DOE Review 09/20/2016

Division of Compensation Analysis and Support Technical Basis Document for the Hooker Electrochemical Company Niagara Falls, New York	Document Number: DCAS-TKBS-0009 Effective Date: 09/13/2016 Revision No.: 03 Page 1 of 23
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
4/4/2011	4/4/2011	0	Changes Battelle-TBD-6001 Appendix to a standalone document. Revises dose models to eliminate dependence on Battelle-TBD-6001. Provides more detailed description of dose models. Incorporate review comments.
06/16/2011	06/17/2011	1	Revision initiated to correct errors in Tables 2, 3, and 6. Renumber tables after Table 4. Added language on page 10 to indicate the 95th percentile of the airborne values was used. Corrected typographical error on page 7 and 14.
11/10/2015	12/08/2015	2	Revision initiated to include information about a Special Exposure Cohort designation for Hooker. Revision also incorporates changes due to new information describing the operations at Hooker.
09/01/2016	09/13/2016	3	Revision initiated to include discussion about ingestion intakes. Also revised Table 4 to correct units. Revised Table 5 to correct values in the third column. Corrected photon exposures in Table 7. Various editorial changes to text.

1.0 Introduction

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean, nor should it be equated to, an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in sections 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. A DOE facility is defined as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program);" and with regard to which the DOE has or had a proprietary interest, or "entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services." 42 U.S.C. § 7384l(12). On the other hand, an AWE facility means "a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling." 42 U.S.C. § 7384l(5). The Department of Energy (DOE) determines whether a site meets the statutory definition of an AWE facility and the Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Accordingly, a Part B claim for benefits must be based on an energy employee's eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility's designated time period and location (i.e., covered employment). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at an AWE facility is categorized as employment either (1) during "a period when the employer was processing or producing, for the use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining and milling," (i.e., the operational period); or (2) during a period that NIOSH has determined that "there is a potential for significant residual contamination outside of the period in which weapons-related production occurred," (i.e., the residual contamination period). 42 U.S.C. § 7384l(3).

Based on the abovementioned definition for eligible employment during an AWE facility's operational period, NIOSH includes radiation exposures incurred in the performance of duty,

such as medical X-rays received as a condition of employment for participating in DOE projects, at an AWE facility in dose reconstructions. This may include radiation exposure related to the Naval Nuclear Propulsion Program and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the operational period. In contrast, only two categories of radiation exposure as defined in 42 U.S.C. § 7384n(c)(4) should be included in dose reconstructions for claims involving employment during the residual contamination period. First, NIOSH must include exposures to radiological contaminants resulting from activities that had a nuclear-weapon nexus or conducted by or on behalf of the DOE (with an exclusion of activities related to, among other things, the Naval Nuclear Propulsion Program) that took place during the operational period. 42 U.S.C. § 7384n(c)(4)(A). Second, radiation doses from sources not included in the first category but which cannot be distinguished through reliable documentation should also be included in dose reconstructions. 42 U.S.C. § 7384n(c)(4)(B). Furthermore, because all DOE-related activities have ceased during the residual contamination period, NIOSH does not include doses from medical X-rays performed during the residual contamination period (NIOSH 2007) in dose reconstructions.

Likewise, NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment for DOE-related activities at an AWE facility. Therefore these exposures are not included in dose reconstructions for either the operational or residual contamination period (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

The following information from the Department of Energy's Office of Health, Safety and Security EEOICPA Find Facilities webpage defines the EEOICPA covered periods for the Hooker Electrochemical Company.

Site:	Hooker Electrochemical Company
Location:	Niagara Falls, New York
Covered Period:	1943-1948, Residual Radiation 1949-1976

This document contains a summary of the description of the site as well as the Atomic Energy Commission activities performed there, and provides the technical basis to be used to evaluate the occupational radiation doses for EEOICPA claims.

2.0 Site Description and Operational History

The Hooker Electrochemical Company (Hooker) was located in Niagara Falls, New York. From January, 1943 until June, 1948 under contract No W-7405 eng-28 with the Manhattan Engineer District (MED), Hooker manufactured various organic chemicals including xylene hexafluoride (P-45), xylene hexachloride, and Miller's Fluoro Lubricant (MFL). While these processes in themselves did not involve radioactive materials, during part of this period, hydrochloric acid, a

byproduct of the P-45 process, was used to chemically treat uranium bearing C-2 slag as a precursor to uranium recovery (DOE 1985, pg 58).

The Hooker site used under the MED program was the "D" area, 5.5 acres located on the north bank of the Niagara River in Niagara Falls, NY, about 2 miles east of the falls. Five buildings on this site, D-5, 6, 7, 8 and 9 were used under the contract with MED (1943-48). The bulk of uranium handling was conducted outdoors in an area by the railroad siding north of these buildings. This activity involved the chemical processing of uranium-bearing slag for recovery purposes (DOE 1985, Olotka 1979).

