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| **Site Profile for Simonds Saw and Steel** | | Effective Date: | 04/18/2011 |
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Subject Expert(s): Shelby L. Gubin, Robert Vogel

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| Approval: | Richard E. Merrill Signature on File for<br>Joseph S. Guido, Document Owner | Approval Date: | 04/18/2011 |
| Concurrence: | Signature on File<br>John M. Byrne, Objective 1 Manager | Concurrence Date: | 04/13/2011 |
| Concurrence: | Signature on File<br>Edward F. Maher, Objective 3 Manager | Concurrence Date: | 04/13/2011 |
| Concurrence: | Signature on File<br>Kate Kimpan, Project Director | Concurrence Date: | 04/13/2011 |
| Approval: | Signature on File<br>James W. Neton, Associate Director for Science | Approval Date: | 04/18/2011 |

☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

**FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.**

## PUBLICATION RECORD

| EFFECTIVE DATE | REVISION NUMBER | DESCRIPTION |
|---|---|---|
| 05/31/2005 | 00 | New Technical Basis Document: Basis for the Development of an Exposure Matrix for Simonds Saw and Steel, Lockport, New York. First approved issue. Incorporated formal internal and NIOSH review comments. No training required. Initiated by Cindy W. Bloom. |
| 07/08/2005 | 00 PC-1 | Approved page change revision corrects Table 15 on page 27. No changes were needed as a result of NIOSH formal review. Retraining is not required. Initiated by Cindy W. Bloom. Approval:<br><br>Signature on File 06/21/2005<br>Cindy W. Bloom, TBD Team Leader<br><br>Signature on File 06/21/2005<br>Judson L. Kenoyer, Task 3 Manager<br><br>Signature on File 06/21/2005<br>Richard E. Toohey, Project Director<br><br>Signature on File 07/08/2005<br>James W. Neton, Associate Director for Science |
| 04/18/2011 | 01 | Revision initiated to incorporate SEC-00157 information as directed by NIOSH. Includes information on the SEC class. Section 3.4 was revised to reflect the inability to reconstruct thorium exposure during the operational period and the associated tabulation of internal exposure values (Table 20). The description of the derivation of the external exposure dose estimates along with the associated dose tabulation (Table 20) was revised to remove consideration of external exposure from thorium during the operational period. Additional changes include the following: The calculation of intake quantities from plutonium (Table 20) was revised to maintain consistency between trace radionuclides and those in which they are mixed. Deleted options of associating class S plutonium with class M uranium and vice versa. The site description and the associated dose calculations tabulated in Sections 3 and 4 (Tables 12 and 15) were revised to reflect the change in the end of the operational period and the concurrent change to the start of the residual period. The medical X-ray examinations section was revised. The tabulation in Table 20 was updated. Revised the methodology for assessment of internal exposure which includes the reconstruction exposure from thoron. Table 3 was added to show the number of rolling days for each year. Tables 8, 9, 10, and 11 were modified to include 1957 in the assessment of internal intake using air monitoring data. Information was added to section 3.1.2 detailing air sampling results for rolling activities on the 10 inch mill and for uranium forging activities (Tables 12, 13, 14 and 15 added). Intake rates in Table 17 were revised to account for the reduced use of engineering controls during the post 1952 time period (i.e., intake rates calculated for the initial operations period, 1948, were assigned from 1953 through 1957). Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Joseph S. Guido. |

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AEC | U.S. Atomic Energy Commission |
| CFR | Code of Federal Regulations |
| cm | centimeter |
| d | day |
| DOE | U.S. Department of Energy |
| dpm | disintegrations per minute (also d/m) |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act of 2000 |
| EPC | Exposure Point Concentration |
| ft | foot |
| FUSRAP | Formerly Utilized Sites Remedial Action Program |
| GM | geometric mean |
| GSD | geometric standard deviation |
| hr | hour |
| ICRP | International Commission on Radiological Protection |
| IMBA | Integrated Modules for Bioassay Analysis |
| in. | inch |
| keV | kilovolt-electron, 1,000 electron volts |
| L | liter |
| lb | pound |
| m | meter |
| MAC | maximum allowable concentration |
| MCNP | Monte Carlo *n*-particle |
| mg | milligram |
| mrad | millirad |
| mR | milliroentgen |
| mrem | millirem |
| mrep | millirep |
| NIOSH | National Institute for Occupational Safety and Health |
| NLO | National Lead of Ohio |
| NYOO | New York Operations Office |
| pCi | picocurie |
| POC | probability of causation |
| R | roentgen |
| s | second |
| SEC | Special Exposure Cohort |
| U.S.C. | United States Code |

| | |
|---|---|
| WG | workgroup |
| yr | year |
| µg | microgram |
| µm | micrometer |
| § | section or sections |

## 1.0 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in 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 staff in the completion of the individual work required for each dose reconstruction.

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 [AWE] facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA, as amended, provides for employees who worked at an AWE facility during the contract period and/or during the residual period.

Under EEOICPA, employment at an AWE facility is categorized as either (1) during the DOE 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 after the period in which weapons-related production occurred). For contract period employment, all occupationally derived radiation exposures at covered facilities must be included in dose reconstructions. This includes radiation exposure related to the Naval Nuclear Propulsion Program and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the covered period. NIOSH does not consider the following exposures to be occupationally derived (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

For employment during the residual contamination period, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) [i.e., radiation doses received from DOE-related work] must be included in dose reconstructions. Doses from medical X-rays are not reconstructed during the residual contamination period (NIOSH 2007). It should be noted that under subparagraph A of 42 U.S.C. § 7384n(c)(4), radiation associated with the Naval Nuclear Propulsion Program is specifically excluded from the employee's radiation dose. This exclusion only applies to those AWE employees who worked during the residual contamination period. Also, under subparagraph B of 42 U.S.C. § 7384n(c)(4), radiation from a source not covered by subparagraph A that is not distinguishable through reliable documentation 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.

This document provides an exposure matrix for workers at the facility listed as Simonds Saw and Steel Company (Simonds) in Lockport, New York. Simonds was involved primarily with the rolling of natural uranium rods as well as the rolling of some depleted and enriched uranium and thorium rods. After the U.S. Atomic Energy Commission (AEC) contract operations, Simonds became known as Guterl Specialty Steel. The facility is now owned by Allegheny Ludlum Corporation.

Through December 31, 1957, NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal and external radiation dose received as a

result of operations involving the use of thorium (HHS 2011). Accordingly, a special exposure cohort class has been designated for "All Atomic Weapons Employer employees who worked at Simonds Saw and Steel Co. from January 1, 1948 through December 31, 1957, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort".

For any claim referred to NIOSH regarding an employee,

- Who was employed during the Special Exposure Cohort (SEC) period but because of limited employment during this period is not a member of the SEC, or

- Who is a member of the SEC and whose cancer is not defined as a specified cancer under EEOICPA (and so is not eligible for compensation under EEOICPA without a dose reconstruction),

NIOSH will continue to attempt to complete a dose reconstruction, using whatever information is available about that member's entire work history and available bioassay and monitoring data, and using the guidance in this site profile document.

Section 2 describes the Simonds site and operations that pertain to possible radiation exposures and discusses radiation source terms. Section 3 provides guidance for the determination of internal exposure. Section 4 provides guidance for the determination of external doses from measured doses or for periods for which records of measured doses are missing. Section 5 discusses doses from residual exposure.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 6.

## 2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

The information that follows applies to a period of AEC operations at Simonds Saw and Steel from February 24, 1948, to December 31, 1957 (Leiton 2010), involving AEC-contracted uranium and thorium work. This analysis assumed that the residual contamination period was from January 1, 1958, through the present, although the buildings were closed and the contaminated areas were isolated as of May 1, 1983.

The Simonds radiological source term consisted primarily of natural uranium metal, uranium oxides, and uranium's short-lived progeny. Long-lived progeny in the uranium series prevent significant ingrowth past $^{234}$U in the $^{238}$U decay series and beyond $^{231}$Th in the $^{235}$U decay series. The source term included smaller amounts of thorium metal and thorium oxides.

The first known rolling of uranium at Simonds occurred February 24, 1948, prior to the contractual agreement with the AEC. The first contract, AT-30-1-Gen-339, negotiated with the AEC New York Operations Office (NYOO), was initiated in May 1948, and was renewed annually through February 1952. AT-30-1-Gen-339 was officially closed on July 21, 1952. Simonds continued work under subcontract S-4 (effective March 1, 1952, through December 31, 1956) to the National Lead of Ohio (NLO) in Fernald, Ohio, contract AT (30-1)-1156 with NYOO (Author unknown, no date a).

While a majority of documents state that no uranium or thorium was processed for the AEC at Simonds after 1956, some documents indicate that approximately 13 tons of uranium slabs were produced in April 1957. NLO Production Order Request # A-60 in April 1957 states that the work was not to be billed because it was applied to research and development (NLO 1957). In reference to

Production Order # A-60, a subsequent June 1957 memo states that 26,860 pounds of normal uranium forged slabs had been shipped via truck from Simonds to Superior Steel Corporation on April 29, 1957 (McCreery 1957). This signifies that the work associated with the production order request had been completed. Subsequent documents indicate the final contract closure occurred sometime in late 1957; the exact date is unknown (Ericson 1957a,b; Zimmerman 1957).

In 1956, Simonds reportedly requested that NLO survey the thorium work that consisted of drop forging, rolling on the 16-in. bar mill, and finishing on the strip mill (Wunder 1956). This was reportedly commercial work for Babcock & Wilcox that was to occur in June 1956, but it might not have occurred until July 1956 (NLO 1956).

## 2.1 SITE DESCRIPTION

The Simonds buildings most associated with AEC operations were referred to as Building A (also known as Buildings 6 and 8) with the 16-in. and 10-in. rolling mills and Building B (also known as Building 3) with the hammer forge shop (Ford Bacon & Davis Inc. 1981). Wallace-Murray Corporation purchased the Simonds facility in 1966 and operated it until 1978. Guterl Specialty Steel purchased the site in 1978 and, upon bankruptcy (1982), transferred a portion of the site to Allegheny Ludlum Corporation, which continued operations in the areas purchased. The areas excluded from the transfer (called the “excised area”) remains under the ownership of Guterl Specialty Steel Corporation (a Chapter 7 bankrupt corporation). As of March 31, 2011, the facility is owned by Phersas.

Vitkus (1999) described the former Simonds site as a 28-hectare (one hectare equals 2.47 acres) area bordered by Ohio Street to the east, residential and commercial properties to the north, U.S. Route 95 to the west, and the New York State Barge Canal to the south. As of 1999, the property was grouped into three areas:

- The Allegheny Ludlum Corporation, which includes four buildings constructed after the termination of AEC activities
- The 3.5-hectare landfill area in the northwest corner of the site
- The 3.6-hectare excised property, which includes nine buildings that existed during the AEC activities in the southeast corner of the site (Vitkus 1999).

Table 1 lists the buildings that probably existed at the time of AEC operations.

Table 1. Simonds buildings where contamination has been found.

| Building number | Building letter[a] | Use |
|---|---|---|
| 1 | | Manufacturing |
| 2 | | Manufacturing |
| 3 | B | Grinding and rolling, hammer forge shop |
| 4 | | Manufacturing |
| 5 | | 25-cycle heat exchanger |
| 6 | A | 16-in. rolling mill |
| 8 | A | 10-in. rolling mill |
| 9 | | Manufacturing |
| 35 | | Grinding and roll staging |

a. Nomenclature used in 1981 report (Ford Bacon & Davis 1981).

Figure 1 shows the location of the Simonds site and the boundaries of the Allegheny Ludlum and excised properties (Earth Tech 2010).

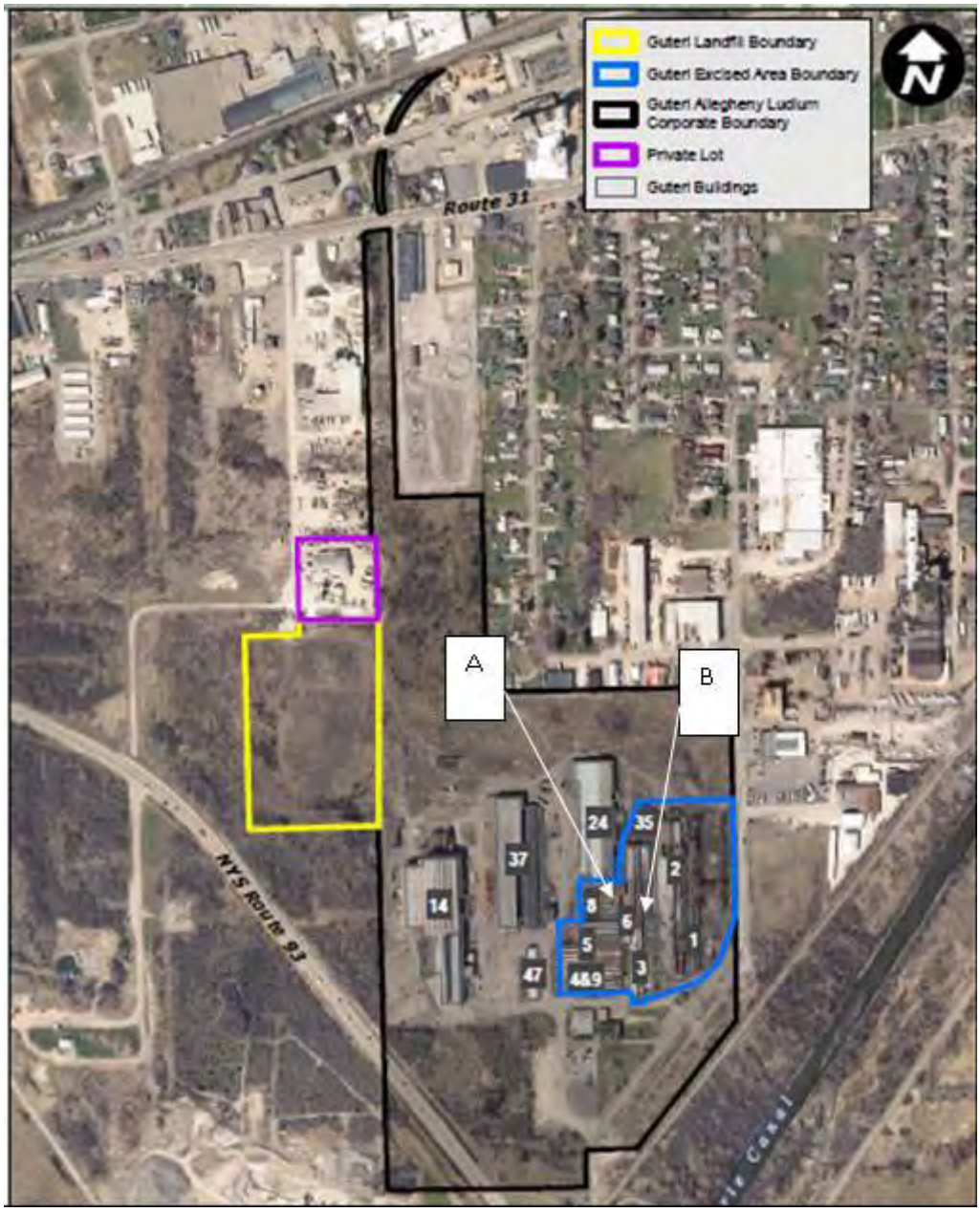


Figure 1. Aerial view of Simonds Saw and Steel. Source: Modified version of an image from USACE (2010).

## 2.2 PROCESS DESCRIPTION

"An experimental [uranium] run was made at Simonds Saw & Steel on February 24" (AEC 1948a). Massachusetts Institute of Technology studies showed satisfactory results and arrangements were made to roll a carload of uranium metal beginning on March 29, 1948 (AEC 1948b).

Materials for processing arrived, at least in the early years, in boxcars. Crated or palleted ingots or billets were placed in a temporary storage area. Just before rolling, workers uncrated the ingots or billets and rigged them for transfer by crane to the weigh station. According to a report on rolling procedures in 1951, the billets were initially either 5-1/8 in. in diameter and 15 to 20 in. long or 4-1/4 in. in diameter and 20 to 22 in. long (Smith 1951). The rolling reduced them to rods of 7/8-in. diameter, each weighing approximately 200 lb. Thus, each turning was approximately 75 to 100 billets.

After weighing, the ingots or billets were transferred into a furnace. A gas combustion furnace was used in the early years and occasionally thereafter. About January 1950, a heated lead bath furnace was installed to reduce the airborne radioactivity. The ingots or billets were loaded into the lead furnace, which was of a "Ferris wheel" type design for submerging and carrying the charge through the heated lead bath. It is not known how many billets the furnaces could handle at once, but it is known that each billet was in the furnace for about 40 minutes. The heated ingots or billets were transferred with tongs and a roller table (a table with rollers on top to reduce friction and ease heavy material transfers) to the 16-in. mill and rolled in two of its four stands. Depending on size, the bar could have been cut at the shears midway in the rolling operation. After rolling, the rods were quenched (either pressure quenched or dipped in a tank) and transferred in bundles by crane to the shipping area, where they were placed in tared H-beams, weighed, and loaded into railcars from the shipping dock (DOE 1979; Keller 1979). AEC noted that trucks rather than railcars were being used as of August 1950, which eliminated daily handling and shoring of the load by shippers (Heatherton 1950a). The process generated a considerable amount of waste, as evidenced from a 1952 Tonawanda Progress Report (AEC 1952): "Approximately fifty drums of [uranium-contaminated] scrap and oxide were received from Simonds at the completion of the January rolling."

The majority of the AEC work involved the task of rolling uranium, but occasionally tests were run to see if different coatings or methods would either produce a better product or reduce worker exposure. AEC reported on the rolling of copper-clad uranium on March 7 or 8, 1951 (Heatherton 1951a), which was deemed unsuccessful due to increased product problems and increased air concentrations.

Simonds Saw and Steel performed hot forging of uranium and thorium metal - uranium on an experimental basis, and thorium mostly on a production basis. The metals were usually forged and then rolled into rods (Huke 1951). This was apparently the primary method for processing thorium at Simonds (Murray 2010).

Information on Simonds uranium forging is limited, but records indicate that "*some 15 of* [or?] *20 ingots were processed in the hammer forge shop*" (Keller 1979). The AEC concluded that forging was a very dusty operation and, based on health considerations, recommended not using the process for uranium (Heatherton 1950b). A 1957 document refers to the production of 26,860 pounds of uranium forged slabs that had been shipped by truck to Superior Steel Corporation (McCreery 1957).

In 1956, Simonds reportedly requested that NLO survey the thorium work that consisted of drop forging, rolling on the 16" bar mill, and finishing on the strip mill (Wunder 1956). This thorium work was reportedly commercial work for Babcock & Wilcox and was to occur in June 1956. However, this work was reportedly completed in July 1956 (Heatherton 1956).

In 1952, Fernald became the primary AEC site for processing uranium, and the Simonds uranium processing activities were significantly reduced. Simonds received odd lots that could not be easily processed at Fernald. "A few of the later lots of material were depleted uranium and several were enriched to the extent of about 2.5% [by mass]" (Keller 1979).

## 2.3 SOURCE TERM

Numerous documents provide summaries of Simonds Saw and Steel's operational history, including the estimated total quantities of uranium and thorium metals that were processed. The documents typically state that between 25 and 35 million pounds of uranium and approximately 30,000 to 40,000 pounds of thorium were rolled from February 24, 1948 until operations ceased sometime in 1957 (Vitkus 1999). Information on material processing was compiled from all available Simonds-related documents and places the total quantities of uranium and thorium processed at 11,500 tons and 114,000 pounds respectively (NIOSH 2010b). These values exceed the amounts stated in various documented historical narratives by about a factor of three.

"Over 99 percent of all Simonds uranium work consisted of rolling on the 16-inch bar mill" (Keller 1979) in Building A (Building 6). Before the NLO subcontract, as much as 500,000 or 600,000 lb of uranium were processed per month (Keller 1979). Several small lots of uranium bars and thorium ingots were run through the 10-in. rolling mill in Building A (8), and approximately 15 to 20 ingots were processed in the hammer forge shop in Building B (3). Figures 2, 3, and 4 show the layouts.

