Office of Compensation Analysis and Support Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, Lackawanna, New York; Period of Operation: 1949-1952	Document Number: OCAS-TKBS-0003 Effective Date: 7/27/2006 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 41
Subject Experts: Sam Glover, Dave Allen Approval: Signature on File Date: 07/27/06 James W. Neton, Associate Director for Science	Supersedes: ORAUT-TKBS-0001-Rev 01

TABLE OF CONTENTS

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	12/17/2002	0-A	New document to establish the technical basis for the development of a radiation exposure matrix for Bethlehem Steel Corporation. Initiated by Jeri L. Anderson.
03/31/2003	03/31/2003	00	First approved issue of ORAUT-TKBS-0001.
06/29/2004	06/29/2004	01	Approved issue of Revision 01.
7/27/2006	7/27/2006	00	Approved issue of Revision 0 of OCAS-TKBS-003. This supersedes rev. 1 of the previous ORAUT-TBKS-0001.

1.0 INTRODUCTION

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH and its contractors in the completion of the individual work required for each dose reconstruction.

This technical basis document (TBD) specifically addresses exposures incurred by workers as a result of a contractual agreement between Bethlehem Steel in Lackawanna, NY (a designated atomic weapons employer (AWE) facility) and the U.S. Department of Energy or its predecessors. Dose reconstructors should use the information in this TBD to evaluate the DOE derived occupational radiation dose for workers at Bethlehem Steel. These doses include external and internal radiation sources as well as occupationally required diagnostic x-ray examinations.

Employment at an AWE facility is categorized as either (1) during the contract period (*i.e*., when the AWE was processing or producing material that emitted radiation and was used in the production of an atomic weapon), or (2) during the residual contamination period (*i.e*., periods that NIOSH has determined there is the potential for significant residual contamination outside of the period in which weapons-related production occurred). For contract period employment, all occupationally-derived radiation exposures at the facility must be included in dose reconstructions. NIOSH does not consider the following exposures to be occupationally-derived:

- radiation from naturally occurring radon present in conventional structures; and
- radiation from diagnostic X-rays received in the treatment of work-related injuries.

For residual contamination period employment, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) (*i.e.,* radiation doses received from DOE/AEC-related work) must be included in dose reconstructions. Radiation dose received from DOE/AEC-related work includes: (1) radiation from radon consistent with NIOSH's policies for including such radiation in the contract period; and, (2) medical screening X-rays, but not diagnostic X-rays for the treatment of work-related injuries. It should be noted that: (1) under subparagraph A of § 7384n(c)(4), radiation associated with the Naval Propulsion Program is specifically excluded from the employee's radiation dose; and, (2) under subparagraph B of this section, radiation from a source not covered by subparagraph A that cannot be reliably distinguished from radiation that is covered by subparagraph A is considered part of the employee's radiation dose. This site profile covers only exposures resulting from nuclear weapons-related work. Exposures resulting from non-weapons related work, if applicable, will be covered elsewhere.

Many sources of information were evaluated and utilized in the preparation of this TBD. These include transcripts of worker outreach meetings, worker interviews and comments, multiple reviews by EEIOCPA Advisory Board's contractor SC&A, and information gathered at various Department of Energy record repositories including, but not limited to, the Environmental Measurements Laboratory (EML) and Hanford.

This document is divided into the 6 sections. These are: 1) Introduction; (2) Site description and operational history; (3) Estimation of Internal Exposure; (4) Estimation of External Exposure; (5) Occupational Medical Dose; and (6) Occupational Environmental dose.

In this document the word "facility" is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy facility" as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l (5) and (12)).

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

2.1 Background of rolling operations conducted by AEC 1948-1952

Bethlehem Steel Corporation was one of several steel mills that contributed to the production of uranium metal rods used by Hanford for the production of plutonium. The principle means of producing uranium rods During World War II was an extrusion process conducted at Hanford. Rolling of uranium metal rods was investigated at Joslyn Manufacturing and Supply Co. during and after the war effort to evaluate methods to improve product quality and reduce losses of product during the manufacturing process. Another development that promised improvements in the production of uranium metal rods was the successful rolling of lead dipped uranium billets by Joslyn in 1948, which, according to the early AEC reports, were far superior to the Hanford materials in terms of blistering. Hanford stopped extruding uranium rods in 1948. Rolled uranium rods manufactured offsite of Hanford were found to be a less expensive process and possessed metallurgical advantages over the extrusion process (DOE 1997).

As of 1947, postwar production of uranium was transferred to the US Atomic Energy Commission (AEC) New York Operations Office (NYOO). Safety aspects of these operations fell under the Health and Safety Laboratory (HASL) for the stated reason that many of these facilities were small and lacked the resources for evaluating worker health (AEC 1949b). HASL (later to be renamed the Environmental Measurements Laboratory) had responsibility for these programs until 1954 with the implementation of parallel production centers in St. Louis and Cincinnati and reorganization of uranium production responsibilities to other offices of the AEC (AEC 1958, p 10).

During the time frame of 1947 to 1954, the period in which the TBD is concerned, NYOO had broad responsibility for the procurement and processing of uranium for weapons production. These responsibilities included acquisition of raw ore materials from Africa and other sites; all aspects of its storage; processing of the raw ore; preparation of uranium oxide; conversion to green salt (UF_4); preparation of uranium metal billets; and the rolling of the billets into rods. The uranium metal was delivered as billets to two mills (as of 1949), Simonds Saw and Steel Company, Lockport, New York and Vulcan Crucible Steel Company, Aliquippa, Pennsylvania who rolled the billets into rods which were shipped to Hanford (AEC 1949a, p3). Joslyn Manufacturing and Supply Co. continued to provide additional capacity during start-up of the rollings at Simonds as ~150 tons of uranium per month was needed by Hanford (AEC 1948c, p 128). It is known that other rolling mills also participated in rolling operations during this early time period. Simonds Saw and Steel Co. later became the principle manufacturer of rods as Vulcan was unable to roll the larger billets coming from Mallinckrodt.

During the war, permissible levels for natural uranium dust in air were set at 500 $\mu g/m^3$ for insoluble uranium compounds and 150 $\mu g/m^3$ for soluble compounds. After the war, the University of Rochester lowered its recommendation for soluble uranium compounds to 50 $\mu g/m^3$ on the basis of chemical toxicity, which is equivalent to 70 disintegrations per minute per cubic meter (alpha activity of ^{234}U and ^{238}U). The University based this level primarily on animal studies. The Medical Division of the New York Operations Office felt that a "maximum permissible level" was really unknown and should be based on human data. Therefore, 50 $\mu g/m^3$ level was referred to as the "preferred level" (AEC 1949b). Many AEC contractors used the term Maximum Allowable (air) Concentration (MAC)

interchangeably with “preferred level” and often reported air-sampling results as multiples of the MAC (NLO 1952b; AEC 1953). As of 1949, NYOO did not recommend the use of respirators (AEC 1949a).

Several operations conducted as part of the uranium processing at Bethlehem Steel are important to have a conceptual understanding of their impact on exposure during the activities conducted at the Lackawanna Plant. These include:

Furnace heating: In some cases uranium was preheated in the furnace and then further heat treated in a lead or salt bath.

Lead bath heating: Similar in nature to the furnace heating, uranium rods and billets were immersed in a molten lead bath to heat them to the desired temperature for rolling. The lead also served to provide a partial coating for reduction of uranium dust during the operations.

Salt bath heating: Similar in nature to the furnace heating, a molten salt bath was used to heat the uranium rods and billets prior to rolling. This salt also provided a protective covering which significantly reduced the uranium oxide formation and airborne contamination levels during rolling.

Centerless grinding: The canning process required a precision ground uranium piece. HW-19066 describes the process of centerless grinding using a No. 3 Cincinnati Centerless Grinder using initial (rough) pass removing 0.005”-0.010” with finishing passes removing 0.001”-0.002”. The basic principle was for the cutting pressure of the grinding wheel to keep the rod in contact with the rest blade and the regulating wheel. The rotation of the regulating wheel causes the rod to rotate at a constant peripheral speed and the inclination of the regulating wheel axis moves the work from the front to the rear of the machine. The operation of grinding uranium required the use of a constant flow of coolant..

Hand grinding: Some reports indicate that grinding of the rods was a component of the work performed by the Lackawanna facility. Other facilities indicated the need to perform both centerless grinding and hand grinding of materials. Hand grinding may have been used to remove surface imperfections prior to rolling as well as cleanup of the slugs after they were sheared into 4” and 8” pieces. Since the product sent to Hanford included both rods and slugs, hand grinding was considered as a potential exposure source and data at Joslyn was evaluated to compare the source term with the assigned intake levels.

Medart straightening: Uranium rods and in some cases slugs were straightened. In some cases this was done prior to centerless grinding, in others simply to improve the product straightness prior to shipment to Hanford where final machining was undertaken.

Billet: Large cylinder of uranium metal up to 5” in diameter and up to 2 feet in length weighing between 125 to 500 pounds.

Rod: Uranium billets were rough rolled and then finished rolled into long, thin rods. The rods were often the final product shipped to Hanford.

Slug: Uranium rods were cut into 4” and 8” pieces called slugs (sometimes at Hanford, sometimes at a facility offsite to Hanford) which were dipped and canned for use in the reactors.

2.2 Bethlehem Steel Corporation

Bethlehem Steel Corporation was one of the largest steel manufacturers in US history, with an annual output of material after World War II that exceeded twice the output of the entire country of Germany at that time (Leary 1987). Bethlehem Steel acquired the Lackawanna facility in 1922. While Bethlehem Steel had widespread holdings in ship building and other interests, only the facilities located in Lackawanna, NY are the subject of this TBD. Diagrams of the site are available (Leary 1987) to provide a reference to the scale of this 1300 acre complex which employed approximately 20,000 workers during this time period.

The U.S. Atomic Energy Commission (AEC) contracted with Bethlehem Steel Corporation (BSC) to develop improved rolling mill pass schedules using a continuous rolling mill. These rollings were tied strongly to the design of the Fernald facility which was to be based on a continuous rolling mill technology such as that used at BSC whose design was to be developed by Birdsboro corporation (Summary 1951). Many documents associated with the development of the uranium rolling program and its progress have been obtained by NIOSH and its contractors and may be referenced for additional detail including, but not limited to HW-13168, HAN-21441, HAN-30471, HAN-30686, HAN-30987, HAN-31429, HW-14816, HW-20548, GEH-17116, HAN-20104, HW-24222, HW-20548, HW-22474, HW-22878, and a series of unnumbered Bethlehem Steel memos obtained from Hanford which are contained in the NIOSH Site Research Database (SRDB).

Programmatic goals associated with these rollings were (HW-24849):

- To evaluate the continuous rolling mill as a source of uranium rods for the plutonium production program at Hanford and Savannah River;
- Information gained during these rollings would be used for the design of the Fernald plant;
- Evaluate technological improvements leading to reduced oxidation of uranium metal by the use of lead bath and salt bath heating (using a combination of lithium and potassium carbonate salts) would reduce losses during rolling; and,
- Evaluate the metallurgical implications of heat treatments to improve quality during irradiations.

Review of the historical records show that BSC conducted this work under the oversight of HASL, Hanford Works, and National Lead of Ohio (DOE 1985). Records indicate that BSC participated in both experimental and production runs. The purpose of this program included the following:

- Finish rolling of bars rough rolled at Simonds Saw or Aliquippa Forge (Summary 1951);
- Comparison of lead bath and salt bath heating on product and process quality;
- Heat treating rods and billets rolled or to be rolled at other facilities which in some cases also included grinding as part of this preparation; and,
- Production runs of uranium rods from rough rolled rods.

The uranium billets were prepared by Mallinckrodt Chemical in St. Louis, Missouri, shipped to the rough rolling mill and then shipped to Lackawanna in freight cars. The freight cars, which were spotted at the BSC plant, served as storage for the uranium billets during the week (Range 1976;

ORNL 1980; DOE 1985). The rolling experiments generally took place on weekends because the mills were in full use 5 days per week. The work only involved the 10-in. bar mill and associated billet preparation and handling equipment (LaMastra 1976; Range 1976; Thornton 1977; ORNL 1980; DOE 1985). Review of Hanford documents also shows that some activities involved only the heat treatment of metal rods and billets in the salt bath to get the proper grain structure in the metal preferred for irradiation of the material at Hanford. These grain structures, known as the alpha, beta and gamma phases, describe the metallurgical properties of the material and are not associated with radioactivity in this context.

According to some accounts, material accountability practices for the project included collection of scale, residue, fine debris, and cropped ends. Worker accounts (6-19-2006) reported the use of vacuum cleaners to assist in the cleanup in many areas. These materials were packaged, and returned to the AEC which had a documented scrap recovery program (LaMastra 1976; Range 1976; ORNL 1980; DOE 1985). Radiological surveys in 1976 and 1980 of the original facility and equipment, which were still in existence, identified no residual contamination above natural background levels (LaMastra 1976; ORNL 1980; DOE 1985).

A number of documents provide conflicting information regarding the time period during which the rollings occurred. Some references indicate that all work occurred between 1949 and 1951 (Summary 1951; LaMastra 1976; ORNL 1980). However, other reports indicate that eight additional rollings occurred in 1952 (Bowman et al. 1952; Hershman 1952; NLO 1952a; DOE 1985), although they were reported to be production rollings. A letter from a labor representative in October 1979 asserted that six to eight rollings took place in 1955 although no verification of these dates has been found (Kosanovich 1979, 2004). The work was transferred to the Fernald Plant around September 1952 as it began pilot and then full scale operations (NLO 1952a; LaMastra 1976; Range 1976). Information obtained from the rolling experiments at BSC was used in the design of a rolling mill at the National Lead Company plant in Fernald, Ohio, which began production in 1953 (LaMastra 1976; Range 1976). Table 1 lists the dates of rollings at BSC for which documentation has been found.

