ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, Lackawanna, New York; Period of Operation: 1949-1952	Document Number: ORAUT-TKBS-0001 Effective Date: 06/29/2004 Revision No.: 02 Controlled Copy No.: _____ Page 1 of 37
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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.
Draft	12/17/2002	0-B	Changes in response to internal and NIOSH review comments.
Draft	12/17/2002	0-C	Changes in response to NIOSH review comments.
Draft	12/17/2002	0-D	Changes in response to NIOSH review comments.
Draft	12/17/2002	0-E	Changes in response to NIOSH review comments.
03/31/2003	03/31/2003	00	First approved issue.
Draft	02/19/2004	01-A	Revision to incorporate occupational X-ray doses from the OTIB-0006 and to incorporate estimates of ingestion intakes. Initiated by Jeri L. Anderson.
Draft	04/27/2004	01-B	Revision to incorporate additional OCAS comments. Initiated by Jeri L. Anderson.
06/29/2004	06/29/2004	01	Approved issue of Revision 01. Initiated by Jeri L. Anderson.
Draft	5-9-05	02-A	Revision to incorporate changes, including comments by the public and SC&A. 5-4-05
Draft	5-25-05	02-B	To incorporate comments by Jim Neton
Draft	5-27-05	02-D	To incorporate residual contamination and changes to contaminated clothing.

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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 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 and the U.S. Department of Energy. 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. Other non-DOE derived sources of exposure that are covered under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA), such as exposure from radiography operations, are addressed in a separate document.

This document is divided into the 6 sections. These are: 1) Introduction; (2) Site description and operational history; (3) Occupational Internal Dose; (4) Occupational External Dose; (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 steels mills that contributed to the production of uranium metal rods used by Hanford for the production of plutonium. During World War II, the principle means of producing uranium rods 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 fell under the auspices of 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 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. 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 fabrication program are important to have a conceptual understanding of their impact on exposure during the activities conducted by Bethlehem Steel at the Lackawanna Plant. These include:

Furnace heating: Uranium billets and rods were heated to the desired temperature in large furnaces. Bare uranium material was the most hazardous to roll because of the rapid surface oxidation and production of dust. In some cases bare uranium was preheated in the furnace and then further heat treatment conducted in the 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 up 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 for rolling. This salt also provided a protective covering which reduced the uranium oxide formation and airborne contamination levels during rolling.

Centerless grinding: The canning process required a precision ground uranium piece. AEC 1949f 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 water to prevent the uranium from burning and sparking which in turn significantly reduces the airborne hazard as evidenced by the air monitoring data.

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 to Hanford included both rods and slugs, hand grinding was considered as a potential source and data at Joslyn was evaluated to compare the source term with the assigned intake levels for the 1949-1950 and the 1951-1952 periods.

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. Bethlehem Steel acquired the Lackawanna facility in 1922. While Bethlehem Steel had widespread holdings in ship building and other interests, 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). Several programmatic goals associated with these rollings were (AEC 1952d):

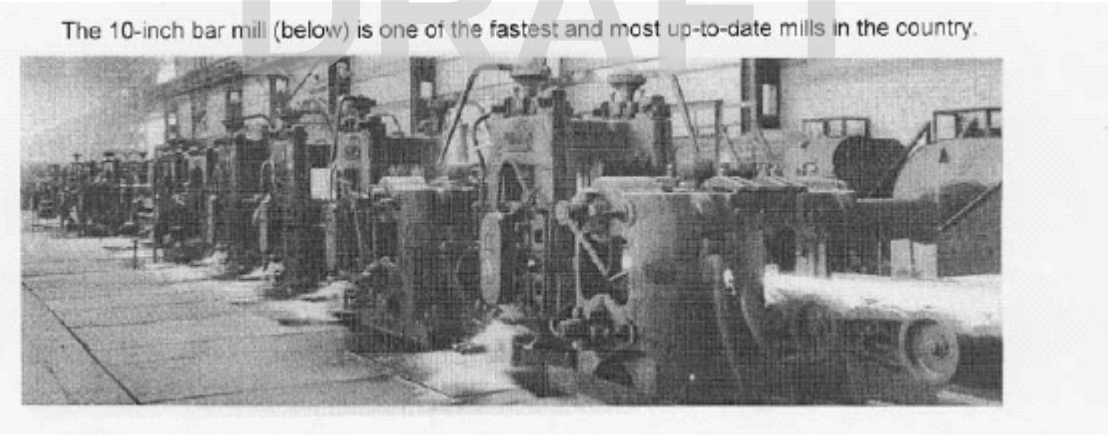
- To evaluate the continuous rolling mill as a source of uranium rods for the plutonium production program at Hanford and Savannah River;
- Information gained during these rollings would be used for the design of the Fernald plant;
- Evaluate technological improvements leading to reduced oxidation of 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;
- 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 bar straightening and grinding as part of this preparation;
- 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, indicate the metallurgical properties of the material and are not associated with radioactivity in this context.

Figure 1: 10-inch bar mill at Lackawanna (INSERT REFERENCE)



Because of material accountability procedures, scale, residue and cropped ends were collected and fine debris was vacuumed, packaged, and returned to the AEC (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).

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 claims that six to eight rollings took place in 1955 although no verification of these dates has been found (Kosanovich 1979). The work was supposedly transferred to the Fernald Plant around September 1952 (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. These 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). Documents also report 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 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 testimony to provide the basis for the estimates that follow (SC&A 2005, p 46). The application of complementary Simonds Saw and Steel data to supplement the Bethlehem Steel data was reviewed and found to be an acceptable approach (SC&A 2005).

While the operations involving the processing of uranium were limited to the 10” continuous rolling mill and associated handling facilities, 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.

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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 Sheets 6191, and 6192
July 29, 1951	Sunday	Experimental #2	24	Lead/salt	Y	Summary 1951 Sample sheets 6425, 6436, 6437
August 26, 1951	Sunday	Experimental #3	32	Lead/salt		Summary 1951 AEC 1951b HW22347
September 30, 1951	Sunday	Experimental #4	43	Lead/salt	Y	Sample sheet 6539 HW 23910
October 28, 1951	Sunday		93	Salt	Y	AEC 1951a Sample sheets 6532, 6533
January 26-27, 1952	Saturday, Sunday	Production	25	Salt	Y	AEC 1952b AEC 1952c Sample sheets 6543, 6544, 6545
Early 1952	Unknown	Heat treat, cut, straightened	37	Salt		AEC 1952d
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		
August 31, 1952	Sunday	Production	219	Salt		
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	157	Salt		Bowman 1952
October 31, 1952	Friday	Production	219	Salt		Bowman 1952

1951: Six rolling days, plus assume one January, February, March, May, June, November, December (13 rollings)
1952: 11 rolling days, plus assume one for May, June, July, November, December (16 rollings)

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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, Lackawanna, NY 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 samples and urinalysis 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 descaling device (AEC 1948b). Simonds Saw and Steel data from the October 1948 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 (AEC 1949f). 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 will be included in the site profile being prepared.