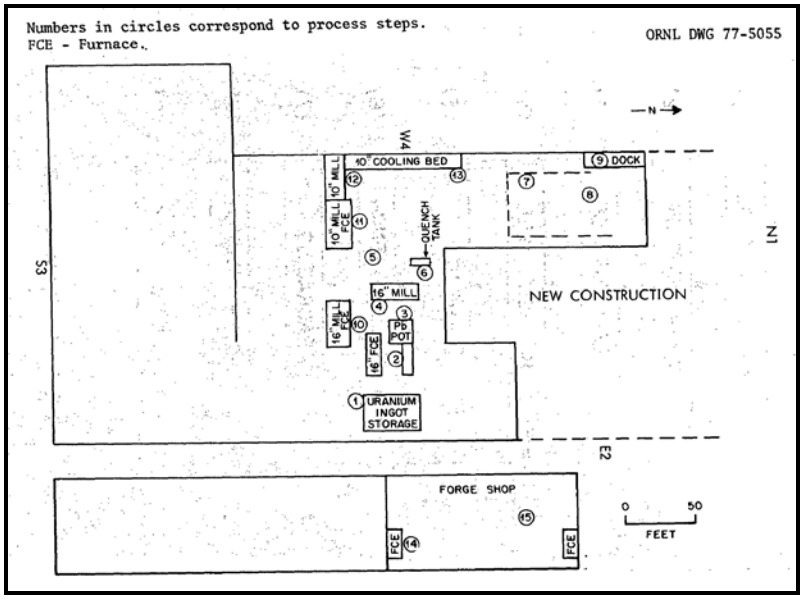


Figure 2. Simonds rolling mills and hammer forge areas. Buildings 6 (16 inch mill), 8 (10 inch mill) and 3 (forge shop) (DOE 1979).

The processing occurred in turnings of about 15,000 to 20,000 lb each. There were approximately 312 turnings per year from 1948 to 1952. At the end of the initial AEC contract, turnings reportedly decreased to 29 turnings in 1953, 56 in 1954, 58 in 1955, and 22 in 1956 (Keller 1979). It appears that a rolling turn takes up one shift (Schumann 1953), so there were about 156 days per year, two shifts each day, devoted to AEC work from 1948 to 1952. This translates into 31 of 52 weeks or approximately 60% of the time was spent on AEC work. Documentation of specific rolling dates was available only for those periods included in the reports of AEC visits. Based on the number of turnings reported by Keller (1979), the number of uranium rolling days can be estimated as 15, 28, 29, and 11 rolling days for 1953, 1954, 1955, and 1956, respectively. Although not reported by Keller, rolling of uranium has been confirmed during at least one period in 1957 (Ericson 1957a,b; Zimmerman 1957). The total quantity reported to be rolled in 1957 was approximately 26,860 lbs. Based on what is known about uranium processing rates at Simonds, the number of days associated with this operation would be less than two days.

For fiscal year 1950 (beginning October 1949), Simonds agreed to meet the AEC rolling requirements, as high as 170 tons per month, so AEC consolidated most of its rolling operations at Simonds (AEC 1949a).

A national steelworkers' strike began in October 1949. "A short-term agreement between the steelworkers' union and company officials at Simonds Saw & Steel Company was reached. This will allow the October uranium rolling to take place as scheduled" (AEC 1949b). Simonds planned to roll 160 tons of uranium in November because it had negotiated a short-term contract through December 1, 1949. No uranium was to be rolled in December 1949, but rolling was to resume in January 1950 (AEC 1949b).

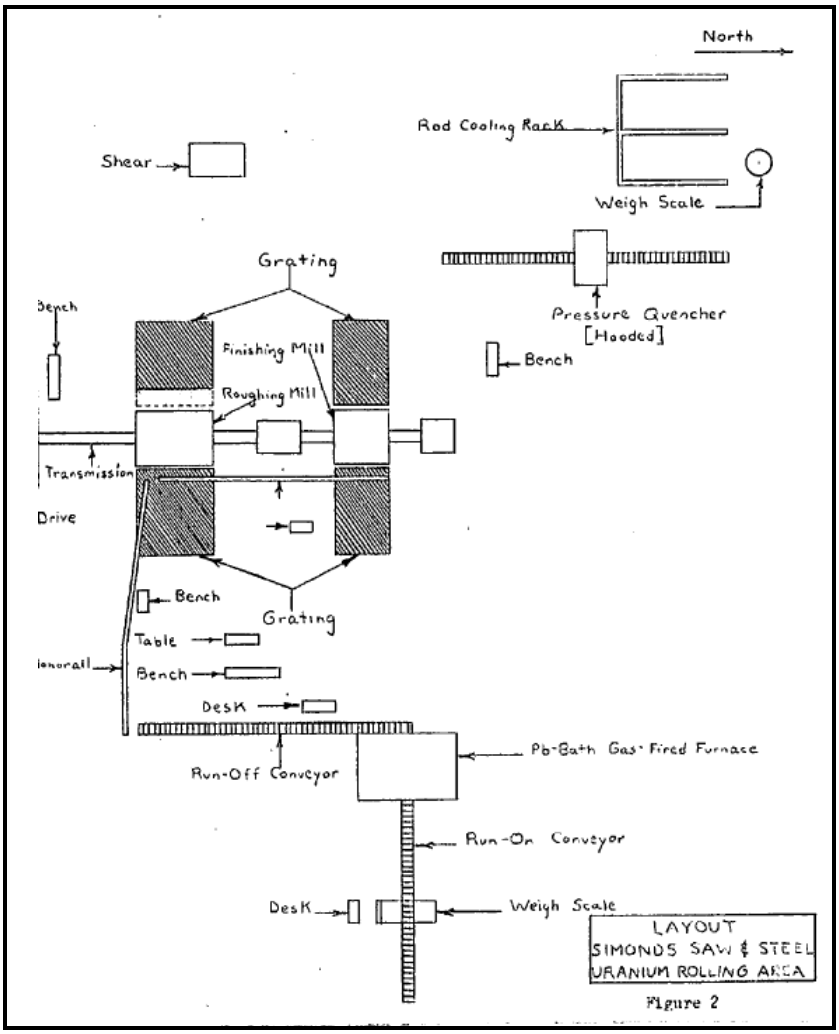


Figure 3. Simonds 16-in. rolling mill area, Building 6 (Klevin and Weinstein 1953b).

The earliest document located regarding thorium rolling at Simonds Saw and Steel is correspondence dated August 1951 (Huke 1951). In relation to thorium, it states:

> *Approximately two tons of thorium metal were rolled at Simonds Steel Co., Lockport, New York on August 16, 1951 … We believe that this is the first time that thorium billets have been rolled directly to rods on what might be termed production scale. Previously, billets were forged to 2" squares and then rolled. … Most of the material received consisted of 3-in. diameter round billets in the range of 15-in. long.*

The statement, *"Previously, billets were forged…and then rolled…"* indicates that thorium forging and rolling were performed prior to August 16, 1951. However, since insufficient information is available to determine an accurate thorium-processing start date, NIOSH assumes that thorium processing began coincident with the start of AEC-contracted work at Simonds in February 1948.

Tonawanda Area reported that 36 thorium billets were shipped to Simonds for rolling on November 19, 1951 (AEC 1951a), that no thorium metal was rolled in January 1952, and that there were no plans to roll thorium at Simonds for the next few months (AEC 1952). Inventory amounts of thorium were shown for May, September, and November 1952 (AEC 1953). In November 1952, 8,500 lb of thorium were to be rolled (Belmore 1952). An additional thorium rolling took place in

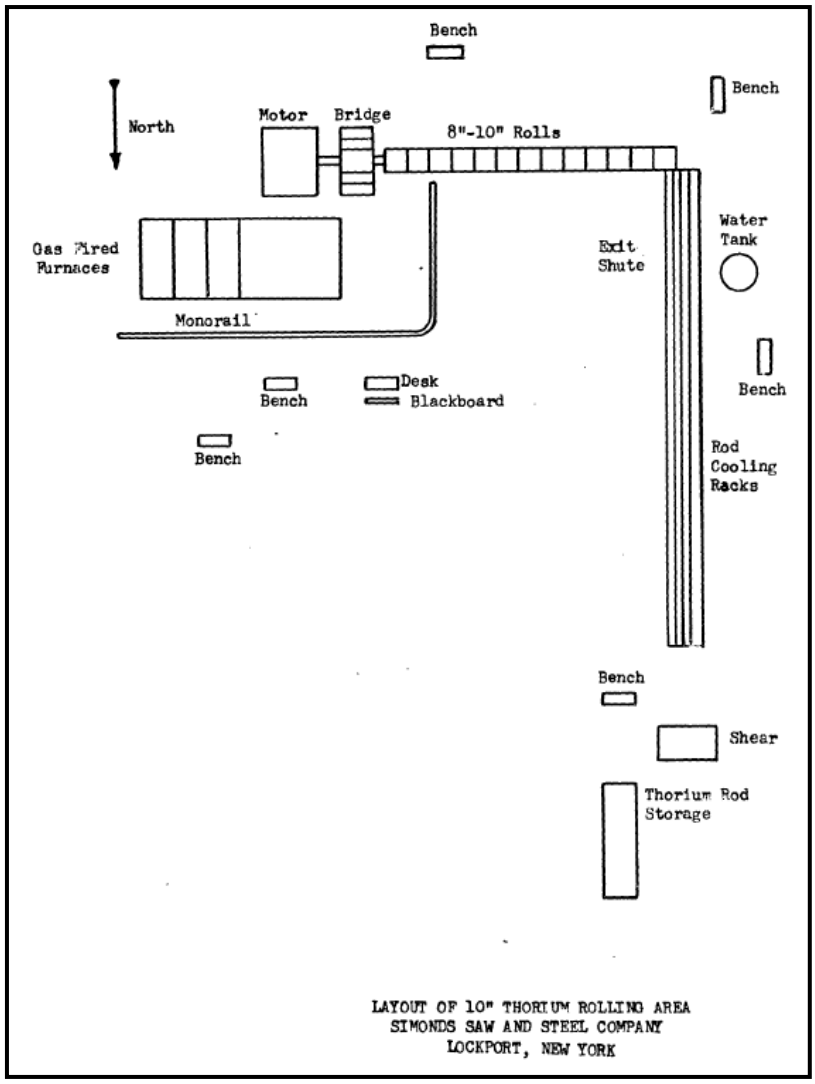


Figure 4. Simonds10-in. thorium rolling area, Building 8 (Klevin and Weinstein 1953c).

August 1954 (Harris 1954). Documents indicate that thorium-forging work was performed in May and July 1956 (Magoun and Yocco 1956; NLO 1954–1956). The largest single thorium rolling known was performed in December 1953 (Wunder 1953, p. 6**)** in which 21 tons (455 ingots) of thorium were rolled in a three-day period.

In December 1948, Tabershaw (1948) mentioned a group of 150 Simonds workers. In February 1949, Tabershaw (1949) mentioned that there were 180 Simonds workers who had been examined and that 57 were intimately exposed to uranium. Air-sampling data indicated that there were 13 to 28 rolling mill workers considered in the airborne uranium exposure studies on any one shift. Simonds worked two shifts and, because only a few workers worked the first shift, the maximum number of workers included in any of the studies was 45 (one study reported 48 workers, but only 45 were identified in the job categories). A film badge record includes 21 workers in October 1949 (AEC 1949c).

Table 2 lists the job categories included in the AEC and NLO exposure studies, but the AEC reports indicated that workers switched categories. In addition, it was noted that workers could have worked

on both the 16-in. and the 10-in. bar mill. No specific worker data were found in relation to the limited forging of uranium.

Table 2. Some job titles involved in uranium rolling.

| | |
|---|---|
| Assistant foreman | Rod stamper |
| Billet loader | Roller #1 (rougher) |
| Dippers | Roller #2 (finisher) |
| Drag down man | Run-out |
| Foreman | Shear man |
| Furnace man (heater) | Shippers |
| Heater helper | Straightener |
| Hook man | Stranner |
| Poke-in | Weighers (rod) |
| (Pressure) quencher | Weigh in (weigh up) |

The documents that relate to Simonds do not mention area access controls, so it is not clear who had access to the areas where the AEC rolling occurred.

As noted above, Simonds worked two shifts. AEC reports indicate that a shift lasted from 8 to 11 hours, with the typical shift lasting about 10 hours. These work hours included at least 45 minutes for locker room and lunchtime.

## 2.4 SAFETY

Early in the contract, the AEC (Wolf 1948) provided safety recommendations for the uranium rolling operations at Simonds, including exhaust ventilation, a central vacuum cleaner, floor grating, and high-pressure water nozzles for descaling (page 3 of the 4 pages of recommendations was missing). AEC air-sampling and radiation surveys were recommended to ensure that the engineering controls were adequate.

### 2.4.1 Workplace Contamination Controls

The main AEC safety recommendations for Simonds involved workplace contamination controls, which consisted primarily of ventilation controls and cleaning to minimize uranium dust in the workplace. There was little mention of external radiation safety practices. AEC reports documented incremental improvements in Simonds contamination control programs (AEC 1948c,d, 1949d,e, 1950; Heatherton 1950a,b, 1951b; Klevin 1951). Over time, Simonds went from no ventilation controls to local ventilation exhausts over the 16-in. rolls and a central vacuum cleaner to replace broom sweeping by December 1948. In January 1949, a local exhaust was installed over the descaler. No local ventilation was described for the 10-in. rolling mill or the limited forging work. As of January 1950, a lead bath furnace was being used to reduce airborne contamination. Plexiglas shields were installed at some point to help contain contaminants and to direct airflow to the exhaust system. Dust collectors were added to the exhaust system to reduce uranium releases. Grating was used on the floor to minimize contact with the settling radioactive dust that could become airborne again. A partially legible AEC memorandum from August 5, 1948, indicates that the “mill crew” had two sets of clothing. The November 1948 AEC production report states that uniforms and gloves were provided to workers (AEC 1948e).

As of January 10, 1949, the “complete ventilation had been installed, vacuum exhaust vented outside the mill area and exhaust fan from pressure quencher exhausted through roof” (AEC 1949d), but the floor gratings had not been obtained. AEC noted inexplicably large air concentrations near the pressure-quenching and rod-stamping areas, which were within a few feet of each other. AEC

thought that perhaps the descaling machine was throwing off large chunks of uranium, which were being caught on the air sampler. "It was noted that occasional stinging particles were caught on the face and hands of the man doing the [air] sampling." In addition, the time to quench rods had been increased from 75 to 200 minutes per shift to improve scale removal, which factored into air concentration exposure estimates.

By April 5, 1949, a large pedestal fan was used to blow air across the pressure-quenching and rod-stamping areas, which reduced worker exposure in these areas, but caused a general increase of uranium air concentration in other mill areas.

By June 13, 1949, a stack ventilation dust collector was in use, although it appeared to be collecting only about one-tenth of the expected emissions (Reichard 1949). By September 7, 1949, the air velocity was increased with the expectation that the collection efficiency of the Aerodyne Concentrator would increase by 70% to 90% (Hershman 1949).

On July 12, 1949, AEC requested funding to install a lead bath furnace at Simonds. Uranium billets were being heated in a combustion gas atmosphere, where reportedly about 0.5% (by weight) of the billet was converted to an oxide, "most of which is eventually reprocessed to metal" (Reichard 1949). AEC noted that the lead bath would eliminate the brushing of uranium from the furnace and reduce exposures. December 1949 was dedicated to clean thoroughly areas most likely to be contaminated. Airborne radioactivity was expected to be at its lowest level yet during the January rolling (AEC 1949a, 1950), which involved a trial run of 10 tons of uranium (AEC 1949f, 1950) and the initial use of the lead bath. AEC noted that the lead bath was removed by September 1954 (Klevin 1954).

By January 1950, rods were cold stamped to reduce airborne materials (AEC 1950).

AEC reports document the effectiveness of recommended contamination controls, but noted inconsistency in their implementation. Available documentation indicates that after 1953, the engineering controls that were previously installed were not consistently used. The AEC and NLO constantly reminded Simonds Saw and Steel Co. to use the vacuum cleaner instead of broom sweeping the uranium dust areas. Simonds Saw and Steel's use of the Plexiglas shields, floor grating, and ventilation system dust collectors appear to have been intermittent. Throughout the periodic air monitoring reports published by the AEC there are frequent accounts of the failure of Simonds to either implement recommended exposure control practices or to continue to adhere to such practices. The concerns that were conveyed by the AEC are best summarized in a November 1954 memo in which it is stated:

> *On the rolling of October 9-11, 1954, a NLO Health and Safety representative was present. In his report, reference 5, mention was made of some of the "doubtful practices" noted.*
>
> *This included:*
>
> 1. *Dropping of billets on floor prior to rolling*
> 2. *Wire brushing billets to observe temperature*
> 3. *Sweeping of floor instead of vacuum cleaning*
> 4. *Use of cloth gloves*
> 5. *Eating in vicinity during rolling*
>
> *These practices have been going on for as long as anyone connected with the operations can remember. … Rolling has continued with the thought that as soon as other facilities become more fully developed future fabrication at Simonds will be almost nil. It is planned to extrude the depleted uranium orders at Wolverine Tube and*

> *extrude the thorium material at Bridgeport Brass in Adrian Michigan. Both of these facilities should be satisfactory from a health and safety standpoint* (Polson 1954).

In addition, the practice of wearing dedicated anti-contamination clothing also appears to have been sporadic. AEC and NLO reports mention dedicated work clothes, but actual use of these clothes is not clear. Cotton gloves appear to have been worn intermittently. In later years, there is mention of dust masks and respirators, especially in conjunction with the enriched uranium and the thorium processing, but it was noted that respirator use was intermittent, if not rare, during AEC material processing.

In late 1953 Heatherton (1953a) stated that to decontaminate Simonds, the ventilation over the bar mill would be removed rather than left for future rollings. He pointed out that cleaning up from a single thorium rolling would result in less overall costs than maintaining the ventilation and that the workers would be provided with respirators.

The wearing of dedicated anticontamination clothing at Simonds appeared to be sporadic. AEC and NLO reports mention dedicated work clothes, but actual use is not clear. Cotton gloves appear to have been donned intermittently. In later years, there is mention of dust masks and respirators, especially in conjunction with the enriched uranium and the thorium processing, but it was noted that respirator use was intermittent, if not rare, during processing of AEC materials.

An NLO memorandum (Polson 1954) states that during the next several rollings:

> *…all operators have worn coveralls and caps supplied by NLO. Shoe covers are available but the men do not care to wear them. We have supplied respirators in the past but very few are worn continuously.*
>
> *Recently, we rolled enriched materials there (P.O. 296) and the men were concerned about its increased toxicity. Almost everyone wore coveralls, hats, shoecovers and respirators. Some, however, wore no protective equipment.*
>
> *For these past rollings, the two dust hoods over the 16-inch mill were used. There are no hoods over the 10-inch mill. The mill area has been cleaned after each rolling as well as possible considering the type of floor (steel plates).*

NLO concluded that as soon as other rolling facilities became available they would be used rather than Simonds.

### 2.4.2 Air Concentrations

During World War II, permissible levels for uranium dust in air were set at 500 µg/m$^3$ for insoluble uranium compounds and 150 µg/m$^3$ for soluble uranium compounds. After the war, the University of Rochester lowered its recommendation for soluble uranium compounds to 50 µg/m$^3$ based on the chemical toxicity, which is equivalent to 70 dpm/m$^3$ of natural uranium. This level was based primarily on animal studies. The Medical Division of NYOO felt that a "maximum permissible level" was unknown and should be based on human data. Therefore, the 50 µg/m$^3$ level was referred to as the "preferred level" (AEC 1949g). Some reports refer to a maximum allowable concentration (MAC), which was the same as the preferred level.

From 1948 to 1951, the NYOO made several site visits to survey air quality. As better radiological controls were put in place, the air concentrations were lowered by a factor of 10 or more (AEC 1948c,d, 1949d,e, 1950; Heatherton 1950a,b, 1951b; Klevin 1951).

In response to the January 1950 survey results, AEC (1950) reported:

> *The fact that a residual air contamination of the order of 25 µg/m$^3$ [35 dpm/m$^3$] exists, even after a thorough cleaning and a full month of no rolling indicates two things:*
>
> *The entire mill has a low level of uranium contamination.*
>
> *It will probably be impractical to reduce the airborne uranium level consistently below 15 µg/m$^3$.*

Heatherton (1950b) reported that air sampling results from forge-hammering operations ranged from 76 to 260 times the preferred level in the general air and from 220 to 400 times the preferred level in the breathing zones of some of the men handling the billets.

In January 1951, Simonds dip-quenched rather than pressure-quenched the rods, leaving more scale, which was evident as oxide dust on the floor of the rod-stamping area and resulted in increased air concentrations (AEC 1951b). AEC also reported that the Simonds Plexiglas shields were not in place due to an oversight.