The covered period for Hooker Electrochemical is listed by the Department of Energy's Office of Worker Advocacy as 1943 through 1948 and includes both radioactive material processing and nonradioactive chemical production activities for the MED (DOE 2009). The only weapons-related radiation exposure occurred while processing uranium contaminated slag for MED. A 49' x 28' x 25' cinder block building to contain some of the necessary equipment was constructed under a letter of intent dated May 1944. Construction was completed and the building turned over to the Operating Department on July 11, 1944 (Dowling 1944). No documentation was found indicating there were other sources of radiation, commercial or weapons-related, at Hooker Electrochemical.

An MED medical clearance document indicated the P-45 contract (which including the slag concentrating) had ended on 1/15/1946 (Mears 1946). Supplemental agreement number 7 to the Hooker contract was dated 9/30/1945 and included a cost estimate to maintain the plant in standby from 11/1/1945 to 4/30/1946 (MED 1945). Another document indicated that the MED work at Hooker had shut down in October 1945 (Young 1985). This document also indicates the plant started back up in 1947 to make lubricants however, a monthly report from September 1944 indicates that P-45 production was cutback 50% to permit the manufacture of the fluorinated lubricant MFL (Tybout 1944). Therefore, the restart is not an indication that the P-45 (or slag concentrating process) restarted. Taken together, these documents indicate the slag concentrating work was placed in standby on 11/1/1945.

This document establishes the period of operational radiation exposure from July 11, 1944 to November 1, 1945. It is possible that the slag-processing occurred for an even shorter period since some start up period would be expected. This analysis assumes a period of residual radioactivity exposure from November 1, 1945 to October 11, 1976, the date when measurements for radiation and radioactivity onsite were made and it was concluded that no elevated levels of radioactivity were onsite (DOE 1977).

3.0 Process Description

The MED radiation work at Hooker Electrochemical was the concentration of uranium from slag, which had been sent to the Hooker site from the Electrometallurgical Company or Electromet (DOE 1985). This material was primarily reduction pot liners (dolomite) used in the reduction of UF_4 to uranium metal.

The process, sometimes referred to as a thermite process, consisted of combining UF_4 with Mg metal in a steel reduction container, often referred to as a pot or a bomb. The material was heated until the following reaction occurred.

$$UF_4 + 2Mg \rightarrow U + 2MgF_2$$

The reaction was exothermic so, once the ignition point was reached, the reaction proceeded rapidly throughout the reduction pot resulting in a molten mixture of metallic uranium and MgF_2. The two molten substances separated due to different specific gravities then cooled and solidified. The solid uranium metal pooled in the bottom of the pot and the MgF_2 solidified above. The inside of the reduction pot was lined with refractory material in order to prevent the reaction from involving the steel reduction pot, as well as providing thermal insulation to protect the pot and to allow time for the reaction products to separate before they began to solidify.

At Electromet, the refractory lining was fused dolomite that was placed in the pot as a fine powder between the inner walls of the pot and a mandrel. The mandrel was jolted to pack the dolomite into place around the sides and bottom of the pot. Once the UF_4 and Mg mixture (the charge) was poured into the pot, additional dolomite was added to the top to complete the refractory envelope.

After firing, the pot was allowed to cool and then emptied. The process involved opening the pot then chipping and dumping the contents on a 4 mesh grate (1/4"). The MgF_2 had solidified so it would consist of large "lumps" containing some uranium due to incomplete separation. This was known as C-1 slag or rich slag (meaning rich in uranium). The liner was not involved with the chemical reaction so it was largely still in a powder state and came out of the pot as such. Because some of the liner was in direct contact with the reaction, the liner did contain some uranium contamination. This material was known as C-2 slag, or lean slag or C-liner.

The C-1 slag was packaged and shipped to another site to reclaim the uranium contained in it. The C-2 slag, however, was considered too low in uranium concentration for recovery to be economically feasible.

3.1 Process at Hooker

Two process descriptions for the work at Hooker were found. Both are similar but do vary in some details. The first description comes from a "Data Sheet for Industrial Hazards", dated December 8, 1944 (MED 1944). This document indicates 10 tons of material per month was processed and the material was 90% MgF and 10% CaO. The description of the process is:

> "*Slag is received in barrels containing about 500 lbs. The barrels are opened and the material is dumped on a conveyor belt which carries it up a ramp to one of the three digest tanks. 40 barrels are added to each tank. Waste HCl from the P-45 plant is passed into the digest tank and the pH is adjusted to 4.0 by the addition of water. After the tank has been filled, the contents are agitated for 20 hours. About once in two days a tank is emptied, which is sufficient turn-over to take care of waste HCl. At the completion of the digest the slurry is neutralized by dumping 100-lb. bags of lime into the tanks from an overhead platform, pumped to a plate and frame press, and filtered. The*

filtrate is passed off into the sewer; the precipitate is washed several times and rebarreled. Slag is concentrated from about 1 lb. [of uranium] to 5 or 10 lbs. [of uranium] by weight."

