

3.1 BOUNDING INTERNAL EXPOSURES

To estimate internal exposures from slag handling and processing, NIOSH collected C-2 slag data from ElectroMet, Mallinckrodt (MCW), and Fernald for use in the PER. These data are reproduced here in Exhibit 1. The highest observed uranium air concentration, 839 dpm/m^3, was a breathing zone sample for an operator dumping a drum of C-liner (slag) from a drum dumper at Fernald. In Appendix AA to TBD-6001, NIOSH assumed that the median exposure for a scrap recovery operator was 822 dpm/m^3. This median value of 822 dpm/m^3 is virtually identical to the maximum value observed when actually handling slag. It should be noted that in Appendix AA, NIOSH assumed that the median value was a constant, bounding value. If NIOSH had chosen to use the maximum observed air concentration from handling C-2 slag rather than the median determined from Appendix AA, they would have arrived at essentially the same bounding value for inhalation exposure during the operation period. Thus, use of the median value as proposed in Table AA.1 of Appendix AA is a bounding value.

However, as SC&A noted in its review of Appendix AA, while the values in Table AA.1 are bounding, the values were based on assumptions that raise questions of plausibility when using surrogate data. The use of data on slag handling as was done in the PER is scientifically sound and constitutes a more plausible approach to bounding inhalation intakes than the use of scrap recovery data from Battelle 2006.

Finding C: *NIOSH should consider revising Appendix AA to base internal exposures on surrogate slag handling data, rather than on surrogate data from TBD-6001 scrap recovery operations.*

While *Finding C* relates to Appendix AA of TBD-6001, it also relates to the PER, since NIOSH links the two documents in demonstrating its ability to "estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class." Specifically, NIOSH states in Section 7.1.1 of NIOSH 2010 that:

> *NIOSH considers the data utilized in this evaluation report of sufficient quality and quantity to support the Battelle-TBD-6001 Appendix AA methodology as a bounding dose reconstruction approach for Hooker Electrochemical internal doses.*

We believe that plausibility of the Appendix AA methodology would be enhanced if it were based on slag handling rather than scrap recovery data. We recognize that the numerical values would be essentially the same, based on the discussion provided above.

3.2 BOUNDING EXTERNAL EXPOSURES

NIOSH recovered data on external exposures to C-2 slag from the LOOW and from the St. Louis Airport Storage Site. Data from the St. Louis Airport Site are particularly useful for a bounding calculation. MCW stored C-2 slag at the Airport Site from 1946 to 1953. This slag was produced by the same process used by ElectroMet (i.e., reduction of UF_4 with magnesium in a reaction bomb). As described in Section 2 above, the slag from ElectroMet was shipped to Hooker for acid leaching.

MCW conducted a radiological survey of the Airport Site slag pile in 1948 and determined that the exposures measured "on top of pile at waist height" were 1.6 mrep/hr gamma and 11.5 mrep/hr beta (Caplan 1949).[2] By comparison, in TBD-6001, NIOSH assumed a <u>median</u> photon exposure rate of 0.08 mR/hr (0.528 mR/calendar-day × 365 calendar-days/300 work-days × 1 work-day/8 hr) for a scrap recovery operator working 48 hours per week.[3] The exposure of 0.528 mR/calendar-day was pro-rated in Appendix AA based on the time a worker at Hooker would spend handling barrels of slag (i.e., one day per month).

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[2] The rep (or mrep) is an historical unit (*roentgen-equivalent-physical*), which is variously equated to 83 to 95 ergs/g. It is claimant favorable to assume that roentgens (R or r in the records), rep, and rem are equivalent [ORAUT-TKBS-0028-6 (ORAUT 2005)].

[3] This median exposure is calculated assuming that the average exposure to a worker standing 1 m from a 55-gal drum of uranium is 0.28 mR/hr, and that the GSD of the lognormal distribution is 5 (Battelle 2006, Sections 7.1 and 7.2).

NIOSH concluded in Section 7.3.1 of the PER that:

> *The exposure rate listed for the Saint Louis Airport Storage site in 1948 is cited as being on top of the slag storage pile. Although the size of this pile is not known, based on the generation rate cited in 1945 (80,000–90,000 pounds every month to six weeks) (Simons, 1945), it would easily exceed any quantity of material that would be handled or stored at the Hooker Electrochemical site. Based on these data, a bounding deep and shallow dose can be based on the values measured in 1948 (11.5 mrep/hr beta and 1.6 mrep/hr gamma).*

The statement that bounding deep and shallow doses can be based on the values measured in 1948 appears to be at odds with a statement made previously in the PER. In Section 7.1.3, NIOSH states the following:

> *NIOSH considers the data utilized in this evaluation report of sufficient quality and quantity to support the Battelle-TBD-6001 Appendix AA methodology as a bounding dose reconstruction approach for Hooker Electrochemical external doses.*

Finding D: *NIOSH should clarify whether 1.6 mrep/hr for gamma and 11.5 mrep/hr for beta or the values contained in Tables AA.3 or AA.4 of Appendix AA should be used for a bounding calculation.*

3.2.1 External Photon Exposure

SC&A ran a separate calculation to determine whether a photon dose of 1.6 mrep/hr was, indeed, bounding. We assumed that the slag, containing 0.2% natural uranium, formed a pile of infinite thickness, and obtained dose conversion factors for U-238, U-234, Th-234, and Pa-234m from Table III.7 of Federal Guidance Report (FGR) No. 13 (EPA 1999). With these assumptions, we calculated a dose rate of 0.009 mrem/hr. If the slag contained 1% U, the external dose rate would be 0.043 mrem/hr. Clearly, using a gamma dose of 1.6 mrep/hr is bounding. However, we are troubled by the fact that measured dose is so high. To achieve a dose of this level, the infinitely thick slag pile would need to contain about 40% U. As another reality check, we note that a worker standing 1 m from a large uranium slab (40 × 60 × 10 cm) would receive a photon dose of 0.145 mrem/hr (Anderson and Hertel 2005).

Since there are large differences between the various estimates of external exposure based on calculations and measurements, we ran an MCNP calculation as described in Appendix A. The MCNP calculation was designed to mimic the geometry and slag composition that existed at Hooker. The calculated dose to a worker standing 1 ft from a barrel of slag containing 1% U was 0.015 mR/hr, a value consistent with that calculated using FGR No. 13.

Finding E: *While clearly bounding, the measured gamma dose from the St. Louis Airport Site slag pile may not be representative of C-2 clag.*

3.2.2 External Exposure to Non-Penetrating Radiation

Turning next to the measured non-penetrating dose of 11.5 mrep/hr, we note that this is not a contact dose, but rather a dose measured waist-high. The appropriateness of using this value to bound the dose to the hands and arms, as proposed by NIOSH, requires further examination. For example, a beta dose of 66 mrep/hr was measured at the edge of a slag barrel at MCW Plant 4 (ORAUT 2009, Table A-33). This measurement suggests that the dose to the hands and arms might not be bounded by using the measured value of 11.5 mrep/hr for the Airport Site.

