ORAU Team **Dose Reconstruction Project for NIOSH** An Exposure Matrix for Superior Steel, Carnegie, Pennsylvania, Period of Operation: January 1, 1952 through December 31, 1957	Document Number: ORAUT-TKBS-0034 Effective Date: 05/03/2005 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 23
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	12/28/2004	00-A	New Technical Basis Document: Basis for the Development of an Exposure Matrix for Superior Steel, Carnegie, Pennsylvania. Initiated by Shelby L. Gubin.
Draft	12/29/2004	00-B	Modified to address ORAU Team review comments: corrected errors and clarified text. Initiated by Cindy W. Bloom.
Draft	02/15/2005	00-C	Modified to address OCAS comments and typographical errors. Nonpenetrating doses were modified. Some annual doses in Tables 9 and 11 were modified. Initiated by Cindy W. Bloom.
Draft	02/25/2005	00-D	Modified to address OCAS comment. The DOE Office of Worker Advocacy website changed their description of Superior Steel activities. Initiated by Shelby L. Gubin.
Draft	04/21/2005	00-E	Modified intakes based on assuming 95th percentile of air concentrations per OCAS. Initiated by Cindy W. Bloom.
Draft	04/22/2005	00-F	Deleted last 3 rows (GMs and GSDs) of Table 1 to eliminate confusion per OCAS. Initiated by Cindy W. Bloom.
05/03/2005	05/03/2005	00	First approved issue. No training required. Initiated by Cindy W. Bloom.

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
BZ	breathing zone
cm	centimeter
dpm	disintegrations per minute (also d/m)
ft	foot
FUSRAP	Formerly Utilized Sites Remedial Action Program
GA	general area
GSD	geometric standard deviation
h	hour
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kilovolt-electron
L	liter
m	meter
mg	milligram
mR	milliroentgen
mrem	millirem
mrep	millirep
NYOO	New York Operations Office
pCi	picocuries
R	roentgen
s	second
U.S.C.	United States Code
y	year
µg	microgram
µm	micrometer

1.0 INTRODUCTION

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute for Occupational Safety and Health (NIOSH) 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 facility" or a "Department of Energy facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. Sections 7384l (5) and (12)].

This document provides an exposure matrix for workers at the facility listed as Superior Steel Corporation in Carnegie, Pennsylvania. At the time of U.S. Atomic Energy Commission (AEC) contract operations, the company was known as Superior Steel Corporation. Later it was known as Copper Weld Inc. and as Lot and Block 102J210. Other names associated with the site are Lange Machinery Company, Inc.; J.G. Industries, Inc.; Carnegie Industrial Park, and Superior Tube Company (ORNL 1981, Young 1985). The site was reportedly located at the intersection of Hammond and Superior Streets and/or Hammond and Gregg Streets (Young 1985).

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

The information that follows supports an assumed period of AEC operations at Superior Steel from January 1, 1952, through December 31, 1957, involving AEC-contracted uranium work. This analysis assumed that the residual contamination period was from January 1, 1958 through the present.

The Superior Steel radiological source term consisted primarily of natural uranium metal, uranium oxides, and natural 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.

Letter Contract AT(30-1) -1412 (a unit price contract) was awarded to Superior Steel in June 1952, because it was one of the few companies that had the technical expertise to roll and clad metal strip and plate (Young 1985). The effective date of the contract was June 27, 1952. According to Young (1985), AEC security inspection records indicate that work began in March 1953, although it was also noted that Superior Steel was an accountable station for handling source and fissionable materials by November 1952. It wasn't unusual for AEC work to start at a site several months before a contract was official, so this analysis assumes that the work began on January 1, 1952.

The original Superior Steel contract is unavailable, but a contract was also awarded to Metals & Controls for similar work and it was assumed that the same boilerplate contract articles were included (Young 1985, AEC 1952). The contract originated from the AEC New York Operations Office. The contract was transferred for administration to the Oak Ridge Operations Office and on October 15, 1954 was transferred to the Savannah River Operations Office. According to the Savannah River Operations Office, Superior Steel contract files have been destroyed. However, correspondence files relating to the work done by Superior Steel indicate they rolled, cut and finished uranium metal into strip under a cost plus fixed fee contract (Young 1985). The contract was terminated on or about September 30, 1957 (Young 1985). The withdrawal of Superior Steel's source and fission material accounting station authority was recorded on November 27, 1957 (Young 1985). This analysis assumes that the AEC operations ceased on December 31, 1957

2.1 SITE DESCRIPTION

ORNL (1981) reports that the Superior Steel uranium operations occurred in a large steel building that was divided into three areas. These areas (ORNL 1981) are shown in Figure 1:

> *The former mill area (Area A), the former motor room (Area B), and the former rolling area (Area C).*
>
> *Area A (… approximately 24,000 ft.²) originally contained the salt bath, roughing mill, brushing station, finishing stands and shear, and was the location where the majority of the uranium metal handling and shaping is believed to have occurred ...*
>
> *Area B housed the former motor room and control panels for the mill. This area (approximately 8250 ft.²) contained the large motors that provided power to the mill equipment in the adjacent room (area A). This area was considered the "clean" side of the mill, where the atmosphere was controlled to provide proper conditions for motor and instrument operation…*
>
> *Area C (…approximately 12,000 ft.²) was originally the location of the tail end of the mill process where the metal was rolled for shipping, or prior to further handling. Two pits at the south end of the building … indicate the prior locations of the bliss downcoiler* [a machine to coil the metal] *and upender* [a tool to tilt a roll of material 90 degrees].