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.

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- 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 (AEC 1949f). 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 1951d): "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".

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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, 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*

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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 some 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.

The ICRP added the heavy worker classification to cover such workers as firemen, construction workers, and farmers. Heavy workers are assumed to perform 1/8 of their time in heavy exercise and 7/8 in light exercise, while light workers are assumed to spend one-third or their time sitting and two-thirds of their time involved with light exercise. Light exercise consists of performing duties at one-third of the highest work load and is comparable to working in the laboratory and workshops, active housecleaning, painting and woodworking and is assigned a breathing rate of 25 L/min. Heavy exercise is likened to working at 2/3rds of the maximum work rate not exceeding 2 hours (ICRP 66) and is assigned a breathing rate of 50 L/min. Heavy breathing also affects the breathing deposition patters as provided below. The EPA likens light exercise to an average person dancing, pushing a wheelbarrow with a 15 kg load, simple construction and stacking firewood (EPA 1985, p 36) while heavy exercise is characterized by cross-country skiing, rock climbing, stair climbing with a load, playing squash and handball, and chopping with an axe. The EPA further recognized that physical conditioning is also an important factor regarding ventilation and as such the workers would have been conditioned to their working environment. For these reasons, this estimate of breathing at the ICRP 66 heavy worker rate will be used for the determination of intake and dose for all workers at Bethlehem Steel.

3.2.2 Exposure Time

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 nearly impossible 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 weekends. Reports from 1951 and 1952 indicate that, with the exception of the April 1951 (Summary 1951), February 1952 (AEC 1952d), August 1952 (Bowman et al. 1952), September 1952 (Schneider and Yocce undated) and October 1952 rollings, rollings 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 eight documented rollings, it was assumed that one rolling each took place in May, and June, July, November and December resulting in sixteen 10-hour workdays.

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 to the 95th percentile of the area air concentration distribution 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, both will be considered for each case and the most favorable for the case at hand will be used.

3.2.5 Oral Breathing

The ICRP discusses two distinctive breathing patterns, nasal augmenters and predominantly oral breathers. EPA (1985) also discusses the importance of nasal and oronasal breathing in ventilation and found that approximately 15% of the population are habitual oronasal or “mouth” breathers. Most individuals switch from nasal to oronasal breathing patterns after reaching ventilation rates greater than 30 to 35 L/min (known as normal augmenter). The primary affect of breathing type is to affect the deposition characteristics of the ICRP 66 lung model as the ventilation rate is a function of exercise level.

ICRP 66 models the mode of breathing to allow for the change from 100% nasal breathing to a mixture oral and nasal breathing at elevated ventilation rates (>2 m^3 h^{-1}). The ICRP also states in the

application of these models that the patterns associated with normal augmenters be defined as the typical adult male ventilation pattern. This recommendation was based on Miller et. al.(ICRP 2003) who concluded that it is unrealistic to consider the case of a pure mouth breather. Miller's recommendation appears to be based largely on the idea that the affect of the breathing habit is overshadowed by the other uncertainties associated with any lung model. It is important to note that the heavy worker composite includes periods of time (heavy exercise) where the worker's ventilation rate is 3 m^3 h^{-1}. A substantial portion (50%) of the air is breathed thru the mouth during heavy exercise using the ICRP model.

Breathing habit affects the deposition profile in the lung. Bolch et. al. (2001) evaluated the uncertainty in deposition profile taking into account numerous variables, including breathing habit. The uncertainty of the deposition fraction (geometric standard deviation) in various regions of the lung was calculated for various sizes of mono-disperse particulate. ICRP 66, however, assumes that workers inhale a distribution of particle sizes, making a direct comparison is difficult. However, Table 7 of the Bolch publication indicates that the geometric standard deviation (GSD) is less than 1.5 for most particles deposited in the deep lung. Although higher GSDs are noted for very large and very small particles, the fraction of these deposited in the deep lung is small. Because of this, it is assumed that the uncertainty in the deposition of respirable, polysized particles is lognormally distributed with a GSD of 1.5.

Combining this uncertainty (GSD=1.5) with the uncertainty in the Simonds Saw air concentration data (GSD= 8.37) yields a GSD of 8.69. Almost all of the combined uncertainty is due to the air concentration GSD of 8.37. The 95th percentile of the Simonds air concentration distribution results in an airborne concentration of 553 times the maximum allowable concentration (MAC), while the combined distribution increases the 95th percentile by 6.5% to 589 MAC.

In order to determine intake from airborne concentrations, it is necessary to estimate an individual's exposure time. For BSC exposure estimates, it is assumed that each individual worked 10 hours per day and was exposed 100% of that time to the 95th percentile of the facility air concentration. The original HASL reports that provided the air sample results at Simonds Saw and Steel contained time motion studies, which indicated no one worked 100% of the time in the highest airborne areas. If it is assumed that only 39 minutes of a 10 hour day were spent elsewhere (6.5% of 10 hours), the exposure from the 95th percentile of the combined distribution is equal to that estimated using the 95th percentile of the facility distribution for 10 hours per day.

The above analysis indicates that uncertainty in breathing habits is negligible compared to the uncertainties associated with the evaluation of air concentration, exposure time, and work location. The claimant favorable assumptions made for work location (95th percentile of the air concentration distribution), and exposure time (100%) appear to provide a sufficiently favorable estimate that would compensate for slight differences in intake due to biological variability. This is consistent with the conclusion of Miller that was adopted in ICRP publication 66.

3.2.6 Evaluation of the internal dosimetry parameters on intake and dose

Evaluation of modeled intake

To evaluate the reasonableness of the model used to estimate intake in this TBD, NIOSH has compared measured urinary excretion values for Simonds Saw and Steel workers to those predicted using the default values in this TBD (i.e., continuous 10 hour per day 1.7 m^3/hr inhalation of 553 MAC air of 5 um particle size). The urine samples, which were collected from most of the individuals performing the uranium rolling activity on 10/27/1948, were collected at various intervals for several

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days following the rolling The predicted values, along with distribution of measured urine data for each day, is provided in Figure 2.

Figure 2: Box and whisker plot showing the 95% confidence limits, mean, inter-quartile range, and outliers for bioassay data conducted at Simonds Saw and Steel following the October 27, 1948 rolling compared to expected urinalysis results from a 10 hour, 553.5 MAC exposure using Type M and S materials for a heavy worker model.