With regards to the skin other than the hands and arms, NIOSH has proposed using a relationship where the non-penetrating dose to the balance of the body is 10 times the photon dose at 1 ft (Battelle 2006, Section 3.3.1). Anderson and Hertel (2005) determined that the photon dose (including Bremsstrahlung) at 1 ft from a uranium slab is 2.08 mrem/hr. Thus, the beta dose to other skin on a worker's body can be estimated to be 20.8 mrem/hr for a worker in close proximity to large natural uranium source at all times. Since a worker would not be exposed to a pure uranium source and since a worker's exposure to the source would not be full time, a value of 20.8 mrem/hr for beta exposure to skin other than the hands and arms should be bounding.

In TBD-6001 (Table 3.4), NIOSH cites the beta surface dose rate from a natural uranium slab as 233 mrad/hr. This is apparently a measured value. NIOSH assumed that this was the arithmetic mean of a lognormal distribution with an assumed geometric standard deviation (GSD) of 5. They further assumed that the worker spent 50% of the time with his hands in contact with the uranium slab, incurring a dose of 33.2 mrem/hr. This methodology was carried forward to Appendix AA (Table AA.3), where the dose was pro-rated to 11 mR/calendar-day, based on handling barrels of slag 1 day per month.

Unlike the photon dose, the argument that a beta dose of 11.5 mrep/hr is bounding is less clear. We believe that the beta dose model in TBD-6001 is flawed, because there is no scientific basis for the assumption that the surface exposure of 233 mrad/hr is the arithmetic mean of a lognormal distribution with a GSD of 5. If 233 mrad/hr is a measured value, then it is highly unlikely that the measurement uncertainty would support a GSD of 5. This suggests that assuming a median value of 33 mrem/hr is not warranted as the appropriate metric for exposure to a uranium slab 50% of the time. (Note that in Appendix AA the median is used as the bounding value and not as input to a distribution.)

These various estimates of beta dose described above are summarized in Table 3-1.

Table 3-1. Estimates of Surface Dose Rates

Dose Rate	Basis for Dose Rate Estimate
11.5 mrep/hr	Measured waist high above slag pile
233 mrad/hr	Contact dose from natural uranium slab
20.8 mrem/hr	10 times calculated photon dose (including Bremsstrahlung) at 1 ft (proposed for skin other than hands and arms)
33.2 mrem/hr	Calculated median based on average of 233 mrad/hr, GSD of 5 and 50% of time in contact with source based on TBD-6001. Basis for Appendix AA, Table AA.3 calculations
66 mrep/hr	Measured at edge of slag barrel

Since creating plausible, bounding estimates from the information provided in Table 3-1 involves a significant measure of subjective judgment, we performed the MCNP calculations presented in Appendix A. The calculated contact dose was 0.85 mrem/hr, which is about a factor of 40 lower than that used in Table AA.3 of Appendix AA. It is about a factor of 14 lower than the measurements made at the Airport Site slag pile. Thus, either the measured value at the St. Louis Airport site or the value based on TBD-6001 should provide a reasonable basis for a bounding calculation. However, for reasons discussed above, we believe that the measured data from the slag pile are a more plausible source of surrogate data.

3.3 BOUNDING DOSES DURING THE RESIDUAL PERIOD

3.3.1 External Exposure during the Residual Period

The PER notes that external doses during the residual period in Appendix AA are based on exposure to surface contamination at the end of the operating period with no diminution during the residual period. The specific methodology is based on Table 7.3 of TBD-6001, which lists the median exposure to an operator standing on a contaminated surface as 0.376 mR/calendar-day. NIOSH provided information to assist SC&A in understanding the source of this exposure metric, since it could not be readily derived from the information in TBD-6001 (Allen 2010). The starting point was general area samples taken near a scrap processing furnace (TBD-6001, Table 8.23), which list average general area values of 900 dpm/m^3 (trays) and 200 dpm/m^3 (calciner), yielding an overall average general area value of 550 dpm/m^3. This was converted to a geometric mean (GM) of 151 dpm/m^3, based on a lognormal distribution with a GSD of 5. Assuming deposition for 1 year at a deposition velocity of 7.5E-04 m/s, the contamination factor is 2.37E+04 m and the annual areal deposition is 3.57E+06 dpm/m^2 (151 dpm/m^3 × 2.37E+04 m). From this, the external exposure rate can be determined to be 0.002 mR/hr (or 0.013 mR/calendar-day) using the conversion factor in Table 3.10 of TBD-6001 of 5.61E-10 mR/hr per dpm/m^2. Due to spreadsheet error, the hourly exposure had been calculated to be 0.376 mR/calendar-day. In this calculation, no credit is taken for the fact that the surface contamination is only 0.2% U, and no credit is taken for possible source term reduction during the residual period. Thus, an external exposure during the residual period of 0.013 mR/calendar-day should be bounding, based on the model and assumptions used by NIOSH.

However, one can question the average general area air sample of 550 dpm/m^3 on which the deposition estimate is based. This dust level was obtained from scrap recovery operations, which are questionable surrogates for slag processing. To further explore this issue, we examined the airborne dust sample data from C-2 slag handling reported in Tables 6-1, 6-2, and 6-3 of the PER (see Exhibit 1). Most of the data reported in those tables are breathing zone data, which would overstate surface deposition. The values are summarized in Table 3-2. The cited values are generally the average of several samples, but are individual measurements in some cases.

It is apparent from Table 3-2 that an average concentration of 550 dpm/m^3 is bounding, even though it is based on operations different from those involved in slag handling.

Table 3-2. Airborne Dust Concentrations from Handling C-2 Slag

Data Source in NIOSH 2010	Average Concentration (dpm/m^3)
Table 6-1 (ElectroMet)	456, 398
Table 6-2 (Mallinckrodt)	154, 80, 200, 245, 112, 154, 77, 149, 27, 81, 57
Table 6-3 (Fernald)	247, 191, 255, 206, 224, 13, 309, 63, 78, 480, 682

Considered on another level, the model for external exposure based on surface deposition prior to the end of operations may not be appropriate at Hooker. As described in Section 2 above, about 20 tons of slag remained at Hooker, at least until sometime in 1958. The presence of this slag is not explicitly considered in the surface deposition model, although it could be argued that assuming a constant source term throughout the residual period in some way compensates for the presence of slag after cessation of operations. As described in Section 3.2, a worker standing on a surface of infinite depth contaminated with 0.2% uranium would receive a miniscule dose of 0.009 mrem/hr, which is not significantly different from the external exposure of 0.002 mR/hr calculated from the surface deposition model.