Several documents report that AEC personnel were present during all rolling operations and several site visit reports have been obtained that document these visits. AEC personnel conducted air and surface radioactivity monitoring and checked personnel involved in the rolling for contamination during some of these rollings (LaMastra 1976; ORNL 1980; DOE 1985). Some reports indicate that no records are available of these monitoring activities (LaMastra 1976; Range 1976; ORNL 1980). As of 1976, it was believed that if monitoring records ever existed, they were not retained (LaMastra 1976). Uranium metal accountability records apparently were destroyed (Range 1976). Review of AEC historical records, however, has produced several documents containing air sampling data from the Health and Safety Laboratory (HASL) and National Lead Company for the rollings shown in Table 1. These documents are supplemented with data collected at other facilities conducting similar work and worker accounts to provide the basis for the estimates that follow (SC&A 2005a, p 46). The application of Simonds Saw and Steel data to supplement the Bethlehem Steel data was reviewed and found to be an acceptable approach (SC&A 2005a). This approach is described in detail later in this document. Many documents were available form the Hanford archives because the work was associated with improvements to the irradiation of uranium fuel for plutonium production.

While the operations involving the processing of uranium were limited to the 10” continuous rolling mill and associated handling facilities (Figures 1 and 2), the time lapse and complexity of the site make clear evaluation of exposure potential by job title difficult. The 10” continuous rolling mill and associated localized bar material handling facilities were completed in 1947 with monthly capacity measured in thousands of tons of steel per month. The process was also known to create widespread contamination within the mill area during the processing of the uranium. Therefore all

workers at Bethlehem Steel in Lackawanna will be evaluated as having a potential for internal and external exposure as if they worked in the rolling mill during these operations. These evaluations are explained in the following sections.

Figure 1: 10-inch bar mill at Lackawanna circa 1950 (Walker 2005)

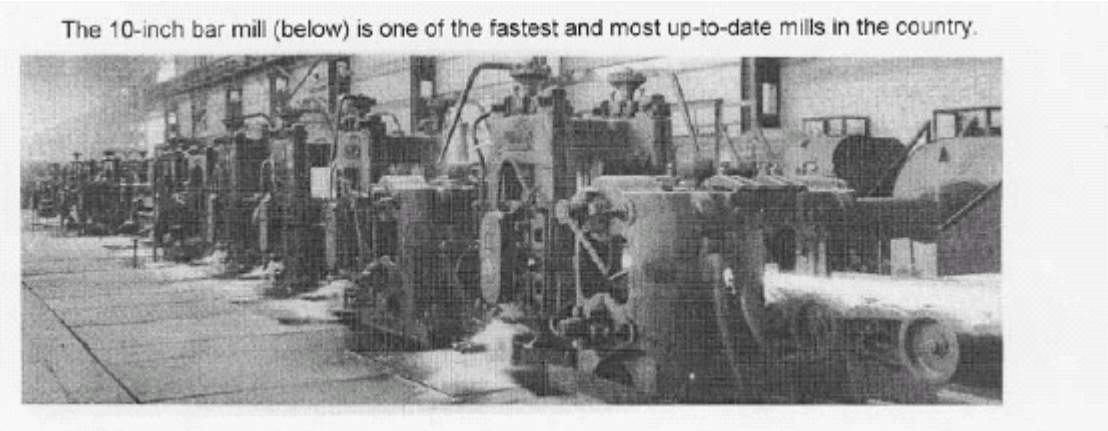


Figure 2: Lackawanna continuous stand rolling mill diagram as provided by a retired employee and drafted by SC&A (SC&A 2005).

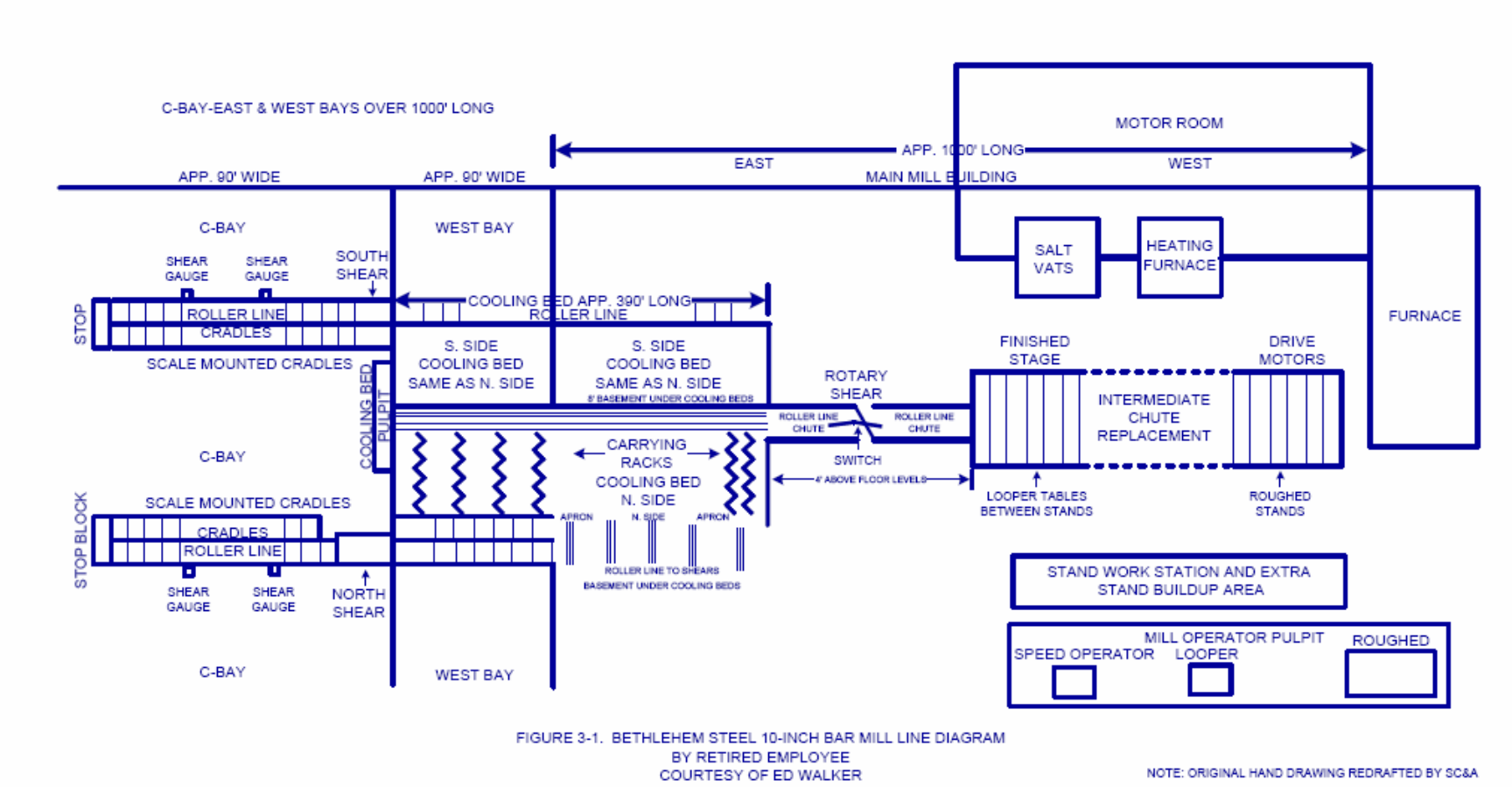


FIGURE 3-1. BETHLEHEM STEEL 10-INCH BAR MILL LINE DIAGRAM
BY RETIRED EMPLOYEE
COURTESY OF ED WALKER

NOTE: ORIGINAL HAND DRAWING REDRAFTED BY SC&A

Table 1: Documented rollings at Bethlehem Steel Corporation, Lackawanna, New York

Date	Day	Type or designation	Billets rolled	Bath type	Air Sample Data	Reference
April 26-27, 1951	Thurs., Fri.	Experimental #1	26	Lead/salt	Y	Summary 1951 AEC 1951b Sheets 6191, and 6192
July 29, 1951	Sunday	Experimental #2	24	Lead/salt	Y	Summary 1951 Sample sheets 6425, 6436, 6437
August 27, 1951	Sunday	Experimental #3	32	Lead/salt		Summary 1951 HW-22347
September 30, 1951	Sunday	Experimental #4	43	Salt	Y	Sample sheet 6539 HW 23910
October 28, 1951	Sunday	Lackawanna #5	93	Salt	Y	HW-22975 Sample sheets 6532, 6533
January 26-27, 1952	Saturday, Sunday	Production	25 plus 4 tons heat treated only	Salt	Y	AEC 1952b HW-23399 HW-24849, HW-23269 Sample sheets 6543, 6544, 6545
February 16, 1952	Saturday	Production	120 30 tons	Salt		HW 23697
March 15, 1952	Saturday	Production	218	Salt	Y	NLO 1952b Sample sheets 6573, 6574
April 12, 1952	Saturday	Production	222	Salt		NLO 1952a
August 17, 1952	Sunday	Production	157	Salt		Bowman 1952
August 31, 1952	Sunday	Production	219	Salt		Bowman 1952
September 14, 1952	Sunday	Production	303	Salt	Y	Schneider Sample sheet IH33, IH34, IH35, IH36
September 22, 1952	Monday	Production	302	Salt		Schneider
October 19, 1952	Sunday	Production	60 tons	Salt		Hershman 1952

1951: Six rolling days, plus assume one January, February, March, May, June, November, December (13 rollings). There was no Experiment #6 at Lackawanna (cancelled after rough rolling).
1952: 10 rolling days, plus assume one for May, June, July, November, December (15 rollings)

2.3 Simonds Saw and Steel Co.

Several companies participated in the uranium rolling production for Hanford as has been previously discussed. The data that exist for these companies may be useful for supplementing the dose reconstruction effort at Bethlehem Steel Corporation provided that the processes are similar and can be determined to represent bounding conditions for the assessment of dose.

Simonds Saw and Steel began rolling uranium in February of 1948 and continued as a principal source of rolled uranium for several years as previously discussed in this TBD. An AEC visit to Simonds in October of 1948 collected a variety of air and urine samples from the workers prior to the implementation of any air control measures (AEC 1948a). The next visit (Dec 1, 1948), improvements included exhaust ventilation provided over each of the operating rolls, the central vacuum cleaner was to be discharged outside, and temporary enclosure was provided over the descaling device (AEC 1948b). Simonds Saw and Steel data from the October 1948 (before ventilation changes) will be the only Simonds Saw and Steel data used to support the internal dose estimates for the Lackawanna facility.

While a complete description of the Simonds Saw and Steel is the subject of a different TBD (ORAUT-TBKS-0032), some discussion is warranted on why this represents a bounding condition. A visit by Hanford personnel to Simonds discusses the operation and layout of the facility in early 1949 (HW-19066) after several health control measures had been implemented (HW-19066). The rolling mill facility was described in one of several large buildings constructed of steel and masonry with a dirt floor. The uranium rolling equipment was located at one end of the building on a steel plate platform about 2 feet above the floor. The report indicated that the equipment was previously used for rolling steel and was still occasionally used for that purpose. This differs markedly from the Bethlehem Steel situation where uranium rollings were conducted on a very limited scale amidst high volume steel rollings. The report provides detailed information on the processing of the uranium rods at Simonds and also verifies that the air sample collection data were obtained using the same methods as discussed by other HASL documents. Diagrams are available for the Simonds Saw and Steel facility in several AEC reports and are included in the Simonds Saw and Steel Technical Basis Document.

An AEC New York Operations Office (NYOO) report of a visit to Simonds Saw and Steel Company in Lockport, New York, on October 27, 1948, describes occupational radioactive dust exposures between 8 and 190 times the MAC depending on the type of job performed (AEC 1948a). This report indicates a 10-hour workday. In addition, it states "…where the maximum amount of alpha was present, a concentration of more than 1000 times the preferred level, the beta activity of the same sample was less than 0.5 times the tolerance (40,000 beta disintegrations per cubic meter). For this reason it is felt that the exposure to beta emitting dust is of negligible consequence as compared to any concomitant alpha dust exposure" (AEC 1948a). This survey occurred during a production rolling. During experimental rollings, generally less than 50 billets were rolled. From the job analysis sheets, apparently 180 billets were rolled October 27, 1948 at Simonds.

Simonds Saw and Steel represents a bounding case for Bethlehem Steel exposures to uranium based on the following:

Size: Simonds was a smaller facility and the processes were close to one another. Air concentration data for general area samples would tend to be higher because of the cross-talk between locations. Also, contamination would have remained more localized and thus more available for resuspension and thus air concentration data from the much larger rollings quantity would have been greater.

- Material: Simonds Saw and Steel was processing bare metal uranium rods for the October 27, 1948 and preceding rollings. This type of material is more susceptible to oxidation than lead bath heated or salt bath heated uranium and thus increases the uranium oxide dust production. All rollings which are known to have occurred at the Lackawanna plant were lead or salt bath heated.