Another document (Thomas 1944) describes the testing performed on the material and development of the process used at Hooker including design calculations. The testing found that screening the slag through a 20 mesh screen would efficiently separate some rich slag. Therefore, the process was to screen the slag first and redrum the "lumps". About 20% of the incoming slag was "lumps". The material that made it through the 20 mesh screen would then be digested in a tank with the waist HCl. The design calculations were for 20 drum of screened slag per day weighing 275 pounds each. Also the operation was to run 26 days per month (6 days per week).

While Thomas indicates the slag came in at a rate of 20 drums weighing 275 pounds each day, the other document implies 40 drums weighing 500 pounds constitutes a batch without any indication of the time frame. The incoming rate in Thomas would be equal to 71.5 tons per month while the MED document indicates the rate was 10 tons per month without indication of incoming or outgoing.

In order to determine the production rate at Hooker, three potential interpretations were developed.

1. Forty drums weighing 500 pounds each were brought in each day (MED description assuming daily)
2. Forty drums weighing 500 pounds each were brought in once per month (equal to 10 tons per month incoming slag)
3. Twenty drums weighing 344 pounds each were brought in daily (Thomas indicated the 275 pound drums had already been screened so 275 pounds represent 80% of the incoming drum weight).

3.2 ElectroMet Slag Production

In order to evaluate the credibility of these interpretations, it is necessary to determine the amount of slag available from Electromet. Between 1943 and 1945, the MED produced 2969 tons of uranium metal (AEC 1951). Both Mallinckrodt and Electromet were major producers and it is reasonable to assume that Electromet produced half of this quantity (1485 tons).

A typical reduction bomb is described as being 40 inches long with a 10.125 inch inner diameter. A mandrel, tapered from 8.75 to 9 inches, is inserted into the bomb and used to tamp the dolomite powder into a lining (Spedding 1945, pg. 14) so the lining then has an average thickness of 0.625 inches. Assuming the same thickness for the top and bottom results in a lining volume of 823.5 cubic inches (13490 cubic centimeters). Assuming a density of 2 g/cc (Spedding 1945, Table 10), the liner would weigh 59.4 pounds. The bomb was filled with 168 pounds of UF4 and excess magnesium metal for the reaction. The overall yield of uranium metal (after reduction and casting) was about 93% (Spedding 1945, pg. 54). Therefore, the 168 pounds of UF4 would produce about 118.4 pounds of U metal. This results in a ratio of 0.5 pounds of

lining per pound of uranium metal. That implies Electromet could have produced 744 tons of lining.

That estimate relies in part on the density of the lining. The density of a dry chemical is variable and dolomite has been reported to be anywhere from 55 pounds/ft^3 (0.88 g/cc) (NLA) to 2.88 g/cc (Vulkan 2008, Table 4.47b). Since the dolomite is jolted into place it is packed and likely more dense than the 0.88 g/cc which is intended for determining storage capacity of bulk dolomite. That value would then be low for this application. The 2.88 g/cc reference is a dolomite brick after it is fired. Firing would normally fuse the brick into a single unit increasing its density. Therefore, that value would also not be appropriate for this application. Spedding (table 10 pg. 43) reported a packing density of 2 g/cc for electrically fused dolomite. Since that document discusses the dolomite in the context of uranium reduction, this appears to be an appropriate reference.

One estimate that does not depend on the density is to use the cost information in Spedding. The cost estimate indicated the liner cost 8.65 cents per pound of uranium produced. It also indicted the raw material cost 13.5 cents per pound of refractory. Unfortunately, it is not clear if this is the raw dolomite or fused dolomite. Spedding (pg. 42) indicated some dolomite was electrically fused at Electromet so Electromet had the capability of buying raw dolomite and fusing it on site. This process involved heating the dolomite to high temperatures to drive off the CO2 component leaving MgO and CaO. The CO2 accounts for about 48% of the raw dolomite weight. So the estimate could be indicating 13.5 cents per pound of raw dolomite which would be equivalent to 25.9 cents per pound of fused dolomite liner. With these two interpretations, the cost based estimate results in a total liner production at Electromet of either 496 tons or 951 tons.

Several other reference are available for the amount of liner used in a reduction pot. The first (Huke 1944, pg. 15) is a report dated January 27, 1944 pertaining to the loss of material at Mallinckrodt. A mass balance for Plant 4 at Mallinckrodt indicates the material going into a reduction pot was 135 pounds of green salt (UF4), 55 pounds of liner and 24 pounds of magnesium. This equals 0.41 pounds of liner per pound of UF4. A second reference (Thayer 1955) indicated the reduction pots used 0.432 pounds of liner per pound of UF4. A third reference (Electromet 1943, pg. 6) is a report discussing the development of the reduction process and mentions that for the chosen size of the reduction pot "the quantity of dolomite required was decreased from 0.7 pounds per pound of salt to 0.4 pounds". In this case, "salt" is referring to green salt, a term for UF4. Using an overall metal yield of 93%, these three values (0.41, 0.432 and 0.4) would result in an estimated lining inventory at Electromet of 858 tons, 910 tons and 842 tons respectively.