Schumann (1953) mentions the rolling of enriched uranium in January 1953. Heatherton (1953b) describes the radiological conditions:

> *On January 17, 1953, rolling of special "E" material was done at Simonds Saw & Steel Company. Rolling operations were done on the 16-inch bar mill and the 10-inch bar mill. Ventilation on the 16-inch mill was the same as normally used in uranium rolling operation at the Simonds plant. No ventilation was provided for the work on the 10-inch mill …*
>
> *Air dust levels measured in the survey would not be noticeably different if normal or depleted material were rolled…*
>
> *… weighted exposures ranged from 5.4 to 130 times the MAC.*
>
> *Air dust respirators were worn by all mill workers at the time of rolling…The actual operation time was only about 80 minutes.*
>
> *General air results indicate an overall contamination of the building as a result of performing the operation without ventilating.*

In November 1953, Heatherton (1953a) implied that no enriched uranium was rolled between January and November 1953. In October 1954, Yoder (1954) reported on the rolling of 36 tons of depleted uranium billets. Air samples collected during this visit could have been compromised because of missing air sampling heads. Makeshift sample heads were made by taping the filter paper to the female adapter for the regular sampling heads and leaving about the same open area on the paper as for the normal heads. Two operations were measured slightly above the MAC, and the rest were less than the MAC (Yoder 1954).

Thorium air concentration results from July 1956 are probably measurements related to the commercial thorium work process arranged by Babcock Wilcox. These results appear generally lower than the November 25, 1952, results (NLO 1956).

### 2.4.3 Contamination and Radiation Levels

While visiting Simonds on or before October 18, 1948, to survey a broken roller for disposition determination, AEC measured ambient radiation levels from a few milliroentgen per hour to greater than 25 mR/hr about 6 ft in front of the furnace. Further investigation was recommended (Heatherton 1948).

The summary report notes that alpha contamination measured from 2,500 to 40,000 dpm/100 $cm^2$ in the mill area from October 1948 to January 1949. Most of the mill area beta/gamma readings were less than 2 mR/hr. The highest reading was an area on the floor near the furnace that measured 15 mR/hr beta/gamma, and elevated readings were found near East Roller #1 and the Shear (AEC 1949h).

"A radiation survey was made of the entire area surrounding the plant and all the other buildings with a Zeuto. Alpha readings were negligible" (AEC 1949h). (A Zeuto was a portable ionization chamber. The early models were used to measure alpha contamination; some models also measured beta and gamma radiation.)

## 2.5 INCIDENTS

There were four incidents reported.

- An AEC employee, noted while sampling air in January 1949 that his face and hands were occasionally stung by particles that could have come from the descaling machine (AEC 1949d).

- A flying chip embedded itself in the flesh of the inner thigh of a rod stamper (Heatherton 1951a). This could have been a chip from the die head or the hammer rather than a chip of uranium.

- A rod stamper had a chip of material taken from his wrist; Klevin (1951) reported the uranium mass of the chip as 1.5 µg (in the data reports, the Greek γ was used to mean micrograms).

- In March 1952, there was a concern about an "allergic" reaction by a doctor and a nurse at a local hospital who were treating a Simonds 10-in. bar mill worker (Tabershaw 1952). The rumor was enhanced by reports of several other Simonds workers who complained of dermatitis. The dermatitis was limited to the day shift and cleared up within a week or so. The dermatitis was unlikely to be a result of radiation or uranium exposure.

## 2.6 PHYSICAL EXAMINATIONS – X-RAYS

NIOSH is required to account for dose from medical X-rays performed on an EEOICPA-covered site (either the covered site where the AWE work was being performed or a covered site where medical X-rays were performed as a service). Simonds X-rays were performed off-site at a non-covered commercial facility (Tabershaw 1948). Therefore, the dose from medical X-rays does not need to be accounted for in the overall estimated dose calculation (ORAUT 2011).

## 2.7 SUMMARY ASSUMPTIONS: OPERATIONAL PERIOD, WORKDAYS, WORK HOURS, WORK CATEGORIES

Section 2.3 of this analysis assumes there were 156 days of uranium rolling per calendar year before 1954 and decreased substantially beginning January 1, 1954. Considering the uncertainty involved in the determination of the number of rolling days, the value used in the remainder of this analysis for the

period beginning on January 1, 1954 is assumed to be 20% of the period year's values (i.e. 31 per year). A summary of the number of rolling days per year is contained in Table 3. Table 4 lists the number of uranium rolling days and the number of nonrolling days for certain periods, which are based on the needs of subsequent analysis which will be presented later in this document. It was assumed that there were two work shifts of 10 hours each. It was assumed that operations in 1953 continued at the same level as those in 1952, although the available records indicate significant curtailment at the end of 1953.

Table 3. Number of assumed workdays per year.

| Period | Number of rolling days | Period | Number of rolling days |
|---|---|---|---|
| 02/24/1948 – 12/31/1948 | 130 | 01/01/1953 – 12/31/1953 | 31 |
| 01/01/1949 – 12/31/1949 | 156 | 01/01/1954 – 12/31/1954 | 31 |
| 01/01/1950 – 12/31/1950 | 156 | 01/01/1955 – 12/31/1955 | 31 |
| 01/01/1951 – 12/31/1951 | 156 | 01/01/1956 12/31/1956 | 31 |
| 01/01/1952 – 12/31/1952 | 156 | 01/01/1957 – 12/31/1957 | 31 |

Table 4. Number of assumed workdays and uranium-rolling days.

| Start | End | Rolling workdays | Non-rolling workdays | Workdays |
|---|---|---|---|---|
| 2/24/1948 | 12/1/1948 | 130 | 72 | 202 |
| 12/1/1948 | 4/5/1949 | 52 | 38 | 90 |
| 4/5/1949 | 4/13/1950 | 156 | 112 | 268 |
| 4/13/1950 | 1/1/1954 | 585 | 387 | 972 |
| 1/1/1954 | 1/1/1957 | 94 | 689 | 783 |

Mill workers whose duties involved or put them near the 10-in. and 16-in. bar rollers were likely to have the largest internal and external radiation exposures. Workers involved in experimental radioactive material forging were likely to have had large exposures for much shorter durations, and so it is reasonable to group them with the mill workers. The records made no mention of restricted access in any of the milling work areas, so although it is likely that workers not involved in uranium or thorium production processes had much lower exposures, the mill worker exposures were used to bound exposures for these other workers. This analysis did not divide Simonds workers into exposure categories.

While different tasks in the mill resulted in differences in exposures, it is evident from the records that the mill workers did not always perform the same tasks. Workgroup exposure assignments are based on data that are suggestive of worker exposures and further modified by uncertainty parameters to ensure that the reconstructed dose distributions capture the larger exposures. Depending on the organ of interest and the supplemental data associated with a specific claim, additional considerations might be appropriate.

## 2.8 CLEANUP AND THE RESIDUAL CONTAMINATION PERIOD

In November 1953, Blythe (1953) requested that arrangements be made for NLO to oversee the decontamination of Simonds. NLO raised a concern that additional thorium work could be requested within the next 6 months, but it appears that some cleanup could have taken place in late 1953 or early 1954. AEC-related work was performed at Simonds in April 1957 and final contract closure

occurred sometime in late 1957; therefore, the operational year was extended by 1 year to the end of 1957 (Leiton 2010).

The Formerly Utilized Sites Remedial Action Program (FUSRAP) began in 1976, and Simonds was revisited to determine if there was residual activity. DOE (1979) reported on a radiological survey in October 1976 to characterize the property for FUSRAP. At the time of the survey about 50 of the 450 people employed at the Simonds site worked in Buildings A (6 and 8) and B (3).

A radiological survey in October 1976 identified contamination (primarily $^{238}U$) in and around onsite buildings. (Uranium-238 is the predominant isotope by mass in natural uranium and is more easily identified than the other isotopes, so some records could refer to it as $^{238}U$ rather than natural uranium, which consists of approximately equal activities of $^{234}U$ and $^{238}U$ plus a smaller amount of $^{235}U$. Reported $^{238}U$ quantities could include all the uranium activity or just part, depending on actual analysis techniques and reporting procedures.)

Guterl Specialty Steel, who had bought Simonds, filed for bankruptcy in 1982 and closed its doors on May 1, 1983. Allegheny Ludlum purchased the site in 1984. The buildings used for uranium and thorium rolling and some others were in a fenced-off area referred to in a survey by the Oak Ridge Institute for Science and Education as the *excised area* (Vitkus 1999), and no work was being done there. Buildings 1, 2, 3, 4, 5, 6, 8, 9, and 35 are in the excised area. The building walls are brick and sheet-metal paneling, and the floors consist primarily of compacted dirt with some areas of concrete or brick. In 1999, the horizontal surfaces were found to contain excessive amounts of dust and debris. Buildings 6 and 8, where the rolling took place, had steel plates on the floor with dirt and cinders beneath. The majority of the equipment used during AEC work was still present in 1999. The buildings were isolated at the time of closing and exhibited leaking roofs, broken windows, and similar conditions. Although it is likely that the contaminated buildings/areas have remained inaccessible to Simonds site employees since May 1, 1983, this site profile assumes that residual contamination exposures could have occurred through the present.

A site remedial investigation was conducted under the direction of the U.S. Army Corp of Engineers starting in 2007 and completed in 2010 (USACE 2010).

## 3.0 ESTIMATION OF INTERNAL EXPOSURE

The primary sources of internal radiation exposure at Simonds were uranium and thorium dust produced from the manipulation and oxidation of the metals during rolling and related processes. In the early years, natural uranium was rolled. There is reference to some use of uranium enriched to 2.5% or less and to depleted uranium in the later years of AEC work.

The AEC measured particle sizes at Simonds using a “modified cascade impactor” (Spiegl et al. no date). The sampler was 3.5 ft from the floor and 4 ft from the uranium billet during roughing and finishing. The four mass median diameter distribution measurements ranged from 1.22 to 1.80 µm with indication that the values increased over time. The reported geometric standard deviation (GSD) of each measurement was about 2.5. When adjusted for density, these results are consistent with International Commission on Radiological Protection (ICRP) Publication 66 default parameters for particle deposition (ICRP 1994a), so dose reconstructions should assume ICRP Publication 66 defaults (including a 5-µm activity median aerodynamic diameter).

### 3.1 URANIUM

Human and animal studies have indicated that oxides of uranium can be very insoluble (ICRP 1995), which indicates absorption type S (0.1% and 99.9% with clearance half-times on the order of 10 minutes and 7,000 days, respectively). Other *in vitro* dissolution studies of compounds found at

uranium facilities have shown that oxides of uranium exhibit moderate solubility (Eidson 1994; Heffernan et al. 2001), which suggests absorption type M (10% and 90% with clearance half-times on the order of 10 minutes and 140 days, respectively). *In vitro* dissolution tests on oxides produced from uranium metal during depleted uranium armor penetrator tests have indicated multicomponent dissolution rates, with 25% of uranium dissolving with a half-time of less than or equal to 0.14 days and 75% dissolving with a half-time of 180 days. Because there was no specific information on the solubility of aerosols produced during operations, this analysis assumed that both types M and S were available. The selection of absorption type should depend on the organ of interest.

### 3.1.1 Uranium Bioassay

Individual uranium urinalysis data are available for some Simonds workers. Urine samples were not collected from all uranium workers at Simonds, so the lack of bioassay for an individual should not result in a conclusion of no internal exposure. The uranium urinalyses for Simonds workers range from 0 to 0.272 mg/L. AEC (1950, Table 4, footnote) notes that the 0.272-mg/L value from November 4, 1949, was obviously contaminated, but the only basis for this appears to be that the result was large. This analysis assumes that the 0.272-mg/L result was valid. The next largest result was 0.164 mg/L.

Many of the early samples were collected for understanding the relationship between exposures and urinalyses results. AEC (1949h) stated:

> *In order that some correlation could be obtained between uranium exposure of individuals in this area and the amount of uranium found in their urine, urine samples were obtained from 10 different individuals for 3 days before a rolling period, each day during the rolling period, and 4 samples taken twice weekly after the rolling had ceased.* [Urinalysis data that completely matched this quote have not been located.]

Although the AEC quote above indicates that multiple acute or short chronic intakes could best describe the exposures, the contamination of the workplace likely caused continual, albeit lower, intakes. Chronic exposure assumptions are used to fit the multiple intakes at Simonds.

The uranium fusion photofluorimetry urinalyses performed by the University of Rochester and the AEC NYOO were similar to those performed at other AEC facilities. The default detection threshold for uranium urinalysis is assumed to be 10 µg/L based on a reported sensitivity of 5 to 10 µg/L for uranium fluorimetry urinalysis in the early years (Wilson 1958). Several early Simonds bioassay reports noted that the results of less than 0.01 mg/L were insufficient for reliable detection (Author unknown 1948). A set of bioassay results dated November 4, 1949, includes the note, "Urines had to be treated with concentrated $HNO_3$" (AEC 1949i). No reason was given. Heatherton (1950a) thought the uranium urinalyses for August 14 and 28 were higher than usual, possibly because they were associated with workers from the second shift, which reportedly had less supervision (analysis errors, sample contamination, and high internal exposures several hours before preroll sample collections were also listed as possibilities for the elevated urinalyses). AEC noted that some results were collected before rolling and some were collected after rolling. About half of the geometric means (GMs) for urinalyses that appear to be before rolling are higher than the GMs for postrolling urinalyses. Information on the time that had elapsed after rolling and before a prerolling sample collection was not available. In addition, some postrolling samples might have been collected at the rolling day's end (i.e., at the very end of rolling, not after rolling).

For unmonitored workers or unmonitored periods, this Site Profile analyzes the bioassay results to provide estimates of coworker uranium intakes.

The first available bioassay samples for Simonds were dated November 1, 1948; urinalyses are reported fairly regularly through December 15, 1950. The last available set of sample results was reported for December 20 and 22, 1952. No specific incidents were associated with any of the samples. One worker, who reportedly had two embedded metal chips removed from his skin, had no bioassay results dated after the two incidents. Results for two people, who were listed on data sheets where the plant was listed as NYOO, were not included in the analysis; one person's result was listed as 0; the other results were associated with an NYOO employee who visited multiple AEC facilities. Results dated December 14 and 15, 1950, appeared to be parts of the same set, so were combined and assumed to all be dated December 14, 1950. The bioassay data used in the coworker exposure analysis are summarized in Attachment A. For each bioassay date, geometric means were estimated by ranking the data, determining the z-scores, and plotting the respective z-score versus the natural log of the data. A line was fit to the data, and e raised to the line's y-intercept value was assumed to be the GM and e raised to the slope value was assumed to be the GSD of the data. Results reported as zero were ranked, but used only indirectly in the fitting of the line. The 84th percentile was estimated as the GM multiplied by the GSD. Before November 17, 1949, the number of results for a given date ranged from 10 to 16. The statistical fit parameter ($R^2$) results averaged 0.86 and ranged from 0.65 to 0.96, and were considered adequate for this set of data.

The daily uranium excretion in urine was calculated by multiplying the results in milligrams per liter by reference man's daily urine output (1.4 L/d) (ICRP 1975). Attachment A shows the bioassay results used in the intake analyses. Table 5 summarizes the estimated geometric median, 84th percentile, and maximum uranium urinalyses used to derive intakes from three chronic inhalation intake regimes: February 24, 1948 to December 1, 1948; December 1, 1948 to December 15, 1950; and December 15, 1950 to December 31, 1956. Based on the limited information available in regards to the activities in 1957, the intake for that year was assumed to be equal to the prior year (1956). Graphs showing the fits of these intake regimes are shown in Attachment B. Additional intakes and alternate periods were tried, but fits were not more satisfactory than those chosen. When intakes are estimated from bioassay data, the mode of intake is usually assumed to be inhalation, unless there is information that indicates that other modes of intake are more likely. When using bioassay data, the inhalation intake model assumes that some of the intake behaves as ingested material. In general, intakes from bioassay will be larger when an inhalation rather than an ingestion intake is assumed.

The intakes were calculated with Integrated Modules for Bioassay Analysis (IMBA) Expert™ OCAS-Edition, Version 3.2.20, assuming an absolute uniform error of 1 and normal error distributions for each bioassay result. The GSDs for the intakes were calculated by dividing the intake from the 84th-percentile regime by the intake from the GM intake regime. Table 6 lists the inhalation intake distributions from the analyses of the Simonds uranium urinalysis data, assuming that either a type M or a type S (but not both) intake occurred. Intake rates are adjusted from milligrams/day to picocuries/day by multiplying by 682.91 pCi/mg.

The maximum GSD is rounded up to 3 and is used for all intake regimes. In addition, a factor is applied to the intake values to account for possible biases in data measurements and applicability of assumed intake regimes to coworkers; for example, an unmonitored worker might be better represented by the larger bioassay results. Because the analyses are being used in a compensation program, only a positive bias factor is applied. For Simonds, a bias factor of 2 is assumed for coworker intakes. The effect of the chosen bias factor is to move the calculated fit lines for the GMs up by a factor of 2, which results in most of the bioassay data being less than the adjusted fit line.

Table 5. Bioassay results from coworker data.[a]

| Bioassay date | GM bioassay (mg/L) | 84th-percentile bioassay (mg/L) | Maximum[b] bioassay (mg/L) |
|---|---|---|---|
| 11/1/1948 | 0.021 | 0.045 | 0.140 |
| 11/3/1948 | 0.022 | 0.042 | 0.090 |
| 11/4/1948 | 0.022 | 0.043 | 0.070 |
| 11/8/1948 | 0.011 | 0.018 | 0.030 |
| 11/11/1948 | 0.016 | 0.031 | 0.050 |
| 11/15/1948 | 0.016 | 0.035 | 0.050 |
| 1/6/1949 | 0.006 | 0.016 | 0.018 |
| 4/27/1949 | 0.017 | 0.028 | 0.036 |
| 11/4/1949 | 0.016 | 0.036 | 0.272 |
| 11/17/1949 | 0.001 | 0.010 | 0.164 |
| 1/6/1950 | 0.002 | 0.009 | 0.026 |
| 1/19/1950 | 0.010 | 0.024 | 0.035 |
| 5/15/1950 | 0.005 | 0.014 | 0.022 |
| 5/23/1950 | 0.008 | 0.019 | 0.034 |
| 8/14/1950 | 0.027 | 0.041 | 0.102 |
| 8/28/1950 | 0.016 | 0.022 | 0.033 |
| 9/23/1950 | 0.002 | 0.009 | 0.020 |
| 9/25/1950 | 0.011 | 0.018 | 0.024 |
| 10/20/1950 | 0.006 | 0.026 | 0.067 |
| 10/25/1950 | 0.005 | 0.016 | 0.043 |
| 11/9/1950 | 0.003 | 0.010 | 0.030 |
| 11/16/1950 | 0.005 | 0.014 | 0.028 |
| 12/14/1950 | 0.006 | 0.015 | 0.080 |
| 12/20/1952 | 0.016 | 0.035 | 0.066 |
| 12/22/1952 | 0.015 | 0.033 | 0.054 |

a. Multiply results in mg/L by 1.4 L/d to obtain results in milligrams/day for use in IMBA.
b. No one worker had maximum bioassay results.

Table 6. Inhalation intakes (mg/d) based on coworker data.[a]

| Start | End | Type | Intake rate | GSD (Type M) | Type | Intake rate | GSD (Type S) |
|---|---|---|---|---|---|---|---|
| 2/24/1948 | 12/1/1948 | M | 0.422 | 1.98 | S | 12.6 | 1.99 |
| 12/1/1948 | 12/15/1950 | M | 0.173 | 2.25 | S | 1.76 | 2.58 |
| 12/15/1950 | 12/31/1956 | M | 0.329 | 2.16 | S | 5.32 | 2.15 |

a. Section 3.3 details the implementation of these calculated intake rates, including consideration of exposures in 1957 and consideration of degradation of engineering controls during the post 1952 period.

### 3.1.2 Uranium Air Sampling

Air sampling was performed at Simonds during some of the uranium rolling campaigns (AEC 1948c,d, 1949d,e, 1950; Heatherton 1950a,b, 1951b; Klevin 1951; Klevin and Weinstein 1953a; Schumann 1953). The air samples consisted of collection on filters of radioactive particulate from breathing zones, general areas, processes, and effluents. AEC (1948c) states the general method of air sample collection and analysis:

> *The* [airborne] *radioactive dust samples were collected on 1-1/8-in. diameter Whatman #41 filter discs, using a standard Fischer pump employed by the Medical Division, NYOO, a Wilson pump, and a small, light, air compressor with a Universal motor. The rate of flow found to be most suitable for collection purposes at the concentration sampled was 0.0175 cubic meters per minute. The collection period varied from 30 seconds to 45 minutes, depending upon conditions of operation and dust loading. All dust samples collected were counted on a flat plate alpha counter at the New York*

*Health Instrument Laboratory. Attached to this report are the dust sample records, containing both general air and breathing zone samples which have been used in all calculations to evaluate the employees' exposure to radioactive dust.*

The alpha activity measured on the filter was used to determine airborne alpha activity concentrations. The AEC matched these air concentration determinations with information about worker categories, locations, tasks, and workers' time at each location or task. For some tasks and locations, multiple samples were collected; the mean count rate was calculated and used to calculate an average air concentration.