- Ventilation: Ventilation at Simonds Saw and Steel consisted of natural convection during the October 27, 1948 rolling except for a single small hood at the quench station (a process not used at the Lackawanna rolling mill) which was unable to contain significant loss of material from that operation (HW-19066). This localized source of ventilation would have had no impact on the 95% concentration data used for these estimates. Similar levels of contamination were observed at Joslyn Manufacturing and Supply Company during the rolling and machining of bare uranium rods (AEC 1952e). Furthermore, the general area samples collected at Simonds Saw and Steel were much higher than those at the Lackawanna facility, indicating that the ventilation at Simonds was not an effective mechanism for contamination reduction.

- Process: Simonds Saw and Steel was more labor intensive and hands on than the process conducted at the Lackawanna plant. Some of the highest air concentration levels at Simonds were observed during operations involving the dragging of the rolled rods across the contaminated floor. The facilities at Lackawanna were state of the art (the 10" continuous mill was completed in 1947 (Leary 1985)) and were designed to reduce the amount of labor involved in the production process.

- Air sampling: Air sampling data was collected and analyzed by the same organization (HASL) using the same methods as discussed in Section 3.1. Breathing zone samples collected at Simonds Saw and Steel on October 27, 1948 were taken during the worst part of the process for short durations (~1 minute) which provides an upper bound to the overall breathing zone estimates.

- Rolling volume: Simonds Saw and Steel replaced Joslyn as the rolling mill of choice for the AEC program. Any rollings conducted at the Lackawanna rolling mill would have been small and experimental in nature in the 1949-1950 time frame. While rolling volume does not impact the breathing zone estimates, the amount of residual activity will be affected by the total amount of material rolled. Rolling volume would play an important part in determining total rolling time.

- Capacity: The amount of material run at the Lackawanna plant was a small fraction of their actual capacity. The full application of a 10 hour day at these levels is a significant overestimate.

Finally, Merrill Eisenbud stated the following in the May-June 1951 HASL monthly report (AEC 1951a): "Dust samples were taken at the Bethlehem Steel Plant to evaluate continuous rolling of uranium. The lead bath results were comparable to those obtained at Simonds Saw and Steel during periods when no ventilation was used. For a second test, one set of rods was rolled after heating in a mixed salt bath. The air samples for this set were significantly lower than those for the lead bath test".

3.0 ESTIMATION OF INTERNAL EXPOSURE

3.1 Health and Safety Laboratory Air Monitoring Program

The production of rods by US industrial facilities had been intended to be of short duration to support the war effort, however, it became apparent to NYOO in 1949 that these resources would be used for an indefinite period (AEC 1949b, p5). Concerns mounted over known exposures to radioactive materials which exceeded even war year standards promulgated by the University of Rochester. These levels were much higher than standards being proposed and which were eventually adopted. HASL implemented a program of air sampling at many of these facilities to evaluate and reduce the exposures to workers. These programs and mitigating ventilation plans for these facilities were discussed in the May 1948 NYOO monthly report (AEC 1948c, p140).

From the early days of operation, the Health and Safety Laboratory (HASL) of the Atomic Energy Commission (AEC) relied on time weighted average exposure measurements to assess inhalation hazards in the workplace. A brief description of the HASL methodology, and its relation to ICRP 75, is provided below.

A detailed description of the HASL methods and background on air monitoring and exposure assessment was provided in a 1973 write-up in the HASL manual (chapter B-04, The Application of Air Sampling in the Evaluation and Control of the Occupational Environment, AEC 1973). The detailed description of the concept of representative workplace monitoring was written by A.J. Breslin, Director, Health Protection Engineering Division, HASL. It should be noted that Mr. Breslin was one of the sample collection scientists for the Bethlehem Steel Corp uranium dust monitoring data. Breslin's write-up provides a detailed discussion of the type of samples taken, how they were taken, how they were analyzed, and how the results should be interpreted. The discussion of sampling locations, designation of sampling sites and the job task analysis sheets contained in this document are consistent with the sampling strategy employed at both Simonds Saw and Steel (SSS) and Bethlehem Steel Corporation (BSC). Early HASL procedure manuals were primarily focused on the chemistry, so earlier versions of the text may not exist (personal communication, Dr. Isabelle Fisenne). The following text, excerpted from the HASL manual, provides a description of the various sample types that were used by HASL to evaluate representative exposure.

> ***Breathing Zone Samples***- *Typically, a worker performs a few operations in which he may come into close or direct contact with the hazardous material. Examples of these operations are operating a machine tool, charging a furnace, working at a chemical hood, changing the glove on a dry box, or any one of a hundred maintenance tasks that involve the dismantling of or entrance to equipment. At jobs such as these, dust concentrations are apt to be much greater than in the general area. Therefore, these activities may influence the average exposure far out of proportion to their duration.*
>
> *To measure accurately the concentration to which a worker is exposed while performing such a task, a breathing zone (BZ) sample must be collected. The sampling instrument is held in the vicinity of the worker's breathing area for the duration of the task. It should be held as close to his nose as possible short of interfering with his freedom of movement, because in situations where dust is escaping from a small aperture, concentration gradients around a source can be sharp. In one uranium plant, samples collected one foot apart at certain operations have shown concentration differences of twenty-fold. On the other hand, a sample collected so close as to interfere with the worker's movements is invalid because the job cannot be*

performed in the normal fashion. A small deviation in work habit may alter the dust concentration markedly.

***General Air Samples**- Usually, the total time spent by a worker on operations requiring BZ samples constitutes a small fraction of the day. There are, of course, exceptions… Worker exposure during the balance of the work day may be characterized by samples collected of the general air (GA) in the area that he occupies.*

A GA samples is one that is collected at a fixed location during a sustained sampling period. To be meaningful, the sample must be collected within an occupied area but also it must be away from dust sources except those that may dominate the area. Customarily, the sampling instrument is placed at a height from four to six feet from the floor although in a heavily trafficked area, the instrument must be placed over the heads of the workers to avoid interference with the normal work routine….

***Process Samples**- There is yet another kind of air sample that is often useful, the process sample. It is used to identify sources of air contamination or to determine the relative strengths of two or more sources. Process samples are distinguished from BZ and GA samples by the fact that they are taken in and around process equipment at locations where employees normally are not exposed. For this reason they should never be used in the evaluation of occupational exposure.*

As an example, a process sample might be collected directly over a furnace to determine the amount of radioactivity that is carried by convection from the furnace to the room. The concentration at that point is not representative of an employee's exposure.

These sampling methods meet the most current recommendations from ICRP Publication 75 (ICRP 1997) regarding the collection of representative samples for the purpose of determination of exposure. As indicated in the excerpts below from the HASL procedures manual, the BZ samples collected by HASL were held in a position to represent the breathing zone and are not associated with a fixed sampler. Because of this, the ICRP 75 recommendation that samples collected from area samplers be corrected to breathing zone would not be appropriate for these samples. General area (GA) samples were taken with the expressed purpose of evaluating non-localized releases to which an employee could be exposed during the course of the day. Finally, process samples (P) that were obtained during the measurement period were to assess source terms and are not indicative of concentrations to which workers may have been exposed. Further evidence of the breathing zone sampling location comes from typical operations at National Lead which states, "BZ (breathing zone) samples were collected by holding the sampling device in the immediate vicinity of the worker's head, in front of the shoulder area."

Samples were collected on 1 1/8" disks of Whatman #41 filter paper which provide high efficiency collection of particles in the particle size range. These filters have a maximum flow rate of about 20 L/min (0.020 m^3/min). The procedure for the collection of samples at Simonds Saw and Steel on October 27, 1948 is discussed by the HASL representative in the report (AEC 1948a). Further discussion of the counting methods employed by the HASL is contained in the procedure "Determination of Uranium in Air Dust Samples by Alpha Counting Methods" (AEC 1949c) and by direct account of one of the HASL laboratory employees (personal communication, Dr. Naomi Harley, 2004). While the current standards for documentation of calibration of the counting and sampling equipment have changed significantly since the early days of industrial hygiene, the relative contribution to uncertainty in the measured air concentration associated with these factors is very

small compared to the large changes in air concentration as a function of time and location. While this TBD does not use time weighted averages to determine exposure to uranium dust, HASL reported very good agreement in comparing time weighted averages of exposure with results obtained from personal lapel-mounted air samplers after they became available in the late 1960s (Breslin 1967). This agreement provides additional support for the reliability of the data and the use of time-weighted average air sample results to estimate exposure.

3.2 Parameters affecting intake estimates and uncertainty at Bethlehem Steel

A number of parameters must be specified in order to determine radiation dose from inhalation and ingestion of uranium (e.g. breathing rate) and associated uncertainty with these estimates. The recommended default values from the ICRP in Publication 66, *Human Respiratory Tract Model for Radiological Protection,* shall be used unless otherwise specified. The following discussion addresses the parameters to be used for the reconstruction of internal dose at the Lackawanna, NY facility.

3.2.1 Breathing Rate

ICRP 66 provides for two distinct types of workers, *light workers* and *heavy workers*. Both represent a composite of various levels of exercise. These composites represent an average breathing rate of 1.2 m^3/hr for light workers and 1.7 m^3/hr for heavy workers. This document will assume a classification of all workers at BSC as heavy workers with a breathing rate of 1.7 m^3/hr as a claimant favorable assumption using standard nasal augmenter breathing pattern.

3.2.2 Exposure Duration

In order to determine the total amount of uranium inhaled it is necessary to multiply the airborne concentration by the breathing rate and the time the individual is exposed to that concentration. This gets even more complicated when it is realized that not only does the air concentration vary by location, but also by time. Also, many individuals will move about from location to location throughout the day including break rooms, bathrooms, lunch rooms, etc. HASL recognized this need and developed the methods to determine a time weighted exposure. Such a study was conducted at Simonds Saw and Steel. The individual tasks were timed at various locations, and these exposure times were combined with the air concentrations in the locations to obtain a time-weighted average air concentration. However, no such estimate was conducted at Bethlehem Steel.

Without a time motion study of various tasks, it is necessary to develop a claimant favorable approach to determine the appropriate exposure location and duration. For lack of better information, each individual will be assumed to be exposed for the purposes of internal dose estimation, 100% of the time for each 10 hour day of uranium rolling. This value will be treated as a constant for purposes of uncertainty analysis to be discussed later. Further discussion of exposure time with respect to internal dose from residual contamination will be discussed later in this document.

The number of exposure hours per year was determined by assuming twelve 10-hour workdays per year for 1949 and 1950. This assumption is conservative considering no documentation indicates any rollings took place during those years. If there were rollings, it is assumed they took place only on one weekend day per month. Reports from 1951 and 1952 indicate that, with the exception of the April 1951 (Summary 1951), January 1952 (HW-23399), February 1952 (HW-24849), August 1952 (Bowman et al. 1952), September 1952 (Schneider and Yocce undated) and October 1952 rollings, activity occurred on only one weekend day per month. For 1951, an additional 10 hours was added to account for the additional weekday in April, resulting in thirteen 10-hour workdays. For 1952, in

addition to the ten documented rollings days, it was assumed that one rolling each took place in May, and June, July, November and December resulting in fifteen 10-hour workdays. Assumptions of 10 hour work rolling days are very claimant favorable estimates based on review of documented rollings which occurred at Lackawanna. For estimates of non-rolling day exposure to residual contamination, 50 weeks of five 10 hour work days minus the number of rolling days were used. Residual contamination is discussed in greater detail later in this document. All partial months shall be treated as full months of exposure.

3.2.3 Exposure Location

As mentioned previously in this document, the exposure location can be difficult to determine. This estimate accounts for location uncertainty by assuming everyone was exposed in an occupation equivalent to the 95th percentile of the area air concentration distribution or other bounding estimates of intake which is explained later in this document.

3.2.4 Absorption Type

The dose derived from inhaling radioactive material depends on the solubility of the material inhaled. The solubility is a parameter describing the rate at which the material is absorbed from the lungs into the bloodstream. The most likely form of airborne uranium at Bethlehem Steel is various uranium oxides. These oxides tend to be absorbed at rates that are between type M and type S parameters described in ICRP 66. The absorption type will affect the dose of organs; however, no one type is favorable to all organs. Type S (very insoluble) will cause higher doses to the respiratory tract than type M but lower doses to systemic organs. Therefore, since the true absorption likely falls between type M and type S, the most favorable solubility type for the case at hand will be used.

3.3 Inhalation Exposure Dosimetry at Lackawanna

3.3.1 Method of analysis

The air sample data from Bethlehem Steel originally consisted of a total of 191 legible air sample results and 13 illegible results drawn and analyzed by the HASL. These samples were collected on various days of rolling in 1951 and 1952. Original records were reviewed by NIOSH and its Advisory Board to determine some of the values because of the poor quality of some of the copies of onion skin type records. The final data set used for the analyses below consisted of 204 total samples with only 1 sample being considered illegible and thus not used. Additionally, 5 samples were quality control samples and were excluded from the analysis of air concentration.