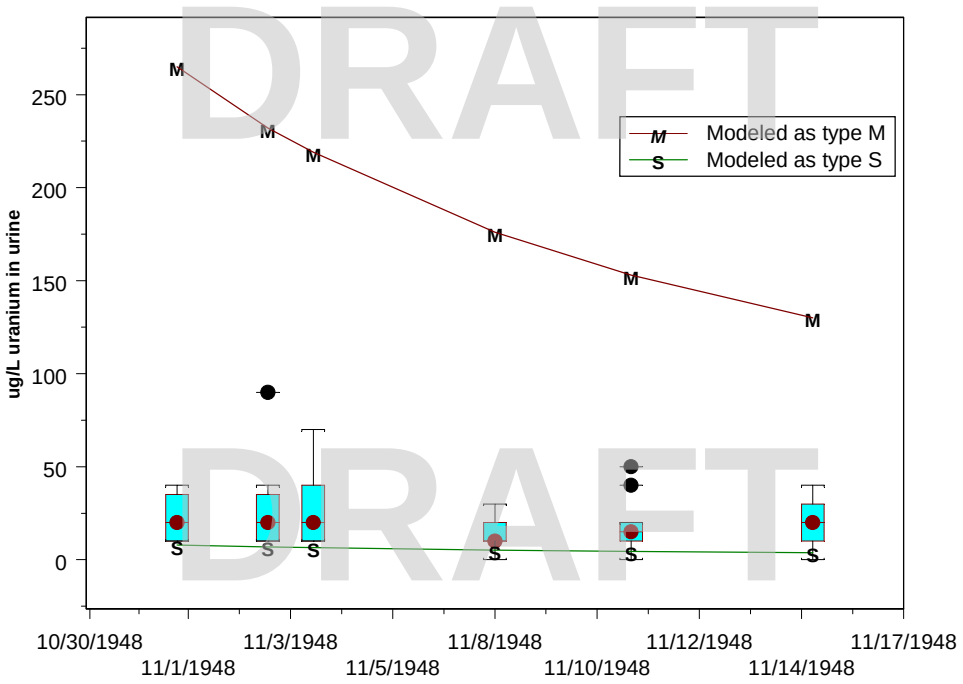

Figure 2 indicates that the parameters used in the TBD over predict the actual urine results measured at Simonds after the 10/27/1948 rolling for a type M uranium compound. As a claimant favorable assumption, exposures to type M compounds of uranium are used in the TBD to calculate dose for all systemic organs. Because the TBD overestimates the amount of systemic uranium to such a large degree, it could be argued that it is not necessary account for other routes of uptake by the bloodstream such as ingestion or wounds. It is also apparent that the assumptions in this estimate account for variations in other parameters, such as breathing rate, breathing mode, exposure time, and airborne activity concentration.

Even though the estimated excretion rate for type S material is below the observed urinalysis data, the air concentration data are believed to provide an upper bound to the intake of insoluble (type S) materials. In the TBD, type S intakes are used to estimate doses for cancers associated with the respiratory tract. Type S material under predicts the urine results because very little material is absorbed into the blood stream and excreted in the urine. The major removal mechanism for type S material is through the physical clearance mechanisms of the lungs. This mechanism ultimately results in the material being cleared through mucociliary action and swallowed, thus resembling ingestion. Also, being very insoluble, very little of the material is taken up by the gastrointestinal tract and so the material is eliminated from the body rapidly (within days of being swallowed). This causes the dose to systemic organs to be much smaller for this type of material inhalation.

An inhalation of type S material would however, produce more dose in the respiratory tract than an inhalation of type M material. However, as noted previously, no material is likely to behave exactly as one of the two default type considered here. More likely the material will exhibit an absorption rate somewhere in-between the type M and type S material defaults. U_3O_8 is one of the likely uranium oxides present in a steel mill and solubility studies indicate that this material exhibits a lung removal half time of approximately 120 days. In comparing to the ICRP 66 default lung absorption types, it can be seen that type M demonstrates approximately a 140 day lung removal half-time and type S a 1400 day lung removal half-time.

Evaluation of the urinalysis data with respect to a type M inhalation predicted from the highest urine samples provides an intake estimate of approximately 225,000 dpm or exposure to approximately 190 MAC air for 10 continuous hours. This is the value calculated by HASL for the time-weighted average of the highest exposed individual on 10/27/1948. This agreement indicates a type M absorption rate is the most realistic absorption rate for the inhaled material. This analysis notwithstanding, the TBD will assign the most favorable solubility type for each dose reconstruction.

<u>Evaluation of the 95th percentile</u>

Concerns about workers performing jobs for which no data was obtained has also been reviewed. One such task was the grinding of uranium. Air sample data from grinding operations at the BSC Lackawanna facility consists of a single process sample with a measured value of 4900 dpm/m^3. Process samples were not intended by HASL to be used for the purpose of exposure assessment but rather for the determination of source terms (see previous discussion on the HASL air monitoring program). Additional research at Joslyn Steel revealed additional measurements of hand grinding of uranium rods with an average breathing zone concentration of 393 dpm m^{-3} (N=3) while centerless grinding had an average air concentration of 25 dpm m^{-3} (N=16). Therefore, the application of the 95% value of all data at Lackawanna is considered bounding for this operation.

Finally, the data by location at Simonds Saw and Steel and the Lackawanna plant was evaluated in Figures 3, 4, and 5 against the assigned air concentration. Figure 3 shows Simonds Saw and Steel location specific distributions for all air samples. The worst case location at Simonds was also evaluated in Figure 4 as the front and opposite side of stands 1 and 2 on October 27, 1948, for which twelve breathing zone samples were collected. While it is evident that two of the three instantaneous concentration measurements for the front of stand 1 exceed the 95% assigned value, it is also to be understood that these are one minute samples taken during the worst part of the operation and these conditions are estimates of the worst case rather than average breathing zone values. Figures 5 and 6 substantiate the evaluation of the 1951-1952 estimate of intake by comparing the data from the different locations to the 95% facility concentration value. It is obvious that the geometric mean for all locations is significantly below the assigned level.

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Figure 3: Box and whisker plot showing the 95% confidence limits, geometric mean, and interquartile range for short term air concentration data (both breathing zone and general area samples) by area at Simonds Saw and Steel on 27, 1948.