AEC used the information on work tasks with the measured air concentration to determine an average air concentration weighted by the exposure time and summed these average air concentrations to determine a daily time-weighted average air concentration for specified job categories. These air concentration results are further analyzed here to determine group GMs. The daily time-weighted average air concentrations were weighted further by the AEC-reported number of workers exposed at a given concentration. The GMs of the workgroups' daily time-weighted average air concentrations were calculated and used to derive the intake rates. The GSDs of the job category concentrations and the workgroup concentrations were determined to provide an indication of the distribution of the data (the latter GSD includes consideration of the number of people included in each category in the AEC study). This analysis assumed that, because the data are limited and rigorous analyses to determine distribution type are not likely to be meaningful, a lognormal distribution could represent the time-weighted exposures and the subsequently derived annual organ doses.

Table 7 lists the GMs and GSDs for the job category and the workgroups' daily time-weighted average air concentrations. In addition, the simplified estimated intake rates assumed from review of the air exposures over time are presented.

Table 7. Daily time-weighted average uranium air concentrations.

| | **Air sample collection dates** | | | | |
|---|---|---|---|---|---|
| | **10/27/1948** | **12/1/1948** | **1/10/1949** | **4/5/1949** | **5/2/1949** |
| Number of categories | 9 | 9 | 9 | 9 | 10 |
| GMs (dpm/m$^3$) | 1,977 | 860 | 523 | 263 | 226 |
| GSDs | 3.0 | 1.9 | 2.9 | 1.8 | 1.8 |
| Number of workers | 32 | 30 | 28 | 30 | 40 |
| GMs (dpm/m$^3$) | 1,842 | 853 | 455 | 266 | 256 |
| GSDs | 3.0 | 1.9 | 3.2 | 1.8 | 1.9 |
| Estimated air concentration (dpm/m$^3$) | 2,000 | 1,000 | 1,000 | 250 | 250 |
| | **1/9/1950** | **1/10/1950** | **4/13, 4/14, or 4/18 1950** | **5/17, 5/18, or 5/22 1950** | **8/14–16/1950** |
| Number of categories | 10 | 10 | 13 | 13 | 11 |
| GMs (dpm/m$^3$) | 190 | 180 | 90 | 75 | 96 |
| GSDs | 1.8 | 1.9 | 1.9 | 2.7 | 1.5 |
| Number of workers | 40 | 40 | 45 | 45 | 38 |
| GMs (dpm/m$^3$) | 205 | 199 | 88 | 82 | 89 |
| GSDs | 1.9 | 1.9 | 1.9 | 2.7 | 1.5 |
| Estimated air concentration (dpm/m$^3$) | 250 | 250 | 150 | 150 | 150 |
| | **1/9–10/1951** | **8/20–21/1951** | **1/1–31/1952** | **9/12/1952** | **1/4–21/1953** |
| Number of categories | 10 | 13 | 13 | 13 | 11 |
| GMs (dpm/m$^3$) | 161 | 97 | 96 | 129 | 141 |
| GSDs | 2.8 | 1.4 | 1.5 | 1.6 | 2.4 |
| Number of workers | 38 | 42 | 42 | 43 | 34 |
| GMs (dpm/m$^3$) | 161 | 100 | 94 | 125 | 138 |
| GSDs | 2.8 | 1.4 | 1.6 | 1.7 | 2.7 |
| Estimated air concentration (dpm/m$^3$) | 150 | 150 | 150 | 150 | 150 |

The air sampling reports show time-weighted air concentrations measured at the plant during rolling operations before and after improvements in processes, ventilation systems, and safety practices. As discussed in Section 2.4.2, exposure conditions were constantly changing but had a general downward trend in the early years.

A simplified but representative set of intake rates was determined by a graphing and estimating technique because there were 15 sets of natural uranium air concentration data and the workgroups' daily time-weighted average air concentration results were changing over time.

Figure 5 shows the GMs, maximums, and minimums of the workgroups daily time-weighted average air concentrations for the 15 air sampling periods. The numerical results and the graph were used to estimate periodic intake rates, which are summarized in Table 7 and shown on the graph as estimated weighted exposures. A GSD of 3.0 (the largest calculated GSD associated with the data) was assumed to calculate the 95th-percentile estimated air concentrations shown in Figure 5.

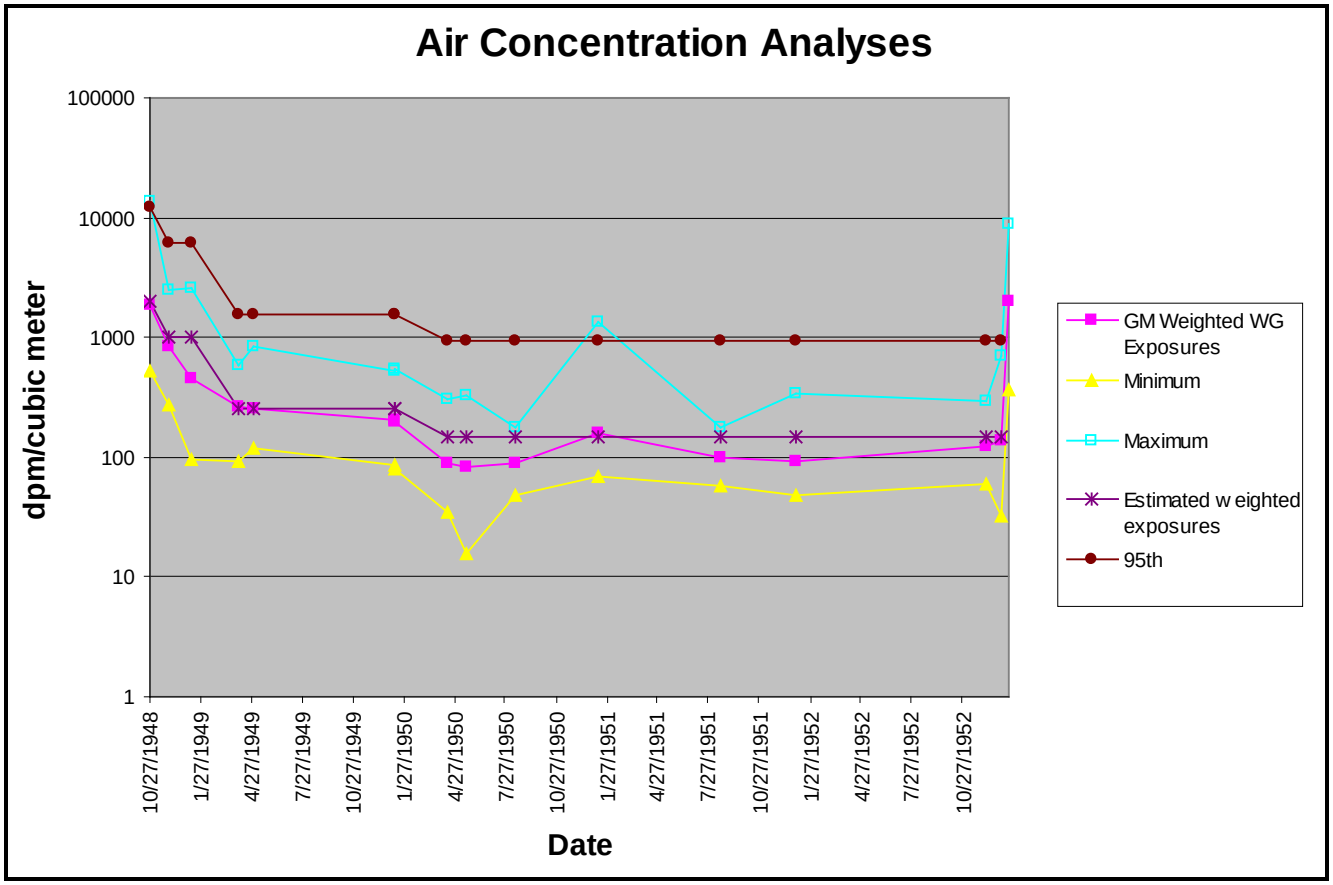


Figure 5. Workgroups' daily time-weighted average uranium air concentrations and estimated weighted exposures.

This analysis of intakes based on air concentrations assumed that uranium rolling took place between February 24, 1948, and December 31, 1957. Rolling was assumed to occur for 13 days of every month from February 24, 1948, to December 31, 1953, based on 312 turnings/year and double shifts. The time assumption for the later period – January 1, 1954, to December 31, 1957 – was reduced to 20% (as discussed in Section 2.7 above).

The breathing rate is based on the default for light work shown in ICRP Publication 66 (ICRP 1994a, Table 6, p. 23). Intakes in picocuries were calculated by dividing the estimated air concentration by 2.22 dpm/pCi and multiplying this result by the breathing rate and the assumed number of hours

exposed at the given concentration. Several assumptions included in the dose reconstruction are likely to be overestimating assumptions, which increase the estimate of the median intakes from air concentrations. Table 8 lists estimated annual inhalation intakes during rolling based on air concentrations.

Table 8. Uranium inhalation exposures during rolling operations.

| Work period | | Number of potential AEC workdays | Air concentration ($pCi/m^3$) | Breathing rate ($m^3/hr$) | Hr/workday | Intake (pCi) |
|---|---|---|---|---|---|---|
| 2/24/1948 | 12/1/1948 | 130 | 9.01E+02 | 1.2 | 10 | 1.41E+06 |
| 12/1/1948 | 4/5/1949 | 52 | 4.50E+02 | 1.2 | 10 | 2.81E+05 |
| 4/5/1949 | 4/13/1950 | 156 | 1.13E+02 | 1.2 | 10 | 2.11E+05 |
| 4/13/1950 | 1/1/1954 | 585 | 6.76E+01 | 1.2 | 10 | 4.74E+05 |
| 1/1/1954 | 12/31/1957 | 125 | 6.76E+01 | 1.2 | 10 | 1.02E+05 |
| **Total** | | | | | | **2.48E+06** |

There was a potential for internal exposure to resuspended material from the AEC work during non-AEC operations. To estimate exposure from resuspended materials, this analysis assumed that surfaces in the building became contaminated by deposition of uranium dust during rolling operations.

The level of contamination was determined by multiplying the air concentrations listed in Table 8 by the indoor deposition velocity and the assumed deposition time, which for uranium was 20 hours per rolling day. The indoor deposition velocity is dependent on the physical properties of the room (air viscosity and density, turbulence, thermal gradients, surface geometry, etc.). It is also dependent on the physical properties of the aerosol particles (such as diameter, shape, and density). These characteristics are not known, so the terminal settling velocity was calculated for an aerosol with the ICRP Publication 66 default particle size distribution of 5-µm activity median aerodynamic diameter (ICRP 1994a). The calculated terminal settling velocity was $7.5 \times 10^{-4}$ m/s, which is within the range of deposition velocities ($2.7 \times 10^{-6}$ to $2.7 \times 10^{-3}$ m/s) measured in various studies (NRC 2002).

The calculated surface contamination level created from airborne dusts during the uranium rolling from February 24, 1948, to December 31, 1957, was $1.11 \times 10^{7}$ $pCi/m^2$ (approximately 240,000 dpm/100 $cm^2$). The assumption was made that all the surface contamination was present for the entire period of AEC operations. Therefore, using a resuspension factor of $1 \times 10^{-6}$/m (Abu-Eid et al. 2002), the air concentration due to resuspension would have been 11.0 $pCi/m^3$. This value compares favorably with the air concentration of 25 $\mu g/m^3$ (17 $pCi/m^3$) reported by the AEC in 1950 during an extended period without rolling operations and with the assertion by AEC within that same document that it would be 'impractical to reduce the airborne uranium consistently below 15 $\mu g/m^3$ (10.2 $pCi/m^3$) (AEC 1950). Table 9 lists the assumed annual inhalation intake received from resuspension of deposited material. (Table 11 lists the intakes in Table 9 added to the intakes in Table 8.)

Table 9. Annual inhalation exposures during non-AEC operations from resuspension of deposited uranium dust.

| Work period | | Hr/ workday | Non-U rolling workdays per work period | Breathing rate ($m^3/hr$) | Resuspended air concentration ($pCi/m^3$) | Intake (pCi) |
|---|---|---|---|---|---|---|
| 2/24/1948 | 12/1/1948 | 10 | 72 | 1.2 | 11.0 | 9.52E+03 |
| 12/1/1948 | 4/5/1949 | 10 | 38 | 1.2 | 11.0 | 5.02E+03 |
| 4/5/1949 | 4/13/1950 | 10 | 112 | 1.2 | 11.0 | 1.48E+04 |
| 4/13/1950 | 1/1/1954 | 10 | 387 | 1.2 | 11.0 | 5.12E+04 |
| 1/1/1954 | 12/31/1957 | 10 | 919 | 1.2 | 11.0 | 1.21E+05 |
| **Total** | | | | | | **2.02E+05** |

When using air concentrations to calculate inhalation intakes, the dose reconstructor should also consider ingestion intakes. NIOSH (2004) states that the daily ingestion rate in picocuries can be estimated by multiplying the daily air concentration in picocuries per cubic meter by a factor of 0.2 for an 8-hour workday. For a 10-hour workday, the multiplier would be 0.223. The daily ingestion rates during AEC uranium work are estimates based on the air concentrations in Table 7. The daily ingestion intakes from resuspended uranium are estimates from Table 9. The ingestion intakes are then the sum of the products of the ingestion intake rates and the number of workdays exposed at the calculated levels. The ingestion intakes in Table 10 apply to all workers.

Table 10. Estimated amount of uranium ingested (pCi) (based on Tables 7 and 8).

| Work period | | U rolling workdays | U ingestion rate during uranium rolling (pCi/workday) | Non-U rolling workdays | U ingestion rate during normal operation (pCi/workday) | Intake (pCi) |
|---|---|---|---|---|---|---|
| 2/24/1948 | 12/1/1948 | 130 | 2.01E+02 | 72 | 2.46E+00 | 2.63E+04 |
| 12/1/1948 | 4/5/1949 | 52 | 1.01E+02 | 38 | 2.46E+00 | 5.32E+03 |
| 4/5/1949 | 4/13/1950 | 156 | 2.51E+01 | 112 | 2.46E+00 | 4.20E+03 |
| 4/13/1950 | 1/1/1954 | 585 | 1.51E+01 | 387 | 2.46E+00 | 9.77E+03 |
| 1/1/1954 | 12/31/1957 | 125 | 1.51E+01 | 919 | 2.46E+00 | 4.15E+03 |
| **Total** | | | | | | **4.97E+04** |

Estimated uranium intake rates based on air concentrations are listed in Table 11.

Table 11. Estimated uranium intake rates based on time-weighted air concentrations.

| Start | End | Intake route | Absorption type | Intake (pCi/d) |
|---|---|---|---|---|
| 2/24/1948 | 12/1/1948 | Inhalation | M, S | 5.04E+03 |
| 2/24/1948 | 12/1/1948 | Ingestion | (a) | 9.36E+01 |
| 12/1/1948 | 4/5/1949 | Inhalation | M, S | 2.29E+03 |
| 12/1/1948 | 4/5/1949 | Ingestion | (a) | 4.26E+01 |
| 4/5/1949 | 4/13/1950 | Inhalation | M, S | 6.05E+02 |
| 4/5/1949 | 4/13/1950 | Ingestion | (a) | 1.12E+01 |
| 4/13/1950 | 1/1/1954 | Inhalation | M,S | 3.87E+02 |
| 4/13/1950 | 1/1/1954 | Ingestion | (a) | 7.19E+00 |
| 1/1/1954 | 12/31/1957 | Inhalation | M, S | 1.53E+02 |
| 1/1/1954 | 12/31/1957 | Ingestion | (a) | 2.84E+00 |

a. Ingestion absorption type should be selected consistent with that for inhalation.

Periodically, Simonds Saw and Steel rolled enriched uranium and depleted uranium. The maximum enrichment of uranium processed at Simonds is unknown. Available documents indicate that uranium as high as 2.5% enrichment was processed (Keller 1979). However, Fernald had two standard operating procedures for rolling uranium at Simonds, one for up to 2.75% enrichment (Schlitz 1954) and another for up to 7.2% enrichment (Schlitz 1955). Air monitoring data associated with these activities are summarized in Tables 12 and 13. In the enriched uranium air study, a weighted exposure was calculated for the brief (80-minute) activity for the lowest- and highest-exposed individual. These were 0.9 MAC-days and 22.0 MAC-days for the South Side Rougher and North Side Stranner respectively (Heatherton 1953b). These exposure rates correspond to daily weighted activities of 5.3 MAC and 128 MAC respectively.

Forging operations using uranium were periodically conducted. Air sampling data for uranium forging operations conducted on April 18, 1950 and July 12, 1956 are summarized in Tables 14 and 15. The April 1950 survey is discussed in an AEC air monitoring report (Heatherton 1950b) which states:

*The forge-hammering operation was very dusty. Individual general air dust samples collected in the vicinity of the forging were from 76 to 260 times the preferred level. Samples collected in the breathing zones of men handling the billets with tongs were 220 to 400 times the preferred level.*

Table 12. Air concentrations during rolling – enriched uranium on 10″ mill.[a]

| Location | Air concentration (dpm/m$^3$) |
|---|---|
| **Breathing zone air concentrations** | |
| Foreman | 701 |
| Rougher, south side | 372 |
| Rougher, north side | 1,061 |
| Finisher, south side | 406 |
| Stranner, south side | 5,031 |
| Stranner, north side | 9,001 |
| Poke-in, north side | 2,061 |
| Straightener, north side | 6,081 |
| Straightener, run out | 8,011 |
| Rod stamper and straightener | 2,041 |
| **General area air concentrations** | |
| Behind rod straightener | 208 |
| Mill floor during cleanup | 300 |
| Mill floor during rolling | 2,867 |
| Rod area during rolling | 1,678 |
| Furnace area during rolling | 2,186 |
| Near bull head | 1,196 |
| 10 foot east of mill | 83 |

a. Source: Information for this table, including location descriptions, is from Heatherton (1953b).

Table 13. Air concentrations during rolling – molybdenum depleted uranium on 16″ mill.[a]

| Location | Air concentration (dpm/m$^3$) | | |
|---|---|---|---|
| | High | Low | Average |
| **Breathing zone air concentrations** | | | |
| Rougher, east side | 20 | 15 | 18 |
| Rougher, west side | 209 | 5 | 51 |
| Finisher, east side | 452 | 47 | 192 |
| Finisher, west side | 2,866 | 939 | 1,903 |
| **General area air concentrations** | | | |
| Weigh-in and furnace area | 440 | 106 | 297 |
| West side of mill | 193 | 16 | 58 |
| East side of mill | 460 | 122 | 336 |

a. Source: Information for this table, including location descriptions, is from Schumann (1953).

Table 14. Airborne uranium dust from forging – April 18, 1950.[a]

| Location/comment | Air concentration (dpm/m$^3$) |
|---|---|
| **General area** | |
| Three feet above<br>5” billet forged to 1 15/16” | 7,600<br>5,200<br>6,400<br>12,000 |
| Forging 2 billets | 13,000<br>3,800 |
| **Breathing zone** | |
| Operator, east side forge | 11,000 |
| Tong man, east side of forge | 20,000 |

a. Source: Information for this table, including location/comment descriptions, is from Air and Urine Data (1949–1954, pdf pp. 58-60).

Table 15. Airborne uranium dust from forging – July 12, 1954.[a]

| Location/comment | Air concentration (dpm/m$^3$) |
|---|---|
| **General area** | |
| Hammer, south | 140<br>1,600<br>820<br>870<br>220 |
| East of 7 ton hammer, between hammer and furnace | 630 |
| 35 feet SEE of press | 100 |
| 35 feet from hammer (lunch) | 1100<br>990<br>850 |
| Bench (lunch area), north | 100 |
| Bench, SW of hammer ( lunch) | 27 |
| Lunch area, SSW hammer | 48 |
| 15 feet SW of hammer | 160 |
| 20 feet SW of hammer | 43 |
| 1 foot south of 7 ton | 2,100<br>10,000 |
| SE of 7 ton | 15,000 |
| 6 feet | 180 |
| 5 feet | 72 |
| **Breathing zone** | |
| Hammer operating position downward | 310<br>270<br>500 |
| Charg. atop unit | 240<br>370<br>400 |
| NW corner of hammer-2 ingots | 1,900<br>3,500 |
| Around hammer | 8,300<br>29,000<br>3,600<br>650 |
| Opening furnace door, removing ingot | 4,500 |

| Location/comment | Air concentration ($dpm/m^3$) |
|---|---|
| SW of 7 ton hammer | 5,600<br>6,000<br>2,200 |
| NE of 7 ton hammer | 730<br>770<br>950<br>4,000 |

a. Source: Information for this table, including location/comment descriptions, is from Air and Urine Data (1949–1954, pdf pp. 145-148).

