ORAU Team **Dose Reconstruction Project for NIOSH** Technical Basis Document: Basis for the Development of an Exposure Matrix for Aliquippa Forge, Pennsylvania, Period of Operation: January 1, 1947 through February 28, 1950	Document Number: ORAUT-TKBS-0021 Effective Date: 11/18/2005 Revision No.: 00 PC-1 Controlled Copy No.: _____ Page 1 of 26
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12/21/2004	11/18/2005	00 PC-1	Approved page change revision. Modified to note the covered period and the period of operation on page 1, 19 and in Section 2.0 on page 5. Modified pages 20, 21, and 22 in response to comments and guidance from OCAS. Updated Section 1.0 (page 5) standard wording. No sections were deleted. Retraining is not required. Initiated by Cindy W. Bloom. Approval: Signature on File 11/09/2005 Cindy W. Bloom, TBD Team Leader Signature on File 11/15/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 11/15/2005 Patricia C. Kimpan, Project Director Signature on File 11/18/2005 James W. Neton, Associate Director for Science

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, 1,000 electron volts
L	liter
m	meter
MDA	minimum detectable activity
mg	milligram
mR	milliroentgen
mrem	millirem
mrep	millirep
NYOO	New York Operations Office
PA	posterior-anterior
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" (AWE facility) or a "Department of Energy facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [EEOICPA; 42 U.S.C. Sections 7384I(5) and (12)].

EEOICPA, as amended, provides for employees who worked at an AWE facility during the contract period and/or during the residual contamination period.

Employment at an AWE facility is categorized as either (1) during the contract period (*i.e.*, when the AWE was processing or producing material that emitted radiation and was used in the production of an atomic weapon), or (2) during the residual contamination period (*i.e.*, periods that NIOSH has determined there is the potential for significant residual contamination outside of the period in which weapons-related production occurred). For contract period employment, all radiation exposures must be included in dose reconstructions. For residual contamination period employment, only the radiation exposures defined in 42 U.S.C. § 7384n(c)(4) (*i.e.,* radiation doses received from DOE/AEC-related work) must be included in dose reconstructions. 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 Aliquippa Forge in Aliquippa, Pennsylvania. At the time of U.S. Atomic Energy Commission (AEC) contract operations, Aliquippa Forge was known as Vulcan Crucible Steel Company. Vulcan Crucible was primarily involved with the rolling of natural uranium. Some time after AEC operations ended, the facility became known as Universal Cyclops. The facility is now owned by the Beaver County Corporation for Economic Development.

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

The Department of Energy's Office of Worker Advocacy lists the Aliquippa Forge covered period from 1947 to 1950. The information that follows supports an assumed period of AEC operations at Aliquippa Forge from July 23, 1948, through February 28, 1950, involving AEC-contracted uranium work. It is also assumed that a preemployment occupationally required medical x-ray examination

might have occurred as early as January 1, 1947. This analysis assumed that the residual contamination period extended from March 1, 1950, through May 31, 1978, and from December 1, 1987, to May 17, 1993.

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

Vulcan Crucible Steel Company produced uranium rods for the AEC from billets primarily by rolling. Operations with uranium at Vulcan Crucible began when a trial rolling occurred on July 23, 1948 (Jones 1948). The AEC contract for production work (AEC 1948a) was initiated on August 16, 1948, and was extended through February 28, 1950 (Belmore 1950; Wallo 1981). The rolling operation ended on March 30, 1949 (AEC 1949a) with decontamination consuming the rest of the contract's term. Decontamination was completed by the Vulcan Crucible in 1950 in accordance with then-current AEC guidelines.

The site consisted of about 19 buildings. The majority of the AEC work occurred in Building 3, the rolling mill. Survey results for Building 8 indicate its involvement with uranium activities (Adams and Payne 1992a; 1992b). In addition, there were indications of uranium in the locker room, tool room, and some areas outside Building 3. Figure 1 shows the layout of the site circa 1990 and Figure 2 shows the layout of the area that encompassed uranium operations. A sketch from 1948 (AEC 1948b) indicates that at least part of the Building 3/8 area was referred to as C Mill. That sketch showed billets in an area known later as Building 8 and a boxcar containing billets and rods to the northwest of Building 8; it also showed the lockers, showers, and toilets to the east of Building 3.