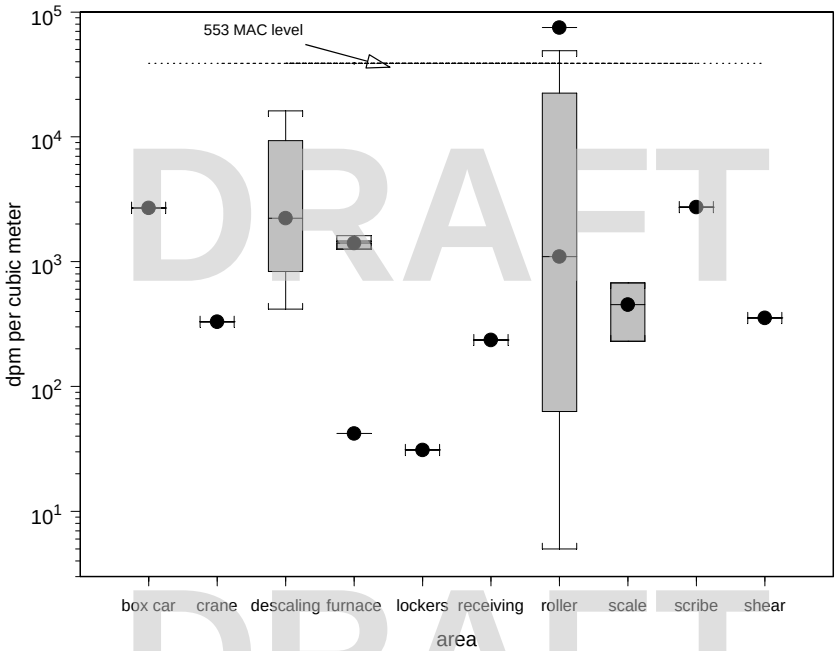

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Figure 4: Results of twelve short term breathing zone samples at Simonds Saw and Steel, October 27, 1948, at stands 1 and 2, front and opposite sampling locations and comparison to the 95% assigned exposure level of 553 MAC (MAC=70 dpm)

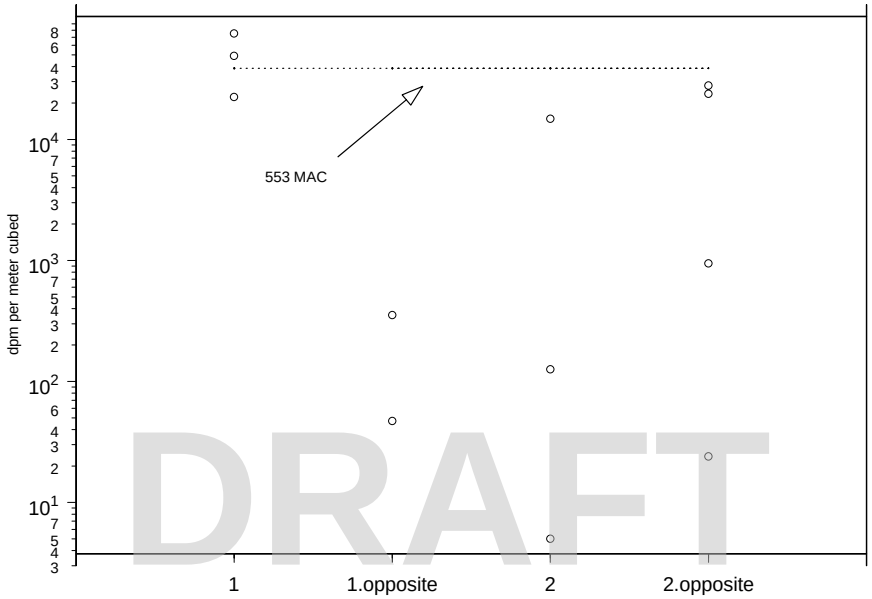

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Figure 5: : Box and whisker plot showing the 95% confidence limits, geometric mean, and interquartile range for short term air concentration data (including breathing zone, general area and process samples) by area for all samples collected at Bethlehem Steel in Lackawanna and compared to the 95% assigned exposure level of 20.8 MAC (MAC=70 dpm).

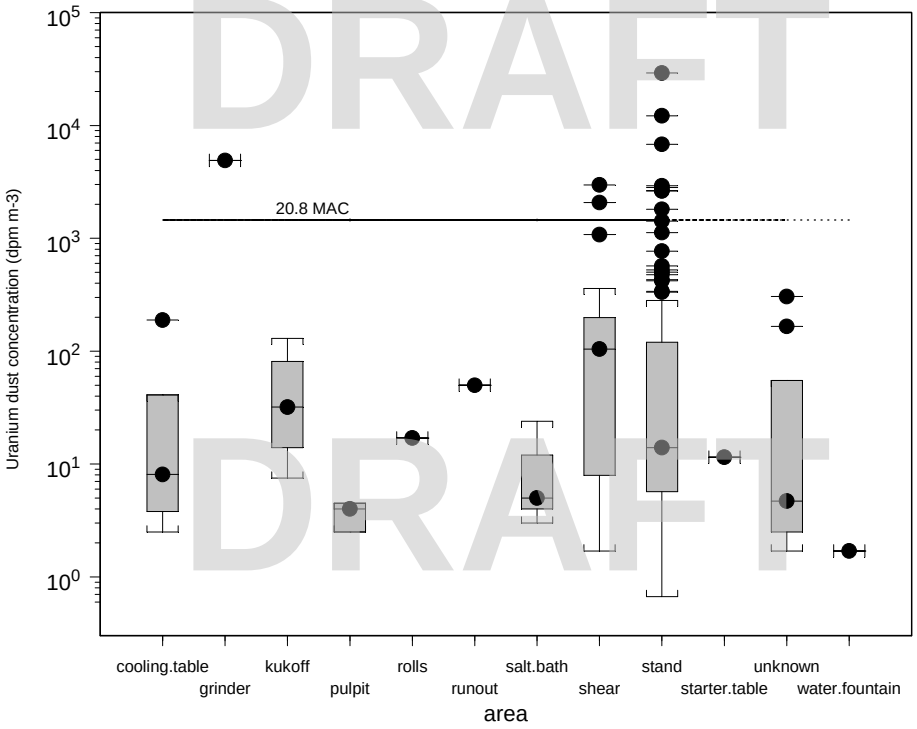

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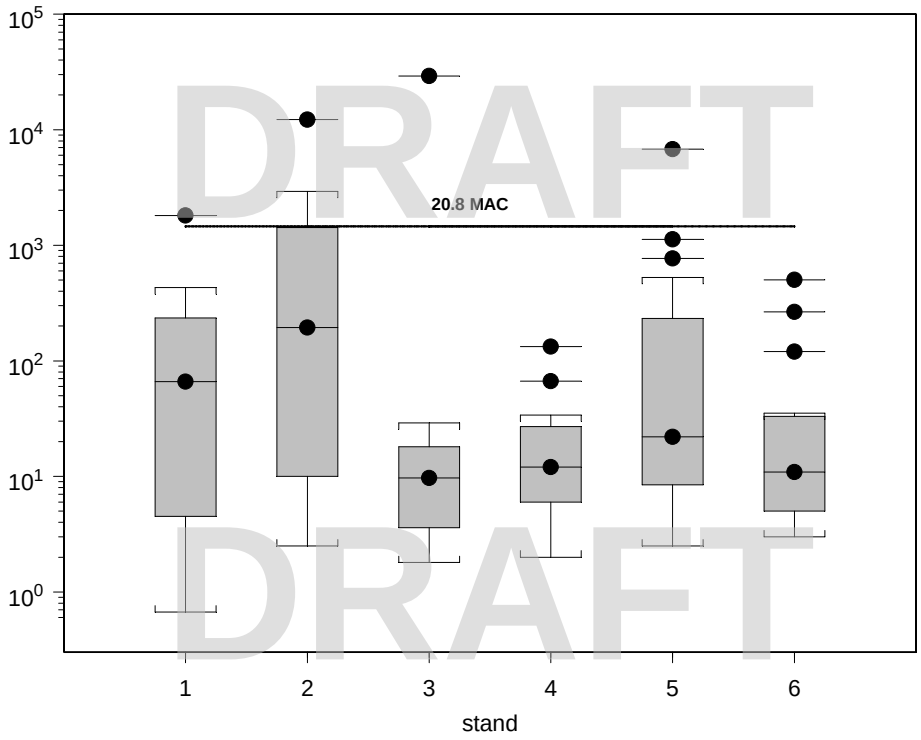
Figure 6: Comparison of all data collected at or near the rolling mill stands at Bethlehem Steel during 1951 and 1952.