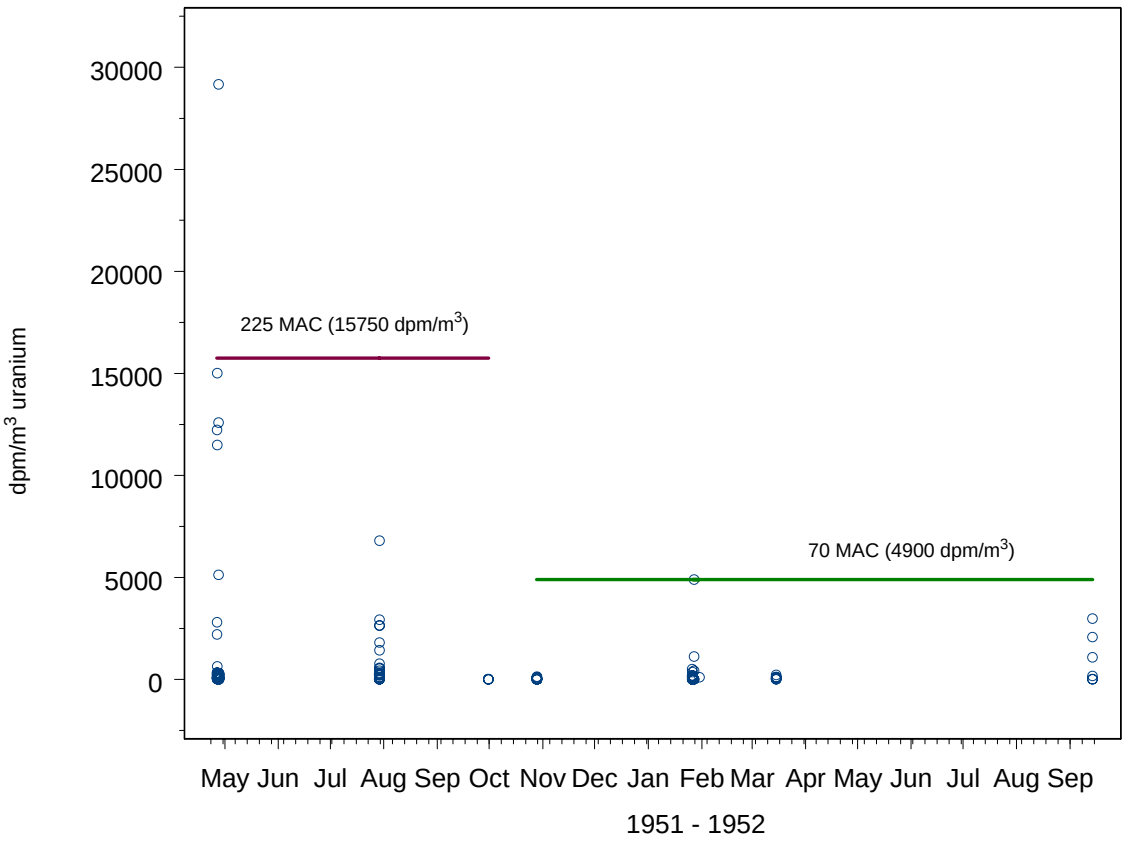
The samples were divided into time periods based on the technology being employed (lead bath or salt bath heating). The following general methods were applied for the analysis of all time periods with specific information being further discussed in individual sections. All valid results, including process samples, were sorted, log transformed, and plotted on a probability plot. The plot contained the z-score (number of standard deviations from the mean) on the X axis and the log transformed data on the Y axis. This allows for a linear regression to be performed on the data to determine the best fitting straight line. This technique provides a goodness of fit value (utilizing the R squared parameter) as well as an equation for the straight line. The slope of the line then is equal to the log of the Geometric Standard Deviation (GSD) and the Y intercept is equal to the log of the Geometric Mean (GM).

No records of any air sampling are known to exist for the 1949-1950 time period at Lackawanna as was previously discussed. This period was evaluated using the data collected at Simonds Saw and Steel on 10/27/1948, prior to the implementation of any ventilation controls.

Data from the 1951-1952 time period was divided into two periods to reflect changes that occurred in the processing technologies (e.g. the change from lead bath and salt bath heating to only using salt bath heating). These analyses are explained in detail below. Figure 3 provides a graphical presentation of all the measured air monitoring data at Bethlehem Steel which further validates the need to split the period.

The significant reduction in exposure levels during the later period (October 1951 thru December 1952) created a situation where source terms other than the rolling operation may have been the limiting air concentration. It was determined that the grinding operations provided the highest exposure estimates as explained in the following section. In summary, there are three periods used for evaluation of internal dose: (1) January 1949 to December 1950; (2) January 1951 thru September, 1951; and (3) October 1951 thru December 1952. Finally a special exposure scenario for workers who participated in the cutting of cobbles has been established and is described in Section 3.3.5.

Figure 3: Plot of all air monitoring results for natural uranium from Bethlehem Steel.



3.3.2 Evaluation of inhalation exposure for the 1949-1950 time period

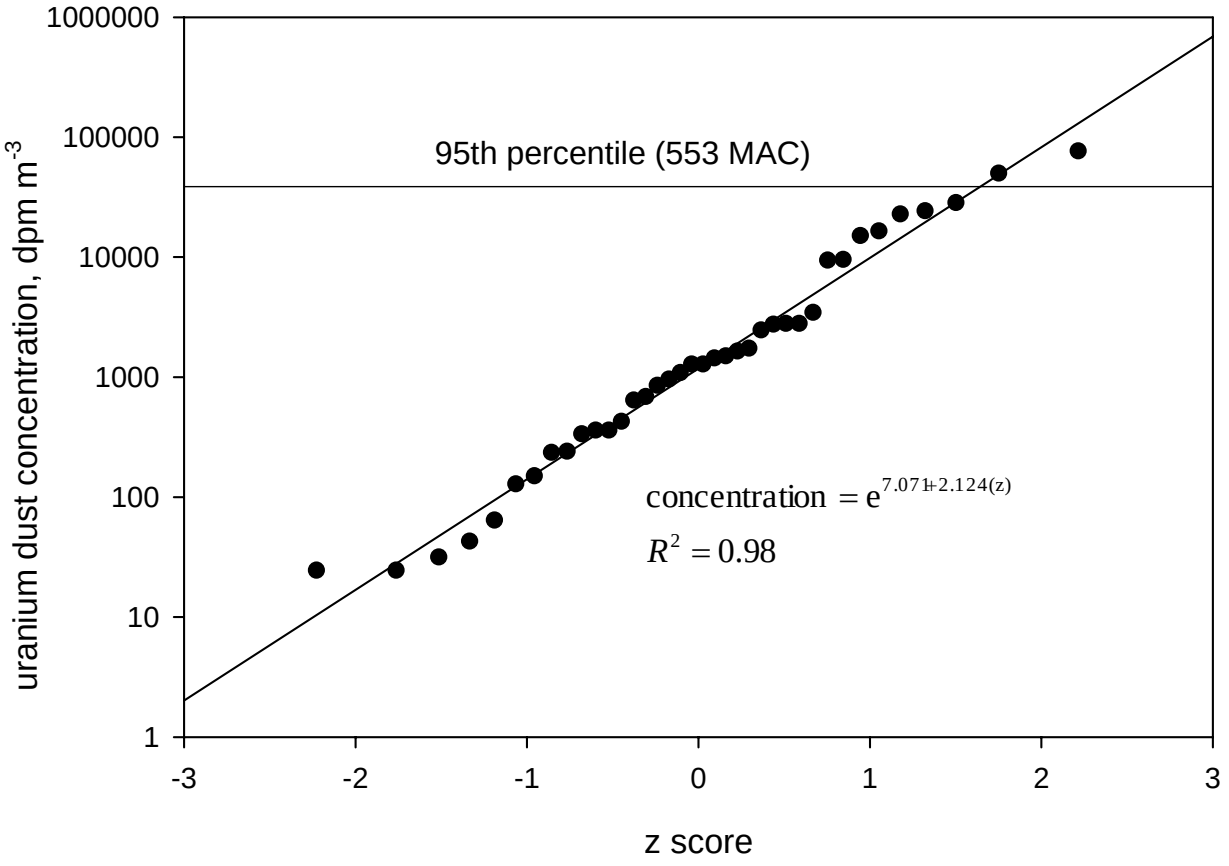
No contemporary record of Bethlehem Steel processing uranium for the DOE or its predecessors prior to 1951 has been found by NIOSH. The sources of information which have been used to justify this period are the 1976 memo from ERDA (Range 1976) which provides details recalled by retirees of the AEC who had knowledge of the operations, a memo by a plant radiological control engineer (LaMastra 1976) who used the 1976 memo from Range as a source along with discussions with plant personnel, and a 1977 memo from Thornton as part of the ERDA resurvey program who based the times from a discussion with LaMastra. No documentation had been reviewed for the preparation of this memo by Range which is cited by other reports and dates were specified as being approximate.

No records exist which document rollings at Bethlehem Steel during 1949-1950. Because of this, data from Simonds Saw and Steel will be used as a surrogate for the determination of dose for these years. The use of Bethlehem Steel data for uranium dust exposure assessment prior to 1951 is inappropriate because lead bath heating may not have been performed. Certainly salt bath heating was not being evaluated until 1951. The appropriateness of using Simonds Saw and Steel as a surrogate facility was discussed earlier in this document and was the subject of significant review by the Advisory Board on Radiation and Worker Health.

The visit by HASL to Simonds Saw and Steel on October 27, 1948 collected 37 samples to evaluate the time weighted average exposure to various job categories at the plant. These included 22 breathing zone samples and 15 general area samples. Several controls and a sample from the stack were also collected. The median length of time of collection for a breathing zone sample was 0.71 minutes (range 0.5 to 2.5 minutes) while general area samples typically were collected for a much longer time (median 15 minutes, range 3 to 45 minutes). The changes in time were used by HASL to prevent severe dust loading of the filters in areas with high expected dust concentrations and increased sampling times to improve statistics associated with the counting in areas of expected low concentrations.

The data from both plants includes various locations throughout the mill areas. Some of these locations represent higher air concentrations than others. Therefore, assigning the distribution may underestimate an individual's intake for someone located in one of the higher air concentration area for extended periods of time. In order to prevent this from occurring, the 95th percentile of this distribution will be assumed for exposure estimates. This value will be assumed to be present in the breathing zone 100% of the time and be assigned as a constant. Figure 4 provides a plot of the distribution of uranium concentrations observed at Simonds Saw and Steel during this period of no ventilation. The 95th percentile of this distribution, 553 MAC (38,710 dpm m^{-3} of natural uranium), will be used as the basis for evaluation of inhalation exposure during this time period.

Figure 4: Graph of the distribution and fit of uranium dust concentration data taken from Simonds Saw and Steel on October 27, 1948 (MAC=70 dpm m^{-3}).



3.3.3 Determination of inhalation exposure for the early 1951 time period

As previously discussed, the air sample data from Bethlehem Steel consists of a total of 204 air sample results, drawn and analyzed by the Health and Safety Laboratory and National Lead. Personnel from National Lead, who conducted the last analysis, were originally from HASL and used the same approaches and time weighted averages. These samples were collected on various days of rolling in 1951 and 1952. Sample types included general area, breathing zone, and process samples. Of the 204 samples, one sample was illegible (after reviewing the original records) and 5 were quality control samples which were not used for these analyses.

Evaluation of the data shows that changes in the process methods clearly impacted the air concentration data which was reflected in the monthly HASL reports and also reports of by Hanford personnel participating in the development. An early period from January 1951 to September 1951 was identified in which lead and salt bath technologies were both being evaluated at Bethlehem Steel.

It was further recognized that the number of breathing zone samples was a much lower fraction of the total as compared to the Simonds Saw and Steel measurements used to evaluate the 1949 to 1950 time period. For this reason, a breathing zone sample surrogate (BZ-GA) was developed by evaluating the breathing zone to general air sample concentrations at Simonds Saw and Steel and applying this factor to the general air samples during this early 1951 period. Data analysis for this time period was then conducted using the same methods as previously discussed. Figure 5 shows a graphical analysis of data from this time period prior to augmentation. Figure 6 shows the analysis of the augmented data set (includes BZ-GA samples). The 225 MAC (15750 dpm m^{-3}) air concentration represents the 95% level which shall be used for analysis of uranium air concentration during rollings days for this early 1951 period.

Previous sections in this TBD discuss the role that the BSC Lackawanna rolling mill played in the development of continuous rolling experiments for Hanford and also for the comparison of lead and salt bath heating. Only the first four experimental runs conducted in 1951 were known to have used the lead bath heating. Air sampling was conducted on three of those experiments. While it is known that the salt produced a more effective coating for reducing oxidation hence uranium dust, the data has been evaluated together for determination of the 95% air concentration data.

Figure 5: Graph of the distribution and fit of uranium dust concentration data, prior to augmentation with BZ-GA samples, taken at Bethlehem Steel from January 1951 thru September 1951 for only those samples obtained for the time (MAC=70 dpm m^{-3}).