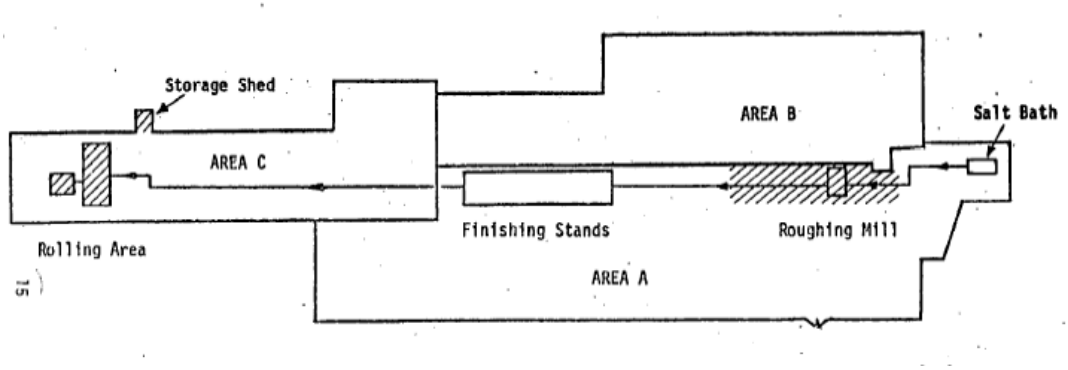

Figure 1. Superior Steel processing areas (ORNL 1981).

Figure 2. shows the line as operated at Superior Steel.

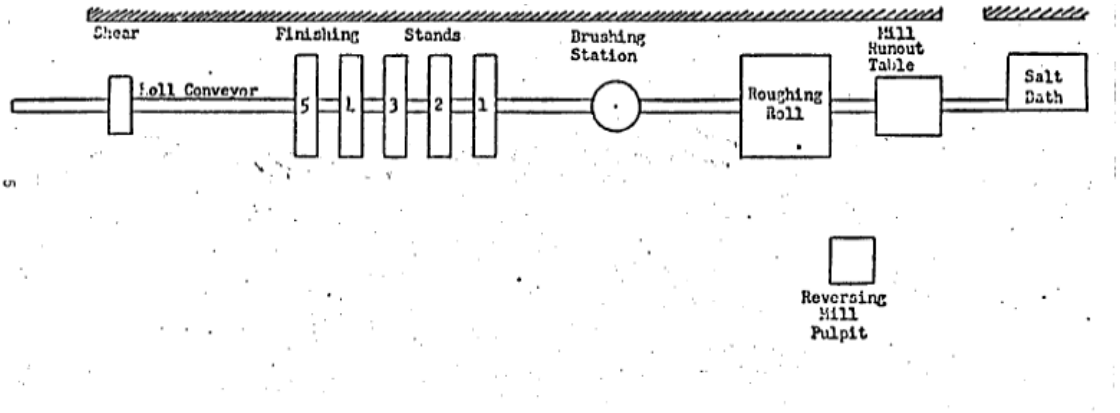

Figure 2. Superior Steel uranium mill layout (ORNL 1981).

2.2 PROCESS DESCRIPTION

In 1952, there was interest and demand for flat, plate type reactor fuel elements, because it was determined that this geometry provided greater surface-to volume ratio than cylindrical fuel leading to more efficient use of uranium in reactors.

The process at Superior Steel is as follows (AEC 1953a, 1953b, 1995a):

1. A 1" thick slab of uranium any where from 61" to 89" long and from 5.5" to 7" wide was placed into a rectangular steel vessel containing the salt bath (50% LiCl and 50% KCl by volume).

2. The salt bath was heated in a gas-fired furnace to a working temperature of around 1200 ºF for about 45 minutes and then removed from the furnace. In 1953, a new furnace was installed that included a salt bath, which eliminated removal of the salt bath from the furnace to remove the uranium slab for rolling.

3. The slab was moved by overhead crane to the rolling mill table.

4. The slab was passed through a roughing roll 5 times and sent through the finishing stands, (there were 5 finishing stands, but they were not all operational during two of the four AEC visits.).

5. The strip was then cut if desired, and transferred with tongs by 10 mill hands to a cooling area.

Final thicknesses were between 182 and 191 mils. (E. I. du Pont de Nemours 1954)

Young (1985) notes:

> *According to general correspondence, work done by Superior Steel was of a developmental nature. This work was limited to the production of flat plates of uranium metal in support of the Savannah River Operations Office fuel element development program… The scope of the contract provided by the Savannah River Operations Office is quoted in part as follows:*
>
> > *"…by commercial methods receive uranium from supplier, inspect, straighten as required, scalp by milling, planning [sic] and/or spot grinding, preheat in molten salt, hot*

roll (taking required temperature and time data), crop and shear to length, number, acid pickle (including packing for shipment to heat treating facility and receiving heat treated strip), flatten acid pickle, machine into full length strips of specified dimensions and tolerances, deburr, gauge finish inspect, metallurgically sample (but not in excess of reasonably commercial sampling methods and not including metallurgical tests), package and prepare finished plate and furnish labor for packaging and preparing scrap for shipment."

In 1954, Superior Steel proposed an increase in contractual requirements, calling for minimum production quantities over a 5-year period. AEC rejected the proposal and the work continued on a developmental basis. Superior Steel processed AEC uranium intermittently for periods lasting from one to two days. One AEC employee recalled that most of the work was done on weekends when the plant would otherwise be idle, but other documents, including the AEC (1953 a, b; 1955 a, b) air monitoring studies during uranium rolling, indicated that Superior Steel rolled on weekdays (Young 1985).