All the estimates above depend on the assumption that Electromet produced half of the MED's uranium metal. An estimate that does not involve that assumption utilizes a 1946 document (Gates 1945 pg. 22) that lists the amount of raw materials consumed by Electromet during normal operations. It indicates 110,000 pounds of electrically fused dolomite and 24,000 pounds of Kelly Island dolomite are necessary for 60 days of production. The Kelly Island dolomite would need to be electrically fused before use and that process would reduce the weight to approximately 52% of the original weight. Adjusting for this, and assuming 31 months of

operations between Electromet startup (4/1/1943) and Hooker shutdown (11/1/1945) produces an estimate of 950 tons of fused dolomite used at Electromet.

The estimates presented here range from 496 tons to 951 tons. However, two of these estimates are outliers. The 496 ton estimate assumes the dolomite purchased was raw dolomite and electrically fused on site. Gates however, lists electrically fused dolomite separate from Kelly Island dolomite. This could mean that most of the dolomite purchased was already electrically fused and the 496 ton estimate can be disregarded. The 744 ton estimate depends on the density of the packed dolomite liner. This parameter is variable and since estimates that do not depend on it are available, this value should be disregarded. That leaves estimates of 951, 858, 910, 842 and 950 tons. These values involve different methods, parameters and references but produce reasonably good agreement. Also, the use of these estimates later in this document depends on an approximate value so a closely matched range is sufficient.

3.3 Mass Balance

A mass balance was performed to determine which of the interpretations in section 3.1 are credible. For this mass balance, parameters taken from the experimental and design document (Thomas 1944) were used and are listed below.

- The incoming slag is made up of 80% fines and 20% lumps
- The fines are assumed to be uranium contaminated fused dolomite (CaO MgO)
- The lumps are assumed to be uranium contaminated MgF2
- Uranium content in the fines = 0.84%
- Uranium content in dry concentrate = 9.87%
- Moisture content in concentrate = 41.4%
- Lumps are assumed to have the same uranium content as the dry concentrate
- These parameters result in a uranium content of 2.65% for the incoming slag
- Work consisted of 26 eight hour days per month
- Work period was 7/11/1944 to 11/1/1945 (~15.5 months)

The interpretations in section 3.1 differ by the incoming slag rate.

Interpretation 1 = 40 barrels weighing 500 pounds coming in 26 days per month
Interpretation 2 = 40 barrels weighing 500 pounds coming in 1 day per month
Interpretation 3 = 20 barrels weighing 344 pounds coming in 26 days per month

Using this information, a mass balance was calculated. Table 1 below shows the results of several parameters for each interpretation. Results are listed on a per month and total (entire project) basis.

Table 1: Mass Balances for Each Processing Interpretation

Table 1 Mass Balances for Each Processing Scenario			
Parameter	**Scenario 1**	**Scenario 2**	**Scenario 3**
% moisture in concentrate	41.4%	41.4%	41.4%
%U in fines	0.84%	0.84%	0.84%
% U in dry concentrate	9.87%	9.87%	9.87%

Incoming # of drums per day	40	1.54 (avg)	20
Weight of each drum (pounds)	500	500	343.75
Fraction that are fines	0.8	0.8	0.8
% U in incoming	2.65%	2.65%	2.65%
Monthly Rate			
Tons of incoming slag per month	260	10	89.375
Tons of fines per month	208	8	71.5
Tons of U per month	1.75	0.0672	0.60
Tons of concentrate (dry) per month	17.7	0.68	6.09
Tons of concentrate (wet) per month	30.2	1.16	10.4
Project Totals (assumes 15.5 months of operations)			
Total tons incoming	4030	155	1385
Total tons fines	3224	124	1108
Total tons concentrate (dry)	274	10.6	94.3
Total tons concentrate (wet)	468	18.0	161

Interpretation 1 requires over 3000 tons of liner material to be processed at Hooker. Since the Electromet plant did not produce that much liner (section 3.2) it is clear that this interpretation is incorrect. This interpretation came from MED 1944 assuming the 40 drums weighing 500 pounds each was a daily event. Interpretation 2 assumes that is a monthly event based on the 10 ton per month rate in that document. However, when compared to the design criteria for the project (Thomas 1944), this rate is almost 9 times lower than the design rate. This is possible but not very credible unless there was a large change in direction between design and operation. For interpretation 3, the 10 ton per month rate in MED 1944 matches well with the 10.4 tons/month for the wet concentrate. Since the document does not specify if the 10 tons/month is wet or dry concentrate or slag, this is not a disqualifier for this interpretation. The total of 152 tons listed in Mears matches reasonably well with the 161 tons of wet concentrate produced. This document indicates the 152 tons processed is slag but it is possible this is just an error and it is really slag concentrate. The 152 tons processed is also in reasonable agreement with the 155 tons of slag associated with interpretation 2.