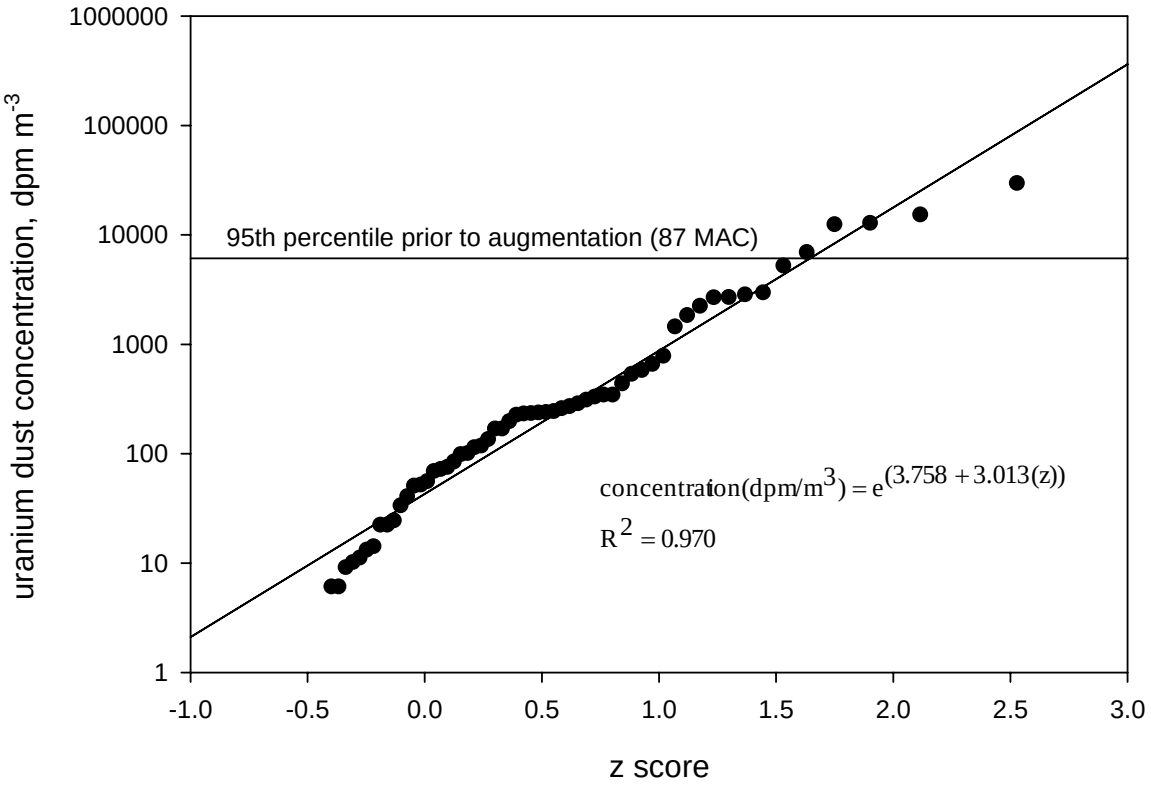
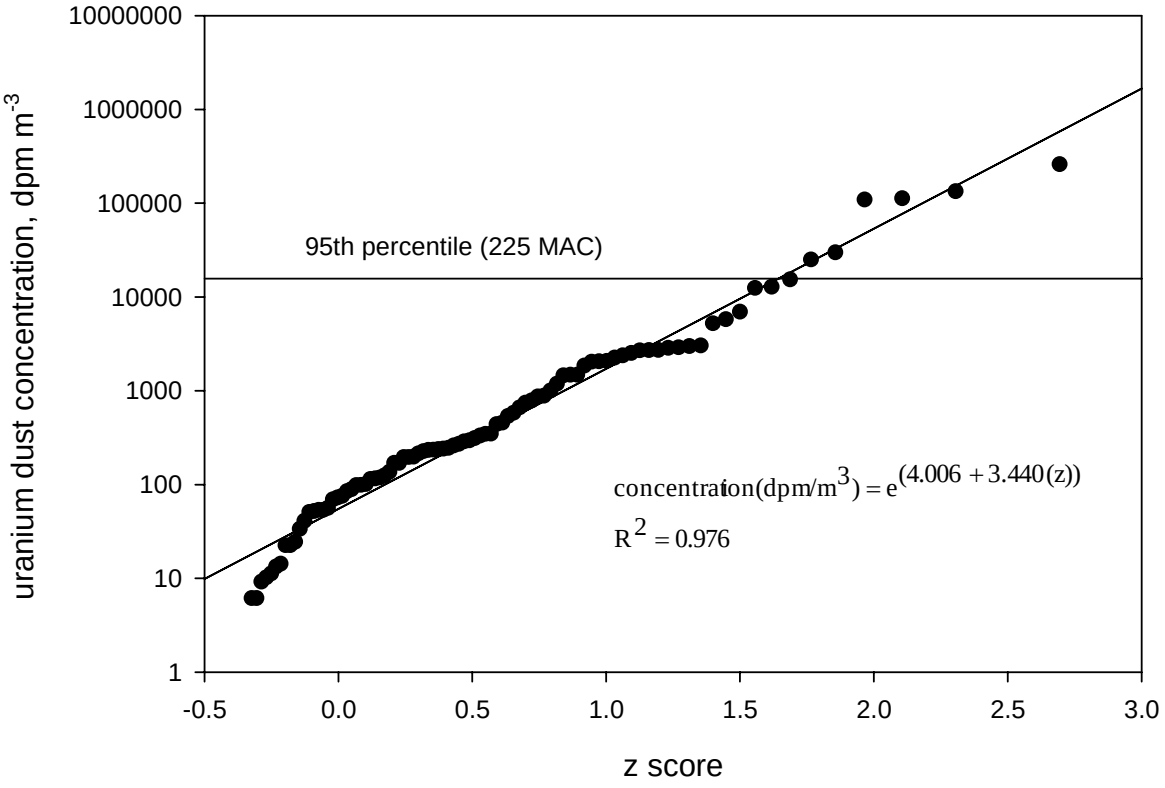


Figure 6: Graph of the distribution and fit of uranium dust concentration data taken at Bethlehem Steel from January 1951 thru September 1951 augmented to include BZ-GA samples (MAC=70 dpm m^{-3}). 225 MAC (1575 dpm m^{-3}) is the air concentration level to be used for the assessment of rolling day intakes for this period.



3.3.4 Determination of Inhalation Exposure for the late 1951 thru 1952 time period

The majority of uranium airborne contamination in the early period at Bethlehem Steel was caused by the actual rolling of uranium metal. However, after the salt bath furnace was utilized, airborne contamination from the rolling operations were greatly decreased. The median value of all the air samples collected in this period are slightly less than 0.2 MAC which raises the concern regarding previously minor sources of airborne contamination. These other sources would have to be distant from the rolling operations otherwise airborne contamination would be measured, at least partially, on the air samples taken near the rolling operations.

Grinding of the uranium billets to remove surface imperfections was a documented operation at Bethlehem Steel for some of the rollings. A single process air sample was obtained for this operation. The air sample (70 MAC) was actually the highest recorded at Bethlehem Steel during the later time frame. This value was used to estimate the air concentrations for the later period at Bethlehem Steel.

As with previous periods, it is assumed that the operators inhaled this concentration continuously for a 10 hour work day on which uranium rolling occurred. Based on measurements conducted at the Joslyn Steel plant taken while grinding on uranium metal (both breathing zone and general air samples), air concentration ranged from 0.4 MAC to 17 MAC. Harris indicated that portable grinding operations result in an average daily concentration of 5.7 MAC. This indicates the 70 MAC concentration determined from a process sample provides an upper bound to the operation.

While there may have been other sources of airborne contamination, however, it is likely that this estimate is a bounding estimate except for an exposure category of workers (cobble cutters) discussed below. For other sources to be bounding, they would have to produce greater than 700 MAC-hours of exposure per day (70 MAC times 10 hours per day). This would require amy other operation to not only create higher air concentrations, but to do so routinely. The most likely routine source of elevated airborne activity that has been postulated at Bethlehem Steel is the cutting of cobbles (Transcript November 28, 2005).

3.3.5 Determination of intakes to cobble cutters (1949 thru 1952)

Cobbles are essentially bent rods that occur when a bar of metal misfeeds from one stand into the next. Based on BSC worker input, cobbles would have been removed from the mill in the most expeditious manner possible, utilizing an overhead crane whenever possible. This is confirmed in the documentation NIOSH reviewed on cobbles, which indicates that there is a fairly short time span between a cobble and the next sample passing through the stand. This was a result of workers cutting the cobbles at the stands only if it were necessary for their removal from the mill. The cobbles were then taken elsewhere for any additional cutting to return it to scrap (Transcripts for worker testimony 7-19-2006). Records from other rolling mills show that the AEC had an active scrap processing program to reprocess the uranium. Potential methods of cutting cobbles included torch cutting, power saw, and shears. Worker accounts from several meetings indicate that torch cutting was the method employed. NIOSH has previously expressed reservations that, while this practice might have been used to cut steel cobbles, it would not necessarily be the best method to cut uranium. This is due to the pyrophorric nature of uranium which would have a tendency to ignite while being cut with a torch. The worker's recollections, however, will be accepted at face value and torch cutting of uranium will be assumed in NIOSH's approach to estimating exposure to cobble cutters.

Test and production records (summarized in Table 2) indicate that during initial testing, a higher percentage of cobbles occurred. This higher rate of cobbling is offset by the lower number of rods rolled. An evaluation of these records (Table 3) indicates the number of cobbles per day was relatively constant. During the production phase, when only salt bath preheating was done and during which time the estimate of exposure is the lowest, there were an average 3.6 cobbles per day. In a worker outreach meeting held June 19, 2006, several workers provided expert input regarding cobbles. The time required to cut cobbles varied between 5 minutes and an hour and cut in a similar time compared to steel. Information from worker accounts (Transcript November 28, 2005) also indicated that some cobbles are cut loose at the rollers and others are drug out of the mill using a crane and cut up elsewhere. It is likely the more extensively twisted cobbles would be the ones that are cut (at least initially) at the rollers and the remainder of the cutting to reduce the cobble to scrap would occur on the floor. Worker discussions further indicate that, while several individuals may have cut the cobbles at the rollers to most efficiently remove it with the assistance of the crane, a single worker would have completed the process on the floor. Analysis of the time per rod rolled during air monitoring shows that cobbling did not grossly impact the production rate, further indication of the efficiency of the removal process.

The exposure to the cobble worker will be evaluated based on an average of 2 hours per day engaging in torch cutting of cobbles. The time is based on an average reported during worker interviews and compared to published values for the cutting of stainless steel with acetylene torch which reported cutting time for stainless steel ranging from 2 to 4.2 minutes (3.6 minute mean) per cut of a 5 cm stainless steel pipe of 0.4 cm wall thickness (Newton 1987). Air concentrations are based on expected sustainable levels of contamination of 600 MAC, which is higher than the largest air concentration documented at Bethlehem Steel and is higher than the air concentration used to evaluate exposures at Bethlehem Steel during the 1949 to 1950 time span. This air concentration is based on estimated bounding levels of sustainable airborne contamination concentrations over the course of this two hour period from torch cutting (SC&A 2005a and Transcript November 28, 2005). The value also corresponds well to the concentration observed during the cutting of stainless steel pipe with a torch (Newton 1987), although study design limits the conclusions that can be drawn from this comparison

A 0.5 µm AMAD particle size will be used based on estimates from the torch cutting of other materials (Newton 1987). While not reported directly in the study, AMAD observed for torch cutting was approximately 0.5 to 1 µm AMAD (personal communication M. Hoover). 0.5 µm AMAD has been chosen as the most claimant favorable for dose evaluation. The remaining 8 hours of exposure will be evaluated based using 70 MAC as the concentration which is bounding of non-rolling operations during all the various operational phases at the mill as discussed above. While it is likely that these workers did not perform rolling operations, their known occupation in the mill and possible involvement in other dust generating tasks warrants consideration at the standard occupational level. Ingestion will be evaluated using the standard methods described for all workers.

As described above, the cobble cutter model is intended to cover workers with sustained torch cutting exposures, and is not to be used for incidental or otherwise short-term work in this capacity. Discussions with BSC workers indicate that number of workers engaged in uranium cobble cutting is small (i.e. potentially limited to a few workers). In fact, one site expert indicated that he was the only person who cut uranium cobbles during the covered period. Because NIOSH follow-up on this assertion could not definitively establish that this may have been the case, dose reconstructors should evaluate each claim to determine if there was a potential that the worker could have been engaged in torch cutting of uranium. Likely job titles that should be considered include scrappers, scarfers, and laborers. The decision as to whether a worker cut cobbles should also consider any additional supporting information that may be available. This includes the computer assisted telephone interview (CATI) and additional claimant / worker interviews that may have been conducted. Dose reconstructors should exercise extreme care in making this judgment and, when the determination is ambiguous, the exposure scenario (i.e., general model or cobble cutter model) that provides the higher dose to the organ should be used in the dose reconstruction.