2.3 SOURCE TERM

Little information was found regarding the Superior Steel source term. AEC performed security inspections at Superior Steel on "May and November 1954 and 1955, in June 1956 and in January 1957" according to Young (1985), indicating that there was something to inspect on these dates. The DOE (2005) Office of Worker Advocacy website reported, "Superior Steel produced uranium strip and rolled uranium slabs for use by the Savannah River Laboratory. In 1955, for example, they hot rolled twenty-five tons of uranium into strip." AEC (1953a, b, 1955a, b) health and safety reports show four rolling dates, May 13, 1953, August 3, 1953, May 9, 1955, and September 19, 1955. The last three of the reports mention the number of uranium slabs rolled, 23, 30 and 30, respectively. AEC reported that six of the slabs rolled on May 9, 1955 were enriched uranium. E. I. duPont de Nemours & Co. (1954) reported, "a second rolling of uranium slabs to flat strips" after an initial rolling on August 3, 1953. On February 22 and 23, 1954, fifty-two slabs were rolled. Thirty-one of the rolled slabs were sheared on March 3, 1954. The reference to an initial rolling on August 3, 1953, appears to be a reference to a type of rolling, not the initial uranium rolling at Superior Steel.

Based on the limited information regarding source term and throughput, this document assumed that Superior Steel rolled uranium 8 hours per day, 2 days per week, 50 weeks per year, which is 800 hours per year.

The contract information was also considered to provide increased confidence that the assumed AEC uranium work-hours are reasonable, although probably overestimated. The total amount paid to Superior Steel by AEC through fiscal year 1957 was $356,849 (Young 1985). The contract was a unit price contract. An AEC (1949a) contract with Vulcan Crucible (later known as Aliquippa Forge) to do uranium rolling work listed a rate of $132 per mill-hour in 1949. Although rates might have differed between contractors and throughout the years, this value provides a way to determine a rough estimate of Superior Steel's mill hours by dividing the amount paid by the mill hour rate. This gives a total of 2700 hours or about 450 hours per year. Because additional payment may have been due Superior Steel and because the actual Superior Steel mill-hour rate is unknown, the 450 hours per year is only used to give some credibility to the assumption of 800 hours per year.

2.4 SAFETY

Young (1985) reports, “there are no indications of AEC responsibility or involvement in monitoring the personal health of workers at the Superior Steel facility where uranium metal was processed.” However, four AEC health and safety visits to the mill during uranium operations are documented (AEC 1953a, b 1955a, b).

AEC personnel recorded visits to Superior Steel dated May 13, 1953, August 3, 1953, May 9, 1955 and September 19, 1955, which resulted in a number of recommendations to improve the safety of the uranium rolling operation. As of the third visit, none of these recommendations had been implemented. By the fourth visit, some safety recommendations had been implemented, but the process had been modified and introduced additional contamination.

2.4.1 Workplace Contamination Controls

In health and safety reports, AEC recommended ensuring the salt coating remained on the uranium or providing ventilation over the rolls. Additionally the rolling mill table and conveyor and shear table were to be vacuumed after each break in the rolling cycle. Gloves were recommended for rolling mill personnel and were to be burned after use and disposed of with uranium oxide scrap stored in drums. Face shields were recommended for workers tending the salt bath or loading slabs on the conveyor. AEC also pointed out that workers should be informed of the health and safety precautions necessary in handling uranium.

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 their recommendation for soluble uranium compounds to 50 µg/m^3 based on the chemical toxicity, which is equivalent to 70 dpm/m^3 for natural uranium. This level was based primarily on animal studies. The Medical Division of the AEC New York Operations Office (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 1949c). Some of the Superior Steel reports refer to a maximum allowable concentration (MAC) of 100 dpm/m^3.

There were four documented visits to Superior Steel during operations by the AEC (1953a, b, 1955a,b). All the visits reported airborne contamination in excess of recommended levels. The results were mixed with either most of the recommendations not being incorporated or proving to be ineffective.

AEC noted a lack of ventilation over the rolls in May and August 1953 and May 1955 (AEC 1953a, b; 1955a), evidenced in part by the dust clouds observed around the roughing roll area. AEC recommended that ventilation be added over the rolls and over the shears. Dripping water on the hot rolls contributed to the airborne uranium concentrations, and this was to be avoided.

A furnace that included a salt bath was added prior to the August 1953 AEC survey. A pneumatic cut-off device attached to a “fork-lift type conveyance” replaced the conventional shear as of August 1953 (AEC 1953b). AEC (1953b) also noted that “two large vacuum cleaning units” were made available to Superior Steel for the duration of the contract. As of September 19, 1955, local exhaust ventilation was provided at the roughing roll, but a new dust source was introduced.

Man-cooling fans were used to reduce air concentrations during the May 1955 processing. Although these did appear to reduce concentrations in the process areas, it is likely they caused further spread of contamination (1955a).

By November 1955, ventilation was added over the roughing mill and the shear station. This reduction of air concentrations was offset by the set up of a brushing station to remove the salt coating on the uranium, which was thought to cause pitting. The brushing caused increased air concentrations, as did the lack of a salt coating on the uranium when it went through the rolling stands. Clouds of dust were also noted during stamping (AEC 1955b).