Documentation of an April 1956 hammer-forging operation did not contain any monitoring data. However, it did provide the following descriptive information (Magoun and Yocco 1956):

> *No salt or other coolant or oxidation inhibitor was used in this operation. Because of this, appreciable amounts of uranium oxide were formed on the slabs and thrown into the surrounding air by the heavy blows of the forge hammer. The operating personnel in the area were protected by respirators during the time the forging hammer was in use.*

### 3.1.3 Comparison of Uranium Bioassay and Air Concentration Estimates

Summary estimates of uranium intakes (unadjusted for bias) shown in Section 3.3 are based on Simonds workers' bioassay data. The estimates of intakes from air concentrations, which started high, decreased over time, and then leveled, tend to confirm the time pattern of intake from bioassay. The limited bioassay data indicate that the exposure rate might have increased in later years. The operational data and the air data neither confirm nor deny the increased intake rate determined for bioassay data in later years. There is indication that the throughput decreased significantly in later years, but this is offset both by the processing of some enriched uranium with its higher specific activity (radioactivity per unit mass) and the reportedly reduced use of safety equipment, such as local ventilation.

Differences in the values of intake estimates from air and bioassay data are likely due to a multitude of factors, but the more significant factors are the assumptions regarding the time patterns of intakes and the absorption types of the material. For interpretation of the air and bioassay data, intake pattern assumptions were simplified based on the limited information. If the time patterns of intake are assumed reasonable, it appears reasonable to conclude that workers were not exposed to a source term that was clearly pure type M or pure type S.

Graphs in Attachment B show how predicted urinalysis results from air concentrations compare to coworker bioassay data. Graphs also show the fits of the coworker data used to obtain the three chronic uranium intakes summarized in Table 17.

### 3.1.4 Depleted, Enriched, and Recycled Uranium

Records for Simonds indicate that small quantities of depleted and enriched (up to 2.5% by mass) uranium were processed after 1951. Because the Simonds air samples were counted either with parallel-plate alpha counters or with alpha scintillation detectors, which detect radioactivity rather than mass, there is no need to adjust measured air concentration results for assumed uranium enrichment or depletion, even when the results were reported in micrograms per cubic meter.

Enrichment or depletion would affect assumptions about the radioactivity in the mass of the uranium released or measured because of differences in specific activities (activity per mass). Because this

increase or reduction is no more than a factor of 3 for these limited processing campaigns, and because more than 99% of the material was natural uranium, this analysis makes no adjustment for specific activity. However, because of the unknown enrichment for a given period and the unknown fraction of enriched material processed for a given period, this document assumes that intakes calculated from air data are $^{234}U$ for the purpose of calculating internal organ doses.

Heatherton (1953b) reported the results for an air sampling survey during enriched uranium rolling on January 17, 1953, at the 10-in. bar mill. The operation lasted for 80 minutes (versus the typical 8 to 10 hours). The GM concentration for 80 minutes was about 2,000 dpm/$m^3$ with a GSD of 3.0 (this is shown in Figure 5 as the last air sample). In reality, the actual worker exposure would have been lower by about a factor of 6, giving a daily weighted concentration of 330 dpm/$m^3$. Heatherton (1953b) noted that there was no ventilation at the 10-in. bar mill and that air dust respirators were worn by all mill workers at the time of the survey. Ventilation was recommended for any future work on the 10-in. bar mill. Because the number of uranium rolling days in 1953 was estimated to continue at 156 days (versus the estimated 15 days calculated in Section 2), it is believed that there is a sufficiently large overestimate of intake to not adjust intake rates for this work. For later years, where 28, 29, and 11 days of rolling are assumed and 31.2 is used in the intake calculations, the margin is not as large, but it is also likely that smaller runs were being made during this period that might not have consumed two full operating shifts per day.

Recycled uranium might have been processed at Simonds after 1952. An estimate of contaminants that might contribute the most to internal doses, based on a review of recycled uranium contaminants at the Hanford and Fernald sites, is shown in Table 16. It is unlikely that recycled uranium would constitute the entire Simonds source term. The activity fractions are based on the specific activity of depleted uranium, which increases the proportion of the contaminants by activity. The contaminant levels for depleted uranium overestimate the contaminants in uranium of normal enrichment by about 40%. The contaminants are assumed to be in the form of oxides.

Table 16. Estimate of contaminant activity fractions in a recycled depleted uranium source term (pCi contaminant per pCi uranium).

| Uranium | Np-237 | Pu-239 | Tc-99 |
|---|---|---|---|
| 1 | 0.00182 | 0.00261 | 0.379 |

## 3.2 THORIUM

NIOSH has determined, and the Secretary, Health and Human Services has concurred, that it is not feasible to reconstruct internal radiation dose from exposure to thorium for individuals who worked at Simonds Saw and Steel during the operational period (HHS 2011).

## 3.3 OCCUPATIONAL INTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

The assumed uranium photofluorimetry urinalysis detection threshold is 10 µg/L. Uranium is assumed to be of natural enrichment, although small amounts of both depleted and 2.5% enriched uranium were rolled after 1951. The recycled uranium contaminants should be accounted for after 1952 using the activity fractions in Table 16. Uranium oxides can be either absorption type M or S. Neptunium oxides are type M. Plutonium oxides are assumed to be type M or S.

The assumed operational exposure period is from February 24, 1948, to December 31, 1957, which this analysis assumes to be the uranium intake period. The period January 01, 1957 through December 31, 1957 was added in accordance with the findings of the Special Exposure Cohort Evaluation Report (NIOSH 2010b). The uranium intake during this period is assumed to be equal to that in the preceding year. For unmonitored workers or unmonitored periods, Table 17 lists intake

rate assumptions for natural uranium and thorium along with GSDs. The intake mode is chronic. The dose distribution is assumed to be lognormal with a geometric standard deviation of 3. Intake rates are based on the data shown in Table 6, however, to account for the degradation in engineering controls (as noted in Section 2.4.1), intake rates for the post 1952 period were set equal to those calculated for the initial 1948 time frame. Additionally, the intake rates for 1957 are set equal to those in 1956. Use of the 1948 data allows for the potential for elevated intakes which would not have been reflected in the available bioassay dataset (which ends in 1952) since during this initial period operations were conducted without engineering controls. Intakes shown in Table 17 may be applied to uranium workers in the 10 inch mill and forge area for this same reason.

## 4.0 ESTIMATION OF EXTERNAL EXPOSURE

Individual external dosimetry results for Simonds consist of doses reported for 20 workers for the period from October 11 to 19, 1949 (AEC 1949c). A limited exposure period of less than 2 weeks might not be representative of exposures received during the 9 years of AEC operations at Simonds, so external doses based on supplementary data are provided.

Table 17. Internal exposure summary for operational period February 24, 1948, to December 31, 1957.

| Radionuclide | Start | End | Intake route | Absorption type | Intake (pCi/d) | GSD |
|---|---|---|---|---|---|---|
| U-234[c] Choose M or S intake scenario, not both. | 2/24/1948 | 12/1/1948 | Inhalation | M | 5.76E+02 | 3.0 |
| | 12/1/1948 | 12/15/1950 | Inhalation | M | 2.36E+02 | 3.0 |
| | 12/15/1950 | 12/31/1952[a] | Inhalation | M | 4.49E+02 | 3.0 |
| | 1/01/1953 | 12/1/1957[a] | Inhalation | M | 5.76E+02 | 3.0 |
| | 2/24/1948 | 12/1/1948 | Inhalation | S | 1.72E+04 | 3.0 |
| | 12/1/1948 | 12/15/1950 | Inhalation | S | 2.40E+03 | 3.0 |
| | 12/15/1950 | 12/31/1952[a] | Inhalation | S | 7.26E+03 | 3.0 |
| | 1/1/1953 | 12/31/1957[a,b] | Inhalation | S | 1.72E+04 | 3.0 |
| Np-237 | 1/1/1953 | 12/31/1957[b] | Inhalation | M, if U is M | 1.05E+00 | 3.0 |
| | 1/1/1953 | 12/31/1957[b] | Inhalation | M, if U is S | 3.13E+01 | 3.0 |
| Pu-239 | 1/1/1953 | 12/31/1957[b] | Inhalation | M, if U is M | 1.50E+00 | 3.0 |
| | 1/1/1953 | 12/31/1957[b] | Inhalation | S, if U is S | 4.50E+01 | 3.0 |

a. Intake rates post 1952 were set to those calculated in the initial, 1948 period, in order to account for the reduced use of engineering controls and lack of bioassay data for this later period.
b. Intake rates for 1957 were set equal to those calculate for 1956.
c. If individual bioassay data is available, it should be used instead of the intakes shown which are based on coworker assessment.

For dose reconstruction, when individual film badge data are not available or adequate to assign dose, this analysis provides dose estimated with the assumption that there was a potential for external exposure to natural uranium metal from five sources:

- Submersion in air contaminated with uranium dust
- Exposure from contaminated surfaces
- Exposure to electrons from the surface of the uranium billets and rods
- Exposure to photons from the uranium billets and rods
- Exposure to occupationally required medical X-ray

The majority of photons from natural uranium metals have energies in the range of 30 to 250 keV. Solid uranium objects provide considerable shielding of the lower energy photons and harden the spectrum, which causes the majority of photons emitted from a solid uranium object, such as a billet or a rod, to have energies greater than 250 keV. While solid uranium sources have a hardened photon spectrum, exposure to a thin layer of uranium on a surface results in a larger fraction of

exposure to lower energy photons. This analysis assumed workers were exposed to photon energies in the 30-to-250-keV range, which is favorable to claimants. Nonpenetrating dose from natural uranium consists primarily of electrons with energies above 15 keV. For consistent presentation, exposure or dose is reported as:

- Penetrating, assumed to be associated with photons of energies 30 – 250 keV, and
- Nonpenetrating, assumed to be associated with electrons or energy > 15 keV.

The majority of photons from thorium metals have energies greater than 250 keV, and the solid matrix of billets and rods serves to harden the radiation energy spectrum. However, for the purpose of expediting dose reconstruction, the favorable to claimant assumption is made that workers were exposed to photon energies from 30 to 250 keV.

**Summary of Available Individual Film Badge Data**
AEC (1949c) issued 21 film badges to Simonds workers for the period from October 11 to 19, 1949. One of the badges was lost, so only 20 results were reported. No information was available to indicate when the workers actually wore the badges or where the badges were stored during off hours. The beta results ranged from 160 to 1,250 mR for the period, and both the calculated and derived GMs were 362 with a GSD of 1.6. The gamma results ranged from not reported (less than 50 mR) to 115 mR, and the derived GM and GSD for the set were 63 mR and 1.4, respectively. The calculated GM of the positive gamma results was 73 mR. A quick scoping calculation, which assumed that the badges were worn for 9 uranium rolling workdays and that there were 156 uranium rolling workdays per year, indicated annual beta and gamma doses of 6.3 and 1.1 R, respectively. Assumptions about the length of exposure periods and exposure of the badge while not in use can increase or reduce this scoping value by a factor of about 3.

External exposure estimates summarized in Table 20 in Section 4.4 based on consideration of source term and workplace information are consistent with the limited film badge data. For a 156-day uranium rolling year, Table 20 assumed the annual nonpenetrating exposure is 8.7 R and the assumed annual penetrating exposure is 1.2 R.

## 4.1 SUBMERSION AND CONTAMINATION EXPOSURES

AEC suspended 20 film badges about 5 ft from the floor in the Simonds rolling mill for 192 consecutive hours “to determine the long term direct [external] radiation to individuals” (AEC 1949h). When the badges were retrieved, they were covered with radioactive dust from the plant, which would probably result in an overestimate of the true area radiation levels. The maximum results were reported as 5.6 mR/hr beta and 0.34 mR/hr gamma. This analysis assumed (1) that these results represented the general levels of external exposure from submersion in air and contaminated surfaces at Simonds and (2) that the data distribution was lognormal. The calculated GMs were 1.3 mR/hr with a GSD of 2.3 for nonpenetrating radiation and 0.26 mR/hr with a GSD of 1.2 for penetrating radiation. This assumption does not appear to be inconsistent with the reported Zeuto (portable ionization chamber) beta and gamma readings at Simonds of 2 mR/hr or less for most areas (AEC 1949h), some of which appear to be contact readings. The analysis assumed that the beta reading relates to the nonpenetrating dose and that the gamma reading relates to the penetrating dose. (Table 20 in Section 4.4 lists these assumed exposures during operational years.) This analysis assumed that all workers were exposed to penetrating and nonpenetrating radiation from submersion in air and contamination for 10 hours each workday.

## 4.2 BILLET AND ROD EXPOSURES

Another assumption was that workers received a deep dose due to photon exposure from the uranium billets and rods. The AEC work involved rolling uranium billets of 4- to 5-in. diameters and 15 to 28 in.

long. The billets were rolled into rods 20 ft long of approximately 1.5-in. diameter (Smith 1951). Monte Carlo *n*-particle (MCNP) calculations determined the photon (including bremsstrahlung) dose rate at the surface, 1 ft, and 1 m from a 5-in.-diameter by 28-in.-long cylindrical billet and a 1.405-in.-diameter by 20-ft-long rod. Table 18 lists calculated photon dose rates for the uranium billet and rod (Battelle 2006).

Table 18. Calculated photon dose rate for uranium billet and uranium rod (mrem/hr).

| Distance from source | Billet dose rate | Rod dose rate |
|---|---|---|
| Surface | 7.74 | 5.09 |
| 1 ft | 0.703 | 0.285 |
| 1 m | 0.108 | 0.0883 |

Several air exposure records were reviewed to estimate a worker's time near a billet or rod versus being in the general area. The records indicated that for most workers the time near the uranium billet or rod was less than 5 hr/shift, but some workers could have spent 6.5 hours near the rods and billets. Because workers changed jobs, this analysis assumed that workers were near the billets for 3.5 hr/rolling day and near the rods for 3.5 hr/rolling day. It also assumed that the dose rate at 1 ft was the median dose rate, and the dose rate at the surface was the 95th-percentile rate. The annual penetrating dose rates in Table 20 (Section 4.4) were calculated by multiplying the median photon dose rates by the number of rolling days per year and the 3.5 hours per workday near the billets or the rods.

Shallow doses from the billets and rods were estimated using the measurements in Table 19. The units of measure were reported based on the rep (roentgen equivalent physical), which is a historical unit of dose equivalence approximately equal to a rem. These measurements were taken during an AEC survey in September 1948 (Belmore 1948) at Aliquippa Forge. Radiation measurements at Simonds appear to have been similar, although in general the proximity of the Simonds radiation measurement to the source is not included. However, in April 1948, Hayden (1948a) reported measurements as low as background, 0.1 mrep/hr, up to 40 mrep/hr at 8 in. from a rod storage pile. Direct beta readings were reported as 12 mrep/hr at 2 ft above an unswept steel floor and 4 mrep/hr after sweeping. Measurements taken at 2 in. from the floor dust indicated 20-mrep/hr beta radiation. In May 1948, Hayden (1948b) reported the maximum exposure rate near the rod cooling area as 0.16 mrep/hr and the radiation from the bottom of the quench tank as 25 and 8 mrep/hr at 6 in. and 2 ft, respectively. Reported radiation levels at various Simonds locations ranged from 0.5 to 12 mrep/hr in October 1948 and from 0.5 to 15 mrep/hr in December 1948 (AEC 1949h). In August 1950, Heatherton (1950a) reported radiation levels of 1 mrep/hr within 1 to 50 ft of the Simonds rolls, with a maximum of 10 mrep/hr.

Table 19. Direct radiation measurements from September 1948 (mrep/hr).[a]

| Location of measurement | Dose rate |
|---|---|
| **Billet assumptions** | |
| Contact with floor next to the quench tank where oxide scale has collected | 8 |
| Contact with floor in front of rolls where oxide scale has collected | 5-10 |
| Same location but 18 in. high | 2-5 |
| **Rod assumptions** | |
| 4 ft above a pile of rods in the boxcar | 20 |
| 5 ft from the end of a pile of rods next to the door of the boxcar | 5 |
| 2 ft from the end of the same pile | 13 |

a. Belmore (1948).

This analysis estimated the shallow dose from billets by assuming that the median dose rate was 5 mrem/hr and that the 95th-percentile dose rate was 10 mrem/hr, giving a GSD of 1.5. For rods, the

assumed median dose rate was 5 mrem/hr, and the assumed 95th-percentile dose rate was 20 mrem/hr, giving a GSD of 2.3. These exposure rates were multiplied by the assumed number of hours per workday near the rods or billets (3.5 hours) and by the number of uranium rolling days in the period. Table 20 (Section 4.4) lists the annual doses.

## 4.3 MISCELLANEOUS INFORMATION ABOUT EXTERNAL DOSE

This section includes external dose information that could be of value for specific dose reconstructions. This analysis did not consider such information generically because of its limited applicability or because of limited details.

AEC noted repeated instances of exposure to particles or chips of radioactive material, including stinging particles on the hands and face near the descaler (AEC 1949d) and chips of material imbedded in the skin from work in the rod stamping area (AEC 1951b; Heatherton 1951a). Consideration of exposure due to such materials should consider guidance contained in *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT 2005).

## 4.4 OCCUPATIONAL EXTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

Table 20 summarizes occupational external doses during uranium operations at Simonds.

Table 20. External exposure summary for February 24, 1948, to December 31, 1957.

| Exposure mode | Exposure type | Exposure or dose rate | Basis | Assumed exposure time | Year | Annual exposure | IREP distribution |
|---|---|---|---|---|---|---|---|
| Submersion/ area contamination | Penetrating | 0.26 mR/ hr | Film badge | 2,500 workhours/ yr | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957[a] | 0.582 R<br>0.650 R<br>0.650 R<br>0.650 R<br>0.650 R<br>0.650 R<br>0.650 R<br>0.650 R<br>0.650 R<br>0.650 R | Lognormal GSD 1.2 |
| | Nonpenetrating | 1.3 mR/hr | Film badge | 2,500 workhours/ yr | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957[a] | 2.912 R<br>3.250 R<br>3.250 R<br>3.250 R<br>3.250 R<br>3.250 R<br>3.250 R<br>3.250 R<br>3.250 R<br>3.250 R | Lognormal GSD 2.3 |
| Medical X-ray | | | | | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957 | Not assigned | |

| Exposure mode | Exposure type | Exposure or dose rate | Basis | Assumed exposure time | Year | Annual exposure | IREP distribution |
|---|---|---|---|---|---|---|---|
| U billets | Penetrating | 0.703 mrem/hr | MCNP calculation | 3.5 hr/ rolling day | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957[a] | 0.352 rem<br>0.384 rem<br>0.384 rem<br>0.384 rem<br>0.384 rem<br>0.384 rem<br>0.076 rem<br>0.076 rem<br>0.076 rem<br>0.076 rem | Lognormal GSD 4.3 |
| | Nonpenetrating | 5 mrep/hr | Instrument measurement | 3.5 hr/ rolling day | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957[a] | 2.503 rep<br>2.730 rep<br>2.730 rep<br>2.730 rep<br>2.730 rep<br>2.730 rep<br>0.543 rep<br>0.543 rep<br>0.543 rep<br>0.543 rep | Lognormal GSD 1.5 |
| U rods | Penetrating | 0.285 mrem/hr | MCNP calculation | 3.5 hr/ rolling day | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957[a] | 0.143 rem<br>0.156 rem<br>0.156 rem<br>0.156 rem<br>0.156 rem<br>0.156 rem<br>0.031 rem<br>0.031 rem<br>0.031 rem<br>0.031 rem | Lognormal GSD 5.7 |
| | Nonpenetrating | 5 mrem/hr | Instrument measurement | 3.5 hr/ rolling day | 1948<br>1949<br>1950<br>1951<br>1952<br>1953<br>1954<br>1955<br>1956<br>1957[a] | 2.503 rep<br>2.730 rep<br>2.730 rep<br>2.730 rep<br>2.730 rep<br>2.730 rep<br>0.543 rep<br>0.543 rep<br>0.543 rep<br>0.543 rep | Lognormal GSD 2.3 |

a. 1957 exposure values assumed to be the same as those for 1956.

## 5.0 ESTIMATION OF RESIDUAL EXPOSURE

This analysis assumed that the Simonds residual dose period began on January 1, 1958 (at the end of uranium operations) and continued through the present. An 8-hour workday was assumed for this period.