Finding F: *The PER should recognize that slag was present during the residual period, at least through 1958, and ensure that this information is incorporated into the bounding external exposure calculation for the residual period.*

3.3.2 Internal Exposure during the Residual Period

According to Section 7.2.2 of the PER:

> *Battelle-TBD-6001 Appendix AA presents an assessment of internal exposures during the residual period based on the deposition of airborne contamination during one year of operations and the subsequent resuspension of this material, resulting in an inhalation intake estimate of 1 pCi/d.*

Appendix AA used a resuspension factor of 1E-06/m to estimate the dust concentration during the residual period. In its review of Appendix AA, SC&A requested that NIOSH provide clarification as to how the value of 1 pCi/d was calculated (see discussion of Finding 7 in Section 4.0). If slag handling was primarily done outdoors and the screened slag was then conveyed inside the cinder block building for acid digestion, one could consider the use of general area data from Fernald as a surrogate source (Exhibit 1, Table 6-3). The maximum measured value was 39 dpm/m^3. Based on 1 year's deposition and a resuspension factor of 1E-06/m, the resuspended air concentration would be 0.92 dpm/m^3 (39 dpm/m^3 × 0.00075 m/s × 3.15E07 s/yr × 1E-06/m). This is equivalent to an inhalation intake of 3.2 pCi/calendar-day (0.92 dpm/m^3 × 9.6 m^3/day × 6 days/week × 50 weeks/yr × 1 pCi/2.22 dpm × 1 yr/365 days).

While we do not know how NIOSH arrived at a value of 1 pCi/d for the inhalation dose during the residual period, based on the scoping calculation provided here, it appears that a value on the order of 3 pCi/calendar-day is appropriate for outdoor slag handling operations. This value (i.e., 3 pCi/calendar-day) is not significantly different from that proposed by NIOSH.

As discussed in greater detail in Section 4 (Findings 8 and 9), use of a resuspension factor of 1E-06/m may not be bounding. For workers employed during the first 1 to 3 years at the beginning of the residual period, higher resuspension factors will lead to higher exposures. For workers whose employment begins later in the residual period, a resuspension factor of 10-6/m can become limiting, because higher resuspension factors result in early depletion of the source term.

Finding G: *Depending on employment history, use of a resuspension factor of 1E-06/m for the residual period may not be bounding when calculating inhalation doses. If NIOSH believes that use of this resuspension factor is appropriate, they should provide justification describing, for example, clean-up procedures conducted after the cessation of operations.*

4.0 SC&A REVIEW OF APPENDIX AA TO TBD-6001

In its review of Appendix AA, SC&A made a number of findings (SC&A 2010). The findings are reviewed here in the context of whether they are strictly site profile issues or whether they have relevance to NIOSH's ability to estimate maximum radiation doses under plausible circumstances, as stated in the PER. Assessment of the claimant-favorability and plausibility of the approach to dose reconstruction in Appendix AA is of particular importance, since NIOSH concluded in the PER for SEC-00141 that use of Appendix AA provided a suitable bounding approach. However, see the discussion in Section 3.2 regarding which source(s) to use for bounding external doses.

The findings from SC&A 2010 are discussed below, and the discussion will indicate that the exposures can be bounded, although in some instances, SC&A takes issue as to how the bounding calculations are done.

Finding 1: NIOSH should re-examine the assumption that dumping of barrels could be done in 1 day per month.

This finding was based on the presumption that it would be necessary to process 100 tons of slag (containing 0.2% U) per month to obtain 10 tons of **product** (containing 2% U). Based on 500 lbs of slag per barrel, this would require processing 400 barrels per month. SC&A did not believe that 400 barrels could be processed in only 1 day per month. However, NIOSH pointed out at the November 4, 2010, TBD-6001 Work Group meeting that SC&A had misinterpreted the value of 10 tons per month (from MED 1944, p. 29) as product output rather than slag input. MED 1944 characterized the feed as, "ACTUAL QUANTITY (MONTHLY RATE – 10 tons." The Data Sheet is ambiguous and the 10 tons could be input or output. However, Mears (1946) states that, "Approximately 152 tons of C-2 slag were processed…," suggesting that the 10 tons per month cited in MED 1944 was input. Based on this assumption regarding the input value, only 40 barrels would need to be processed monthly to achieve the specified slag input of 10 tons per month.

In an interview with NIOSH, a former AWE worker at Hooker notes that they initially handled 25 wooden barrels per day, but later increased this to processing 40 barrels per day (Personal Communication 2009a). Barrel handling was done in a building where only [redact] workers were present. Barrels were delivered to the building each night after the operators had left. The barrels were opened and the material was dumped on the floor. Material was then sifted through a grate. Material that did not pass through the grate was shoveled back into barrels, which were resealed and removed during the night when new barrels of slag were delivered. Initially, material passing through the grate was shoveled onto a conveyor, which carried material through a hole in the wall and out of the building to an unknown destination. Subsequently, the material passing through the grate was deposited directly on the conveyor, resulting in the increased throughput of approximately 40 barrels per day. The worker stated that he began this work about March 1944 and continued [redact] for about a year. The worker thought that the slag processing operation was over by [redact] (i.e., March or April 1945).

SC&A believes that the assumption that only about 10 tons of slag were processed monthly needs to be re-examined in view of the worker interview cited above and the large capacity of the slag-handling plant. This is a site profile issue.

Finding 2: NIOSH should account for all activities causing inhalation exposure, not just those involved in dumping barrels of C-2 slag.

In Table AA.1, "Internal Dose Pathways," of Appendix AA, NIOSH lists 156 pCi/d as the inhalation intake for an operator. According to NIOSH, this value is based on Table 8.29 of TBD-6001, where a median inhalation intake rate of 2,920 pCi/calendar-day is quoted for a scrap recovery furnace operator (1951 and earlier) handling trays of scrap. Multiplying the median intake by the exposure factor of 5% for barrel handling, the calculated daily exposure for an operator would be 146 pCi/d (2,920 pCi/calendar-day × 0.05 exposure days/calendar-day), a value similar to that in Table AA.1. SC&A felt that NIOSH had ignored exposure from other operations, such as slag digestion and filtration. NIOSH pointed out at the November 4, 2010, Work Group meeting that the difference between 146 pCi/calendar-day for barrel handling and 156 pCi/calendar-day cited in Table AA.1 is attributable to these other operations. Presumably, the balance of the time (i.e., 95%) was assigned to filtration operations, where the median daily weighted average (DWA) was 10.7 pCi/calendar-day for a filtration operator (TBD-6001, Table 8.29). SC&A (2010) made an independent estimate of exposure to filtration and digestion operations and concluded that the incremental exposure would be about 23 pCi/calendar-day. SC&A believes that this small difference will not significantly affect dose reconstructions and that this finding has been resolved. For reasons subsequently discussed under Finding 3, SC&A believes that an inhalation intake of 156 pCi/calendar-day is bounding.