2.4.3 Contamination/Radiation

Documentation of contamination and radiation levels at Superior Steel during the AEC operations period included the following:

> Alpha contamination, greater than 50,000 dpm/100 cm^2, was found in many locations after the September 19, 1955 uranium rolling. It was noted that a thorough hosing with water reduced the contamination to negligible levels (AEC 1955b). Smears taken on the floor and in the area near the shears ranged from 175 to 11,400 dpm/150 cm^2 of alpha (1953a). (Smear results are usually reported for areas of 100 cm^2, but these results were reported for areas of 150 cm^2.)

No measurements of ambient radiation levels during AEC operations have been found for Superior Steel. Radiation and contamination measured after operations are summarized in Section 5.

2.5 INCIDENTS

No radiological incidents were noted in the available documentation regarding Superior Steel. However, AEC (1953b) noted that Superior Steel mill hands sat on the pile or uranium strips in the storage area.

2.6 PHYSICAL EXAMINATIONS – X-RAYS

No information regarding AEC-required physical examinations for Superior Steel employees has been located.

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

It was assumed that employees worked 8 hours per day for 50 weeks per year, for a total of 2000 hours per year. It was assumed that 100 workdays per year, i.e., 800 work-hours per year, were spent rolling uranium.

No information regarding site access or work categories is available for Superior Steel. Exposure assignments are based on data that are suggestive of workers' exposures and further modified by uncertainty parameters, when appropriate, to ensure that the reconstructed dose distributions capture the larger exposures. No attempt has been made to sort workers into exposure categories. Depending on the organ of interest and the ancillary data associated with a specific claim, additional considerations might be appropriate

2.8 CLEANUP/RESIDUAL CONTAMINATION PERIOD

Young (1985) reported that no documents indicated that a final cleanup and survey of the site were performed as part of the contract close-out process in 1957.

The Formerly Utilized Sites Remedial Action Program (FUSRAP) began in 1976. ORNL (1981) performed a radiological survey on July 31, 1980 to characterize the property for FUSRAP. At the time of the survey, the site was being used to rebuild coke oven doors.

Some contamination (the thatched areas in Figure 1) was identified, primarily near the pits located in Areas A and C and near a storage shed. A buildup of coke dust from the "current" operation and the limited access to areas prevented a rigorous survey (ORNL 1981). Some equipment used during AEC work was still present in 1980. No further information regarding the status of the site since 1985 has been located. It is assumed that the site remains accessible, although Superior Steel is no longer associated with the site.

3.0 ESTIMATION OF INTERNAL EXPOSURE

The primary source of internal radiation exposure at Superior Steel was uranium dust produced from the manipulation and oxidation of uranium metal during rolling and related processes. Natural and enriched uranium were rolled at Superior Steel. It's also possible that Superior Steel rolled recycled uranium after 1952.

3.1 URANIUM

Human and animal studies have indicated that oxides of uranium can be very insoluble (ICRP 1995), indicating absorption type S (0.1% and 99.9% with clearance half-times on the order of 10 minutes and 7000 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) suggesting 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.

Individual uranium urinalysis data are unavailable for Superior Steel workers and none are known to exist. This document analyzes air monitoring data for use in reconstructing internal doses.

3.1.1 Uranium Air Sampling

Air sampling was performed at Superior Steel during some of the uranium rolling (AEC 1953a, b; 1955 a, b). The air samples consisted of collection on filters of radioactive particulate from breathing zones (BZs), and general areas (GAs) during processing. The alpha activity measured on the filter was used to determine airborne alpha activity concentrations. When multiple samples at a location were collected, AEC used the mean air concentration in subsequent calculations. At most facilities, the AEC matched air concentration determinations with information about worker categories, locations, tasks, and workers' time at each location or task; however, AEC noted that this was not feasible at Superior Steel (Harris 1953), but did not include the reasoning for this conclusion.

Four AEC reports of measured uranium air concentrations have been found for Superior Steel. Not all locations were measured each time. Although it is likely that workers at one steel mill would have similar duties as at another steel mill, it was not considered expedient to try to determine time-weighted exposures for Superior Steel workers. In addition, changes in the process and the safety controls resulted in both increased and decreased exposure for any given period. In this document, an estimate of intake was made by estimating the 95th percentile of the average air concentrations, summarized in AEC 1955b. This was done by sorting and ranking the dated results in Table 1, calculating the z-score of each rank, log transforming the air concentrations, plotting the z-scores versus the natural logarithms of the air concentrations and fitting a line to this data. The y-intercept of the line raised to e was assumed to be the 50th percentile air concentration and the slope of the line raised to e was assumed to be the geometric standard deviation, GSD. The line fit was satisfactory (the fit parameter, R^2 equaled 0.9884: a value greater than 0.9 indicates a reasonable fit). The 95th percentile air concentration was determined by multiplying the GSD, 5.63, raised to the 1.645 power, by the 50th percentile result, 597 dpm/m3. The calculated 95th percentile air concentration is 10250 dpm/m3. This air concentration was used to estimate workers' internal exposures. It should be noted that although some concentrations reported for Superior Steel are fairly large, these are not outside the range of concentrations measured at other steel mills doing AEC work, such as Aliquippa Forge, Bethlehem Steel, and Simonds Saw and Steel. Based on the time and motion studies at other AEC-contracted steel mills, there is no reason to believe that any one worker would be exposed consistently to only large or small air concentrations for extended periods during uranium processing. The calculated 95th percentile air concentration was used to calculate upper estimates of internal exposures.