Table 2: Summary of Uranium Cobbles at Bethlehem Steel Corporation

Date	Type or designation	Billets rolled	Bath type	Air Sample Data	Number of cobbles/rods rolled	Cobbling rate observed	Reference
April 26-27, 1951	Experimental #1	70 (many rolled in only 1 or 2 stands to work on process). 26 rolled for all stands for Hanford evaluation	Lead/salt	Y	2/26*	3.8%	Summary 1951, Reichard 1951 Sheets 6191, and 6192
July 29, 1951	Experimental #2	24	Lead/salt	Y			Summary 1951 Sample sheets 6425, 6436, 6437
August 27, 1951	Experimental #3	32	Lead/salt		1/10*	10%	Summary 1951 AEC 1951b
September 30, 1951	Experimental #4	43	Salt	Y	0/7*	0	Sample sheet 6539 HW 23910
October 28, 1951	Lackawanna #5	93	Salt	Y			AEC 1951a Sample sheets 6532, 6533
January 26-27, 1952	Production	25 plus 4 tons heat treated only	Salt	Y	3/25	12%	AEC 1952b AEC 1952c AEC 1952d, HW-23269 Sample sheets 6543, 6544, 6545
February 16, 1952	Production	120 30 tons	Salt		1/120	0.8%	HW 23697
March 15, 1952	Production	218	Salt	Y	3/204	1.5%	NLO 1952b Sample sheets 6573, 6574
April 12, 1952	Production	222	Salt		1/219	0.5%	NLO 1952a
August 17, 1952	Production	157	Salt		5/157	3.1%	Bowman 1952
August 31, 1952	Production	220	Salt		4/220	1.8%	Bowman 1952
September 14, 1952	Production	303	Salt	Y	-		Schneider Sample sheet IH33, IH34, IH35, IH36
September 22, 1952	Production	302	Salt		-		Schneider
October 19, 1952	Production	60 tons (~240 billets)	Salt		-		Hershman 1952

Table 3: Evaluation of Cobble rate at Bethlehem Steel Corporation

	Exposure rate (MAC*)	Average number rods rolled/day	Cobbling rate	Cobbles/rolling day
Experimental with lead/salt	225	42	8%	3.5
Experimental with salt only	70	68	5%	3.5
Production with salt only	70	200	1.8%	3.6

*MAC =Maximum air concentration=70 dpm for natural uranium

3.4 Evaluation of ingestion dose

Ingestion intakes can be most closely related to surface contamination values. Very few measurements exist for surface contamination. However, airborne contamination levels and surface contamination levels are generally related. To evaluate the relationship between air contamination and surface contamination, NIOSH reviewed the available air and surface contamination measurement at Simonds Saw and Steel and Bethlehem Steel. At Simonds Saw Steel these measurements were taken during a uranium rolling campaign on 10/27/48, while at Bethlehem Steel data were available for a rolling on 9/14/1952. The Bethlehem Steel surface contamination data were obtained by smears wiped over a 100 cm^2 area. As such, they represent only the removable portion of the contamination. The Simonds Saw surface contamination data were direct measurements that were made with a portable instrument called a Zeuto. This type of instrument has an active surface area that is 3 inches by 4 inches or approximately 75 cm^2.

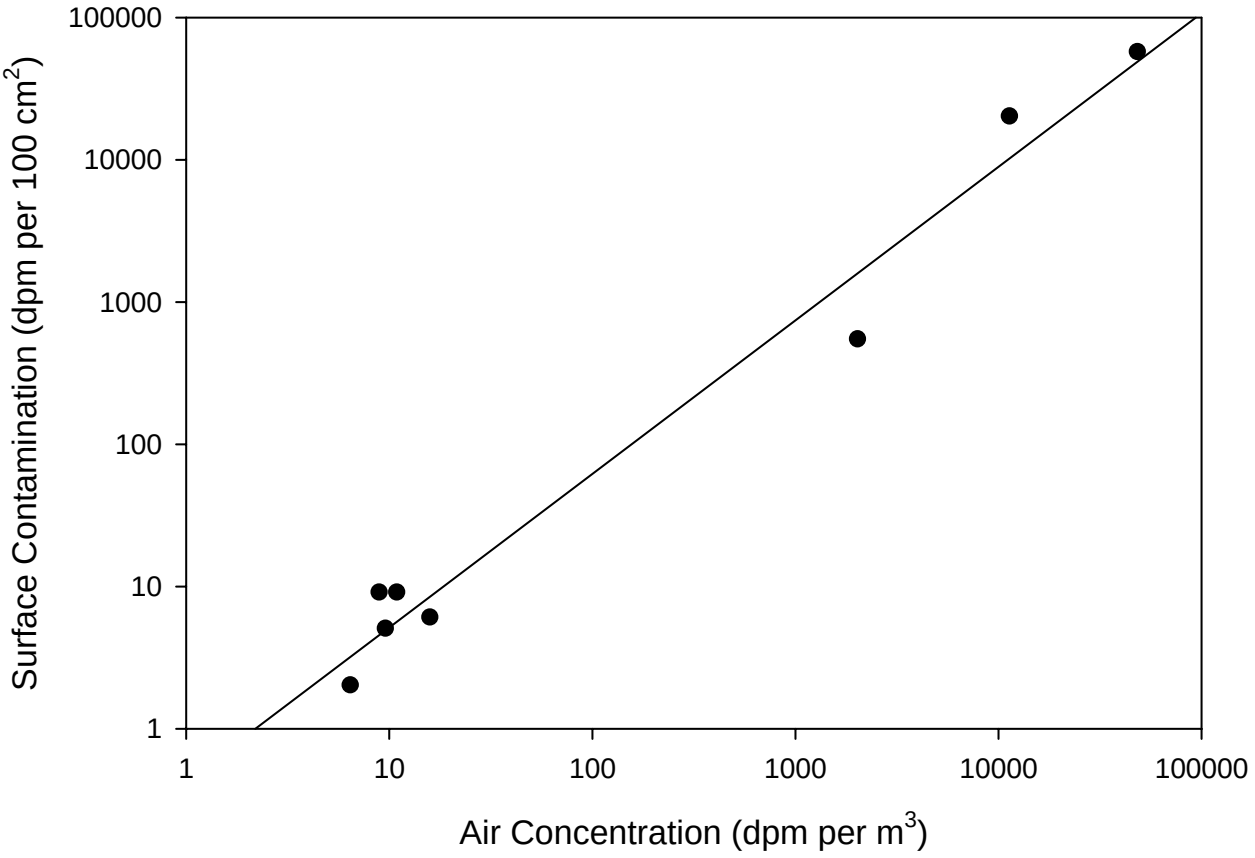
Each rolling stand at both Bethlehem Steel and Simonds Saw were evaluated along with the shear at Bethlehem Steel. Stand #6 at Bethlehem Steel was not evaluated because the surface smear indicated no detectable activity. Where more than one sample was taken, the results were averaged. Table 4 shows the average air and surface contamination measurements for these locations. The surface contamination measurements at Simonds Saw were normalized to 100 cm^2.

The values for each point are plotted in Figure 7. A clear trend can be seen in the graph, which indicates that the surface contamination is proportional to the air contamination. It is also worthy of note that this relationship is internally consistent at the two facilities. That is, high airborne activity is predictive of high surface contamination levels and vice versa. This means that if any large particle surface contamination that does not add to the air concentrations exists, the fraction of surface contamination represented by this is consistent across locations and sites and concentrations. Using this relationship, a model was developed that relates the ingestion rate to air concentrations.

Table 4: Air and Surface Contamination Values

Air sample #	Air concentration (dpm/m^3)	Surf. Contamination location	Surf. Contamination value (dpm/100 cm^2)
Simonds Saw Data			
L709	49000		
L710	75000	east roller 1	50000
L711	22400	west roller 1	35000
Average	48800	Average	42500
L718	14800		
L719	23800		
L720	27900		
L721	943		
L722	836		
L723	418	west roller 2	15000
average	11449.5	Average	15000
Bethlehem Steel Data			
Q921	2076		
Q922	2973	Shear	679
Q923	1080	Shear	404
Average	2043	Average	541.5
Q903	3		
Q905	10	Stand 1	2
Average	6.5	Average	2
Q906	10		
Q908	12	Stand 2	9
Average	11	Average	9
Q909	18		
Q911	14	Stand 3	6
Average	16	Average	6
Q912	13		
Q913	10		
Q920	6	Stand 4	5
Average	9.7	Average	5
Q914	12		
Q915	3		
Q919	12	Stand 5	9
Average	9	Average	9

Figure 7: Graph of observed air concentration and surface contamination levels at Simonds Saw and Bethlehem Steel.



The computer program RESRAD-BUILD contains a model for estimating ingestion intakes from surface contamination levels. The model contains a parameter for the ingestion rate that is expressed in units of m^2/hr, which expresses the amount of contamination ingested as a portion of the contamination contained in an effective area. This is intended to be a multiplier for removable surface contamination which can be used to arrive at an hourly ingestion rate. The default distribution used by RESRAD is a loguniform distribution between 2.8×10^{-5} and 2.9×10^{-4} m^2/hr with a mean of 1.1×10^{-4} m^2/hr. This distribution is provided in NUREG/CR-5512 volume 1, while the development of this parameter is discussed in volume 3 of the same NUREG.

Table 5 lists the average air concentrations and the average surface contamination levels (expressed in dpm/m^2) measured at Simonds Saw and Bethlehem Steel. It also lists the estimated hourly inhalation and ingestion rates inferred from these data. The hourly inhalation rate is based on the assumed 1.7 m^3/hr breathing rate. The hourly ingestion rate is based on the upper bound of the distribution provided in NUREG/CR-5512 of 2.9×10^{-4} m^2/hr. The table also included the calculated

ingestion rate as a fraction of the inhalation rate. This is simply the calculated ingestion rate divided by the calculated inhalation rate.

Table 5: Calculated Inhalation and Ingestion Rates

Air Concentration (dpm/ m^3)	Surface Contamination (dpm/ m^2)	Hourly inhalation rate (dpm/hr)	Hourly ingestion rate (dpm/hr)	Fractional ingestion rate
48800	5666667	82960	1643.33	0.019809
11449.5	2000000	19464.15	580	0.029798
2043	54150	3473.1	15.70	0.004521
6.5	200	11.05	0.06	0.005249
11	900	18.7	0.26	0.013957
16	600	27.2	0.17	0.006397
9	900	15.3	0.26	0.017059
9.7	500	16.43	0.15	0.008824
			Average	0.013202

Ingestion intakes at Bethlehem Steel will use the highest of these fractional rates (0.0298). This rate will be multiplied by the applicable inhalation rate to obtain the ingestion rate. In this way, the ingestion rate will change as the estimated conditions at the facility change.

3.5 Evaluation inhalation and ingestion due residual contamination

Residual contamination of the facility following rolling operations would have been present in the form of uranium oxide dust on the floor and other horizontal surfaces. No surface or airborne contamination surveys could be found from Bethlehem Steel during days in which only steel was processed. However, it was noted that uranium rolling occurred primarily on weekends because the 10" continuous bar mill was being fully utilized for steel production during the week.

The principal product of the continuous rolling mill at Bethlehem Steel, measured in thousands of tons per year, was steel. On days in which Bethlehem Steel was not rolling uranium, steel was being produced. The production of steel generates large quantities of dust and debris. As steel is rolled, a coating of this dust is likely to settle on top of any uranium contamination. This would act as a protective layer making it less likely that the uranium would be resuspended. However, it is possible that as uranium contamination is resuspended in the air, it settles back to horizontal surfaces and essentially forms a mixture of uranium and steel. This would allow uranium to continue to be resuspended but only as part of a mixture. The resuspension of material requires some mode of force, such as ventilation, foot or vehicular traffic, etc. It is likely the same type of forces exist whether the mill was rolling steel or uranium. It is therefore, likely that the same mass of material is resuspended at anyone time. As the steel debris builds up, this resuspended material is composed of fractionally less uranium and more steel.

The dose from residual contamination was determined based on the above concepts which result in the resuspension of contamination. The uranium contamination was assumed to be diluted by additional rollings of steel in-between uranium rollings. For the purposes of this model, it has been assumed that an equal mass of steel is added to the uranium each day. This is a conservative estimate because the steel production was measured in thousands of tons per year while uranium

was rolled only on a limited basis (on the order a few hundred tons). The material available for resuspension one day after a uranium rolling would therefore be one part uranium and one part steel. On the following day, the material would be one part uranium and two parts steel and so on.

While rolling operations could result in high localized air concentrations, air concentrations from resuspension of residual contamination would be more consistent throughout the area. Therefore, the median general air concentrations are used as the starting point. This value is then assumed to decrease in the days following uranium rolling as described above. The average air concentration due to resuspension of residual contamination can be estimated by the following expression.

$$C_{Avg} = C_{Int.} * \frac{\int_{1}^{30} dt/t}{29} = C_{Int.} * \frac{\ln(t)_{1}^{30}}{29} = C_{Int.} * 0.117$$

Where:

$C_{Avg.}$ = the average air concentration through the 29 days following a rolling

$C_{Int.}$ = the median general air concentration on the day of rolling

t = the number of days following the day of rolling

The median general area air sample concentrations for the three time periods are listed in table 6.

Table 6: Median General Area Air Sample Concentrations

	Median general area air samples (MAC)
Simonds Saw Steel	4.13
Bethlehem Steel (early)	0.215
Bethlehem Steel (late)	0.081

The same method was used for ingestion, however, the initial concentration was replaced by the daily ingestion rate on rolling days.

3.6 Summary of internal dose guidance for Bethlehem Steel

The following tables summarize the data from the previous sections for the purpose of conducting internal dose estimates at Bethlehem Steel. The rolling data and residual contamination has been averaged over the applicable time frame to determine an intake rate per calendar day. These values should then be applied as a continuous chronic intake to determine dose. While the typical rolling schedule was one per month, several months do not follow this rule. However, for ease of calculation, residual periods were assumed to be 20 work days per rolling. Also, exposures shall be determined as full month time frames for any partial month worked to account for the slightly non-uniform rollings schedule (e.g. if a worker was employed for part of a month, use the entire month).