Finding 3: While SC&A does not agree with some of the underlying assumptions in their approach [to estimating intakes]*, the NIOSH approach appears to be bounding for dose reconstruction. However, our independent analyses indicate that the values for intake rates are unrealistically high.*

This is not an SEC issue. A bounding analysis can be done but, as SC&A pointed out in its review of Appendix AA, there are other operations evaluated in TBD-6001 that could be considered as more appropriate surrogates for the acid leaching and filtration operations at Hooker than handling trays of uranium compounds during scrap reprocessing. For example, one could consider use of the data from **concentrates** in Table 8.2 of TBD-6001. Since the minimum, maximum, and average values for concentrates do not fit a lognormal distribution, Strom (2007, Section 2.1.2.4) recommends using the average and an assumed GSD of 5 to calculate lognormal parameters. This approach results in a 95th percentile value of 153 dpm/m^3, which is equivalent to an inhalation intake of 544 pCi/calendar-day. The concentrates contain an average of 80% U_3O_8 (Christofano and Harris 1960) or 68% U. Adjusting the concentrate exposure for the uranium content of the slag (68%/0.2%) results in an estimated inhalation intake of 1.6 pCi/calendar-day, as compared to 156 pCi/calendar-day in Table AA.1 of Appendix A.

Finding 4: NIOSH should correct the external exposure rates in Table AA.3.

This is not an SEC issue. NIOSH advised SC&A that values in Table AA.3 are in error and will be corrected when Appendix AA is revised. Continued use of the current version of Table AA.3 until the appendix is revised is claimant favorable, since the corrections will reduce the external exposure. The values in Table AA.3, when corrected, will still be bounding, since conservative assumptions based on uranium compounds rather than slag were used to develop the external exposure estimates.

Finding 5: Rather than applying the values in Table 7.3 [of TBD-6001] *as default/bounding values, NIOSH should derive the correct external dose values using MicroShield or MCNP.*

This is not an SEC issue. The uranium source term for materials handling in Table 7.3 of TBD-6001 is based on exposure to 55-gallon drums containing loosely packed uranium (or U_30_8) with a density of 1.6 g/cm^3 that has decayed for 100 days after refining. Based on the specific activity of natural uranium of 684 pCi/mg U, the drum would contain 1.09E+06 pCi/cm^3. The equivalent U content in the C-2 slag would be 4.35E+03 pCi/cm^3, based on an MgF_2 density of 3.18 g/cm^3 (0.002g U/g MgF_2 × 3.18 g MgF_2/cm^3 × 684 pCi/mg U × 1,000 mg/g). The fact that the curie density in 55-gallon drums is about 2.5 orders of magnitude greater than in the C-2 slag supports the use of the median from Table 7.3 as the upper bound for material handling exposures at Hooker. However, the use of a drum of uranium as a surrogate for a drum of slag raises questions of plausibility. As discussed in Section 3.2 and Appendix A, SC&A subsequently conducted MCNP calculations demonstrating that the value of 0.08 mR/hr assumed by NIOSH is bounding, as compared to the value of 0.015 mR/hr calculated here using MCNP.

Finding 6: NIOSH should consider whether use of shallow dose estimates based on slag sampling is a more plausible approach than pro-rating exposures from a large uranium object. Alternatively, NIOSH could consider using a conservative estimate of the concentration of uranium in the barrel, and take into consideration self-shielding and the shielding from the barrel wall using MicroShield or MCNP.

This is not an SEC issue. It raises the question as to whether there are better (more plausible) techniques to estimate shallow doses. For example, NIOSH has suggested in its review of Petition SEC-00141 for Hooker that a value of 11.5 mrep/hr be used for shallow dose, based on measurements taken in 1948 at the top of a pile of C-liner slag at the St. Louis Airport Storage Site (NIOSH 2010). Estimates of exposure to the hands could then be based on the time spent per day with the hands in contact with the barrels of slag and the number of days per month that barrels were handled. However, as discussed under Finding 5 above regarding photon exposure, an alternative, scientifically sound approach would be to calculate the shallow dose exposure using MCNP. SC&A has subsequently conducted such calculations and demonstrated that the assumptions used by NIOSH are bounding.

Finding 7: NIOSH should provide an example calculation showing how they arrived at an inhalation intake of 1 pCi/calendar-day [for the residual period].

This is not an SEC issue; rather it is just a request for clarification of the calculational methodology.

Finding 8: NIOSH should justify the use of a resuspension factor of 1E-06/m.

Finding 8 and Finding 9 are inter-related and integral with SC&A's critique of ORAUT-OTIB-0070 for the Procedures Work Group. If one determined that a resuspension factor of 1E-06/m was appropriate for a given site at the beginning of the residual period based, for example, on evidence that some clean-up had been done when operations were terminated, one can estimate the decay constant and the life of the source based on the equation λ = 24KnH/day, where λ is the source term decay constant, K is the resuspension factor (m-1), H is the room height (m), and n is the air turnover rate (hr-1). Assuming values of K = 10-6/m, n = 1/hr, and H = 5 m, the decay constant is 0.012%/day. In this example, the source term would be substantially depleted in about 23 years, based on the assumed exponential decay. If, on the other hand, the resuspension factor was 1E-04/m based on regular foot and vehicle traffic continuing to disturb the surface, the decay constant would be 1.2%/day and the source term would be depleted in about 83 days. Thus, for two workers employed at the beginning of the residual period, with one having his exposure based on a resuspension factor of 10-4/m and the other having his exposure based on a resuspension factor 10-6/m, the worker with exposure based on the higher resuspension factor would receive the higher dose as long as his employment duration during the residual period was less than 23 years.. However, if a worker was hired after the first year or so of the residual period, his exposure would be lower based on the higher resuspension factor. A resuspension factor should be selected based on the conditions extant at the beginning of the residual period, and a decay rate consistent with that resuspension factor should be used.

In the case of Hooker, the dust source term, based on a resuspension factor of 10-6/m, was not subject to exponential decay, but rather was held constant at its initial value. This would result in a bounding inhalation exposure value for all workers whose employment began about 1 to 2 years after the beginning of the residual period. This would also result in a bounding exposure during the first year of the residual period for any workplace environment where use of a resuspension factor of 10-6/m is specifically justified. For situations where the worker was employed at the beginning of the residual period and workplace conditions support assumption of a higher resuspension factor, then use of 10-6/m may not be claimant favorable.

We recognize that exposures during the residual period are very small, but the calculational approach should justified and scientifically sound.

Finding 9: NIOSH should justify that the approach taken to calculate inhalation exposures during the residual period is bounding, and takes into consideration SC&A's review of ORAUT-OTIB-0070.

As discussed under Finding 8, we believe that use of the source term decay rate should be consistent with the assumed value for the resuspension factor. Resuspension factors should be based, to the extent possible, on expected site conditions at the end of operations. It is not possible to define a set of parameters (i.e., resuspension factor and source term depletion) that is bounding without consideration of the worker's employment history relative to the dates of the residual period.

This is not an SEC issue, but rather an issue as to how to do a bounding calculation.

Finding 10: NIOSH needs to correct the calculation of external exposure during the residual period and revise the basis for converting this exposure to pCi/calendar-day.