Table1. Air concentrations[a]

Sample Type	Location and Description	Alpha dpm/m^3				
		13-May-53	3-Aug-53	9-May-55	19-Sep-55	Maximum
Process Air	Vicinity of Salt Bath	-	250	42	187	250
Process Air	West of Mill runout table	29	861	44	-	861
Process Air	East of Mill runout table	39	1514	78	42	1514
Process Air	Southwest of Roughing Roll (15 ft away)	2350	1254	-	-	2350
Process Air	Roughing roll Feed	1280	38520	330	325	38520
Process Air	Roughing roll Discharge	2150	1660	336	195	2150
Process Air	Northeast of roughing roll (15 ft away)	1400	98	-	243	1400
Process Air	West of flying shear	11	-	-	-	11
Process Air	West of brushing station	-	-	-	2680	2680
Process Air	At brushing station	-	-	-	553	553
Process Air	Northwest of finishing stand #1	310	-	-	360	360
Process Air	Between Finishing stands 1 and 2	-	-	-	797	797
Process Air	Between Finishing stands 2 and 3	660	150	-	-	660
Process Air	Between Finishing stands 3 and 4	375	1263	212	564	1263
Process Air	Between Finishing stands 4 and 5	7200	262	121	480	7200
Process Air	East of Finishing stand 5 (shear)	7600	1950	86	900	7600
Process Air	Northwest of shear	-	-	954	1743	1743
Process Air	Northeast of shear	-	-	-	1840	1840
General Area	Discharge end of stamping table	-	-	-	1768	1768
Breathing Zone	Cutting 1 plate into 3 sections at shear	-	-	9490	-	9490
Breathing Zone	Stamping 3 sections of plate	-	-	20170	8950	20170
Breathing Zone	Handling plate and tossing scrap into drum	-	-	2044	2257	2257

a. Data From AEC 1955b.

This analysis of intakes assumes that uranium processing took place between January 1, 1952, and December 31, 1957. This analysis also assumed that 100 days of every year were spent rolling uranium. It was assumed that uranium processing occurred in 8-hour shifts, although two of the four AEC air sampling reports indicate that processing took less than 6 hours.

The breathing rate is based on the default for light work shown in ICRP Publication 66 (ICRP 1994, Table 6, p. 23). The intakes, in pCi, were calculated by dividing the 95th percentile of the air concentration, 10,250 dpm/m^3, by 2.22 dpm/pCi and multiplying this result by the breathing rate and the assumed number of hours exposed at the given concentration. Superior Steel organ doses from internal exposure are assumed to be a constant distribution. Several assumptions included in the intake/dose reconstruction are likely to be overestimating assumptions.

Tables 2 lists the estimated inhalation intake during AEC uranium processing work.

Table 2. Inhalation exposures during rolling operations.

Work period	Number of years	Number of potential AEC work-hours per year	Air concentration (pCi/m^3)	Breathing rate (m^3/h)	Intake (pCi)
1/1/1952-12/31/1957	6	800	4.62E+03	1.2	2.66E+07

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 concentration, listed in Table 2, by the indoor deposition velocity and the assumed deposition time. The indoor deposition velocity is dependent on the physical properties of the room (such as air viscosity and density, turbulence, thermal gradients, and surface geometry). It is also dependent on the physical properties of the aerosol particles (such as diameter, shape, and density). In this case, 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 0.00075 m/s, which is within the range of deposition velocities (2.7×10^{-6} to 2.7×10^{-3} m/s) measured in various studies (NRC 2002a).

The calculated surface contamination level created from airborne dusts during the uranium rolling from January 1, 1952, to December 31, 1957, was 5.98E+07 pCi/m^2 (1,330,000 dpm/100 cm^2). The claimant-favorable assumption was made that all of the surface contamination was present for the entire period of AEC operations. Thus, using a resuspension factor of 1×10^{-6}/m (NRC 2002b), the air concentration due to resuspension would have been 59.8 pCi/m^3. Table 3 lists the assumed annual inhalation intake received from resuspension of deposited material. The intake listed in Table 3 is added to the intake listed in Table 2 before calculation of annual organ dose: the intakes are adjusted to intakes per calendar day and summed in Table 6.

Table 3. Inhalation exposure during non-AEC operations due to resuspension of deposited uranium dust.

Work period	Number of years	Number of potential nonAEC work-hours per year	Breathing rate (m^3/h)	Resuspended air concentration (pCi/m^3)	Intake (pCi)
1/1/1952-12/31/1957	6	1200	1.2	59.8	5.17E+05

In the case where inhalation intakes are calculated from air concentrations, ingestion intakes are also to be considered. 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. The daily ingestion intake rate from rolling operation is estimated from the air concentration in Table 2. The daily ingestion intake from resuspended uranium is estimated from Table 3. The ingestion intake rates are multiplied by the number of work-hours exposed at the calculated levels and summed. Ingestion intakes per calendar day are calculated and shown in Table 4.

Table 4. Estimated amount of uranium ingested (pCi) (based on Tables 2 and 3).

Work period	Days of uranium rolling	Uranium ingestion rate (during uranium rolling) pCi/d	Days of Non-uranium rolling	Uranium ingestion rate (during normal operation) pCi/d	Intake pCi
1/1/1952-12/31/1957	600	923	900	12.0	5.65E+5

3.1.2 Enriched and Recycled Uranium

Records for Superior Steel indicate natural and enriched uranium were processed. There was no mention of depleted uranium. Because the Superior Steel air samples were counted with alpha detectors, which detect radioactivity rather than mass, there is no need to adjust measured air concentration results for assumed uranium enrichment.