Before AEC uranium and thorium operations ended at Simonds, some cleanup was planned and perhaps performed. In November 1953, Blythe (1953) requested that arrangements be made for NLO to oversee the decontamination of Simonds. Simonds agreed to have six to eight workers for this work, which was to be scheduled on a weekend so it would not interfere with the rolling schedule (Heatherton 1953a). NLO raised a concern that additional thorium work could be requested within the next 6 months. AEC rolling did occur thereafter.

After the Simonds AEC contract work ended, NLO surveyed Simonds in July 1957 to see the effectiveness of decontamination efforts (Heatherton 1957); Table 21 summarizes the results. On July 10, 1957, the forge area, the 16-in. bar mill, the 10-in. strip metal area, and the shipping and receiving areas were surveyed. All of these areas were found to be slightly above background, but at 3 ft about the floor only two small areas exceeded 0.2 mrep/hr beta/gamma. Most contact readings were less than 0.5 mrep/hr (Heatherton 1957) and, while some contamination was found in inaccessible areas, it was estimated that a man would be exposed to less than 10 mrep/week.

Nuclear Science and Engineering Corporation and Carborundum Metals performed surveys in late 1958. The November 1958 survey results do not appear meaningful or consistent with earlier results (Glitzer 1958a). Alpha air activity was reported as 0 dpm with no indication of the air volume collected. The beta air activity was reported as 0 to 2.8 dpm. Smear samples were mostly less than 20 dpm except in the vicinities of the rollers and quenching areas, where the maximum removable activity appeared to be about 42 dpm and the maximum beta activity was 114.4 dpm. A second set of survey results dated 13 days later showed a maximum removable alpha activity of 404 dpm. A review

Table 21. Measured radiation levels on July 10, 1957.[a]

| Location | Contact (mrep/hr) beta/gamma | Beta (mrep/hr) 3 ft from surface | Gamma (mR/hr) 3 ft from surface |
|---|---|---|---|
| 10-in. bar mill bed | 10 to 20 | 1.0 to 1.7 | 0.04 to 0.05 |
| Front of shear | 1 to 2 | 0.4 | 0.08 |
| Between plates on mill floor | 0.15 | 0.05 | None detected |
| Forge area | 0.7 to 1.2 | 0.2 | 0.02 |
| Top of furnace | 1.0 | No reading | No reading |

a. Heatherton (1957).

of the data indicates that the alpha counting efficiency was lower than the beta counting efficiency. A single soil result, which is not very legible, appears to be reported as 39 mg uranium/gram of soil. After the November 1958 survey, the quench tank was removed and clean steel was placed over the floor (Author unknown, no date b). Smear samples collected by Carborundum Metals on December 12, 1958, were less than 10 dpm alpha and less than 25 dpm beta in the former quenching area (Glitzer 1958b).

ORNL performed a radiological survey in October 1976 to characterize the former Simonds site for FUSRAP (Author unknown, no date c). Removable contamination was not deemed excessive, but radiation exposures of greater than 1 mrad/hr beta/gamma were measured and $^{238}$U soil concentrations were about 21,000 pCi/g under the floor plates. Two soil samples were analyzed isotopically to check for enriched uranium (DOE 1979); the ratios were consistent with natural, not enriched, uranium.

Simonds received essentially pure uranium and thorium metal (no radium) for processing. This is confirmed by the DOE (1979) survey, which reported two radon results of less than 0.4 pCi/L and two measurements to evaluate radon progeny with results of less than 0.001 Working Levels. Assuming 100% equilibrium of the progeny (a maximizing assumption) gave results of all four samples within the normal range of atmospheric radon concentration of 0.1 to 0.5 pCi/L (Eisenbud 1987). Soil concentrations of $^{226}$Ra were equivalent to background concentrations. The largest soil concentration of $^{232}$Th was 11 pCi/g, and 22 of 25 thorium soil samples had concentrations of less than 3 pCi/g. It was noted that $^{238}$U concentrations were at least 100 times the $^{228}$Th concentration, which was assumed to be in equilibrium with $^{232}$Th.

The largest directly measured alpha contamination from DOE (1979) was 4,600 dpm/100 cm$^2$. Beta/gamma levels measured within 40 ft of the 16-in. rolling mill were above 1.0 mrad/hr. On the 16-in. rolling mill, the beta/gamma dose rates were as high as 3.5 mrad/hr. The highest external

gamma level was 0.048 mR/hr at 1 m above the floor in the rolling mill and in the forge shop (Author unknown, no date a).

"On February 7, 1980, DOE determined that the Simonds Steel Division site required consideration for remedial action" (Author unknown, no date c). Guterl Specialty Steel filed for Chapter 11 protection in August 1982 (Author unknown, no date c). The Simonds Steel metal-rolling operation was closed on May 1, 1983 (Author unknown, no date d.). Allegheny International purchased the site in March 1984 (Author unknown, no date c). Although it is very unlikely that residual exposure occurred to site employees after May 1983, the contamination was still present, and this site profile assumes that exposure to residual radioactivity could have continued to occur.

As part of the remedial investigation completed in 2007, a detailed survey was performed of the entire Simonds Saw and Steel facility. Surface contamination measurements performed during this investigation were used to derive Exposure Point Concentration (EPC) values to be used in exposure and risk assessment studies. The EPC values represent 95% upper confidence limit values for each particular parameter reported. Table 22 presents a summary of the EPC values calculated for surface contamination.

Table 22. Exposure point concentrations for surface contamination measurements (beta) (dpm/100 $cm^2$).

| Building | Maximum | Average | EPC value |
|---|---|---|---|
| 1 | 21,000 | 300 | 600 |
| 2 | 140,100 | 200 | 400 |
| 3 | 145,900 | 3,500 | 4,600 |
| 4/9 | 30,700 | 1,100 | 1,300 |
| 5 | 2,200 | 1,000 | 1,200 |
| 8 | 58,300 | 2,600 | 6,800 |
| 24 | 124,200 | 5,400 | 9,300 |
| 35 | 2,800 | 300 | 400 |

Internal exposure during the residual period can be bounded using the methodology in ORAUT-OTIB-0070 (ORAUT 2008). In this methodology, air concentrations at the beginning and end of a period are used with an assumption of an exponential relationship to calculate exposure rates for intervening periods.

The average of general area air sample results reported during air monitoring studies conducted between 1949 and 1953 was used as an estimate of the air concentration at the start of the residual period (AEC 1948c,d, 1949d,e,h, 1950; Heatherton 1950a,b, 1951b, 1953b; Klevin 1951; Klevin and Weinstein 1953a,b). This value was 94 $\mu g/m^3$. This air concentration, which corresponds to an intake rate of 422 pCi/calendar day, would represent an upper bound of the level of airborne contamination present at the cessation of operations, which corresponds to the beginning of the residual period.

EPC values calculated for each of the Simonds buildings (see Table 22) can be used to establish a bounding estimate of the air activity at the time of these measurements (i.e. 2007). The maximum EPC value of 9,300 dpm/100 $cm^2$, applicable to Building 24, can be used to represent the bounding surface contamination present in the facility for performing these resuspension calculations. Using a resuspension factor of $1 \times 10^{-6}$, and assuming that the total uranium surface activity is 1.93 times the total beta value, an intake rate of 5.5 pCi/calendar day would correspond to the 9,300-dpm/100-$cm^2$ surface contamination level. The $1 \times 10^{-6}$ resuspension factor is bounding given that the measured surface contamination levels represent total activity and the amount of removable contamination is a very small fraction of that value.

The intake rates indicated above were used to calculate an exponential rate constant relating the two values, separated by a period of 24 years (1958 to 1982) based on the assumption that the source term would have stayed relatively constant from 1982 (when the facility ceased operations) until the time of the measurements. After 1982, intake rates are assumed to remain constant. This constant is calculated as 0.18/yr and is used to adjust the intake rates in Table 23 to account for the reduction in the intake rate over time.

Consideration of exposure to thorium dust could be included based on the relative fraction of thorium in the process material of 1%. This activity fraction is used to calculate the thorium intakes listed in Table 23. Internal exposure from ingestion would be bounded based on the calculated inhalation intake using the methodology in OCAS-TIB-009 (NIOSH 2004). The contribution from recycled uranium contaminants can be bounded based on the uranium intake and using the nuclide ratios provided in Table 13.

To reconstruct external exposure to residual radioactivity after the end of AEC operations, this analysis assumed that workers were exposed to 0.08 mR/hr penetrating radiation, which was the upper end of the gamma exposure rate readings at 1 m in 1957. The residual penetrating radiation exposure was estimated by assuming that 0.08 mR/hr was the median rate and the beta/gamma exposure rate at 3 ft (0.4 mrep/hr) was the 95th-percentile rate, which yields a GSD of 3.5. A

Table 23. Annual internal and external exposure to residual radioactivity (pCi/d)

| Internal exposure (assign as a constant) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Uranium[a] | | Thorium[b] | | Np-237[e] | | Pu-239[e] | | Tc-99[e] | |
| Year | Inh | Ing | Inh | Ing | Inh | Ing | Inh | Ing | Inh | Ing |
| 1958 | 4.2E+2 | 8.7E+0 | 4.2E+0 | 8.8E-2 | 7.6E-1 | 1.6E-2 | 1.1E+0 | 2.3E-2 | 1.6E+2 | 3.3E+0 |
| 1959 | 3.5E+2 | 7.3E+0 | 3.5E+0 | 7.3E-2 | 6.3E-1 | 1.3E-2 | 9.1E-1 | 1.9E-2 | 1.3E+2 | 2.8E+0 |
| 1960 | 2.9E+2 | 6.1E+0 | 2.9E+0 | 6.1E-2 | 5.3E-1 | 1.1E-2 | 7.6E-1 | 1.6E-2 | 1.1E+2 | 2.3E+0 |
| 1961 | 2.4E+2 | 5.1E+0 | 2.5E+0 | 5.1E-2 | 4.4E-1 | 9.2E-3 | 6.3E-1 | 1.3E-2 | 9.1E+1 | 1.9E+0 |
| 1962 | 2.0E+2 | 4.2E+0 | 2.0E+0 | 4.3E-2 | 3.7E-1 | 7.7E-3 | 5.3E-1 | 1.1E-2 | 7.6E+1 | 1.6E+0 |
| 1963 | 1.7E+2 | 3.5E+0 | 1.7E+0 | 3.6E-2 | 3.1E-1 | 6.4E-3 | 4.4E-1 | 9.2E-3 | 6.4E+1 | 1.3E+0 |
| 1964 | 1.4E+2 | 2.9E+0 | 1.4E+0 | 3.0E-2 | 2.6E-1 | 5.3E-3 | 3.7E-1 | 7.7E-3 | 5.3E+1 | 1.1E+0 |
| 1965 | 1.2E+2 | 2.4E+0 | 1.2E+0 | 2.5E-2 | 2.1E-1 | 4.5E-3 | 3.1E-1 | 6.4E-3 | 4.5E+1 | 9.1E-1 |
| 1966 | 9.8E+1 | 2.0E+0 | 9.9E-1 | 2.1E-2 | 1.8E-1 | 3.7E-3 | 2.6E-1 | 5.3E-3 | 3.7E+1 | 7.6E-1 |
| 1967 | 8.2E+1 | 1.7E+0 | 8.3E-1 | 1.7E-2 | 1.5E-1 | 3.1E-3 | 2.1E-1 | 4.4E-3 | 3.1E+1 | 6.4E-1 |
| 1968 | 6.8E+1 | 1.4E+0 | 6.9E-1 | 1.4E-2 | 1.2E-1 | 2.6E-3 | 1.8E-1 | 3.7E-3 | 2.6E+1 | 5.3E-1 |
| 1969 | 5.7E+1 | 1.2E+0 | 5.7E-1 | 1.2E-2 | 1.0E-1 | 2.2E-3 | 1.5E-1 | 3.1E-3 | 2.2E+1 | 4.5E-1 |
| 1970 | 4.7E+1 | 9.9E-1 | 4.8E-1 | 1.0E-2 | 8.6E-2 | 1.8E-3 | 1.2E-1 | 2.6E-3 | 1.8E+1 | 3.8E-1 |
| 1971 | 4.0E+1 | 8.3E-1 | 4.0E-1 | 8.3E-3 | 7.2E-2 | 1.5E-3 | 1.0E-1 | 2.2E-3 | 1.5E+1 | 3.1E-1 |
| 1972 | 3.3E+1 | 6.9E-1 | 3.3E-1 | 7.0E-3 | 6.0E-2 | 1.3E-3 | 8.6E-2 | 1.8E-3 | 1.3E+1 | 2.6E-1 |
| 1973 | 2.8E+1 | 5.7E-1 | 2.8E-1 | 5.8E-3 | 5.0E-2 | 1.0E-3 | 7.2E-2 | 1.5E-3 | 1.1E+1 | 2.2E-1 |
| 1974 | 2.3E+1 | 4.8E-1 | 2.3E-1 | 4.8E-3 | 4.2E-2 | 8.7E-4 | 6.0E-2 | 1.3E-3 | 8.7E+0 | 1.8E-1 |
| 1975 | 1.9E+1 | 4.0E-1 | 1.9E-1 | 4.0E-3 | 3.5E-2 | 7.3E-4 | 5.0E-2 | 1.0E-3 | 7.2E+0 | 1.5E-1 |
| 1976 | 1.6E+1 | 3.3E-1 | 1.6E-1 | 3.4E-3 | 2.9E-2 | 6.1E-4 | 4.2E-2 | 8.7E-4 | 6.1E+0 | 1.3E-1 |
| 1977 | 1.3E+1 | 2.8E-1 | 1.3E-1 | 2.8E-3 | 2.4E-2 | 5.1E-4 | 3.5E-2 | 7.3E-4 | 4.9E+0 | 1.1E-1 |
| 1978 | 1.1E+1 | 2.3E-1 | 1.1E-1 | 2.3E-3 | 2.0E-2 | 4.2E-4 | 2.9E-2 | 6.1E-4 | 4.2E+0 | 8.7E-2 |
| 1979 | 9.3E+0 | 1.9E-1 | 9.4E-2 | 2.0E-3 | 1.7E-2 | 3.5E-4 | 2.4E-2 | 5.1E-4 | 3.5E+0 | 7.2E-2 |
| 1980 | 7.7E+0 | 1.6E-1 | 7.8E-2 | 1.6E-3 | 1.4E-2 | 2.9E-4 | 2.0E-2 | 4.2E-4 | 2.9E+0 | 6.1E-2 |
| 1981 | 6.5E+0 | 1.3E-1 | 6.5E-2 | 1.4E-3 | 1.2E-2 | 2.5E-4 | 1.7E-2 | 3.5E-4 | 2.5E+0 | 4.9E-2 |
| 1982-present | 5.4E+0 | 1.1E-1 | 5.4E-2 | 1.1E-3 | 9.8E-3 | 2.0E-4 | 1.4E-2 | 2.9E-4 | 2.0E+0 | 4.2E-2 |

| External exposure | | | | | |
|---|---|---|---|---|---|
| Start | End | Exposure | Basis | R/yr | IREP distribution |
| 1/1/1958 | Present | Penetrating[c] | Survey instrument | 0.160 | Lognormal GSD 3.5 |

| | | | | | |
|---|---|---|---|---|---|
| 1/1/1958 | Present | Non-penetrating[d] | Survey instrument | 0.400 | Lognormal GSD 2.6 |

a. Uranium intake should be assigned as 100% U-234. Solubility should be selected as Type M or S, whichever is most favorable to the claimant.
b. An Intake should be assigned at indicated rate to each of the following: Th-232, Th-228, and Ra-228. Solubility should be selected to be favorable to the claimant, consistent with the guidance in ORAUT-OTIB-0060 (ORAUT 2007).
c. Assign as 100% 30 – 250 keV photon
d. Assign as 100% > 15 keV electron.
e. Solubility for recycled uranium components should be selected consistent with that chosen for the associated uranium intake, consistent with ORAUC-OTIB-0060 (ORAUT 2007).

nonpenetrating external exposure was estimated by assuming that the 0.2-mrep/hr beta/gamma reading at 3 ft from the floor in the forge area was the median rate and that the 1-mrep/hr beta/gamma reading at contact was the 95th-percentile rate, which yields a GSD of 2.6. The estimated annual external exposure to residual radioactivity from AEC operations at the site, listed in Table 23, was calculated by assuming that workers were exposed for 2,000 hr/yr.

Internal exposure from thoron was calculated using thorium material concentration (building material, surface soil, subsurface soil, or sediment, whichever is most favorable to the claimant) (Earth Tech 2010). These data, listed in Table 24, provide 95% upper confidence level values (EPCs) for $^{232}$Th and $^{228}$Th in each of the described media. These concentration values were input to the RESRAD-Build computer program using site-specific input parameters in the 2010 Remedial Investigation Report (Earth Tech 2010, Table 6-7) to determine the corresponding thoron concentration. The results of this assessment are summarized in Table 24.

Table 24. Th-232 concentrations from remedial investigation (Earth Tech 2010).

| Building | Th-232[a] (pCi/g) | Area ($m^2$)[a] | Height (m)[b] | Thoron[c] (WL) |
|---|---|---|---|---|
| 1 | 0.51 | 802 | 6 | 0.0022 |
| 2 | 1.65 | 5700 | 10.5 | 0.0037 |
| 3 | 1.16 | 4320 | 10 | 0.0039 |
| 4/9 | 1.16 | 4400 | 10 | 0.0039 |
| 5 | 0.34 | 348 | 5 | 0.0013 |
| 6 | 21.90 | 960 | 10 | 0.074 |
| 8 | 3.03 | 2700 | 10 | 0.01 |
| 24 | 16.44 | 7500 | 10 | 0.056 |
| 35 | 1.33 | 320 | 5 | 0.0051 |

a. Extracted from Earth Tech (2010, Table 6-3).
b. Extracted from Earth Tech (2010, Table 6-7).
c. Calculated using the RESRAD-Build computer program.