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3.3 Inhalation Exposure Dosimetry at Lackawanna

3.3.1 Method of evaluation

The air sample data from Bethlehem Steel consists 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. The 191 results 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). An identical approach was used for the 10/27/1948 data from Simonds Saw and Steel in order to determine the GM and GSD of that distribution of air concentrations

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 a 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.

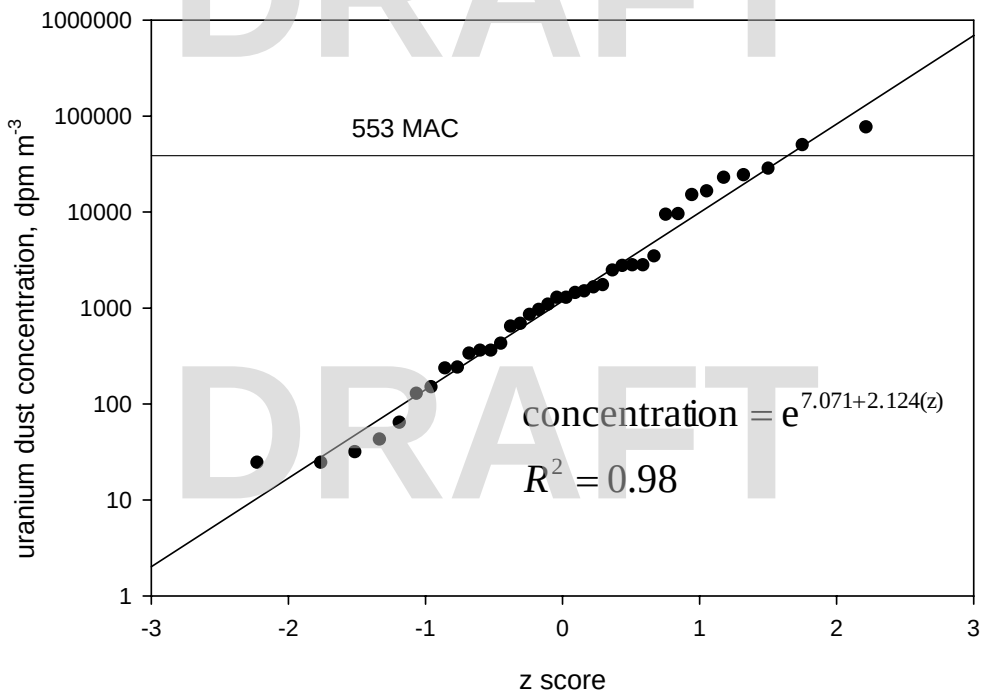
No records exist for 1949-1950 rollings at Bethlehem Steel. Data from Simonds Saw and Steel shall be used as a surrogate for determination of dose. The use of Bethlehem Steel data for uranium dust exposure assessment prior to 1951 is inappropriate because lead bath heating may not have been performed. 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. Furthermore, breathing zone data for hand grinding operations conducted at Joslyn are discussed. The appropriateness of using this limited Joslyn data was also previously discussed in this document.

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 occupations 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 3 shows a plot of the 95% value assigned for the uranium concentration level and compares that to the observed data at the various locations within Simonds Saw and Steel.

Figure 7: 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}).

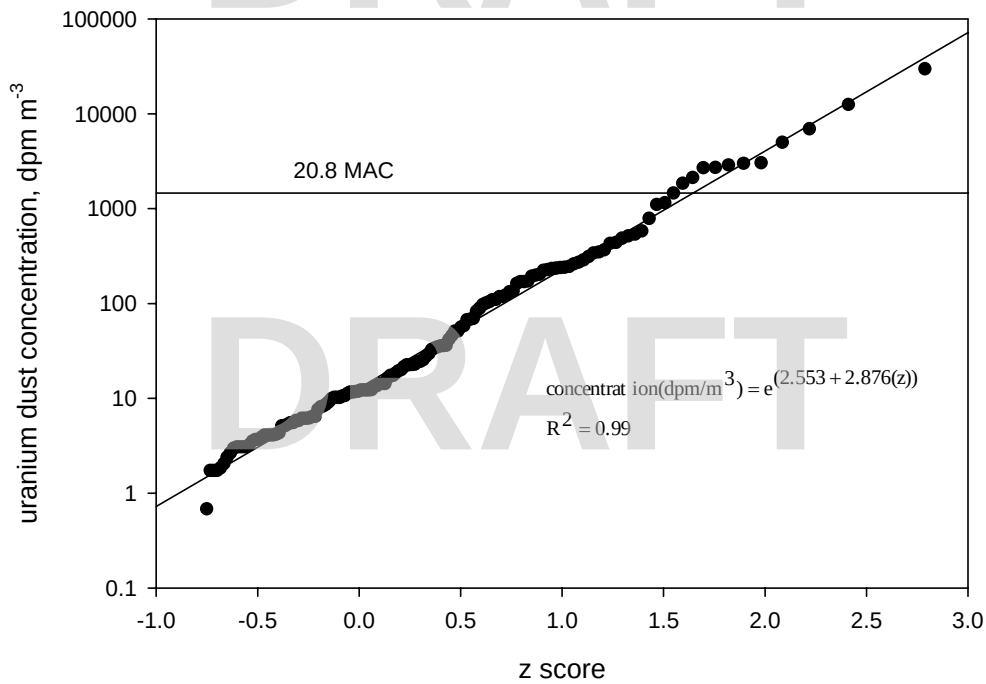


3.3.3 Evaluation of Inhalation Exposure for the 1951-1952 time period

The air sample data from Bethlehem Steel consists of a total of 191 legible air sample results and 13 illegible results drawn and analyzed by the HASL 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. All 191 legible results, including process samples, were sorted, log transformed, and plotted on a probability plot. The plot contained the z-score (# 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). An identical approach was used for the 10/27/1948 data from Simonds Saw and Steel in order to determine the GM and GSD of that distribution of air concentrations.