The uranium billets furnished by the AEC came primarily via boxcar from the Electromet facility in New York and the 300 Area on the Hanford Site in Washington (Stroke 1949a). The billets were 15 to 28 in. long, 4 to 5 in. in diameter, and weighed from 120 to 270 pounds. Vulcan Crucible conducted a rolling operation in Building 3 to reduce the billets to rods about 1.5 in. in diameter with an increase in length of a factor of 9. The billets were heated and rough-rolled twice to increase the length, then finish-rolled and halved before quenching and weighing (Wallo 1981).

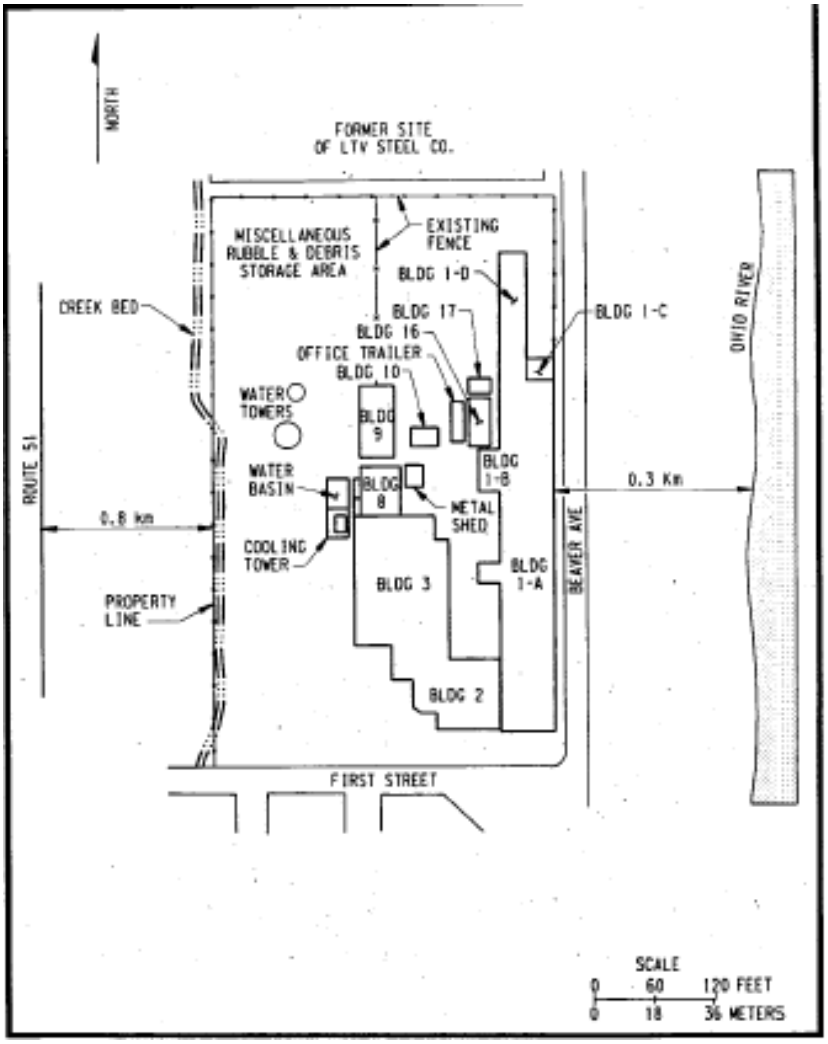

Figure 1. Aliquippa Forge Site circa 1992 (DOE 1996)

The process at Aliquippa Forge consisted of heating the billets to a temperature between 1,050°F and 1,100°F. The drag-down operator used a buggy to move the heated billets from the furnace to the north side of the roughing roll. The billets were passed through the roughing roll two to four times to produce rods of rough dimensions. The rods were then passed through the finishing rolls to achieve the desired dimensions. They were then dragged to the shears, cut in two, and dragged back to the quenching area for descaling. After the rods were stamped, they were conveyed to the shipping and receiving area to be weighed, recorded, and loaded into boxcars (VCSC c.1949; AEC 1949b; Author unknown 1948).