## 6.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

## REFERENCES

Abu-Eid, R. M., R. B. Codell, N. A. Eisenburg, T. E. Harris, and S. McGuire, 2002, *Re-Evaluation of the Indoor Resuspension Factor for the Screening Analysis of the Building Occupancy Scenario for NRC's License Termination Rule,* NUREG-1720; Draft Report for Comment, U.S. Nuclear Regulatory Commission, Office of Nuclear Material and Safety, Division of Waste Management, Washington, D.C. [SRDB Ref ID: 22400]

AEC (U.S. Atomic Energy Commission), 1948a, *Monthly Status and Progress Report for February 1948,* Office of New York Directed Operations, New York, New York, March 5. [SRDB Ref ID: 6257, pp. 66-87]

AEC (U.S. Atomic Energy Commission), 1948b, *Monthly Status and Progress Report for March 1948,* Office of New York Directed Operations, New York, New York, April 6. [SRDB Ref ID: 6257, pp. 86-106]

AEC (U.S. Atomic Energy Commission), 1948c, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust Visit of October 27, 1948*, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 10883]

AEC (U.S. Atomic Energy Commission), 1948d, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust Visit of December 1, 1948*, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 12442]

AEC (U.S. Atomic Energy Commission), 1948e*, Monthly Status and Progress Report for November 1948*, Office of New York Directed Operations, New York, New York, December 13. [SRDB Ref ID: 6257, pp.253-272]

AEC (U.S. Atomic Energy Commission), 1949a, *Monthly Status and Progress Report for April 1949,* Office of New York Directed Operations, New York, New York, December 9. [SRDB Ref ID: 6291, pp. 93-120]

AEC (U.S. Atomic Energy Commission), 1949b, *Weekly Activity Report,* New York Operations Office, September 30, New York, New York. [SRDB Ref ID: 6291, pp. 252-257]

AEC (U.S. Atomic Energy Commission), 1949c, *Radiological Film Badge Report,* New York Operations Office, Radiological Laboratory, October 11-19, New York, New York. [SRDB Ref ID: 12437]

AEC (U.S. Atomic Energy Commission), 1949d, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust Visit of January 10-21, 1949*, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 10908]

AEC (U.S. Atomic Energy Commission), 1949e, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust Visit of April 5, 1949*, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 16230]

AEC (U.S. Atomic Energy Commission), 1949f, *Monthly Status and Progress Report for November 1949,* Office of New York Directed Operations, New York, New York, December 9. [SRDB Ref ID: 6291, pp. 184-216]

AEC (U.S. Atomic Energy Commission), 1949g, *Health Hazards in NYOO Facilities Producing and Processing Uranium (A Status Report, April 1, 1949)*, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 3931]

AEC (U.S. Atomic Energy Commission), 1949h, *Simonds Saw & Steel Co. Summary Report of Three Surveys (Oct. 27, 1948 – Feb. 15, 1949)*. [SRDB Ref ID: 11996, pp. 249–254]

AEC (U.S. Atomic Energy Commission), 1949i, Sample Requisition Sheets 1247 and 1248, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 10223, pp. 7, 8, 11, and 12]

AEC (U.S. Atomic Energy Commission), 1950, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust Visit of January 9, 1950*, New York Operations Office, Medical Division, New York, New York. [SRDB Ref ID: 4609]

AEC (U.S. Atomic Energy Commission), 1951a, *Tonawanda Area Progress Report November 1951,* Tonawanda Sub-Office, Model City, New York. [SRDB Ref ID: 66863, pp. 14–19]

AEC (U.S. Atomic Energy Commission), 1951b, "Sample Req. No. 6745," U.S. Atomic Energy Commission, New York Operations Office, Medical Division, New York, New York, August 28. [SRDB Ref ID: 10191, p. 118]

AEC (U.S. Atomic Energy Commission), 1952, *Tonawanda Area Progress Report for January 1952,* Tonawanda Sub-Office, Model City, New York. [SRDB Ref ID: 9545, pp. 24–27]

AEC (U.S. Atomic Energy Commission), 1953, *Survey of Accounting Control over Source and Fissionable Material, Simonds Saw and Steel Company, Lockport, New York,* New York Operations Office, New York, New York, June 14. [SRDB Ref ID: 6867]

Air and Urine Data, 1949–1954. [SRDB Ref ID: 10191]

Author unknown, no date a, *Authority Review for the Former Simonds Saw and Steel Co., Lockport, New York*. [SRDB Ref ID: 11996, pp. 2–12]

Author unknown, no date b, *Evaluation of Radiation Exposures at the Former Simonds Saw and Steel Company Lockport, New York*. [SRDB Ref ID: 11996, pp. 227–228]

Author unknown, no date c, *Review Summary Report Simonds Steel Division Guterl Specialty Steel Corporation (the Former Simonds Saw & Steel Company, Lockport, New York*. [SRDB Ref ID: 11996, pp. 639–641]

Author unknown, no date d, *Guterl Steel Corporation, Lockport, New York*. [SRDB Ref ID: 11996, pp. 557–561]

Author unknown, 1948, "Uranium Content of Urine Samples from Simonds Steel Mills, Lockport, N.Y." [SRDB Ref ID: 11227]

Battelle, 2006, *Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals,* Battelle-TBD-6000, Revision F0, Richland, Washington, December. [SRDB Ref ID: 30673]

Belmore, F. M., 1948, untitled letter to J. O. Flower (Vulcan Crucible Steel Company), October 22, U.S. Atomic Energy Commission, New York Directed Operations, New York, New York. [SRDB Ref ID: 9948, pp. 6-14]

Belmore, F. M., 1952, "Thorium Rolling – Simonds Saw & Steel Company," memorandum to C. L. Karl (U.S. Atomic Energy Commission, Fernald Area), U.S. Atomic Energy Commission, New York Operations Office, Production Division, New York, New York, November 20. [SRDB Ref ID: 14653]

Blythe, D. J., 1953, "Decontamination of Simonds Saw & Steel Co., Lockport, N.Y.," memorandum to R. C. Heatherton, November 5. [SRDB Ref ID: 11996, p. 681]

DOE (U.S. Department of Energy), 1979, *Radiological Survey of the Former Simonds Saw and Steel Co. Site, Lockport, New York*, DOE/EV-0005/17, Office of Environmental Compliance and Overview, Division of Environmental Control Technology, Formerly Utilized Sites Remedial Action Program, Washington, D.C., November 1979. [SRDB Ref ID: 10877]

Earth Tech, 2010, *Remedial Investigation Report, Former Guterl Specialty Steel Corporation FUSRAP Site, Lockport, New York*, July 2010. [SRDB Ref ID: 89202]

Eidson, A. F., 1994, "The effect of solubility on inhaled uranium compound clearance: A review," *Health Physics*, volume 67, number 1, pp. 1–14.

Eisenbud, 1987, "Environmental radioactivity: From natural, industrial, and military sources (third edition)", Academic press inc., San Diego, New York and London.

Ericson, M., 1957a, "Subcontract No. S-4 – Simonds Saw and Steel Company," letter to W. W. Damewood (U. S. Atomic Energy Commission), National Lead of Ohio, Cincinnati, Ohio, October 1. [SRDB Ref ID: 81562]

Ericson, M, 1957b, telegram to Simonds Saw and Steel Requesting Closure of Subcontract S-4, National Lead Company of Ohio, Fernald, Ohio, September 27. [SRDB Ref ID: 81566]

Ford Bacon & Davis Inc., 1981, *Preliminary Engineering and Environmental Evaluation of the Remedial Action Alternatives for the Former Simonds Saw and Steel Company Site, Lockport, New York,* Salt Lake City, Utah, November. [SRDB Ref ID: 11996, pp. 191–201]

Glitzer, M. S., 1958a, untitled letter to D. H. Mackey (Simonds Saw and Steel Co.), Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania, November 25. [SRDB Ref ID: 11996, pp. 86–90]

Glitzer, M. S., 1958b, untitled letter to D. H. Mackey (Simonds Saw and Steel Co.), Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania, December 3. [SRDB Ref ID: 11996, pp. 92–93]

Harris, W. B., undated, "Health Hazards Involved in Processing Thorium Materials," memorandum to R. L. Kirk, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Laboratory, New York, New York. [SRDB Ref ID: 2791]

Harris, W. B., 1954, "Rolling of Thorium and Uranium at Simonds Saw & Steel Company," memorandum to C.L. Karl (Fernald), U.S. Atomic Energy Commission, Health and Safety Laboratory, Industrial Hygiene Branch, September 3. [SRDB Ref ID: 11996, pp. 537–539]

Hayden, R.E., 1948a, "Metal Rolling at the Simonds Saw and Steel Company of Lockport, New York", memorandum to M. Eisenbud, U.S. Atomic Energy Commission, New York Operations Office, New York, New York, April 13. [SRDB Ref ID: 11232, pp. 13-14]

Hayden, R. E., 1948b, "Contamination of the Simonds Saw and Steel Company at Lockport, New York," memorandum to M. Eisenbud, U.S. Atomic Energy Commission, New York Operations Office, New York, New York, May 19. [SRDB Ref ID: 11229]

Heatherton, R. C., 1948, "Radiation Levels at the Simonds Steel and Saw Company, Lockport, New York," memorandum to F. J. Epp, U.S. Atomic Energy Commission, New York Operations Office, New York, New York, October 18. [SRDB Ref ID: 10225, p. 3]

Heatherton, R. C., 1950a, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust*, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, New York, New York, October 24. [SRDB Ref ID: 17024]

Heatherton, R. C., 1950b, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust*, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, New York, New York, June 21. [SRDB Ref ID: 16310]

Heatherton, R. C., 1951a, "Trip Report – Visits to L.O.O.W. and Simonds Saw and Steel –March 7 and 8, 1951," memorandum to W. B. Harris, U.S. Atomic Energy Commission, New York Operations Office, New York, New York, March 14. [SRDB Ref ID: 81453]

Heatherton, R. C., 1951b, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust*, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, New York, New York, March 20. [SRDB Ref ID: 13653]

Heatherton, R. C., 1953a, "Decontamination of Simonds Saw & Steel Company," memorandum to J. A. Quigley, M.D., November 18. [SRDB Ref ID: 11996, pp. 682–683]

Heatherton, R. C., 1953b, "Air Survey of Special Rolling 'E' Material on 10" Mill Simonds Saw & Steel Company, Lockport, New York," memorandum to J. A. Quigley, April 30. [SRDB Ref ID: 81449]

Heatherton, 1956, *Industrial Hygiene and Radiation Department Monthly Report for July 1 through July 31, 1956*; R. C. Heatherton; August 2, 1956; SRDB Ref ID: 81440

Heatherton, R. C., 1957, "Trip Report to Simonds Saw and Steel Company, Lockport, New York July 10, 1957," memorandum to J. A. Quigley, July 12, National Lead Company of Ohio, Cincinnati, Ohio. [SRDB Ref ID: 11996, pp. 627–629]

Heffernan, T. E., J. C. Lodwick, H. Spitz, J. Neton, and M. Soldano, 2001, "Solubility of airborne uranium compounds at the Fernald Environmental Management Project," *Health Physics*, volume 80, number 3, pp. 255–262.

Hershman, H. J., 1949, "Visit to Simonds Saw & Steel Company," memorandum to Files, U.S. Atomic Energy Commission, Production Division, September 8. [SRDB Ref ID: 10876, pp. 8–9]

HHS (U.S. Department of Health and Human Services), 2011, *Designating a Class of Employees from Simonds Saw and Steel Company, Lockport, New York*, January 6

Huke, F.,1951, “Rolling of Thorium,” memorandum to F M. Belmore, Director (Production Division), August 24. [SRDB Ref ID: 11996, pp. 124–127]

ICRP (International Commission on Radiological Protection), 1975, *Report of the Task Group on Reference Man*, Publication 23, Pergamon Press, Oxford, England.

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

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.

Keller, T. C., 1979, untitled letter to W. E. Mott (U.S. Department of Energy, Division of Environmental Control Technology), Simonds Steel Division, Guterl Specialty Steel Corp, Lockport, New York, January 16. [SRDB Ref ID: 11996, pp. 13–18]

Klevin, P.B., 1951, *Simonds Saw & Steel Occupational Exposure to Radioactive Dust*, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, New York, New York, October 12. [SRDB Ref ID: 13614]

Klevin, P. B., 1954, "National Lead of Ohio Rolling Operations at Simonds Saw & Steel," memorandum to W. B. Harris, U.S. Atomic Energy Commission, New York Operations Office, Industrial Hygiene Branch, Health and Safety Laboratory, New York, New York, September 3. [SRDB Ref ID: 11996, pp. 68–69]

Klevin, P. B., and M. S. Weinstein, 1953a, *Simonds Saw & Steel Occupational Exposure to Uranium*, Simonds-12, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, February 18. [SRDB Ref ID: 17017]

Klevin, P. B., and M. S. Weinstein, 1953b, *Simonds Saw & Steel Occupational Exposure to Thorium*, Simonds-13, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, New York, New York, February 20. [SRDB Ref ID: 17025]

Leiton, R. P., 2010, untitled letter to S. Hinnefeld (National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support), U.S. Department of Labor, Office of Workers’ Compensation Programs, Washington, D.C., August 12. [SRDB Ref ID: 93729]

Magoun, J. W., and A. S. Yocco, 1956, “Trip Report to Simonds Saw and Steel Company, Lockport, New York, on April 19, 1956,” memorandum to A. Stewart, Jr., National Lead Company of Ohio, April 25. [SRDB Ref ID: 81543]

McCreery, F. M., 1957, “Completion of AEC Production Order #A-60,” memorandum to F. L. Cuthbert, June 3. [SRDB Ref ID: 81553]

Murray, B., 2010, “Simonds Saw & Steel Co.(1948-1956),” documented communication with [Name Redacted] (former Simonds Saw & Steel employee) et al., Oak Ridge Associated Universities Team, Oak Ridge, Tennessee, July 13. [SRDB Ref ID: 84727]

NIOSH (National Institute for Occupational Safety and Health), 2004, *Estimation of Ingestion Intakes, Technical Information Bulletin*, OCAS-TIB-009, Revision 0, Office of Compensation Analysis and Support, Cincinnati, Ohio, April 13.

NIOSH (National Institute for Occupational Safety and Health), 2010a, *Radiation Exposures Covered for Dose Reconstructions Under Part B of the Energy Employees Occupational Illness Compensation Program Act*, OCAS-IG-003, Rev. 1, Division of Compensation Analysis and Support, Cincinnati, Ohio, October.

NIOSH (National Institute for Occupational Safety and Health), 2010b, *Special Exposure Cohort Petition Evaluation Report Petition SEC-00157*, Division of Compensation Analysis and Support, Cincinnati, Ohio.

NLO (National Lead Company of Ohio), 1954–1956, collection of air dust analyses for Simonds Saw and Steel Company. [SRDB Ref ID: 14152]

NLO (National Lead of Ohio), 1956, Analytical Data Sheets 8800, 9801, and 9802, February 5. [SRDB Ref ID: 11996, pp. 545–547]

NLO (National Lead Company of Ohio), 1957, *NLO Intra Plant Production Order Request*; April 1. [SRDB Ref ID: 81554]

NRC (U.S. Nuclear Regulatory Commission), 2002, *Technical Basis for Calculating Radiation Doses for the Building Occupancy Scenario Using the Probabilistic RESRAD-BUILD 3.0 Code*, NUREG/CR-6755, Washington, D.C. [SRDB Ref ID: 91669]

ORAUT (Oak Ridge Associated Universities Team), 2008, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities,* ORAUT-OTIB-0070, Rev. 00, Oak Ridge Associated Universities, Oak Ridge, Tennessee, March 10.

ORAUT (Oak Ridge Associated Universities Team), 2005, *Interpretation of Dosimetry Data for Assignment of Shallow Dose,* ORAUT-OTIB-0017, Rev. 01, Oak Ridge Associated Universities, Oak Ridge, Tennessee, October 11.

ORAUT (Oak Ridge Associated Universities Team), 2007, *Internal Dose Reconstruction,* ORAUT-OTIB-0060, Rev. 00, Oak Ridge Associated Universities, Oak Ridge, Tennessee, February 6.

ORAUT (Oak Ridge Associated Universities Team), 2011, *Guidance on Assigning Occupational X-Rays Administered Off Site,* ORAUT-OTIB-0079, Rev. 00, Oak Ridge Associated Universities, Oak Ridge, Tennessee, January 3.

Polson, C. E., 1954, "Contamination – Simonds Steel Company, Lockport, New York," memorandum to J. H. Gibarski, November 22. [SRDB Ref ID: 11996, pp. 71–72]

Reichard, H. E., 1949, "Trips to Simonds Saw & Steel Company and Lake Ontario Ordinance Work," memorandum to Files, U.S. Atomic Energy Commission, Production Division, June 13. [SRDB Ref ID: 10876, pp. 1-2]

Rothenberg, S. A., 1951, "Trip to Lake Ontario Storage Area – December 10, 1951," memorandum to H. Blatz (Radiation Branch, Health & Safety Division), U.S. Atomic Energy Commission, New York Operations Office, New York, New York, December 14. [SRDB Ref ID: 8918, pp. 4-5]

Schlitz, J. F., 1954, *Standard Operating Procedure for Rolling 2.75% Enriched Metal at Simonds Saw and Steel Company, Production Order No. 296 (Section 1.4.3.12)*, FMPC-477 Special, National Lead Company of Ohio, Cincinnati, Ohio, October 20. [SRDB Ref ID: 80177]

Schlitz, J. F., 1955, *Standard Operating Procedure for Rolling 7.2% Enriched Metal at Simonds Saw and Steel Company, Production Order No. 532 (Section 1.4.3.20)*, NLCO-593 Special, National Lead Company of Ohio, Cincinnati, Ohio, November 9. [SRDB Ref ID: 44168]

Schumann, C. E., 1953, *Industrial Hygiene Survey of Uranium Rolling at Simonds Saw & Steel Co.*, National Lead of Ohio, Health & Safety Division, Cincinnati, Ohio, February 5. [SRDB Ref ID: 6866]

Smith, R. J., 1951, "Current Rolling Procedure at Simonds Saw and Steel Company," letter to W. A. Larkin (U.S. Atomic Energy Commission, Oak Ridge Operations Office), U.S. Atomic Energy Commission, New York Operations Office, Production Division, Operations Branch, New York, New York, October 11. [SRDB Ref ID: 4392, pp. 7-8]

Spiegl, C. J., H. E. Stokinger, J. DeVoldre, K. Lauterbach, and S. Dzuibs, undated, *Air Contamination During Uranium Fabrication at Simonds Saw and Steel Company*. [SRDB Ref ID: 11217]

Tabershaw, I. R., 1948, untitled letter to B. S. Wolf, (U.S. Atomic Energy Commission), Liberty Mutual Company, Eastern Medical Division, Loss Prevention Department, New York, New York, December 15. [SRDB Ref ID: 11226, pp. 5-6]

Tabershaw, I. R., 1949, "Visit to Simonds Saw and Steel Company, Lockport, New York," memorandum to M. Eisenbud, U.S. Atomic Energy Commission, New York Operations Office, February 11. [SRDB Ref ID: 10213, p. 7]

Tabershaw, I. R., 1952, "Visit to Simonds Saw and Steel Company, Lockport , New York, on Saturday, March 22, 1952," memorandum to M. Eisenbud, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division, April 2. [SRDB Ref ID: 10213, pp. 1-4]

Taussig, W. A, 1948, "Facilities for Rolling Uranium," memorandum to W. E. Kelley (U.S. Atomic Energy Commission, New York Office of Directed Operations), U.S. Atomic Energy Commission, Cleveland Sub-Office, February 26. [SRDB Ref ID: 11996, pp. 128–131]

USACE (U.S. Army Corps of Engineers), 2010, *Guterl Steel FUSRAP Site Plan Remedial Action Posters*, Buffalo District, October. [SRDB Ref ID: 89201]

Vitkus, T. J., 1999, *Radiological Survey of the Guterl Specialty Steel Corporation, Lockport, New York*, ORISE 99-1699, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee, December. [SRDB Ref ID: 10228]

Wilson, R. H., 1958, "The Hanford Uranium Bio-Assay Program," *Symposium on Occupational Health Experience and Practices in the Uranium Industry*, HASL-58, U. S. Atomic Energy Commission, New York, New York, October 15 -17. [SRDB Ref ID: 7886, p. 89]

Wolf, B. S., 1948, "Recommendation for Proposed Contract - Simonds Saw & Steel Co.," memorandum to F. M. Belmore, U.S. Atomic Energy Commission, May 17. [SRDB Ref ID: 11232, pp. 2-6]

Wunder, G. W., 1953, "Resume Activities Month Ending December 20, 1953," memorandum to C. L. Karl (U.S. Atomic Energy Commission), National Lead Company of Ohio, Cincinnati, Ohio. December 21. [SRDB Ref ID: 81597]

Wunder, G. W., 1956, “Request for Services at Simonds Saw and steel Company, Lockport, New York,” letter to C. L. Karl (U.S. Atomic Energy Commission), May 31. [SRDB Ref ID: 11996, pp. 630–631]

Yoder, J. D., 1954, “Trip to Simonds Saw & Steel Company, Lockport, New York,” memorandum to R. C. Heatherton, October 28. [SRDB Ref ID: 11996, pp. 620–621]

Zimmerman, R., 1957, *National Lead Company of Ohio, Minutes of Management Committee Meeting*, April 29, 1957, National Lead of Ohio, April 29. [SRDB Ref ID: 81555]

**ATTACHMENT A**
**COWORKER BIOASSAY DATA BY SAMPLE DATE**


Uranium urinalyses in mg/L.

| | | <0.01 mg/L insufficient for reliable detection | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 11/1/1948 | 11/3/1948 | 11/4/1948 | 11/8/1948 | 11/11/1948 | 11/15/1948 | Pre roll 1/6/1949 | Pre roll 4/27/1949 | $HNO_3$ treated pre 3rd roll 11/4/1949 | Last day of roll 11/17/1949 |
| 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 0 | 0.007 | 0.004 | 0 |
| 0.01 | 0.01 | 0.01 | 0 | 0.01 | 0 | 0.001 | 0.008 | 0.007 | 0 |
| 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.002 | 0.010 | 0.007 | 0 |
| 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.008 | 0.011 | 0.007 | 0 |
| 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.009 | 0.017 | 0.011 | 0 |
| 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.009 | 0.019 | 0.013 | 0 |
| 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.010 | 0.019 | 0.013 | 0 |
| 0.03 | 0.03 | 0.02 | 0.01 | 0.02 | 0.02 | 0.013 | 0.023 | 0.013 | 0 |
| 0.03 | 0.03 | 0.04 | 0.02 | 0.04 | 0.04 | 0.013 | 0.023 | 0.014 | 0 |
| 0.04 | 0.04 | 0.07 | 0.02 | 0.05 | 0.04 | 0.015 | 0.024 | 0.015 | 0 |
| 0.04 | 0.04 | 0.07 | 0.03 | | 0.05 | 0.018 | 0.029 | 0.016 | 0 |
| 0.14 | 0.09 | | | | | | 0.036 | 0.021 | 0 |
| | | | | | | | | 0.024 | 0 |
| | | | | | | | | 0.027 | 0 |
| | | | | | | | | 0.028 | 0 |
| | | | | | | | | 0.272 | 0 |
| | | | | | | | | | 0 |
| | | | | | | | | | 0 |
| | | | | | | | | | 0 |
| | | | | | | | | | 0 |
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| | | | | | | | | | 0.001 |
| | | | | | | | | | 0.001 |
| | | | | | | | | | 0.001 |
| | | | | | | | | | 0.002 |
| | | | | | | | | | 0.002 |
| | | | | | | | | | 0.003 |