Enrichment could affect assumptions about the radioactivity in the mass of the uranium released during processing, but AEC air sample results taken during the processing of enriched uranium, indicate that the airborne radioactivity concentrations during enriched uranium processing did not exceed those concentrations measured during processing of natural uranium. Because of the unknown enrichment and the unknown fraction of enriched material processed at Superior Steel, this document assumes that intakes are U^{234} for the purpose of internal dose calculation for an organ.

Recycled uranium might have been processed at Superior Steel after 1952. An estimate of contaminants that might contribute the most to internal doses, based on a review of recycled uranium contaminants at Hanford and Fernald, is shown below. It is unlikely that recycled uranium would constitute the entire Superior Steel source term. Also, the activity fractions assume that the uranium specific activity is based on 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 oxides.

Table 5. Estimate of contaminant activity fractions in a recycled depleted uranium source term (pCi contaminant per pCi uranium).

Uranium	Pu-239	Np-237
1	0.00246	0.00182

3.2 OCCUPATIONAL INTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

The assumed operational exposure period ran from January 1, 1952, to December 31, 1957.

Table 6 lists intake rate assumptions for uranium-234. The intake mode is chronic. The dose distribution is assumed to be constant.

Table 6. Internal exposure summary for operational period January 1, 1952, to December 31, 1957.

	Start	End	Intake route	Absorption type	Intake (pCi/calendar-day)
U-234	1/1/1952	12/31/1957	Inhalation	M, S	1.24E+04
	1/1/1952	12/31/1957	Ingestion	(a)	2.58E+02
Pu-239	1/1/1953	12/31/1957	Inhalation	S	3.05E+01
	1/1/1953	12/31/1957	Ingestion	(a)	6.36E-01
	1/1/1953	12/31/1957	Inhalation	M	2.25E+01
Np-237	1/1/1953	12/31/1957	Ingestion	(a)	4.69E-01

a. Choose same f_1-value as used for inhalation per NIOSH (2004).

4.0 ESTIMATION OF EXTERNAL EXPOSURE

No external dosimetry results are available for Superior Steel employees. This analysis estimated dose, assuming 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 slabs and plates,
- Exposure to photons from the uranium slabs and plates, and
- Exposure to an annual diagnostic X-ray.

The majority of photons from natural uranium metals are in the 30 to 250 keV energy range. Solid uranium objects provide considerable shielding of the lower energy photons and harden the spectrum, causing the majority of photons emitted from a solid uranium object, such as a thick plate, to have energies greater than 250 keV. While it is recognized that solid uranium sources will have a hardened photon spectrum, exposure to a thin layer of uranium on a surface will result 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 claimant favorable. Nonpenetrating dose from natural uranium consists primarily of electrons with energies >15 keV. For consistent presentation, exposure or dose is reported as:

- penetrating, assumed to be associated with photons of energies 30 keV or greater, and
- nonpenetrating assumed to be associated with with photons of energies less than 30 keV or with electrons.

Superior Steel processed some enriched uranium. Enriched uranium external doses would be similar or perhaps smaller than those from natural uranium.

4.1 SUBMERSION AND CONTAMINATION EXPOSURES

Information regarding submersion and contamination exposures at Superior Steel is very limited, so data based on a survey at Simonds Saw and Steel, a rolling mill involved in uranium work for the AEC, was used to estimate these exposures. In a survey at Simonds Saw and Steel, the AEC suspended 20 film badges about 5 feet from the floor in the rolling mill for 192 consecutive hours "to determine the long term direct [external] radiation to individuals" (AEC 1949b). 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 results of these measurements are assumed to represent the general levels of external exposure from submersion in air and contaminated surfaces at Simonds. This analysis assumed that the data distribution was lognormal. The calculated geometric means were 1.3 mR/h with a GSD of 2.3 for the nonpenetrating radiation, and 0.26 mR/h with a GSD of 1.2 for the penetrating radiation. The maximum results were reported as 5.6 mR/h beta and 0.34 mR/h gamma. The beta reading is assumed to be related to the nonpenetrating dose and the gamma reading is assumed to be related to the penetrating dose. These assumed exposures at Simonds during operational years are listed in Table 9. This analysis assumed that all workers were exposed to penetrating and nonpenetrating radiation from submersion in air and contamination for each workday for 8 hours/day.

4.2 SLABS AND PLATES EXPOSURES

Another assumption was that workers received a deep dose due to photon exposure from the uranium slabs and plates. According to reports, the AEC work involved rolling uranium slabs 1 in. in thickness, 61 to 89 in. long and 5.5 to 7 in. wide. The slabs were rolled into plates approximately 0.185 in. thick and 25 to 37 ft long cut into sections of about 6 ft. Monte Carlo N-Particle (MCNP) calculations determined the photon (including bremsstrahlung) dose rate at the surface, 1 ft, and 1 m from a 4 in. thick by 16 in. by 24-in. rectangular slab and a 0.18 in. thick by 3.5-in. by 18 in. plate. Table 7 lists calculated photon dose rates for the uranium billet and rod.

Table 7. Calculated photon dose rate for uranium slabs and uranium plates.