Previous sections in this TBD discuss the role that the 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 8: Graph of the distribution and fit of uranium dust concentration data taken at Bethlehem Steel from 1951 to 1952 (MAC=70 dpm m^{-3}).



3.4 Evaluation of ingestion dose

In a review of the revision 0 of this TBD, it was pointed out that the National Commission on Radiological Protection (NCRP) recommends screening limits for soil contamination in NCRP report 129 (SC&A 2005). The screening level recommended by the NCRP was 100 mg per day which was considerably higher than the daily ingestion value used in the previous revision of this document. It was also indicated that this value was considered to be an upper value of true inadvertent ingestion of material in a work environment. Since this TBD assumes the rolling of uranium metal took place only one day per month, it is reasonable to conclude that a considerable amount of other material also was present in the workplace as a byproduct from the rolling of steel. Given the typical production quantities of steel at Bethlehem Steel, it is also reasonable to conclude that the amount of material contaminating the workplace from steel processing is at least as great as that from uranium processing. Given these assumptions, the uranium contamination was likely to comprise no more than 1/30th (one day per month) of the material available for ingestion. This equates to 3.33% of the material or 3.33 mg per day based on the 100 mg per day upper value.

The previous revision to this document utilized Technical Information Bulletin 009 (TIB-009) to assess ingestion intakes. This TIB relates the daily ingestion intake to the estimated inhalation intake. Using

the current estimate of airborne activity in this document, the daily ingestion rate for 1949 and 1950 would be 5.21 mg. This appears to be a reasonable match to the 3.33 mg per day described above and thus indicates that the TIB-009 produces intakes similar to the approach recommended by SC&A.

It is important to point out that TIB-009 indicates the gastro-intestinal absorption value appropriate for the inhalation assumption should be used. Since this document indicates the most favorable of the credible absorption types be used, this GI tract absorption value will either be 2% or 0.2%. It is likely the true value for the uranium oxides the workers were exposed to falls between these values.

Since this TIB-009 assesses ingestion on the basis of air activity, it is also possible to apply it to periods of residual contamination between uranium rollings, once the air activity is assessed.

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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. Therefore, data collected at Simonds Saw and Steel was used to evalaute the residual contamination levels.

An AEC report (AEC 1949b) described a number of samples taken at Simonds Saw and Steel between 10/27/1948 and 2/15/1949. One of the conclusions of this report indicated that the airborne concentration at Simonds decreased rapidly to 0.5 MAC within 2 days of a rolling and remained at that level until the next cycle. It is unrealistic to assume the airborne concentration never decreased. It can however, be assumed from this report that it decreased slowly after the initial rapid decrease. In order to determine intakes from residual contamination, it is necessary to determine the rate of decrease.

Two models were evaluated to assess the magnitude of residual contamination between rollings at Bethlehem Steel. The first model, the dilution model, relies on the concept that oxides from steel rolling would mix with and thus dilute the uranium concentration over time. The second model, the exponential model, attempts to determine the rate of decrease from measurements and apply it to an exponential decrease.

3.5.1 The Dilution Model

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.

This concept leads to a model to estimate the airborne uranium caused by the resuspension of contamination. In this model, the uranium contamination is 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. An initial air concentration of 1.5 MAC would be required in order for this model to produce an air concentration of 0.5 MAC two days after the uranium rolling.

3.5.2 Exponential Model

A second model was developed by evaluating the decrease in surface contamination levels after a rolling. After rolling uranium on 10/27/1948 and 12/1/1948 surface contamination measurements were taken at Simonds. The averages of these readings were 23,000 dpm and 20,000 dpm respectively. A follow-up survey was taken on 2/15/1949, 33 days after the last rolling of uranium at Simonds (1/13/1949). The average value of this survey was 9250 dpm. The surface contamination levels on 1/13/1949 were assumed to be 20,000 dpm based on the similarity in the operational survey data. This implies a decrease in surface contamination levels of approximately 55% in 33 days. If it is assumed that the decrease is exponential, the removal rate can be determined to be approximately 2.4% per day. The initial airborne concentration due to resuspension would have to be 0.525 MAC for this model to produce an airborne concentration of 0.5 MAC on day 2 following a rolling. This value would not fall very fast so a level of approximately 0.5 MAC would be maintained in the plant for several days following a rolling. This appears to be consistent with the report.

3.5.3 Comparing Models

The models were compared and it was found that the dilution model would produce an intake over the first 30 days equivalent to inhaling 5.15 MAC air for one full day. For the same time period, the exponential model would produce an intake equivalent to inhaling 11.2 MAC for one day.

The exponential model would ultimately produce an intake equivalent to inhaling 21.7 MAC for one day while the ultimate intake from the dilution model would be infinite given unlimited time. However, the dilution model does not produce that intake quickly. The integrated intake resulting from the dilution model over a one hundred year period is still only equivalent to a one day intake at a concentration of 15.76 MAC, while the exponential model reaches its ultimate intake within one year. The exponential model appears to be more realistic and more claimant favorable and is the model adopted here for the reasons stated above.

3.5.4 Adoption of the Exponential Model to Bethlehem Steel Corporation at Lackawanna

The airborne concentration due to resuspension at any facility will depend on the level of surface contamination at the facility. The level a surface contamination in turn often depends on the level of airborne contamination during operations. The level of both at Bethlehem Steel during 1951 and 1952 are documented and are considerably lower than the levels documented at Simonds Saw and Steel. This appears realistic since the production rate was considerably lower at Bethlehem Steel as well as from the use of lead and salt bath heating.

A contamination survey was conducted at Simonds on 10/27/1948. The direct readings of alpha contamination in the more highly contaminated areas ranged from 25,000 dpm to 50,000 dpm.

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Assuming that the direct measurement probe had a surface area of about 15 cm^2 , this would equate to a range of about 16 million to 33 million dpm m^{-2}. Assuming a probe area of only 15cm^2 is a bounding condition because results reported for other facilities in this same time frame by HASL were in units of 100 cm^{-2}. Using a resuspension factor of $1x10^{-6}$ m^{-1}, would result in a resuspended airborne concentration of between 16 and 33 dpm/m^3 or about 0.25 and 0.5 MAC. This is consistent with the AEC report indicating the airborne concentration of 0.5 MAC days after the rolling ended. Therefore, is appears airborne contamination levels during residual contamination periods can be estimated from surface contamination levels.

The airborne concentrations at Bethlehem Steel indicated a geometric mean of approximately 1% that at Simonds Saw while the 95th percentile was approximately 3.8%. Applying these values to the measured surface contamination at Simonds produces values between 250 dpm and 1900 dpm per 15cm^2. This is approximately the area of a smear and these values are reasonably consistent with the Bethlehem Steel survey performed on 9/14/1952.

Therefore, both the airborne levels during rollings and the surface contamination levels at Bethlehem Steel appear to be between 1% and 3.8% that of Simonds. Also, the surface contamination levels at Simonds appear to be consistent with the resuspended airborne concentration. Therefore, the resuspension model for Bethlehem Steel (1951 – 1952) is 3.8% that of the Simonds Saw model.