Table 7.3 of TBD-6001 lists the median exposure to an operator standing on a contaminated surface as 0.376 mR/calendar-day. NIOSH provided information to assist SC&A in understanding the source of this exposure metric, since it could not be readily derived from the information in TBD-6001 (Allen 2010). The starting point was general area samples taken near a scrap processing furnace (TBD-6001, Table 8.23), which list average values of 900 dpm/m^3 (trays) and 200 dpm/m^3 (calciner), yielding an average value of 550 dpm/m^3. This was converted to a GM of 151 dpm/m^3, assuming that the data were described by a lognormal distribution with a GSD of 5. Assuming deposition for 1 year at a deposition velocity of 7.5E-04 m/s, the contamination factor is 2.37E+04 m and the annual areal deposition is 3.57E+06 dpm/m^2 (151 dpm/m^3 × 2.37E+04 m). From this, the exposure rate can be determined to be 0.002 mR/hr using the conversion factor in Table 3.10 of TBD-6001 of 5.61E-10 mR/hr per dpm/m^2. Due to spreadsheet error, the hourly exposure had been calculated to be a factor of 100 higher.

This is not an SEC issue.

5.0 REFERENCES

Allen, David 2010. E-mail from David Allen (CDC/NIOSH/OD) to W. C. Thurber (SC&A, Inc.). *Re: Hooker A Question or Two*. June 16, 2010.

Anderson, J.L. and N.E. Hertel 2005. "Bremsstrahlung Doses from Natural Uranium Ingots." *Radiation Protection Dosimetry* (2005), Vol. 115, No. 1-4, pp. 298–301.

Battelle 2006. *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium*, Rev. FO. Battelle Team Dose Reconstruction Project for NIOSH. Battelle-TBD-6001 December 13, 2006. SRDB Ref ID: 30673.

Battelle 2007. *Site Profiles for Atomic Weapons Employers the Refine Uranium and Thorium – Appendix AA Hooker Electrochemical Company*. Battelle-TBD-6001, Appendix AA. June 15, 2007.

Caplan, K.J. 1949. *Health Problems at the Airport Properties*, correspondence to H. E. Thayer from K. J. Caplan (MCW). August 11, 1949. SRDB Ref ID: 11193.

Christofano, E. and W.B. Harris, 1960. "The Industrial Hygiene of Uranium Refining." *Env. Health* 1(5):74-96.

DOE 1977. *Formerly Utilized MED/AEC Sites Remedial Action Program, Radiological Survey of the Hooker Chemical Company, Niagara Falls, New York*, Final Report. U.S. Department of Energy, Washington, DC. SRDB Ref ID: 10797.

DOE 1985. *Formerly Utilized Sites Remedial Action Report Elimination Report for Occidental Chemical Corporation (Former Hooker Electrochemical Company) Niagara Falls, New York,* U.S. Department of Energy, Washington, DC. SRDB Ref ID: 11002, p. 59.

Dowling, Francis A., c. 1944. *Completion Report, Construction of Hooker Electrochemical Company P-45 Plant.* Contract No. W-7405-ENG-28. Tonawanda Area-Manhattan District. SRDB Ref ID: 11002, pp. 102–112.

EPA 1999. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides.* Federal Guidance Report No. 13. EPA-402-R-99-001. Office of Radiation and Indoor Air.

Keller, C.A 1958. Letter from C.A. Keller, Production Division, USAEC to J.P. Murray Y-12 Plant Superintendent, *Transfer of Niagara Falls Slag to Y-12*. June 24 1958. SRDB Ref ID: 64932.

Mears, B.J. 1946. *Medical Clearance on Terminated Madison Square Area Contracts*. War Department, U.S. Engineer Office. SRDB Ref ID: 17125, pp 29–30.

MED 1944. *Medical Section – Manhattan District, Data Sheets for Industrial Hazard Rating*. Manhattan Engineer District. SRDB Ref ID: 16323, pp. 29–30.

NIOSH 2010. *SEC Petition Evaluation Report: Petition SEC-00141 (Hooker Electrochemical).* Rev. 0. March 3, 2010.

Olotka, F.T. 1979. Letter to Mr. William E. Mott, Acting Director, Environmental Control Technical Division, Department of Energy, Washington, DC, SRDB Ref ID: 11002, p. 39.

ORAUT 2005. *Weldon Spring Plant – Occupational External Dosimetry*, ORAUT-TKBS-0028-6, J. Langsted and C. Little, Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. June 24, 2005.

ORAUT 2008. *Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities.* ORAUT-OTIB-0070, Revision 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. March 10, 2008.

ORAUT 2009. *Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St. Louis Airport Site, St. Louis, Missouri*, ORAUT-TKBS-0005, Rev. 02 PC-1, Oak Ridge Associated Universities Team, Cincinnati, Ohio. May 25, 2009.

Personal Communication 2009a. *Personal Communication with Former Hooker Electrochemical "Yard Gang" Employee*; Telephone Interview conducted by the Oak Ridge Associated Universities Team (ORAUT); December 12, 2009. SRDB Ref ID: 77828.

Personal Communication 2009b. *Personal Communication with Former Hooker Electrochemical Chemical Engineer/Operator*; Telephone Interview by the Oak Ridge Associated Universities Team (ORAUT); December 12, 2009. SRDB Ref ID: 77827.

Personal Communication 2010. Letter to Dr. Henry Anderson, Chair, TBD-6001 Work Group. *Re: SEC Tracking Number – SEC-00141*. August 2, 2010.

Sapirie, S.R. 1957. *Low Grade Uranium Residues Stored at the Niagara Falls Site, New York*, correspondence from S.R. Sapirie (AEC) to D.F. Musser (AEC). May 29, 1957. SRDB Ref ID: 6341

SC&A 2010. *Review of the NIOSH Site Profile for the Hooker Electrochemical Company. Battelle-TBD-6001, Appendix AA.* Contract No. 200-2009-28555. SCA-TR-SP2010-0034. September 2010.

Simons, F.W. 1945. *Shipment Security Survey at Mallinckrodt Chemical Works*, correspondence that includes summary of shipments; F. W. Simons; February 15, 1945; SRDB Ref ID: 9161.

Strom, D.F. 2007. *Default Assumptions and Methods for Atomic Weapons Employer Dose Reconstructions*. Battelle-TIB-5000, Rev. 00, Effective date: April 2, 2007.

Young, Charles D. (Aerospace Corporation) 1985. Letter to Arthur Whitman DOE), *Update of Responses to Hooker (OCC) Interrogatories.* February 28, 1985. Ref ID 11002, pp. 63-71.