Table 7: Summary of exposure values during rolling days

Time Period	Air concentration on rolling days	Time (hours/day)	Breathing rate (m^3/hr)	Inhalation during rolling days (dpm/day)	Average inhalation rate on non-rolling (dpm/day)	Ingestion during rolling days (dpm)	Average ingestion rate on non-rolling work days (dpm/day)
All workers except cobble cutters (5 micron particle size)							
1/1/1949 – 12/31/1950	553 MAC	10	1.7	658,070	575	19,610	2,883
1/1/1951 – 9/30/1951	225 MAC	10	1.7	267,750	30	7,979	1,173
10/1/1951 – 12/31/1952	70 MAC	10	1.7	83,300	11.3	2,482	365
Cobble cutters performing other duties (5 micron particle size).							
1/1/1949 – 12/31/1950	70 MAC	8	1.7	66,640	575	19,610	2,883
1/1/1951 – 9/30/1951	70 MAC	8	1.7	66,640	30	7,979	1,173
10/1/1951 – 12/31/1952	70 MAC	8	1.7	66,640	11.3	2,482	365
Cobble cutters during cutting (0.5 micron particle size)							
1/1/1949 – 12/31/1950	600 MAC	2	1.7	142,800	-	-	-
1/1/1951 – 9/30/1951	600 MAC	2	1.7	142,800	-	-	-
10/1/1951 – 12/31/1952	600 MAC	2	1.7	142,800	-	-	-

Table 8: Summary of inhalation exposure values for the periods 1949-1952 at Bethlehem Steel (not including cobble cutters)

Time Period	Number of rollings	Total inhalation from rolling day exposure (dpm)	Total Inhalation from residual contamination (dpm)	Total Inhalation during period (dpm)	Total Inhalation rate (dpm/ calendar day)
1/1/1949 – 12/31/1950	24	15,793,680	275,844	16,069,524	22,043
1/1/1951 – 9/30/1951	10	2,677,500	5,400	2,682,900	9,864
10/1/1951 – 12/31/1952	18	1,499,400	3,378	1,502,778	3,288

Table 9: Summary of inhalation exposure values for the periods 1949-1952 at Bethlehem Steel for cobble cutters

Time Period	Number of rollings	Total inhalation from rolling day exposure (dpm)	Total Inhalation from residual contamination (dpm)	Total Inhalation during period (dpm)	Total Inhalation rate (dpm/ calendar day)	Particle size (µm AMAD)
1/1/1949 – 12/31/1950	24	1,599,360	275,844	1,875,204	2,572	5
		3,427,200	-	3,427,200	4,701	0.5
1/1/1951 – 9/30/1951	10	666,400	5400	671,800	2,470	5
		1,428,000	-	1,428,000	5,250	0.5
10/1/1951 – 12/31/1952	18	1,199,520	3378	1,202,898	2,632	5
		2,570,400	-	2,570,400	5,625	0.5

Table 10: Summary of ingestion exposure values for the periods 1949-1952 at Bethlehem Steel for all workers

Time Period	Number of rollings	Total ingestion during rollings (dpm)	Total ingestion during from residual contamination (dpm)	Total ingestion rate (dpm/ calendar day)
1/1/1949 – 12/31/1950	24	470,652	1,383,716	2,544
1/1/1951 – 9/30/1951	10	79,790	234,581	1,156
10/1/1951 – 12/31/1952	18	44,682	131,365	385

4.0 ESTIMATION OF EXTERNAL EXPOSURE

No external dosimetry data is available for Bethlehem Steel. However, dose rates from submersion in a cloud of dust, direct exposure to uranium metal, and exposure to workers from skin contamination and reuse of their clothing are estimated below using the rolling information, residual contamination, and exposure rate constants for uranium materials.

4.1 Evaluation of external dose from uranium dust

Air concentrations derived in this document were combined with rolling times, number of rollings and the Dose Conversion Factors for ^{238}U and the daughter radionuclides ^{234}Th and ^{234m}Pa from Federal Guidance Report No. 12 (EPA 1993) to determine the external dose due to submersion in a natural uranium dust cloud. Only the skin is reported in Table 10 because all other doses were less than 1 mrem. The maximum annual dose to the skin listed in Table 10 is applied to electron (E > 15 keV) annual dose in IREP using a constant distribution and assuming a chronic exposure.

Table 10: Annual external dose due to submersion in air contaminated with natural uranium dust.

Time Frame	Annual Skin Dose* (Rem)
1949	0.002
1950	0.002
1951	0.001
1952	0.000

* Dose values are rounded to nearest mrem

4.2 Evaluation of external dose from direct contact with uranium billets

External doses from exposure to a uranium source were evaluated using extended (semi-infinite plane) natural uranium source. Estimated surface dose rates of 230 mrad/hr at a depth of 7 mg/cm^2 and 2 mrad/hr at a depth of 1000 mg/cm^2 were obtained from a search of the literature (Coleman, Hudson, and Plato 1983; U.S. Army 1989). Conservative values for the time workers were located relative to the source were based on descriptions of processes and different job types (AEC 1948b). A triangular distribution for electron exposure from uranium was determined in the following manner:

- The minimum was estimated by assuming the worker was 1 meter from an extended uranium source for 1 hour (per 10-hour shift). The estimated dose rate for this scenario was 90 mrad/hr (US Army 1989).

- Survey data of the Simonds facility were used to estimate the mode. The highest value measured during those surveys was 15 mrad/hr (AEC 1949b). To be claimant-favorable, this dose rate was assumed for an entire 10-hour shift.

- A maximum value was estimated by assuming the worker was 0.3 meter (1 foot) from an extended uranium source for 6 hours (150 mrad/hr) and 1 meter away for 4 hours (90 mrad/hr).

Table 11 summarizes annual values for estimated external shallow dose due to electron exposure from uranium. The target organs for this type of exposure are the skin, male genitals, and breast. In the case of cancer of the male genitals or female breast cancer, additional evaluation might be needed to consider shielding and attenuation provided by clothing.

Table 11: Estimated external shallow dose due to electron exposure from natural uranium source.

Time Frame	Annual Organ Dose (Rem)		
	Min.	Mode	Max.
1949	1.08	1.80	15.12
1950	1.08	1.80	15.12
1951	1.17	1.95	16.38
1952	1.35	2.25	18.90

The values in Table 11 are entered in IREP as the annual dose due to electrons (E > 15 keV) using a triangular distribution and assuming a chronic exposure for cases where the target organ is the skin, male genitals, or breast.

The deep dose rate due to photon exposure (dose rate at 1,000 mg/cm^2) from natural uranium was estimated to be 2 mrad/hr (U.S. Army 1989). The estimated 2-mrad/hr deep dose rate from the uranium source is evenly divided between photons with energies E = 30-250 keV and E > 250 keV. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for 30-250 keV photons (NIOSH 2002) were used to calculate the doses listed in Table 12. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for E > 250 keV photons were used to calculate the doses in Table 13. The values in Table 12 and Table 13 are entered into IREP as organ doses due to the appropriate energy photons, using a triangular distribution and assuming a chronic exposure.

Table12: Annual organ doses due to photons (30-250 keV) from natural uranium source for best estimate.

Organ	Annual organ dose (rem)											
	1949			1950			1951			1952		
	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
Bladder	0.004	0.113	0.121	0.004	0.113	0.121	0.005	0.122	0.131	0.005	0.122	0.131
Red bone marrow	0.008	0.057	0.101	0.008	0.057	0.101	0.008	0.062	0.109	0.008	0.062	0.109
Bone surface	0.046	0.110	0.182	0.046	0.110	0.182	0.050	0.119	0.197	0.050	0.119	0.197
Breast	0.005	0.152	0.179	0.005	0.152	0.179	0.006	0.165	0.193	0.006	0.165	0.193
Colon	0.007	0.096	0.103	0.007	0.096	0.103	0.007	0.104	0.112	0.007	0.104	0.112
Esophagus	0.003	0.063	0.087	0.003	0.063	0.087	0.004	0.068	0.095	0.004	0.068	0.095
Eye	0.000	0.113	0.131	0.000	0.113	0.131	0.000	0.123	0.141	0.000	0.123	0.141
Ovaries	0.004	0.087	0.095	0.004	0.087	0.095	0.004	0.094	0.103	0.004	0.094	0.103
Testes	0.004	0.131	0.136	0.004	0.131	0.136	0.005	0.142	0.148	0.005	0.142	0.148
Liver	0.012	0.097	0.102	0.012	0.097	0.102	0.013	0.105	0.111	0.013	0.105	0.111
Lung	0.015	0.090	0.103	0.015	0.090	0.103	0.017	0.097	0.112	0.017	0.097	0.112
Remainder organs	0.011	0.080	0.087	0.011	0.080	0.087	0.012	0.087	0.094	0.012	0.087	0.094
Skin	0.054	0.081	0.089	0.054	0.081	0.089	0.058	0.088	0.097	0.058	0.088	0.097
Stomach	0.005	0.114	0.121	0.005	0.114	0.121	0.006	0.124	0.132	0.006	0.124	0.132
Thymus	0.001	0.128	0.136	0.001	0.128	0.136	0.001	0.138	0.147	0.001	0.138	0.147
Thyroid	0.001	0.131	0.136	0.001	0.131	0.136	0.001	0.142	0.148	0.001	0.142	0.148
Uterus	0.005	0.092	0.100	0.005	0.092	0.100	0.006	0.099	0.108	0.006	0.099	0.108

Table 13: Annual organ doses due to photons (>250 keV) from natural uranium source for best estimate.

Organ	Annual organ dose (rem)											
	1949			1950			1951			1952		
	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
Bladder	0.055	0.109	0.114	0.055	0.109	0.114	0.059	0.118	0.123	0.059	0.118	0.123
Red bone marrow	0.060	0.090	0.110	0.060	0.090	0.110	0.065	0.097	0.119	0.065	0.097	0.119
Bone surface	0.068	0.095	0.107	0.068	0.095	0.107	0.073	0.103	0.116	0.073	0.103	0.116
Breast	0.066	0.112	0.135	0.066	0.112	0.135	0.072	0.121	0.147	0.072	0.121	0.147
Colon	0.054	0.105	0.107	0.054	0.105	0.107	0.058	0.113	0.116	0.058	0.113	0.116
Esophagus	0.054	0.092	0.105	0.054	0.092	0.105	0.059	0.100	0.114	0.059	0.100	0.114
Eye	0.025	0.109	0.117	0.025	0.109	0.117	0.027	0.118	0.127	0.027	0.118	0.127
Ovaries	0.052	0.102	0.115	0.052	0.102	0.115	0.056	0.110	0.125	0.056	0.110	0.125
Testes	0.058	0.117	0.127	0.058	0.117	0.127	0.063	0.127	0.137	0.063	0.127	0.137
Liver	0.059	0.106	0.108	0.059	0.106	0.108	0.063	0.115	0.117	0.063	0.115	0.117
Lung	0.064	0.104	0.110	0.064	0.104	0.110	0.069	0.113	0.119	0.069	0.113	0.119
Remainder organs	0.058	0.098	0.103	0.058	0.098	0.103	0.063	0.106	0.112	0.063	0.106	0.112
Skin	0.075	0.104	0.108	0.075	0.104	0.108	0.081	0.112	0.117	0.081	0.112	0.117
Stomach	0.058	0.110	0.115	0.058	0.110	0.115	0.063	0.119	0.125	0.063	0.119	0.125
Thymus	0.044	0.111	0.126	0.044	0.111	0.126	0.047	0.120	0.137	0.047	0.120	0.137
Thyroid	0.049	0.120	0.131	0.049	0.120	0.131	0.053	0.131	0.142	0.053	0.131	0.142
Uterus	0.051	0.097	0.098	0.051	0.097	0.098	0.055	0.105	0.106	0.055	0.105	0.106

4.3 Evaluation of external dose from residual contamination

The purpose of this section is to provide guidance for the evaluation of external dose from residual contamination and also dose associated with and the reuse of personal clothing between rollings.

An estimate of surface contamination was calculated by using the terminal settling velocity of 0.00075 m s^{-1} (TIB-0004, rev 2) multiplied by the rolling day concentrations and by the amount of time uranium was rolled in one year. The Simonds Saw and Steel concentration data was used for all years to simplify the calculations as it overestimates the later rolling data. This results in contamination of 12,500,000 dpm m^{-2} (1,250,000 dpm 100 cm^{-2}) which exceeds all the measured surface contamination levels. This value was then assumed to be constant thru all years of rolling. The residual contamination value was converted to dose using the dose coefficients for contaminated ground surfaces for U-238 and progeny Pa-234m and Th-234 from Federal Guidance Report No. 12 (US EPA 1993). The doses from contaminated sources are in the following table. Doses were only listed for Skin, Bone Surfaces, and all other organs. The all other organ category is the highest other organ rounded up to the nearest mrem. The doses in Table 14 shall be entered into IREP assuming a photon energy range of 50% 30-250 keV and 50% >250 keV.

Table 14: Annual dose from contaminated surfaces at Bethlehem Steel, 1949 to 1952.

	Skin (rem)	Bone Surfaces (rem)	All other organs (rem)
All years	1.771	0.010	0.005

The use of contaminated clothing following the rolling of uranium as discussed in worker interviews has been given careful consideration. Average dose data from contaminated clothing at Mallinckrodt indicate levels of 1.5 mrem/hour (AEC 1958). Bethlehem Steel doses were estimated using this as a bounding condition based on the types of materials handled and quantity of materials handled at Mallinckrodt. The dose rate was determined assuming the clothing was worn for two work weeks prior to cleaning. Therefore, the annual dose to the skin is determined by assuming 1.5 mrem/hour times 50 hours per week times 2 weeks per month times 12 months per year. This results in an annual dose to the skin of 1.8 rem per year which will be assigned a constant dose rate from electrons with an energy > 15 keV.