**ATTACHMENT A**
**COWORKER BIOASSAY DATA BY SAMPLE DATE**


| | | <0.01 mg/L insufficient for reliable detection | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 11/1/1948 | 11/3/1948 | 11/4/1948 | 11/8/1948 | 11/11/1948 | 11/15/1948 | Pre roll 1/6/1949 | Pre roll 4/27/1949 | $HNO_3$ treated pre 3rd roll 11/4/1949 | Last day of roll 11/17/1949 |
| | | | | | | | | | 0.003 |
| | | | | | | | | | 0.003 |
| | | | | | | | | | 0.003 |
| | | | | | | | | | 0.004 |
| | | | | | | | | | 0.004 |
| | | | | | | | | | 0.006 |
| | | | | | | | | | 0.006 |
| | | | | | | | | | 0.007 |
| | | | | | | | | | 0.010 |
| | | | | | | | | | 0.011 |
| | | | | | | | | | 0.011 |
| | | | | | | | | | 0.013 |
| | | | | | | | | | 0.014 |
| | | | | | | | | | 0.014 |
| | | | | | | | | | 0.015 |
| | | | | | | | | | 0.017 |
| | | | | | | | | | 0.029 |
| | | | | | | | | | 0.030 |
| | | | | | | | | | 0.036 |
| | | | | | | | | | 0.164 |

**ATTACHMENT A**
**COWORKER BIOASSAY DATA BY SAMPLE DATE**


Uranium urinalyses in mg/L.

| Pre roll 1/6/1950 | Post roll 1/19/1950 | 5/15/1950 | Post roll 5/23/1950 | Second shift less supervision | | 9/23/1950 | 9/25/1950 | 10/20/1950 | 10/25/1950 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Pre roll 8/14/1950 | Post roll 8/28/1950 | | | | |
| 0 | 0 | 0 | 0 | 0.015 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.016 | 0.009 | 0 | 0.004 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.017 | 0.012 | 0 | 0.005 | 0 | 0.002 |
| 0 | 0 | 0 | 0 | 0.017 | 0.015 | 0 | 0.005 | 0 | 0.002 |
| 0 | 0 | 0 | 0 | 0.018 | 0.015 | 0 | 0.009 | 0.002 | 0.002 |
| 0 | 0 | 0 | 0 | 0.018 | 0.016 | 0 | 0.009 | 0.002 | 0.002 |
| 0 | 0 | 0 | 0.002 | 0.022 | 0.016 | 0 | 0.009 | 0.002 | 0.002 |
| 0 | 0 | 0 | 0.003 | 0.022 | 0.016 | 0 | 0.009 | 0.004 | 0.004 |
| 0 | 0 | 0.001 | 0.003 | 0.024 | 0.016 | 0 | 0.011 | 0.004 | 0.006 |
| 0 | 0 | 0.002 | 0.003 | 0.028 | 0.017 | 0 | 0.013 | 0.004 | 0.006 |
| 0 | 0 | 0.003 | 0.006 | 0.028 | 0.017 | 0 | 0.013 | 0.008 | 0.008 |
| 0 | 0.001 | 0.005 | 0.013 | 0.028 | 0.017 | 0.002 | 0.014 | 0.012 | 0.010 |
| 0 | 0.002 | 0.007 | 0.014 | 0.031 | 0.017 | 0.004 | 0.014 | 0.012 | 0.010 |
| 0 | 0.002 | 0.007 | 0.014 | 0.033 | 0.019 | 0.005 | 0.015 | 0.022 | 0.010 |
| 0 | 0.003 | 0.008 | 0.016 | 0.033 | 0.019 | 0.005 | 0.015 | 0.024 | 0.010 |
| 0 | 0.006 | 0.008 | 0.016 | 0.035 | 0.019 | 0.005 | 0.016 | 0.027 | 0.017 |
| 0 | 0.007 | 0.012 | 0.016 | 0.035 | 0.025 | 0.014 | 0.018 | 0.028 | 0.017 |
| 0 | 0.008 | 0.014 | 0.016 | 0.037 | 0.033 | 0.014 | 0.023 | 0.044 | 0.019 |
| 0 | 0.012 | 0.015 | 0.017 | 0.046 | | 0.018 | 0.024 | 0.067 | 0.043 |
| 0.001 | 0.013 | 0.015 | 0.017 | 0.102 | | 0.020 | | | |
| 0.001 | 0.013 | 0.015 | 0.017 | | | | | | |
| 0.001 | 0.014 | 0.015 | 0.017 | | | | | | |
| 0.001 | 0.015 | 0.016 | 0.018 | | | | | | |
| 0.001 | 0.015 | 0.016 | 0.019 | | | | | | |
| 0.002 | 0.015 | 0.022 | 0.034 | | | | | | |
| 0.002 | 0.015 | | | | | | | | |
| 0.002 | 0.016 | | | | | | | | |
| 0.003 | 0.016 | | | | | | | | |
| 0.003 | 0.016 | | | | | | | | |
| 0.003 | 0.016 | | | | | | | | |
| 0.003 | 0.016 | | | | | | | | |
| 0.003 | 0.016 | | | | | | | | |

**ATTACHMENT A**
**COWORKER BIOASSAY DATA BY SAMPLE DATE**


| Pre roll 1/6/1950 | Post roll 1/19/1950 | 5/15/1950 | Post roll 5/23/1950 | Second shift less supervision | | 9/23/1950 | 9/25/1950 | 10/20/1950 | 10/25/1950 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Pre roll 8/14/1950 | Post roll 8/28/1950 | | | | |
| 0.004 | 0.017 | | | | | | | | |
| 0.006 | 0.018 | | | | | | | | |
| 0.006 | 0.018 | | | | | | | | |
| 0.006 | 0.018 | | | | | | | | |
| 0.006 | 0.019 | | | | | | | | |
| 0.008 | 0.020 | | | | | | | | |
| 0.009 | 0.020 | | | | | | | | |
| 0.011 | 0.021 | | | | | | | | |
| 0.012 | 0.022 | | | | | | | | |
| 0.012 | 0.022 | | | | | | | | |
| 0.012 | 0.027 | | | | | | | | |
| 0.014 | 0.031 | | | | | | | | |
| 0.014 | 0.031 | | | | | | | | |
| 0.014 | 0.031 | | | | | | | | |
| 0.017 | 0.033 | | | | | | | | |
| 0.018 | 0.033 | | | | | | | | |
| 0.023 | 0.035 | | | | | | | | |
| 0.026 | | | | | | | | | |

**ATTACHMENT A**
**COWORKER BIOASSAY DATA BY SAMPLE DATE**
Page 5 of 6

Uranium urinalyses in mg/L.

| | | | Samples collected at 5 p.m. | |
|---|---|---|---|---|
| 11/9/1950 | 11/16/1950 | 12/14/1950 | Preroll 12/20/1952 | Postroll 12/22/1952 |
| 0 | 0 | 0 | 0.001 | 0.001 |
| 0 | 0 | 0 | 0.002 | 0.003 |
| 0 | 0 | 0 | 0.002 | 0.003 |
| 0 | 0 | 0 | 0.002 | 0.004 |
| 0 | 0 | 0 | 0.004 | 0.004 |
| 0 | 0 | 0 | 0.006 | 0.004 |
| 0 | 0 | 0.002 | 0.006 | 0.005 |
| 0.002 | 0.002 | 0.002 | 0.007 | 0.005 |
| 0.002 | 0.002 | 0.002 | 0.010 | 0.006 |
| 0.004 | 0.002 | 0.002 | 0.010 | 0.006 |
| 0.004 | 0.002 | 0.004 | 0.011 | 0.006 |
| 0.004 | 0.002 | 0.004 | 0.011 | 0.008 |
| 0.006 | 0.004 | 0.004 | 0.011 | 0.008 |
| 0.006 | 0.004 | 0.004 | 0.012 | 0.008 |
| 0.006 | 0.004 | 0.004 | 0.012 | 0.008 |
| 0.006 | 0.004 | 0.005 | 0.012 | 0.010 |
| 0.015 | 0.004 | 0.006 | 0.013 | 0.010 |
| 0.015 | 0.006 | 0.006 | 0.013 | 0.010 |
| 0.030 | 0.006 | 0.006 | 0.013 | 0.010 |
| | 0.006 | 0.006 | 0.013 | 0.011 |
| | 0.006 | 0.007 | 0.013 | 0.012 |
| | 0.006 | 0.007 | 0.014 | 0.012 |
| | 0.009 | 0.007 | 0.015 | 0.013 |
| | 0.009 | 0.008 | 0.015 | 0.013 |
| | 0.009 | 0.008 | 0.016 | 0.014 |
| | 0.009 | 0.008 | 0.016 | 0.014 |
| | 0.009 | 0.009 | 0.016 | 0.015 |
| | 0.009 | 0.009 | 0.017 | 0.015 |
| | 0.009 | 0.010 | 0.017 | 0.015 |
| | 0.011 | 0.011 | 0.017 | 0.015 |
| | 0.013 | 0.011 | 0.017 | 0.016 |
| | 0.015 | 0.015 | 0.017 | 0.016 |
| | 0.015 | 0.015 | 0.018 | 0.017 |
| | 0.017 | 0.015 | 0.018 | 0.017 |
| | 0.017 | 0.015 | 0.018 | 0.017 |
| | 0.017 | 0.016 | 0.020 | 0.018 |
| | 0.017 | 0.017 | 0.021 | 0.018 |
| | 0.020 | 0.019 | 0.022 | 0.019 |
| | 0.022 | 0.024 | 0.023 | 0.020 |
| | 0.028 | 0.080 | 0.023 | 0.021 |
| | | | 0.023 | 0.022 |
| | | | 0.023 | 0.022 |
| | | | 0.024 | 0.022 |
| | | | 0.024 | 0.025 |
| | | | 0.024 | 0.025 |
| | | | 0.024 | 0.026 |

**ATTACHMENT A**
**COWORKER BIOASSAY DATA BY SAMPLE DATE**
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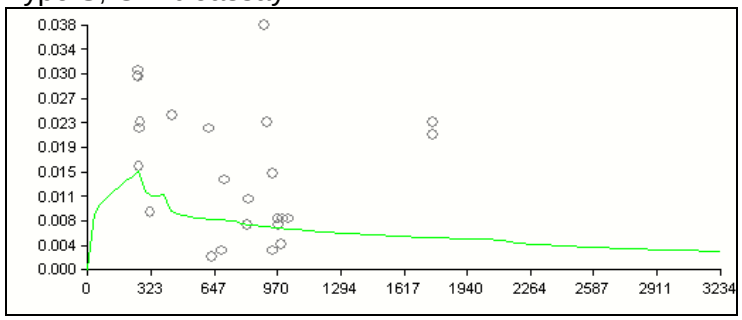
| | | | Samples collected at 5 p.m. | |
|---|---|---|---|---|
| 11/9/1950 | 11/16/1950 | 12/14/1950 | Preroll 12/20/1952 | Postroll 12/22/1952 |
| | | | 0.027 | 0.026 |
| | | | 0.027 | 0.027 |
| | | | 0.028 | 0.029 |
| | | | 0.028 | 0.030 |
| | | | 0.029 | 0.030 |
| | | | 0.029 | 0.032 |
| | | | 0.033 | 0.033 |
| | | | 0.034 | 0.036 |
| | | | 0.037 | 0.036 |
| | | | 0.037 | 0.036 |
| | | | 0.041 | 0.041 |
| | | | 0.044 | 0.046 |
| | | | 0.048 | 0.048 |
| | | | 0.048 | 0.050 |
| | | | 0.056 | 0.053 |
| | | | 0.066 | 0.054 |

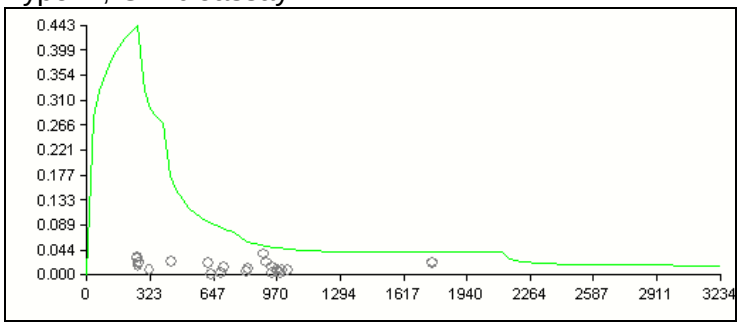
**ATTACHMENT B**
**GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR, AND FITS OF COWORKER BIOASSAY**


The graphs show predicted bioassay results from the estimated air intakes, superimposed on the GM, 84th percentile, and maximum coworker bioassay results. Reasonable fits are starred (*). X-axis is days (0 = February 24, 1948). Y-axis is mg/L.

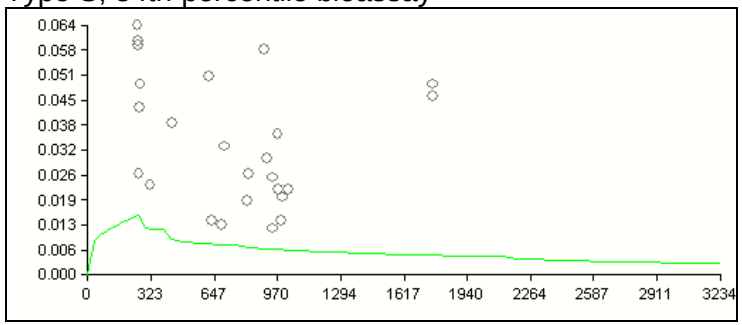
Type S, GM bioassay*



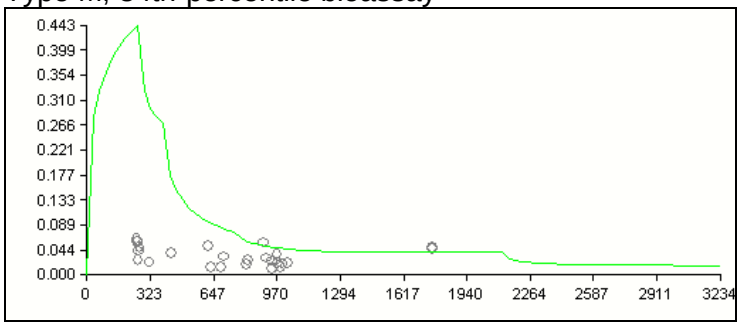

Type M, GM bioassay



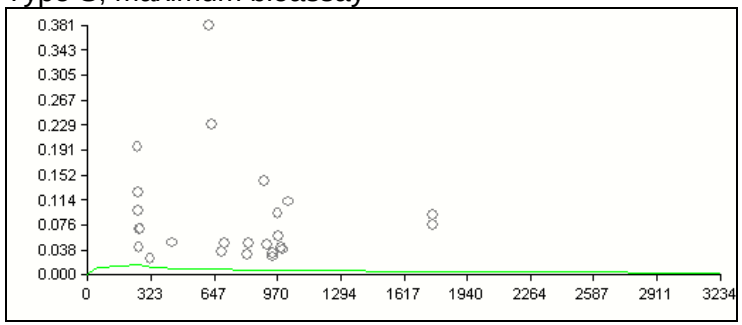

Type S, 84th-percentile bioassay



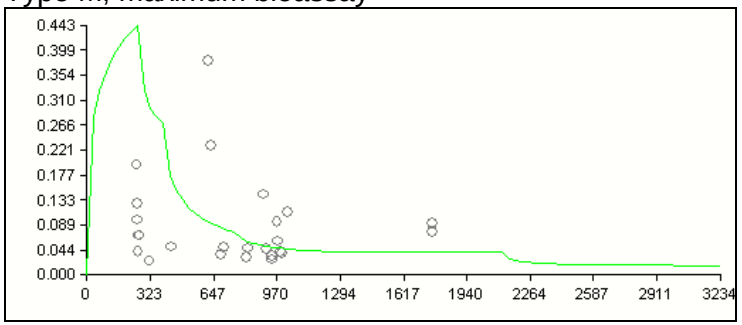

Type M, 84th-percentile bioassay




Type S, maximum bioassay



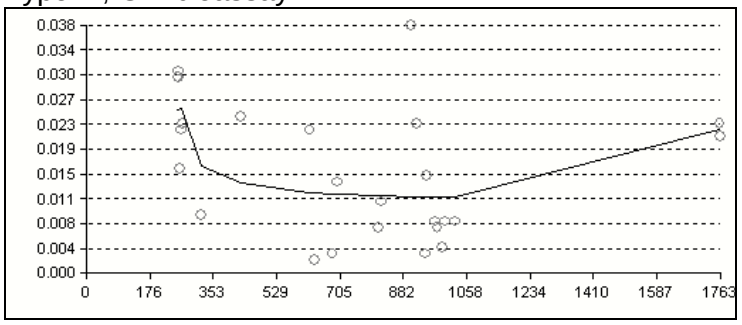

Type M, maximum bioassay*



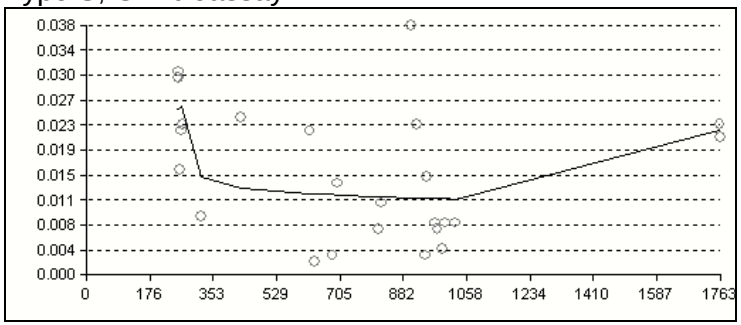
**ATTACHMENT B**
**GRAPHS SHOWING PREDICTED BIOASSAY FROM AIR, AND FITS OF COWORKER BIOASSAY**


Graphs showing fits of coworker bioassay data to three inhalation intakes. X-axis is in days (0 = February 24, 1948). Y-axis uranium urinalyses results in mg/L.

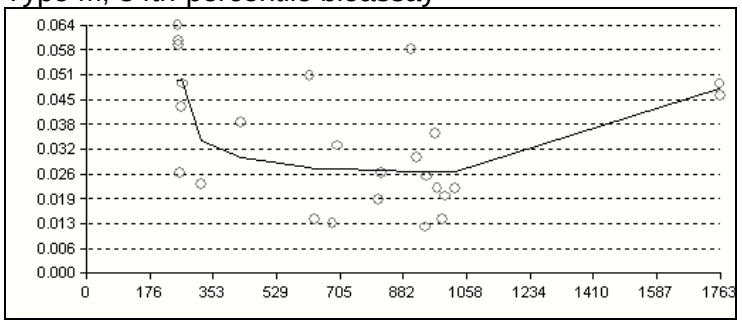
Type M, GM bioassay



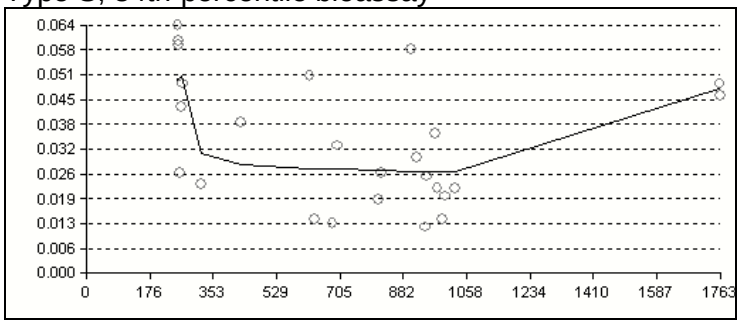

Type S, GM bioassay



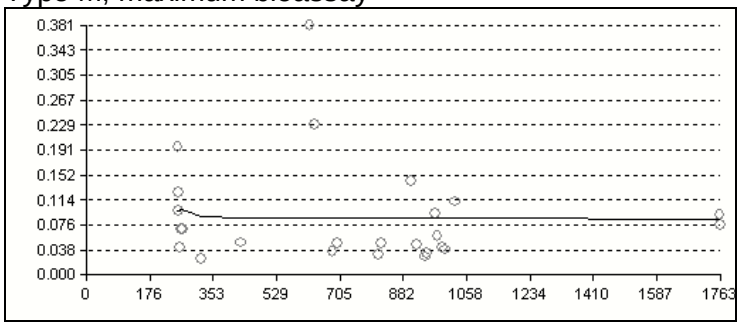

Type M, 84th-percentile bioassay




Type S, 84th-percentile bioassay




Type M, maximum bioassay




Type S, maximum bioassay