In conclusion, interpretation 1 is not possible while both interpretation 2 and 3 are possible. Interpretation 3 requires a belief that Mears was incorrect when it said 152 tons of slag was processed and it was actually slag concentrate. Interpretation 2 requires a belief that the amount of material actually handled was nearly 9 times less than the design capacity of the process. This document will therefore, assume that interpretation 3 is the best description of the production rate at Hooker.

3.4 Work Flow

Thomas (Thomas 1944) includes a cycle of operations that describes each step of the process and the time necessary to perform them. The cycle indicates 2 hours per 8 hour day is necessary to dump the slag barrels and an additional 2 hours necessary to dump and barrel the concentrate.

The remaining part of the day involved steps that do not involve handling the slag directly such as operating the filter press.

Based on Thomas, this estimate will assume 2 hours per day was spent dumping incoming slag barrels and 2 hours per day was spent packing concentrate into barrels.

DOE 1977 indicates the incoming slag was packaged in wooden barrels weighing 500 pounds. Wooden whiskey barrels were commonly used at the time for many purposes. 53 gallon wooden barrels are traditionally used for bourbon whiskey. This estimate will assume the slag was delivered in 53 gallon whiskey barrels.

Thomas indicated daily concentrate would be packaged in three 300 pound barrels. Thomas also indicated the density of the wet concentrate was 1.3 g/cc (82 pounds/ft^3, Thomas 1944 pg. 5). 300 pounds at 1.3 g/cc would occupy approximately 27.7 gallons of space. It is unlikely they only put 27 gallons of material into a 53 gallon barrel. More likely a smaller size was used for the concentrate. 27 CFR 25.11 indicates one barrel as a unit of measure is equal to 31 gallons. This seems to be a reasonable size to contain 27 gallons of material. Therefore, this estimate will assume the concentrate was packaged into 31 gallon barrels.

4.0 Internal Dose

The Secretary of Health and Human Services designated a class of employees at Hooker to be added to the Special Exposure Cohort. The class covers the period from July 1, 1944 to December 31, 1948 based on the inability to estimate the internal exposure with sufficient accuracy. The designation also indicated residual period exposures would be estimated using the techniques in the previous version of this Technical Basis Document. That estimate utilized the operational air concentrations. Together, this implies it was determined that the air concentration estimate was sufficiently accurate for estimating contamination levels but not for estimating operational airborne levels.

Therefore, no internal dose estimate will be provided prior to 1949. Operational airborne concentrations will be estimated below as part of calculating internal and external exposures from contamination.

4.1 Operational Air Concentration

No data were found in the Site Research database related to occupational internal dose during MED work. The work performed at Hooker Electrochemical involved concentrating C-2 slag. Much of that work involved either liquid or material with a high moisture content which would result in little or no airborne activity. The one task involving dry material was the dumping of barrels of slag. The slag came directly from the nearby ElectroMet facility. Two air sample results from handling this material at ElectroMet were found. The first result was an average of an unknown number of samples taken on December 24, 1947, March 30, 1948 and May 14, 1948. The average of the samples was 456 dpm/m^3. The second result was an average of three samples taken between August 17th and the 19th of 1949. The average value was 398 dpm/m^3. Work associated with these samples included shoveling the material into the barrels.

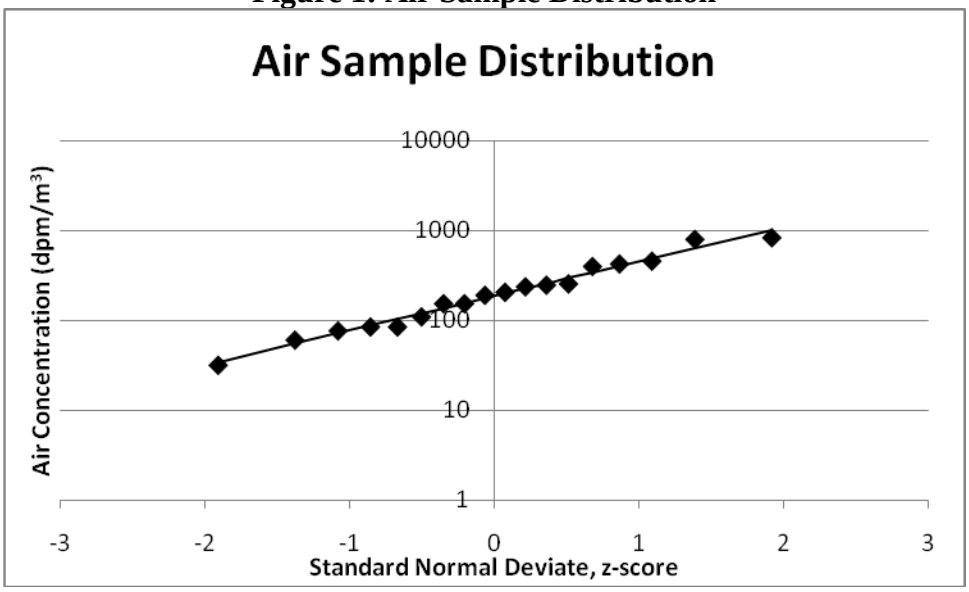
Since there are only two results and they were reported as averages, they provide little information about the variability of the data. Therefore, additional samples associated with handling slag were found at Mallinckrodt and Fernald. These samples are listed in Table 2.