3.5.5 Application

When the exponential model of the Simonds resuspended air is integrated over time to infinity, the resulting intake is equivalent to adding an additional 21.7 MAC of exposure for one work day (1519 dpm days m^{-3}). This value can therefore, be used as if it were the air activity during each day of rolling. It is important to note that even though the value is used as if it occurred in one day, this is simply a mathematical method of calculating the intake. The intake actually occurs over months following the rolling. An average facility air concentration was then determined as follows for the 1949 to 1950 period:

$$1519\frac{\text{dpm} \bullet \text{workday}}{\text{m}^3} * \frac{10\text{ hours}}{\text{workday}} * \frac{1.7\text{ m}^3}{\text{hour}} * \frac{12\text{ rollings}}{\text{year}} * \frac{\text{year}}{365\text{ calender days}} = 849\frac{\text{dpm}}{\text{calender day}}$$

After 1950, the data from Bethlehem Steel itself can be used. As noted above, this data results in a concentration that is 3.8% that of Simonds. Therefore, a value of 0.83 MAC-days should be added to the existing airborne activity estimate for each day a uranium rolling occurred at Bethlehem Steel for the 1951 to 1952 time frame. A calculation similar to that above results in 35.2 and 43.3 dpm of uranium per calendar day inhalation for 1951 and 1952, respectively.

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 entire year to determine an average intake rate. While the typical rolling schedule was one per month, several months do not follow this rule. 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).

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Table 2: Summary of inhalation exposure values for the periods 1949-1952 at Bethlehem Steel

Year	Natural Uranium Air concentration (dpm m^{-3})	Time (work day hours)	Breathing rate (m^3 hr^{-1})	Number of rollings per year	Calender Days per Year	Average inhalation rate (dpm day^{-1})
1949	38744	10	1.7	12	365	21,654
1950	38744	10	1.7	12	365	21,654
1951	1456	10	1.7	13	365	882
1952	1456	10	1.7	16	365	1085

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Table 3: Summary of inhalation exposure values for the periods 1949-1952 at Bethlehem Steel from residual contamination. The integrated air concentration was assigned for a single day for each rolling to maximize exposure.

Year	Integrated Air concentration per rolling (dpm days m^{-3})	Time (work day hours)	Breathing rate (m^3 hr^{-1})	Number of rollings per year	Calender Days per Year	Average inhalation rate (dpm day^{-1})
1949	1519	10	1.7	12	365	849
1950	1519	10	1.7	12	365	849
1951	58.1	10	1.7	13	365	35.2
1952	58.1	10	1.7	16	365	43.3

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Table 4: Summary of combined inhalation and ingestion exposure rates (dpm/day) for natural uranium at Bethlehem Steel for 1949-1952.

		Inhalation rate (dpm/calendar day)			Ingestion rate (dpm/calendar day)		
	# rollings	Rollings	Residual Contamination	Total inhalation rate*	Rollings	Residual Contamination	Total ingestion rate*
1949	12	21,654	849	22,500	284	11.2	295
1950	12	21,654	849	22,500	284	11.2	295
1951	13	882	35.2	917	11.6	0.46	12
1952	16	1085	43.3	1130	14.3	0.57	15

Using heavy worker model from ICRP 66.
*Total rates rounded to three significant digits.

4.0 ESTIMATION OF EXTERNAL EXPOSURE

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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 concentration data during rollings, rolling times, and average residual air contamination data from Table 2 were used in combination with 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 below because all other doses were less than 1 mrem. Table 5 lists external dose estimates for 1949 to 1952. With the exception of dose to the skin, the cumulative 4-year dose for each organ is less than one mrem and is, therefore, not included in the dose estimation. The maximum annual dose to the skin listed in Table 5 is applied to both the electron (E > 15 keV) and photon (E = 30 - 250 keV) annual dose in IREP using a constant distribution and assuming a chronic exposure.

Table 5: Annual external dose due to submersion in air contaminated with natural uranium dust.

Organ	Annual organ dose (rem)			
	1949	1950	1951	1952
Skin	3.80E-03	3.80E-03	1.55E-04	1.91E-04

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 6 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 6: Estimated external shallow dose due to electron exposure from natural uranium source.

Work period	Organ annual 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	1.44	2.4	20.16

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The values in Table 6 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). Table 7 lists annual organ doses due to photons from the natural uranium source. A triangular distribution for these doses was determined by applying the minimum and maximum dose conversion factors (DCF_{min} and DCF_{max}) for 30 - 250 keV photons (NIOSH 2002) to the estimated 2-mrad/hr deep dose rate multiplied by the estimated work times listed in Tables 2 and 3. To calculate the mode value, the dose conversion factor for AP geometry (DCF_{AP}) was used.

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Table 7: Annual organ doses due to photons from contact with uranium metal source (30-250 keV) for overestimate.

Organ	Annual organ dose (rem)											
	1949			1950			1951			1952		
	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
Bladder	0.008	0.210	0.219	0.008	0.210	0.219	0.009	0.227	0.238	0.011	0.279	0.293
Red bone marrow	0.015	0.115	0.190	0.015	0.115	0.190	0.016	0.124	0.206	0.020	0.153	0.253
Bone surface	0.091	0.204	0.332	0.091	0.204	0.332	0.099	0.221	0.360	0.121	0.272	0.443
Breast	0.011	0.215	0.220	0.011	0.215	0.220	0.011	0.233	0.239	0.014	0.286	0.294
Colon	0.013	0.179	0.192	0.013	0.179	0.192	0.014	0.194	0.208	0.018	0.239	0.255
Esophagus	0.007	0.117	0.165	0.007	0.117	0.165	0.007	0.126	0.179	0.009	0.156	0.220
Eye	0.000	0.211	0.258	0.000	0.211	0.258	0.000	0.228	0.280	0.000	0.281	0.344
Ovaries	0.008	0.161	0.178	0.008	0.161	0.178	0.008	0.175	0.193	0.010	0.215	0.237
Testes	0.009	0.262	0.273	0.009	0.262	0.273	0.010	0.283	0.295	0.012	0.349	0.363
Liver	0.024	0.179	0.190	0.024	0.179	0.190	0.025	0.194	0.206	0.031	0.239	0.254
Lung	0.030	0.167	0.195	0.030	0.167	0.195	0.033	0.181	0.211	0.041	0.222	0.260
Remainder organs	0.022	0.149	0.165	0.022	0.149	0.165	0.024	0.161	0.179	0.030	0.199	0.220
Skin	0.103	0.152	0.169	0.103	0.152	0.169	0.112	0.165	0.183	0.137	0.203	0.226
Stomach	0.011	0.228	0.243	0.011	0.228	0.243	0.012	0.247	0.263	0.014	0.304	0.324
Thymus	0.002	0.238	0.247	0.002	0.238	0.247	0.002	0.258	0.268	0.002	0.317	0.330
Thyroid	0.002	0.244	0.250	0.002	0.244	0.250	0.003	0.264	0.271	0.003	0.325	0.333
Uterus	0.011	0.171	0.183	0.011	0.171	0.183	0.011	0.185	0.198	0.014	0.227	0.244

For claims likely to yield a PC < 50%, the values in Table 7 are entered in IREP as the annual organ dose due to photons with energy between 30 and 250 keV using a triangular distribution and assuming a chronic exposure.