5.0 OCCUPATIONAL MEDICAL DOSE

This TBD assumes that all workers received an annual occupationally related diagnostic chest X-ray (Simonds 1948). The exposure geometry was assumed to be posterior-anterior (PA) (NIOSH 2002). Annual X-ray data from OTIB-0006, “Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures” and associated instructions shall be used for the purposes of evaluating occupational medical dose at Bethlehem Steel.

6.0 OCCUPATIONAL ENVIRONMENTAL DOSE

Occupational environmental dose provides a mechanism to account for dose that has not been monitored or attributed to occupational exposure. The exposures of all employees of the Bethlehem Steel Corporation at the Lackawanna plant will be estimated based on the 95% air concentration at the rolling mill for a 10 hour day. This estimate precludes the use of environmental dose which would

be much lower than the exposures estimated. As such, no environmental dose shall be assigned to the workers at this facility.

7.0 REFERENCES

AEC 1948a: AEC (U.S. Atomic Energy Commission), *Simonds Saw and Steel Company, Occupational Exposure to Radioactive Dust: Visit of October 27, 1948*, New York Operations Office [p. 138, Simonds Saw and Steel Company.pdf].

AEC 1948b: AEC (U.S. Atomic Energy Commission), *Simonds Saw and Steel Company, Occupational Exposure to Radioactive Dust: Visit of October 27, 1948*, New York Operations Office [pp. 139-153, Simonds Saw and Steel Company.pdf].

AEC 1948c: AEC (U.S. Atomic Energy Commission). *Simonds Saw and Steel Co. Occupational Exposure to Radioactive Dust, Visit of December 1, 1948*.

AEC 1949a: AEC (U.S. Atomic Energy Commission), *Health Hazards in NYOO Facilities Producing and Processing Uranium: A Status Report- April 1, 1949*, New York Operations Office, Medical Division, April 18.

AEC 1949b: AEC (U.S. Atomic Energy Commission), *Simonds Saw and Steel Company, Summary Report of Three Surveys, (October 27, 1948-February 15, 1949)*, New York Operations Office, Medical Division [p9. 250-252, Simonds Saw and Steel Company.pdf].

AEC 1949c: AEC (U.S. Atomic Energy Commission). Determination of Uranium in Air Dust Samples by Alpha Counting. NYOO-94, December 7, 1949.

AEC 1949d: AEC (U.S. Atomic Energy Commission). Simonds Saw & Steel Co. Occupational Exposure to Radioactive Dust. Visits of May 2-20, 1949.

AEC 1949e: AEC (U.S. Atomic Energy Commission). Results of Dust Samples Collected at Rolling Mill Area, Simonds Saw & Steel Co., July 6, 1949.

AEC 1950a: AEC (U.S. Atomic Energy Commission). Simonds Saw and Steel Co. Occupational Exposure to Radioactive Dust January 6, 9, 10, 1950. February 1, 1950.

AEC 1950b: AEC (U.S. Atomic Energy Commission). Simonds Saw and Steel Co. –Visits of February 13, 14, 17 and 20, 1950. April 16, 1950.

AEC 1951a: AEC (US Atomic Energy Commission). Monthly Report of Field Activities, May –June 1951.

AEC 1951b: AEC (US Atomic Energy Commission). Continuous mill uranium rolling: Lackawanna Plant-Bethlehem Steel Company April 26, 27, 1951 by H.F. Reichard. May 18, 1951.

AEC 1952a: AEC (U.S. Atomic Energy Commission), 1951-1952, “Air dust data from Bethlehem Steel Corporation’s Lackawanna Plant,” New York Operations Office, Medical Division, [pp. 4-11, Bethlehem Steel Site Profile.pdf].

AEC 1953a: AEC (U.S. Atomic Energy Commission), *Simonds Saw and Steel Company, Occupational Exposure to Uranium*, New York Operations Office, Health and Safety Division, February 18 [p. 54, Simonds Saw and Steel Company.pdf].

AEC 1953b: AEC (US Atomic Energy Commission). Investigation of Dust Sources and Their Effect at a Rolling Mill. March 16, 1953.

AEC 1958: Symposium on Occupational Health Experience and Practices in the Uranium Industry. October 15-17, 1958.

Bolch, W.E., Farfan, E.B., Huh, C., Huston, T.E, 2001,: Influences of parameter uncertainties within the ICRP 66 respiratory tract model: particle deposition," Health Physics, 81(4): 378-94.

Bowman 1952: Bowman, H. T., Merrill, P. E., Schneider, C. A., and Yocco, A. S., 1952, *Report on Trips to Bethlehem Steel Corporation, Lackawanna Plant, Buffalo, N.Y.*, Production Division of National Lead Company of Ohio, September 4 [p. 23, NY-Bethlehem Steel.pdf].

Breslin 1967: Breslin, A.J., Ong, L., Glauberman, H., George, A.C., LeClare, P. The Accuracy of Dust Exposure Estimates Obtained from Conventional Air Sampling. American Industrial Hygiene Association Journal. 1967.

Coleman, R. L., Hudson, C. G., and Plato, P. A., 1983, "Depth-dose curves for ^{90}Sr and natural and depleted uranium in mylar," *Health Physics*, 44(4): 395-402.

DOE 1982. DOE (US Department of Energy) Environmental Measurements Laboratory Procedures Manual. 1982.

DOE (U.S. Department of Energy), 1985, *FUSRAP Elimination Report for Bethlehem Steel Corporation, Lackawanna, New York* [p. 64, Bethlehem Steel.pdf].

DOE (U.S. Department of Energy), 2001a, *DOE Standard: Health Physics Manual of Good Practices for Uranium Facilities*, DOE-STD-1136-2000, Change Notice No. 3, December http://tis.eh.doe.gov/techstds/standard/std1136/STD11362000.pdf.

DOE (U.S. Department of Energy), 2001b, *Preliminary Review of the Flow and Characteristics of Recycled Uranium Throughout the DOE Complex 1952-1999*, Vol. 1, *Project Overview*, March http://tis.eh.doe.gov/legacy/reports/reports.html.

DOE 1997 http://www.hanford.gov/doe/history/docs/rl-97-1047/index.pdf

EPA (U.S. Environmental Protection Agency), 1993, *External Exposure to Radionuclides in Air, Water, and Soil*; Federal Guidance Report No. 12, Washington, D.C., September.

Frey, H. C., and A. C. Cullen, 1995, "Distribution Development for Probabilistic Exposure Assessment," Paper No. 95-94.02, *Proceedings of the 88th Annual Meeting of the Air & Waste Management Association*, San Antonio, Texas, June 18-23.

HW-19066: Hanford Works. Rough draft-Health Problems Associated with Investigation of Off-Plant Uranium Rolling. F.E. Adley May 13, 1949.

HW-22975: Hanford works . Experimental rolling of uranium: Lackawanna #3. HW-22975. Dec 13, 1951.

HW-22347: Hanford works. Trip Report: Visits to AEC New York Operations Office, Lackawanna Plant, Bethlehem Steel Company, Argonne National Laboratory August 24-29, 1951. HW-22347.

HW-23399: Hanford works. Trip Report: Development of a Uranium Rolling Process for Fernald. HW-23399. January 29, 1952.

HW-23910: Hanford works. HW 23910

HW-24849: Production Test 313-10506-M Irradiation of Alpha Canned Uranium Slugs from Rods Salt Bath Beta Heat-Treated at Lackawanna. HW-24849. June 27, 1952.

Hershman, H.J., 1952, "Transmittal of the Monthly Progress Report for October, Monthly progress report for October 1952 covering activities at the Tonawanda Sub Office," memorandum to R.J. Smith, October 21.

ICRP (International Commission on Radiological Protection), 1994, *Human Respiratory Tract Model for Radiological Protection*, Publication 66, Pergamon Press, Oxford, England, p. 198.

ICRP (International Commission on Radiological Protection), 1995, *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients*, Publication 71, Pergamon Press, Oxford, England, p. 299.

ICRP 1997. ICRP (International Commission on Radiological Protection) ICRP 75, General Principles for the Radiation Protection of Workers.

ICRP 2003. ICRP (International Commission on Radiological Protection). ICRP Supporting Guidance 3: Guide for the Practical Application of the ICRP Human Respiratory Tract Model. Pergamon Press, Oxford, England.

Kathren, R. L., V. E. Shockley, E. M. Thomas, and T. D. Taulbee, 2003, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, Revision 2, ORAUT-OTIB-0006, NIOSH Dose Reconstruction Project, Cincinnati, Ohio.

Kosanovich, P. (Compensation Agent, L.U. 2603), 1979, letter to Robert Anderson (Bethlehem Steel Corporation), October 19 [p. 36, Bethlehem Steel Site Profile.pdf].

Leary 1987. From Fire to Rust: Business, Technology and Work at the Lackawanna Steel Plant, 1899-1983. Leary, T.E., Sholes, E.C. Buffalo and Erie County Historical Society. 1987.

LaMastra, A., 1976, "Investigation Report: Uranium Metal Rolling, 10" Bar Mill, Lackawanna Plant," report to D. L. Webster, Bethlehem Steel Corporation, June 29. [p. 16, Bethlehem Steel.pdf].

Methner 2001. Methner, M.M., Feng, H.A., Utterback, D.F. Use of Historical Uranium Air Sampling Data to Estimate Worker Exposure Potential to Airborne Particulate in a Uranium Processing Facility. Applied Occupational and Environmental Hygiene. Vol 16 (12) 2001.

Newton 1987. Newton, G.J., Hoover, M.D., Barr, E.B., Wong, B.A., Ritter, P.D. Colletion and Characterization of Aerosols from Metal Cutting Techniques Typically Used in Decommissioning Nuclear Facilities. Am. Ind. Hyg. Assoc. J. 48 (11) 922-932 (1987).

NIOSH (National Institute for Occupational Safety and Health), 2002, *External Dose Reconstruction Implementation Guideline*, Revision 1, OCAS-IG-001, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NIOSH (National Institute for Occupational Safety and Health), 2004, *Estimation of Ingestion Intakes*, Revision 0, Technical Information Bulletin, OCAS-TIB-00?, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NLO (National Lead Company of Ohio), 1952a, *Production Report on the Rolling of Two Hundred and Twenty-two Uranium Billets at Bethlehem Steel Corporation's Lackawanna Plant on Saturday, April 12, 1952*, Contract No. AT(30-1)-1156, April 28 [p. 1, NY-Bethlehem Steel.pdf].

NLO (National Lead Company of Ohio), 1952b, Production Report on the Rolling of Two Hundred an Eighteen Uranium Billets at Bethlehem Steel Corporation's Lackawanna Plant on March 15, 1952, Contract No. AT(30-1)-1156, March 21 [p. 37, Bethlehem Steel Site Profile.pdf].

NLO (National Lead Company of Ohio), 1952c, *Air dust data from last rolling on September 14, 1952 at Bethlehem Steel Corporation's Lackawanna Plant*, Health and Safety Division, September 17 [pp. 12-15, Bethlehem Steel Site Profile.pdf].

ORNL (Oak Ridge National Laboratory), 1980, *Preliminary Survey of Bethlehem Steel, Lackawanna, New York*, March [p. 79, Bethlehem Steel.pdf].

Range, W., 1976, letter to David M. Anderson (Bethlehem Steel Corporation), Energy Research and Development Administration, June 7 [p. 71, Bethlehem Steel.pdf].

Schneider, C. A., and A. S. Yocce, no date, *Report on Rollings and Bethlehem Steel Corporation, Lackawanna Plant, Buffalo, New York*, Abstract, FMPC-79, [p. 35, Bethlehem Steel Site Profile.pdf].

Simonds (Simonds Saw & Steel Company), 1948, *Hazard Identification, Evaluation, and Mitigation*, [pp. 461-464, Simonds Saw and Steel Company.pdf].

Summary (Summary of Experimental Rollings Relating to Fernald Operations), 1951 [p. 20, Bethlehem Steel.pdf].

Thornton, W. T., 1977, "ERDA Resurvey Program – Bethlehem Steel, Lackawanna, NY," report to R. H. Kennedy, Energy Research and Development Administration, March 16 [p. 75, Bethlehem Steel.pdf].

U.S. Army, 1989, Handbook *of Safety Procedures for Processing Depleted Uranium*, Chapter 3, *Safety Considerations for Processing, Handling, and Testing of DU Components*, AMC HDBK 385-1.1-89, Department

Additional communications and reviews that were used as data sources or guidance documents for preparation of this report include:

Deposition 2004a. Deposition of Stanley Tomasik Jr. March 29, 2004.

Deposition 2004b. Deposition of Paul Kosanovich. April 5, 2004.

SC&A 2004. Review of the NIOSH Site Profile for the Bethlehem Steel Plant, Lackawanna, NY. SCA-TR-TASK1-001.

SC&A 2005. Letter report by SC&A regarding the Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, Lackawanna, New York; Period of Operation: 1949-1952, Rev. 02 Draft.

NIOSH 2004a. NIOSH comments on the SC&A Review of the Bethlehem Steel Site Profile December 6, 2004.

NIOSH 2005a. NIOSH comments on the SC&A Review of the Bethlehem Steel Site Profile Specific Responses to Findings, Observations and Procedural Non-Comformances. January 25, 2005

Transcript November 28, 2005. NIOSH and SC&A conference call regarding Bethlehem Steel TBD comment resolution.

Summary Notes June 19, 2006. Bethlehem Steel worker meeting.

Personal communication. Mark Hoover (NIOSH) and Sam Glover (NIOSH). July 26, 2006.