These samples were used to determine the parameters of a lognormal distribution. The analysis resulted in determining a geometric standard deviation (GSD) of 2.43 and a geometric mean (GM) value of 187.7 dpm/m^3. The 95^{th} percentile of this distribution is 806 dpm/m^3. Figure 1 shows the individual data points along with the fit associated with these parameters.

Table 2: Magnesium Fluoride Air Samples

Site	Task	Air Concentration (dpm/m3)	Comments	SRDB reference
ElectroMet	Loading slag into barrels and weighing	456	Average of unknown number of samples	8917 pg 7
ElectroMet	Shoveling slag into drums	398	Average of three	8930 pg 19
Mallinckrodt	Slag Man	154		9340 pg 4
Mallinckrodt	Slag handling	154		11553
Mallinckrodt	Slag Man	77		9341 pg 5
Mallinckrodt	Removing slag drum	237		9443 pg 19
Mallinckrodt	Removing slag drum	60.8		9443 pg 19
Fernald	BZ – dumping can of C-liner	247		34544
Fernald	BZ – dumping can of C-liner	191		34544
Fernald	BZ – dumping can of C-liner	255		34544
Fernald	BZ – dumping can of C-liner	206		34544
Fernald	BZ – dumping drum of C-liner	793		42627
Fernald	BZ – dumping drum of C-liner	829		42627
Fernald	BZ – dumping drum of C-liner	424		42627
Fernald	BZ – dumping drum of slag outdoors	32		42628
Fernald	BZ – dumping drum of slag outdoors	110		42628
Fernald	BZ – dumping drum of slag outdoors	85	Value calculated from average, min and max	42628
Fernald	BZ – dumping drum of slag outdoors	85	Value calculated from average, min and max	42628

Figure 1: Air Sample Distribution



Drum dumping is the highest airborne causing evolution at Hooker but it was performed only two hours per day. The next highest airborne causing evolution would be the filtering and drumming of the concentrate after digestion. The remaining operations were performed in a liquid system. In order to determine an intake associated with filter operations, measurements associated with the digestion of uranium concentrates were considered. Digestion of concentrates involves many of the same basic steps as the concentration of slag at Hooker. A report by Christofano and Harris (Christofano 1960) determined the range of airborne activity associated with digesting uranium concentrates to be between 17 dpm/m^3 and 100 dpm/m^3 with an average concentration of 40 dpm/m^3. They also noted the uranium concentration in the incoming concentrate was 70% to 90% U_3O_8. Using the average (80%) equates to a uranium concentration of 68%. The concentrate being filtered at Hooker is 5.78% uranium. Adjusting the highest air concentration (100 dpm/m^3) down to 5.78% uranium produces a uranium airborne concentration of 8.52 dpm/m^3.

The internal exposure estimate for Hooker will assume individuals are exposed to slag dumping 25% of the time (2 hours per 8 hour workday) and the airborne concentration associated with filter operations the remaining 75% of the time. The 95th percentile of the slag distribution (806 dpm/m^3) will be used along with the bounding value (8.52 dpm/m^3) for the filter operation. This produces an average airborne concentration of 208 dpm/m^3. It is further assumed that the operators worked 8 hours per day, six days per week for 50 weeks per year resulting in 2400 hours of work per year.

This airborne concentration is used in the residual contamination section (Section 6) of this document to calculate the surface contamination value and the internal and external exposures associated with it. No internal exposure estimate will be made during the operational period based on the SEC designation.

5.0 External Dose

No external dosimetry data were found related to occupational external exposure at Hooker during the MED work. Therefore, external exposure was modeled using the computer code MCNP. External exposure associated with the incoming barrels of slag was modeled as well as with a barrel of uranium concentrate and surface contamination.

5.1 Barrels

From Section 3, slag barrels are assumed to be 53 gallon wooden whiskey barrels while concentrate barrels are assumed to be similar except 31 gallon in size. Also, the slag is assumed to be 20% lumps made up of MgF_2 with 9.87% uranium content and 80% fused dolomite with a chemical composition of equal parts CaO and MgO with 0.84% uranium content. The overall uranium content would be 2.65%. Concentrate was 41.4% moisture with the remaining content being MgF_2 with 9.87% uranium making the overall uranium content of the concentrate 5.78%.