Little information is available on the actual uranium rollings that took place at Vulcan Crucible during the AEC contract period. Documents indicate that each rolling operation involved approximately 96 billets in an 8-hour shift (Stroke 1949b; Reichard 1948a). Other documents indicate that Vulcan Crucible had a 9-hour workday with a rolling rate of 11 to 12 billets per hour (Breslin 1949), which seems consistent with the February 1949 workplace monitoring records, if one additional hour is assigned to lunch and breaks. Table 1 summarizes the available uranium rolling information (Jones 1948; Huff 1948; Schier 1948; Author unknown 1948; Reichard 1948b). Although some documentation indicates that 20% of the time at Vulcan Crucible was spent rolling uranium billets for the AEC (Wallo 1981), the AEC contract required that Vulcan Crucible be prepared to perform rolling

work at least two consecutive weeks out of every five consecutive weeks (AEC 1948a), which would be 40% of the time.

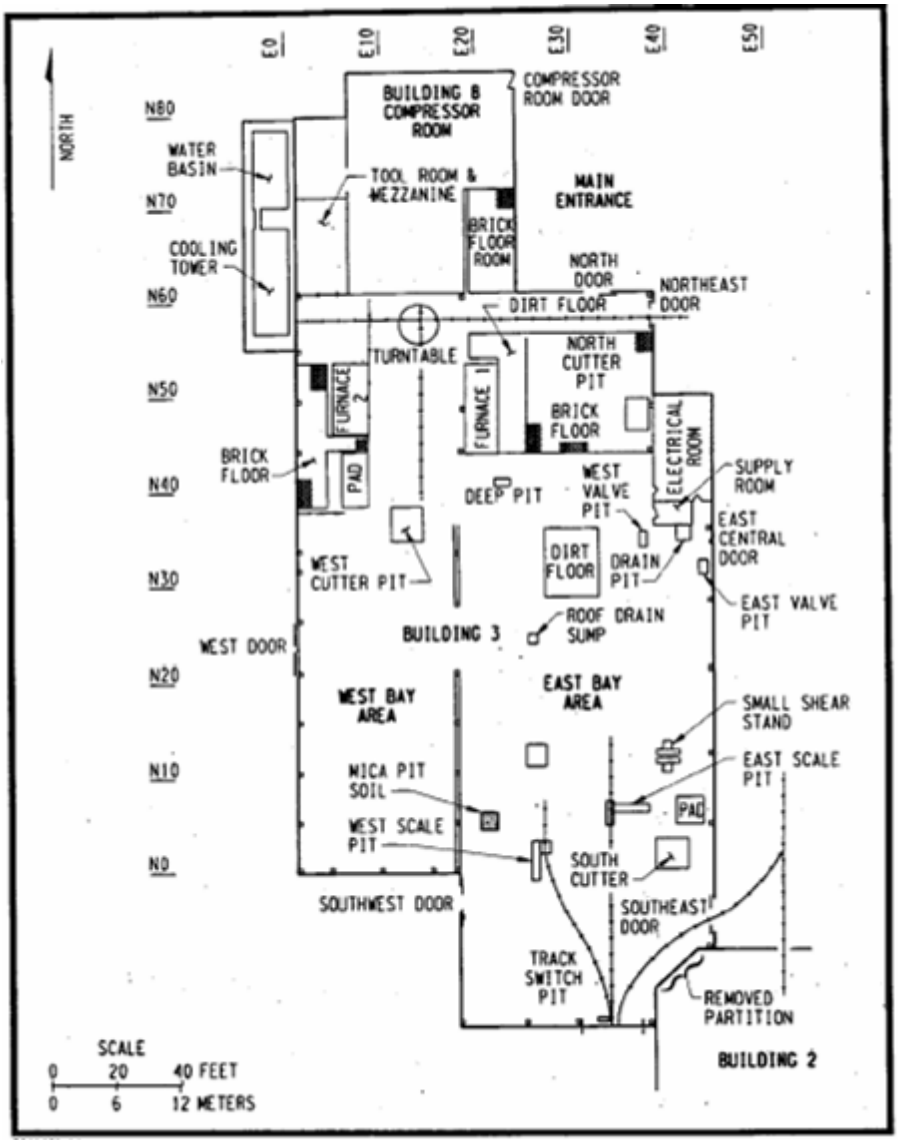

Figure 2. Aliquippa Forge Buildings 3 and 8 where AEC uranium operations occurred (DOE 1996)

Vulcan Crucible employed about 20 to 25 workers at the rolling plant with approximately 20% of the total rolling time occupied by AEC work (Wallo 1981). AEC personnel made occasional visits to assess working conditions in the mill and attended some, but not all, rolling operations.