For cases likely to yield a PC> 50 %, 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 were used to calculate the doses listed in Table 8. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for E > 250 keV photons were used to calculate the doses in Table 9. The values in Table 8 and Table 9 are entered into IREP as organ doses due to the appropriate energy photons, using a triangular distribution and assuming a chronic exposure.

Table 8: 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	0.105	0.110	0.004	0.105	0.110	0.005	0.114	0.119	0.006	0.140	0.146
Red bone marrow	0.008	0.057	0.095	0.008	0.057	0.095	0.008	0.062	0.103	0.010	0.077	0.127
Bone surface	0.046	0.102	0.166	0.046	0.102	0.166	0.049	0.110	0.180	0.061	0.136	0.221
Breast	0.005	0.107	0.110	0.005	0.107	0.110	0.006	0.116	0.119	0.007	0.143	0.147
Colon	0.007	0.090	0.096	0.007	0.090	0.096	0.007	0.097	0.104	0.009	0.119	0.128
Esophagus	0.003	0.058	0.083	0.003	0.058	0.083	0.004	0.063	0.089	0.005	0.078	0.110
Eye	0.000	0.105	0.129	0.000	0.105	0.129	0.000	0.114	0.140	0.000	0.141	0.172
Ovaries	0.004	0.081	0.089	0.004	0.081	0.089	0.004	0.087	0.096	0.005	0.108	0.119
Testes	0.004	0.131	0.136	0.004	0.131	0.136	0.005	0.142	0.148	0.006	0.174	0.182
Liver	0.012	0.090	0.095	0.012	0.090	0.095	0.013	0.097	0.103	0.016	0.120	0.127
Lung	0.015	0.083	0.098	0.015	0.083	0.098	0.016	0.090	0.106	0.020	0.111	0.130
Remainder organs	0.011	0.075	0.083	0.011	0.075	0.083	0.012	0.081	0.089	0.015	0.099	0.110
Skin	0.052	0.076	0.085	0.052	0.076	0.085	0.056	0.082	0.092	0.069	0.101	0.113
Stomach	0.005	0.114	0.121	0.005	0.114	0.121	0.006	0.124	0.132	0.007	0.152	0.162
Thymus	0.001	0.119	0.124	0.001	0.119	0.124	0.001	0.129	0.134	0.001	0.159	0.165
Thyroid	0.001	0.122	0.125	0.001	0.122	0.125	0.001	0.132	0.135	0.002	0.163	0.167
Uterus	0.005	0.085	0.091	0.005	0.085	0.091	0.006	0.092	0.099	0.007	0.114	0.122

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Table 9: 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	0.052	0.110	0.111	0.052	0.110	0.111	0.056	0.119	0.121	0.069	0.146	0.149
Red bone marrow	0.057	0.089	0.109	0.057	0.089	0.109	0.062	0.097	0.118	0.076	0.119	0.145
Bone surface	0.065	0.095	0.106	0.065	0.095	0.106	0.070	0.103	0.115	0.086	0.127	0.141
Breast	0.054	0.116	0.117	0.054	0.116	0.117	0.059	0.126	0.126	0.072	0.155	0.155
Colon	0.051	0.105	0.107	0.051	0.105	0.107	0.055	0.114	0.116	0.068	0.140	0.143
Esophagus	0.051	0.093	0.104	0.051	0.093	0.104	0.055	0.100	0.112	0.068	0.123	0.138
Eye	0.023	0.109	0.115	0.023	0.109	0.115	0.025	0.118	0.124	0.031	0.145	0.153
Ovaries	0.049	0.102	0.114	0.049	0.102	0.114	0.053	0.110	0.124	0.066	0.136	0.152
Testes	0.058	0.117	0.127	0.058	0.117	0.127	0.063	0.127	0.137	0.078	0.156	0.169
Liver	0.055	0.106	0.109	0.055	0.106	0.109	0.060	0.115	0.118	0.074	0.142	0.145
Lung	0.060	0.104	0.110	0.060	0.104	0.110	0.065	0.113	0.119	0.080	0.139	0.147
Remainder organs	0.055	0.098	0.102	0.055	0.098	0.102	0.060	0.106	0.111	0.073	0.130	0.137
Skin	0.071	0.104	0.108	0.071	0.104	0.108	0.077	0.113	0.117	0.094	0.139	0.144
Stomach	0.058	0.110	0.115	0.058	0.110	0.115	0.063	0.119	0.125	0.077	0.147	0.153
Thymus	0.041	0.111	0.120	0.041	0.111	0.120	0.045	0.120	0.130	0.055	0.148	0.160
Thyroid	0.046	0.120	0.128	0.046	0.120	0.128	0.050	0.130	0.139	0.062	0.161	0.171
Uterus	0.048	0.097	0.098	0.048	0.097	0.098	0.052	0.106	0.107	0.064	0.130	0.131

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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.

The surface contamination was calculated by using the terminal settling velocity of 0.00075 m s^{-1} multiplied by the rolling day concentrations and by the amount of time rolled (TIB-0004, rev 2). The Simonds Saw and Steel concentration data was used to simplify the calculations as it overestimates the later rolling data. The resulting contamination of 1,370,000 dpm m^{-2} (137,000 dpm 100 cm^{-2}). 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. They shall be entered into IREP assuming a photon energy range of 50% 30-250 keV and 50% >250 keV.

Table 10: Dose from contaminated surfaces at Bethlehem Steel.

Organ	rem/year
Adrenal	7.38E-03
Bladder	8.14E-03
Bone surface	2.09E-02
Brain	7.72E-03
Breast	1.04E-02
Esophagus	6.86E-03
St Wall	8.07E-03
SI Wall	7.62E-03
ULI Wall	7.83E-03
LLI Wall	7.92E-03
Kidney	8.22E-03
Liver	8.09E-03
Lung	8.59E-03
Muscle	9.95E-03
Ovaries	7.52E-03
Pancreas	7.21E-03
R Marrow	8.37E-03
Skin	3.77E+00
Spleen	8.15E-03
Testes	1.04E-02
Thymus	8.03E-03
Thyroid	8.90E-03
Uterus	7.54E-03

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 one work week prior to cleaning. This results in an annual dose to the skin of 250 mrem per year which will be assigned a constant dose rate from electrons with an enegy > 15 keV.

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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.

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