Distance from source	Slab dose rate (mrem/h)	Plate dose rate (mrem/h)
Surface	8.26	6.27
1 ft	2.08	0.231
1 m	0.373	0.0278

No site-specific information was available to determine the amount of time a worker spent near the uranium forms versus just being in the general area. Records for similar facilities indicate that most workers spend less than 5 hours per shift near the uranium metals, but some workers may spend 7 hours near the uranium metals. This analysis assumed that workers were near the slabs for 3.5 hours per rolling day and near the plates for 3.5 hours per 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 upper 95th percentile.

The annual penetrating dose rates listed in Table 9 were calculated by multiplying the median photon dose rates by the number of rolling days per year and the 8 work-hours per day.

Information regarding shallow doses at Superior Steel was unavailable. Nonpenetrating doses from the slabs and plates were estimated using the measurements in Table 8. These measurements were taken during an AEC survey in September 1948 (Belmore 1948) at Aliquippa Forge. Depleted

uranium dose rate information reported by the Army (1989), indicating a dose rate of 0.205 rad/h at 7 mg/cm^2 at the surface of a clean bare uranium, was also used. Beta dose rates from depleted uranium are larger than dose rates from natural or enriched uranium, because of the larger activity fraction of ^{238}U composition, whose progeny are the significant contributors to beta dose.

Table 8. Direct radiation measurements from September 1948.[a]

Location of measurement	Dose rate (mrep/h)[b]
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" high	2-5
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
b. A rep is an obsolete unit of dose equivalence (roentgen-equivalent-physical) approximately equal to a rem.

The largest dose rate in Table 8 was assumed to the median dose rate, because of the large surface areas of the plates and slabs. The 20 mrep/h was assumed to be equivalent to a dose rate of 20 mrad/h. The upper 95th percentile dose rate was assumed to equal the 7 mg/cm^2 dose rate of 205 mrad/h, giving a GSD of 4.1. These exposure rates were multiplied by the assumed number of uranium contact hours per day (3.5 for the slabs and 3.5 for the plates, respectively) and the number of rolling days per year (100). Table 9 lists these doses.

4.3 OCCUPATIONALLY REQUIRED MEDICAL X-RAY

Information regarding whether or not occupationally required medical X-ray examinations were performed at Superior Steel is unavailable. AEC usually, but not always, required "preemployment" and periodic (annual) medical examinations of workers involved in the larger uranium processing programs. The term "preemployment" as used here, means prior to performing AEC-contracted radiological work. The typical AEC medical program included a preliminary chest x-ray examination with annual examinations thereafter. The type and frequency of x-ray examination should be based on current ORAU Team guidance. Organ doses can be obtained from the current revision of ORAUT-OTIB-0006, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures* (ORAUT 2003).

4.4 MISCELLANEOUS INFORMATION RELATED TO EXTERNAL DOSE

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

AEC noted that workers were sitting on the piles of uranium (AEC 1953b).

4.5 OCCUPATIONAL EXTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

Table 9 summarizes occupational external doses during uranium operations at Superior Steel. A Superior Steel worker's total external exposure for a given year of uranium operations is assumed to be the summation of the listed exposures in Table 9 for that year.

Table 9. External exposure summary for operational period January 1, 1952, to December 31, 1957.

Exposure mode	Exposure type	Exposure or dose rate	Basis	Exposure time assumption	Year	Annual exposure	IREP distribution
Submersion/ area contamination	Penetrating	0.26 mR/h	Film badge	2000 work-h/y	1952 1953 1954 1955 1956 1957	0.520 R 0.520 R 0.520 R 0.520 R 0.520 R 0.520 R	Lognormal GSD 1.2
	Non-penetrating	1.3 mR/h	Film badge	2000 work-h/y	1952 1953 1954 1955 1956 1957	2.600 R 2.600 R 2.600 R 2.600 R 2.600 R 2.600 R	Lognormal GSD 2.3
Medical X-ray					1952 1953 1954 1955 1956 1957	See ORAUT-OTIB-0006, (ORAUT 2003)	
U slabs	Penetrating	0.703 mrem/h	MCNP calculation	3.5 h/rolling-day	1952 1953 1954 1955 1956 1957	0.728 rem 0.728 rem 0.728 rem 0.728 rem 0.728 rem 0.728 rem	Lognormal GSD 2.3
	Non-penetrating	5 mrad/h	Instrument measurement	3.5 h/rolling-day	1952 1953 1954 1955 1956 1957	7.0 rad 7.0 rad 7.0 rad 7.0 rad 7.0 rad 7.0 rad	Lognormal GSD 4.1
U plates	Penetrating	0.285 mrem/h	MCNP calculation	3.5 h/rolling-day	1952 1953 1954 1955 1956 1957	0.081 rem 0.081rem 0.081rem 0.081rem 0.081rem 0.081 rem	Lognormal GSD 7.4
	Non-penetrating	5 mrem/h	Instrument measurement	3.5 h/rolling-day	1952 1953 1954 1955 1956 1957	7.0 rad 7.0 rad 7.0 rad 7.0 rad 7.0 rad 7.0 rad	Lognormal GSD 4.1

5.0 ESTIMATION OF RESIDUAL EXPOSURE

The residual dose period is assumed to begin on January 1, 1958 after the AEC rolling contract ended and to continue through the present. An 8-hour workday is assumed during this period.

No surveys have been found to estimate the levels of radiation and contamination when the AEC work ended in 1957. ORNL (1981) performed a radiological survey in July 1980 to characterize the former Superior Steel site for FUSRAP.