Exhibit 1: Tables Reproduced from the NIOSH SEC Petition Evaluation Report, Petition SEC-00141, Rev. 0, Report Submittal Date May 3, 2010

Table 6-1: Pertinent Air Monitoring Data from ElectroMetallurgical Corporation

Date	Description	Measurement	Reference
December 24, 1947 March 30, 1948 May 14, 1948	Bomb Room, Barrel Slag and weigh	456 dpm/m^3 (average of unknown samples)	SRDB Ref ID: 8917, p. 7
August 17–19, 1949	Shovels slag into lean and rich drums	398 dpm/m^3 (average of 3 samples)	SRDB Ref ID: 8930, p. 19

Table 6-2: Summary of Pertinent Air Monitoring Data from the Mallinckrodt Facility

Date	Description	Measurement	Reference
1948 (Plant 4)	Slag Man (DWA)	2.2 (times tolerance) (154 dpm/m^3)	SRDB Ref ID: 9340, p. 4
1949 (Plant 4)	Slag Man (grinding C-Special)	80 dpm/m^3 (average of 3, high 100, low 70)	SRDB Ref ID: 9340, p. 50
1949	Air concentration posted on building layout—cited as “slag dumpster”	200 dpm/m^3	SRDB Ref ID: 11553
1949	Slag Grinding	245 dpm/m^3 average 194 dpm/m^3 min 288 dpm/m^3 max	SRDB Ref ID: 11553
1949	DWE (slag handling)	1.6 x MAC-AEC Study (112 dpm/m^3) 2.2 x MAC-Mallinckrodt Study (154 dpm/m^3)	SRDB Ref ID: 11553
1950 (Plant 4)	Slag Man (DWA)	1.1 (times tolerance) (77 dpm/m^3)	SRDB Ref ID: 9341, p. 5
1951 (Plant 6E)	Unloaders (removing C-Special drum)	149 dpm/m^3 (average of 2, high 237, low 60.8)	SRDB Ref ID: 9343, p. 19
1952	Changing C-oxide and slag-liner drums	27 dpm/m^3	SRDB Ref ID: 20657
1953	Changing C-oxide and slag-liner drums	81 dpm/m^3	SRDB Ref ID: 20657
1953	Changing C-oxide and slag-liner drums	57 dpm/m^3	SRDB Ref ID: 20657

Table 6-3: Summary of Pertinent Air Monitoring Data from Fernald

Date	Description	Measurement	Reference
1956	BZ-dumping can of C-liner into dumping station (respirator worn)	247 dpm/m^3	SRDB Ref ID: 34544
1956	BZ-dumping can of C-liner into dumping station (respirator worn)	191 dpm/m^3	SRDB Ref ID: 34544
1956	BZ-dumping can of C-liner into dumping station (respirator worn)	255 dpm/m^3	SRDB Ref ID: 34544
1956	BZ-dumping can of C-liner into dumping station (respirator worn)	206 dpm/m^3	SRDB Ref ID: 34544
1956	Dumping C-liner at 2nd floor dumping station, dry area	3.21 x MAC (224 dpm/m^3) (average of 4, above)	SRDB Ref ID: 41025
1958	BZ-[redact] chipping magnesium from C-liner and uranium at the outside William Mill (no respirator worn) Note: 3 samples total – samples may run high and low due to the wind change (this was an outside operation)	262 dpm/m^3 659 dpm/m^3 519 dpm/m^3	SRDB Ref ID: 42627
1958	BZ-[redact] dumping drum of C-liner from the 2nd floor drum dumper Note: 3 samples total	793 dpm/m^3 829 dpm/m^3 424 dpm/m^3	SRDB Ref ID: 42627
1959	Evaluation of emptying gondola loaded with C-liner from Mallinckrodt (material removed from gondola and dropped onto pad) – equipment used: crane with clam – material was moist and damp Note: 29 samples total, all sample results are GA samples downwind of operation	13 dpm/m^3 (average) 3 dpm/m^3 (min) 38 dpm//m^3 (max)	SRDB Ref ID: 42628
1959	Phase III of airport scrap evaluation (cleaning out loose material with push broom) – material was dry and very dusty Note: 12 samples total, all sample results are BZ samples	309 dpm/m^3 (average) 195 dpm/m^3 (min) 627 dpm/m^3 (max)	SRDB Ref ID: 42628
1959	Part of evaluation of C-liner in gondola at rail line at east end of Plant 8 (car emptied by crane) Laborer cleaned at angles and bends where the crane could not reach – material was partially moist and dry. In some places, the material was very hard Note: 25 samples total, all sample results are BZ samples	63 dpm/m^3 (average) 15 dpm/m^3 (min) 181 dpm/m^3 (max)	SRDB Ref ID: 42628
1959	Evaluation of handling Mallinckrodt airport scrap (BZ hand shoveling airport scrap into 30 gallon drums) – material was damp and cakey with no visible dust (no respirator worn) Note: 11 samples total, all sample results are BZ samples	59 dpm/m^3 (average) 19 dpm/m^3 (min) 108 dpm/m^3 (max)	SRDB Ref ID: 42628

Table 6-3: Summary of Pertinent Air Monitoring Data from Fernald

Date	Description	Measurement	Reference
1959	BZ [redact] dumping drum of slag liner into outside crusher dumping station (No respirator worn) Ventilation was said to appear very effective Note: 4 samples total, all sample results are BZ samples	78 dpm/m^3 (average) 32 dpm/m^3 (min) 110 dpm/m^3 (max)	SRDB Ref ID: 42628

Exhibit 1 References

Brealia [sic], A.J. 1949. *Electro Metallurgical Co. Occupational Exposure to Radioactive Dust August 17–19, 1949*. November 10, 1949. SRDB Ref ID: 8930. [A.J. Breslin, New York Operations Office, Atomic Energy Commission]

Caplan, K.J. 1949. From K.J. Caplan (MCW) to Thayer (AEC), Subject: *Dust Study at MCW Plant 4*. February 2, 2949. SRDB Ref ID: 11553.

Caplan, K.J. 1951. From K.J. Caplan (MCW) to Thayer (AEC), Subject: *Results of Dust Study Six-E*. February 26, 1951. SRDB Ref ID: 9343.

Huelston, D.J. 1950a. From D.J. Huelston (MCW) to K.J. Caplan (MCW), Subject: *Mallinckrodt Chemical Works Plant Four Dust Study*. March 1, 1950. SRDB Ref ID: 9340.

Huelston, D.J. 1950b. From D.J. Huelston (MCW) to K.J. Caplan and Mason (MCW), Subject: *Mallinckrodt Chemical Works Plant Four Dust Study Recheck*. June 1, 1950. SRDB Ref ID: 9341.

MCW no date: *MCW Plant 6E, Occupational Exposure to Airborne Contaminants*, MCW-18. References a study done November 18–20, 1953. Mallinckrodt Chemical Works, Industrial Hygiene Branch, Health and Safety. SRDB Ref ID: 20657.

NLO 1956. *Analytical Data Sheet Plant 8, BZ Results*. Fernald. National Lead of Ohio. SRDB Ref ID: 34544.

NLO 1958. *Plant 8 Analytical Data Sheet, Air Dust, 1957–1970*. Fernald. National Lead of Ohio. March 7 to October 13, 1958. SRDB Ref ID: 42627.