One source of 53 gallon whiskey barrels (Kentucky Barrels 2003) indicates the barrel is made with 1 inch thick oak wood and provides dimensions. These dimensions were used to model the barrel in MCNP then the dimensions were adjusted uniformly to achieve an internal volume of 53 gallon. The same model was used for the concentrate barrel after the dimensions were adjusted to achieve an internal volume of 31 gallons.

The slag barrel was modeled so that 343.75 pounds of slag filled the barrel. This results in a density of approximately 50 pounds/ft^3. This is reasonably close to one reference that indicates bulk dolomite has a density of 55 to 60 pounds/ft^3 (NLA). For the concentrate, the density of 1.3 g/cc was used (82 pounds/ft^3, Thomas 1944 pg. 5) and the material was assumed to fill the 31 gallon barrel. This results in a drum with approximately 336 pounds of wet concentrate which is reasonable compared to the 300 pounds indicated in Thomas.

Photon radiation was calculated from both barrels at 1 foot and 1 meter distances. Direct photon radiation as well as bremsstrahlung photons were calculated and added. Beta radiation is largely attenuated by the sides of the barrel. However, the one centimeter and one foot dose rates above the unlidded barrel were calculated. One meter above the barrel was considered unrealistic. Beta radiation levels through the sides of the barrel were attempted. It was determined that it would be difficult to produce an accurate calculation of these levels but also determined that the level would be trivial compared to that above the barrel. Therefore, the levels above the barrel will be used in dose calculations and the one meter beta dose rate will be ignored.

Conversion coefficients listed in ICRP 1996 Table A.1 were utilized for photon exposure rate calculations. Dose conversion coefficients from ICRP 1996 Table A.43 were utilized for beta dose rate calculation. The resulting exposure rates are shown in Tables 3 and 4.

Table 3: Slag Barrel External Exposure Rates

	Photons (mr/hr)	Betas (mrad/hr)
Contact	N/A	2.03
1 foot	2.26E-02	0.467
1 meter	5.42E-03	N/A

Table 4: Concentrate External Exposure Rates

	Photons (mr/hr)	Betas (mrad/hr)
Contact	N/A	4.52
1 foot	4.21E-02	0.863
1 meter	9.18E-03	N/A

5.2 External Exposure from Surface Contamination

Next the external exposure rate from surface contamination was calculated again utilizing the computer code MCNP. The model assumed a large area of contamination (circle with a 100 meter diameter). The contamination was assumed to be evenly distributed over the area. The radioactive components of the contamination were assumed to be naturally enriched uranium in equilibrium with its short-lived decay products. The exposure rate one foot from the surface was calculated assuming a contamination of 1 dpm/m^2 alpha activity. This produced conversion factors that could then be multiplied by the surface contamination values to obtain external exposure rates. The result of these calculations is shown in Table 5.

Table 5: Surface Contamination External Exposure Rates

	Conversion factor	Exposure Rate
Photon	6.79E-10 mr/hr per dpm alpha/m^2	2.74E-04 mr/hr
Beta	6.04E-08 mrad/hr per dpm alpha/m^2	2.44E-02 mrad/hr

The surface contamination level was estimated by assuming the operational airborne activity was deposited with a velocity of 0.00075 m/s. The airborne activity used was the upper bound of the daily average activity from section 4.0 (208 dpm/m^3). The airborne was assumed to deposit for 30 days (TBD-6000) without any removal mechanism. This resulted in a surface contamination level of 404314 dpm/m^2. This value was multiplied by the conversion factors in Table 5 to obtain the estimate of external exposure rates due to surface contamination. The resulting exposure rates are also contained in Table 5.

All beta exposure is entered into IREP as electrons >15keV. Energy distribution of the photon exposure rate from surface contamination was also calculated using MCNP. The energy distribution was determined to be 80.2% <30keV, 12.3% 30 to 250 keV and 7.5% >250 keV. These values should be used in calculating photon dose.

5.3 External Dose Summary

Operators are assumed to spend 2 hours per day (25%) emptying barrels of slag. A similar amount of time is assumed to be spent loading concentrate into barrels (Thomas 1944). Additionally, operators are assumed to be exposed to external radiation from surface contamination 100% of the time. Laborers are assumed to be in the area 100% of the time but not directly handle the material. As such, they are assumed to be exposed 100% of the time to external radiation from surface contamination. Supervisors are assumed to spend 50% of their time in the area but not directly handle material. Clerical or other individuals are assumed to be in the area 5% of the time but not directly handle material.

While handling the material directly, operators are assumed to spend 50% of their time one foot from the barrels and the remaining 50% of the time one meter from the barrels. The operators' hands are assumed be in contact with the material the entire time they are one foot from the barrels. The annual exposure was calculated for photon exposure, skin of the whole body (WB-skin) and the hands and forearms. The overall external exposure estimates for operational periods are shown in Table 6.