> *Only portions of the roughing (breakdown) mill were intact during the survey, all other machinery had been removed and sold or scrapped in previous years. The roughing mill has since been removed. Subfloor pits (approximately 8 ft. deep) over which the former mill, brushing station, finishing stands and shear were originally located were filled in with rubble, with final plans for concreting the surfaces over at floor level.*
>
> *The former mill is presently [1980] being utilized in the rebuilding of coke oven doors. During the rebuilding process, significant quantities of fine coat is removed, part of which becomes airborne and settles out on surrounding surfaces. Use of this operation have resulted in coding the north end of the building with a layer of this material (up to 2 in. thick on the floor).*

Area B was being used for storage purposes in 1980. The two pits were being filled with rubble, with plans to concrete the floor level upon completion. The area was sealed off from the former mill (area A) area with a sheet metal wall and was being used primarily for storage. Parts of the roughing mill and the shear were in a storage warehouse on the industrial park.

ORNL used a gamma scintillation survey meter, a beta/gamma Geiger-Mueller tube with open/closed window, and an alpha scintillation meter for the 1980 survey. A summary of the 1980 survey results is shown in Table 10.

Table 10. Superior Steel measured radiation levels on July 31, 1980[a].

Location	Alpha (dpm/100 cm^2)	U-238 (pCi/g of soil or debris)	Contact (mrad/h) Beta/gamma	Beta (mrad/h)	Gamma (mR/h)
Area A	50 (maximum)		0.01 to 0.04		
Area B	<10				background
Area C (pit)	640	5800	0.8	0.3	0.5 (maximum)
Storage shed	50	1100 under floor	0.25	0.25	0.075 to 0.4 0.09 at 1 m from floor
Outside shed					0.2
Equipment in Storage	<10				0.03

a. ORNL (1981)

Uranium-238 is the predominant isotope by mass in natural uranium and is more easily identified than the other isotopes, so some may refer to uranium as uranium-238 rather than natural uranium, which consists of approximately equal activities of U-234 and U-238 and a smaller amount of U-235. Reported U-238 quantities may include all of the uranium activity or just part, depending on actual analysis techniques and reporting procedures.

Although the measured contamination levels were fairly low in 1980, the survey was hampered by limited access to surface. Also, there was no evidence that any cleanup had occurred at the time of contract termination. To calculate internal exposure from residual activity this analysis assumed that the median uranium exposure was associated with uniform contamination of the buildings to a level of 11,400 dpm/100 cm^2. This was the maximum removable contamination measured in May 1953, but is

assumed to be the uniform surface contamination (fixed plus removable) during the residual contamination period. Using a resuspension factor of 1×10^{-6}/m (NRC 2002b) and an air intake rate of 2,400 m^3 per work year, the calculated uranium annual inhalation intake was 1,230 pCi. Using the method described in Section 3.0, the calculated annual ingestion intake was 25.7 pCi. It was assumed that the Pu-239 and Np-237 intakes occurred with the assumed uranium intakes at the ratios listed in Table 5. Table 11 summarizes residual period intake rates.

To reconstruct external exposure to residual radioactivity after the end of AEC operations, this analysis assumed that workers were exposed to 0.09 mR/h penetrating radiation, which was the only available gamma exposure rate reading at 1 m. The residual penetrating radiation exposure is estimated by assuming that the 1-m value was the median rate and the maximum gamma exposure rate (0.5 mR/h) was the upper 95th percentile, which leads to a GSD of 2.82. The non-penetrating exposure rate was determined by assuming that 5.0, the ratio of non-penetrating to penetrating exposure rates for submersion and contamination external exposures during the operational exposure period, provided a reasonable estimate of the ratio of non-penetrating to penetrating exposure rate during the residual exposure period. The resulting non-penetrating exposure rate is 0.45 mR/h. A GSD of 3.8 for the non-penetrating dose rate was calculated by raising the number, e, to the square root of the sum of the squares of the lognormals of the GSDs of the three distributions (2.3, 1.2 and 2.8) used to calculate the non-penetrating dose rate:

$$GSD = e^{\sqrt{(\ln(\sigma_{g1}))^2 + (\ln(\sigma_{g2}))^2 + (\ln(\sigma_{g3}))^2}}$$

The estimated annual penetrating and non-penetrating external exposures to residual radioactivity from AEC operations at the site, listed in Table 11, were calculated by assuming that workers were exposed for 2,000 hours per year.

Assumptions regarding residual exposures should be consistent with assumptions from the operational period.

Table 11. Annual internal and external exposure to residual radioactivity.

Internal	Start	End[b]	Exposure	Absorption type	Intake (pCi/d)	IREP distribution
U-234	1/1/1958		Inhalation	M, S	3.4E+00	Lognormal GSD 5
	1/1/1958		Ingestion	(a)	7.0E-02	Lognormal GSD 5
Pu-239	1/1/1958		Inhalation	S	8.3E-03	Lognormal GSD 5
	1/1/1958		Ingestion	(a)	1.7E-04	Lognormal GSD 5
Np-237	1/1/1958		Inhalation	M	6.1E-03	Lognormal GSD 5
	1/1/1958		Ingestion	(a)	1.3E-04	Lognormal GSD 5
External	**Start**	**End[b]**	**Exposure**	**Basis**	**R/y**	
	1/1/1958		Penetrating	Survey Instrument	0.180	Lognormal GSD 2.8
	1/1/1958		Non-Penetrating	Survey Instrument	0.900	Lognormal GSD 3.8

a. Choose same f_1-value as used for inhalation per NIOSH (2004).
b. No end date is set, because there is no evidence that the site is restricted or has been remediated.

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