NLO 1959. *Plant 8 Analytical Data Sheet, Air Dust, 1957–1970*. Fernald. National Lead of Ohio. February 6 to December 24, 1959. SRDB Ref ID: 42628.

Schumann and Stefanec 1956. C.B. Schumann and A.J. Stefanec (NLO) to R.C. Heatherton (NLO), Subject: *Exposure Study of Plant 8 to Airborne Radioactive Dust*. December 31, 1956. SRDB Ref ID: 41025.

Various, 1947–1948, *Reports on Dust Hazards at Electrometallurgical Company*; various authors; dates from December 1947 through May 1948; SRDB Ref ID: 8917.

Exhibit 2: Reproduction of Slag Plant Operating Instructions

HOOKER ELECTROCHEMICAL COMPANY
NIAGARA FALLS, N.Y.
FORM-672 4.42

September 12, 1944

OUTLINE FOR OPERATING C-2 SLAG PLANT

Reproduction of Slag Plant Operating Instructions

C-2 slag is a mixture of fine and coarse material. The operation is designed to concentrate the slag and reduce its bulk. There are two main parts in the operation:

1. ACID TREATMENT The fines are dissolved in acid to remove lime. The filter cake from this reaction is one form of this product.
2. SCREENING The rejects from screening the feed are barreled as a second form of product.

PROCEDURE

Charge two or three feet of water into an empty tank equipped with an agitator.

Add 50 barrels of lime as rapidly as possible. The coarse screen rejects should be collected in wooden barrels.

Acid should be turned into the tank as soon as three barrels have been added. Slag should be added steadily and rapidly, so that the tank does not turn acid.

After the slag has been added, continue adding acid until the pH of the solution has dropped to 5. (It is necessary to take frequent tests toward the end of the reaction, since the pH of the solution will drop rapidly once the lime has been dissolved. If the pH drops lower than five, the metal agitator and pipe will chew out rapidly.

When the pH has dropped to 5, discontinue the acid addition and allow the tank to digest for 6 hours, testing the pH hourly.

When the six hour digestion period is complete, it is necessary to adjust the pH. THE SOLUTION MUST BE ALKALINE – pH 7 OR ABOVE, BEFORE FILTERING. Drop in one bag of lime; then test the pH. Add more lime if necessary to make the neces-
sary adjustment. One bag of lime should usually suffice.

Next filter the batch, recycling to the same tank until the filtrate runs clear; then run the filtrate to D tank.

After the filtration is complete, wash the press for at least 12 hours. The wash water may be run to the sewer.

IT IS MOST IMPORTANT THAT ALL THE DISPOSAL ACID BE USED FOR C-2 SLAG. Each hour that acid runs to the lime pit is wasted time for the slag plant. The work SHOULD be planned with this in mind.

The lumps should be rescreened if necessary to free them from fines. The barrels should be reheaded, weighed and stenciled with the net weight, name, (C-2 LUMPS) and lot number. The batch number should also be included.

The filer cake should be packed in metal drums, closed and stenciled with the name (C-2 CONC), net weight and lot number.

Before dumping the filtrate in C tank, a quart sample should be taken and given to the control chemist for testing. If O K, the batch may be dumped into the sewer. If not, see AVT for further instructions.

APPENDIX A: EXTERNAL EXPOSURE TO BARREL OF C-2 SLAG

SC&A calculated the following dosimetric quantities, utilizing the Los Alamos Monte Carlo code MCNPX (LANL 2009):

- Exposure rate
- Ambient dose equivalent, H*(10), from photon radiation
- Ambient dose equivalent, H*(10), from neutron radiation
- Skin dose from beta radiation

Figure A-1. Array of Whiskey Barrels (Kentucky Barrels 2003)

The radiation source was 500 lb (226.8 kg) of C-2 slag in a 50-gal wooden whiskey barrel. MED (1944, p. 29) cited the approximate composition of the slag as follows: 90% MgF [*sic*], 10% CaO, 1% X. "MgF" is actually MgF_2, while "X" stands for uranium, which was rarely identified as such during the Manhattan Project. In a section entitled "Description of Operation," MED (1944, p. 30) states, "Slag is received in barrels containing about 500 lbs." Three paragraphs later is the statement, "Slag is concentrated from about 1 lb. to 5 or 10 lbs. by weight." Allen (2007) apparently interpreted this to mean that 1 lb of uranium was contained in 500 lb of slag. One would then have to ask if the same 500 lb batch would, at the end, contain 5–10 lb of uranium. It is reasonable, based on the entry in the data sheet, to assume that the statements meant to say 1 lb uranium per 100 lb slag, etc.

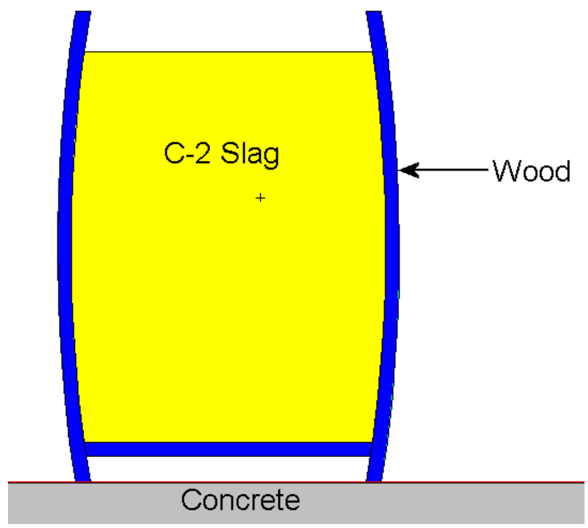

Figure A-2. Cross-Section of MCNP Model of Slag in a Whiskey Barrel

Kentucky Barrels (2003) describes its 53-gal barrels as being made from 1-in-thick staves of American oak (see Figure A-1).[4] The dimensions are given as 53 gallon, 36-in tall, 21-in diameter at the top and bottom, and 24-in diameter in the middle. SC&A constructed an MCNP model of the barrel, representing the outer and inner surfaces by ellipsoids of revolution that conformed to the above dimensions. The interior of the barrel is bounded by an ellipsoid and by two horizontal planes, spaced symmetrically with respect to the center, that delineate the top and bottom of the cavity. The positions of the planes were adjusted to produce a 53-gal interior volume. All the linear dimensions were then reduced in equal proportions to produce a 50-gal volume, as cited by MED 1944. A cross-sectional view of the MCNP model is shown in Figure A-2.

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[4] Kentucky Barrels (2003) states, "By law Bourbon must be made in NEW American white oak barrels." This ensures a supply of used whiskey barrels, which were thus available for transporting slag.