Table 6: External Exposure Summary

	Photon (mr/yr)	WB-Skin (mrad/yr)	Hands and forearms (mrad/yr)
Material Exposure			
Operators	23.8	399	1970
Contamination Exposure			
Operators	0.659	58.6	58.6
Laborers	0.659	58.6	58.6
Supervisors	0.329	29.3	29.3
Clerical	0.0329	2.93	2.93

The photon doses from material should be entered into IREP as 30keV to 250 keV photons with a constant distribution. Photon doses from contamination should be entered into IREP as a constant distribution with the energy distributed as 80.2% <30 keV, 12.3% 30 to 250 keV and 7.5% >250 keV. The WB-skin and hands and forearms doses should be entered as electrons greater than 15 keV with a constant distribution. The 1944 and 1945 doses should be prorated to the fraction of the year the operation occurred based on a start date of July 11, 1944 and an end date of November 1, 1945.

6.0 Residual Contamination

For the purposes of this document, the residual contamination period at Hooker Electrochemical is considered to begin on November 1, 1945 and end on October 11, 1976. The end date is based on the Residual Contamination report (NIOSH 2009) and the date of the radiological survey that concluded that no elevated levels of radioactivity were onsite (DOE 1977 pg 11).

The external dose rates used during this period are the dose rates described in section 5.2 from the surface contamination.

The internal exposure rates are based on the surface contamination values derived in section 5.2 combined with a resuspension factor of $1x10^{-6}$ m^{-1}. NUREG-1720 provides this value as the Nuclear Regulatory Commission's recommendation of an appropriate resuspension factor for license termination screening. The recommendation indicates a resuspension factor of $1x10^{-6}$ m^{-1} is more realistic than the previous value of $1.42x10^{-5}$ m^{-1} and sufficiently conservative for screening analysis. In this analysis, the NRC noted a significant difference between those studies conducted in areas with freshly deposited contamination versus those involving "operating facilities or those undergoing decommissioning". Since the NRC report was associated with decommissioning, they chose to not use those studies involving freshly deposited contamination. The basis for this decision was the assumption that any area undergoing decommissioning would likely be washed down.

At Hooker, the majority of the airborne contamination (and thus the surface contamination) was located where the slag drums were emptied. This work was accomplished outdoors on a concrete pad near the railroad spur. As such, the contamination was exposed to the elements in western New York State. Wind, rain, and snow melt would quickly accomplish the same effect as washing down the area with a water hose. Therefore the resuspension factor from NUREG-1720 appears to be applicable at Hooker.

The surface contamination value was also used to calculate intakes from ingestion during the residual period. OCAS-TIB-009 can be used to estimate ingestion during operational activities but not directly during the residual period when airborne is caused only from the resuspension of surface contamination. Therefore, in order to estimate an ingestion intake, OCAS-TIB-009 was used in combination with the estimate of airborne activity during the operational period. Since surface contamination does not decrease as rapidly as airborne activity after operations have ended, the operational ingestion rate is considered a good estimate of the residual period ingestion rate. The ingestion rate was therefore estimated by multiplying the operational period airborne concentration (208 dpm/m^3) by 0.2 to calculate the work day ingestion intake. Since that factor is based on a 40 hour workweek, the value was adjusted up to a 48 hour workweek. The annual value was then determined and divided by 365 days to arrive at a calendar day ingestion rate of 34.2 dpm/day.

The surface contamination value is based on a bounding estimate of the airborne levels deposited for 30 days with no removal mechanisms. The surface contamination value is then a bounding value. Since both the internal and external exposure estimates are based on this bounding value, the dose estimated during the residual period will be entered into IREP as a constant.

The internal and external values applicable to the residual period are shown in Table 7.

Table 7: Residual Period Exposure Summary

Internal Exposure				
Job Category	Years	Nuclide	Inhalation (dpm/ day)	Ingestion (dpm/ day)
All jobs	1949-1976	U-234	3.2	34.2
External Exposure				
Job Category	Years	Photons (mr/yr)	Skin (mrem/yr)	
Operators	11/1/1945-1976	0.659	58.6	
Laborers	11/1/1945-1976	0.659	58.6	
Supervisors	11/1/1945-1976	0.329	29.3	
Clerical	11/1/1945-1976	0.0329	2.93	

All internal dose is entered into IREP as alpha radiation with a constant distribution. External photon dose should be entered into IREP as a constant distribution with an energy distribution of 80.2% <30keV photons, 12.3% 30 to 250 keV photons and 7.5% >250 keV photons. External skin doses should be entered into IREP as a constant distribution of electrons >15keV.

7.0 Occupational Medical Dose

The War Department memo dated March 8, 1946 indicated the medical requirements included a pre-employment exam including a chest x-ray as well as a monthly blood count and monthly urinalysis. It also indicates there were no special exams and that this schedule was not adhered to after the first year of operation (Mears 1946). No other information regarding occupational medical dose specific to Hooker Electrochemical was found. Information to be used in dose reconstructions for which no specific information is available is provided in ORAUT-OTIB-0006, the dose reconstruction project technical information bulletin covering diagnostic x-ray procedures. The assigned frequency should be only a pre-employment PA chest x-ray.

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