Lee et al. (2003) reported the composition of oak wood as cellulose (49.3%, w/w), hemicellulose (25.9%, w/w), and Klasson lignin (21.7%, w/w). "The Composition of Oak . . ." (n/d) (a Web document without a listed author or publisher) lists proportions of cellulose, hemicellulose, lignin, and other components in various American and European oaks. Cellulose is the main component cited in both references, and is the only one comprising a single chemical compound. In the present analysis, SC&A modeled the oak as being composed of cellulose, which has the chemical formula $(C_6H_{10}O_5)_x$. Dharmadhikari (2008) reports that the density of staves cut from American oak ranges from 0.60 to 0.84 g/cm^3. SC&A assumed a density equal to the lower end of the range, as that would result in the least attenuation of direct penetrating radiation, leading to higher dose rates from external exposure at the side of the barrel, and would therefore be claimant favorable.

The composition of the slag, calculated from information in MED 1944, is shown in Table A-1.

Table A-1. Composition of C-2 Slag

Compound	Fraction
UO_2	1.13%
MgF_2	88.98%
CaO	9.89%
Total	100.00%

The uranium in the slag is assumed to have the isotopic ratio of natural uranium. Uranium-238 is assumed to be in secular equilibrium with its short-lived progeny; ^{234}Th, ^{234m}Pa, and ^{234}Pa. The 6.7-hour ^{234}Pa is the product of the isomeric transition of ^{234m}Pa, which occurs in 0.16% of the disintegrations. Uranium-235 is assumed to be in secular equilibrium with ^{231}Th.

There are three sources of external exposure to direct penetrating radiation; atomic x-rays and gamma rays emitted by the radionuclides in the slag, bremsstrahlung x-rays generated by beta rays, and neutrons resulting from spontaneous fission of the uranium isotopes and from the (α,n) reaction (alpha rays impinging on nuclei of light elements in the slag). SC&A calculated the neutron emission by means of the Sources4C computer code (LANL 2002). Although ^{19}F, the only stable isotope of fluorine, has a relatively high cross-section for the (α,n) reaction, the relatively low energies of the uranium alpha particles produce a low neutron yield, despite the high fraction of fluorine in the slag. Most of the neutrons calculated by the code were from the spontaneous fission of ^{238}U.

In our model, the barrel is located in the center of a stylized cylindrical room, 3-m high, with a radius of 5 m, that is filled with moist air. The walls, floor, and ceiling are concrete that is optically thick. The dose rates from direct penetrating radiation were calculated at 1 ft (30.48 cm) and at 1 m from the exterior of the barrel, at a height of 44.2 cm (one-half the height of the barrel) above the floor. The results of the analysis are shown in Table A-2.

Table A-2. Exposure to Direct Penetrating Radiation From Barrel of C-2 Slag

Radiation	Ambient dose equivalent—H*(10) (mrem/h)		Exposure rate (mR/h)	
	1 ft	1 m	1 ft	1 m
Discrete photons[a]	1.56E-02	3.71E-03	1.34E-02	3.15E-03
Continuous photons[b]	2.20E-03	5.29E-04	1.81E-03	4.32E-04
Neutrons	7.51E-05	2.04E-05	—	—
Total	1.78E-02	4.25E-03	1.52E-02	3.59E-03

[a] Atomic x-rays and gamma rays, which have discrete energies
[b] X-rays generated by beta-bremsstrahlung, whose energy spectra form a continuum

The ambient dose equivalents from photon and neutron radiation were calculated by applying the conversion coefficients listed by ICRP 1996, Tables A.21 and A.42, respectively, to the photon and neutron fluences calculated in the MCNP simulation. The dose rates to the skin from beta rays were calculated by applying the conversion coefficients listed by ICRP (1996, Table A.43) to the electron fluence, which was averaged over the top surface of the slag (contact dose), as well as over a circular area 1 ft above the surface. These results are shown in Table A-3.

Table A-3. Dose to the Skin From Beta Rays From Barrel of C-2 Slag (mrem/h)

Location	Dose rate
Contact	0.85
1 ft	7E-05

If we assume that, for the purpose of estimating external exposure, a worker spent one-half of the time that he was in the vicinity of the slag at a distance of 1 ft from the barrel and the other half of the time at 1 m from the barrel, his average exposure rate would have been 9.4×10^{-3} mR/h. Allen (2007) assigned the external exposure rates from the scrap recovery operation listed by TBD-6001 (Battelle 2006, Table 7.3). The median external exposure of the operator from material handling is listed as 0.44 mR per calendar day, assuming a 40-h work-week. This equates to an average exposure rate of 0.08 mR/h (0.44 mR/d × 365 d/y ÷ 2000 h/y = 0.08 mR/h), about 9 times higher than calculated in our analysis. The non-penetrating (beta) dose to the hands is listed as 182 mrem per calendar day, which is equal to 33.2 mrem/h. This is about 40 times higher than the contact dose rate listed in Table A-3.

If we were to assume that, as stated by Allen (2007), the elemental uranium concentration in the slag were 0.2% instead of 1%, all the calculated dosimetric values listed in Tables A-2 and A-3 would be reduced by approximately a factor of 5.

References

Allen, D. 2007. "Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium: Appendix AA – Hooker Electrochemical Company," Battelle-TBD-6001, Appendix AA, Rev. 0.

Battelle-TBD-6001 2006. *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium*, Rev. FO. Battelle Team Dose Reconstruction Project for NIOSH. December 13, 2006. SRDB Ref ID: 30673.

Dharmadhikari, M. 2008. "Oak Wood Composition." http://www.extension.iastate.edu/NR/rdonlyres/173729E4-C734-486A-AD16-778678B3E1CF/73960/OakWoodComposition.pdf

ICRP 1996. "Conversion Coefficients for use in Radiological Protection against External Radiation," International Commission on Radiological Protection (ICRP) Publication 74. *Annals of the ICRP*, *26* (3/4). Tarrytown, New York: Elsevier Science, Inc.

Kentucky Barrels LLC. 2003. "Vintage Kentucky Whiskey Barrels." http://www.kentuckybarrels.com/vintage-barrels.html

Lee, P.C., S.Y. Lee, S.H. Hong, H.N. Chang, and S.C. Park 2003. "Biological Conversion of Wood Hydrolysate to Succinic Acid by *Anaerobiospirillum succiniciproducens*." *Biotechnology Letters 25*, 111–114. mbel.kaist.ac.kr/lab/publication/int109.pdf

LANL and Texas A&M University. 2002. SOURCES-4C: Code System For Calculating alpha,n; Spontaneous Fission; and Delayed Neutron Sources and Spectra. RSICC Code Package CCC- 661. Los Alamos National Laboratory, Los Alamos, New Mexico.

LANL 2009. MCNP5/MCNPX: Monte Carlo N–Particle Transport Code System Including MCNP5 1.60 and MCNPX 2.6.0 and Data Libraries, RSICC Code Package CCC-740 [Computer software and manual]. Los Alamos National Laboratory, Los Alamos, New Mexico.

MED 1944. *Medical Section – Manhattan District, Data Sheets for Industrial Hazard Rating*. Manhattan Engineer District. SRDB Ref ID 16323, pp. 29–30.

"The Composition of Oak and an Overview of its Influence on Maturation." n/d In *The Composition of Oak*. homedistiller.org/oak.pdf.