As of September 2, 1948, the exhaust ventilation system consisted of two large roof ventilators for the building (AEC 1948b). The ventilator placement was not considered ideal for the uranium rolling operations.

Table 1. Documented uranium rollings at Vulcan Crucible.

Date of rolling	Type	No. of billets rolled
July 23, 1948 [a]	Trial	8
August 23-September 2, 1948 [b]	Production	822 Type B (80 tons)
September 27, 1948 [c]	Experimental forging	50
October 21-November 3, 1948 [d]	Production Experimental forging	Unknown 52 forged
January 3- 15, 1949[e].	Production	982 Type B billets 103 Type C billets (~120 tons)
February 14-23, 1949 [f]	Production	112 “small billets per shift”
March 30, 1949 [g]	Unknown	70 “large billets per shift”

a. Jones (1948)
b. Author unknown (1948)
c. Schier (1948)
d. Hauff (1948), OSTI (2002)
e. Padden (1949)
f. Breslin (1949), OSTI (2002)
g. Breslin (1949)

During the September 1948 AEC visit, a large door and windows at the end of the mill were open, which reportedly carried dust to the southeast of the plant (AEC 1948b). The AEC Medical Division recommended that Vulcan Crucible upgrade the exhaust ventilation system and install a central vacuum to maintain cleanliness. The recommendations were transmitted to Vulcan Crucible on October 14, 1948, as requirements for “the contemplated metal rolling contract” (Belmore 1948). A November 2, 1948, memorandum indicates that the vacuum system had been installed (Reichard 1948a). However, as of the February 15-16, 1949, rolling, the upgrade to the ventilation system had not been made (AEC 1949b), although temporary ventilation over the rollers was provided for that rolling campaign.

AEC visits were made before and after modifications to the ventilation system (Belmore 1948, AEC 1948b, 1949b; Breslin 1949, Klevin 1949). The Monthly Status and Progress Report for April 1949 (AEC 1949a) states:

> *Since the Vulcan Crucible Steel Company cannot handle the larger-size billets which give better casting yields, it was decided to consolidate operation at Simonds. Because of this decision, rolling operations ceased at Vulcan after the March [1949] run. Portable Government property is to be removed immediately. Attached property is to be left at Vulcan, provision will be made for emergency standby facilities until the contract expires in August.*

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 chemical toxicity, which for natural uranium is equivalent to 70 dpm/m^3. 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).

The AEC visited Vulcan Crucible on September 1, 1948, to conduct a health physics survey and “to determine:

1. The type of physical examination given to the men
2. The use of protective clothing, showers, and lunchroom
3. The exposure of personnel to direct radiation
4. The spread of contamination in the plant
5. The concentration of radioactive dust in the air." (AEC 1948b)

Medical examination requirements for Vulcan Crucible uranium workers were specified in October 1948 (Belmore 1948). The AEC staff noted on March 29, 1949, that "a complete blood count, a urine and a chest x-ray were done on all employees exposed in the rolling area before work on the AEC Project was started" (Tabershaw 1949) and "a repeat blood count and urine [medical, not radioactivity analyses] were done on all workers after a period of 6 months." The X-ray examinations were performed by Dr. W. T. Rice, who kept the films in his Rochester, Pennsylvania, office.

As of the September 1, 1948 visit, there were few health physics controls in place. AEC (1948b) noted, "workers furnish and launder their own clothes, shoes and gloves and usually change before going home. Separate lockers are not provided for clean and dirty clothes. Smoking is permitted in the mill and some men were observed smoking with their dirty gloves on. The men also eat their lunch in the vicinity of the mill." In addition, the report noted that workers were loitering or standing near uranium billets or rods, and one even sat on billets while taking a break.

In October 1948, the AEC specified "protective clothing and hygienic procedures" (Belmore 1948). Protective clothing was listed as dedicated work clothing, gloves, and shoes. The AEC recommended that Vulcan Crucible provide workers with clothing that could be kept separate from personal clothes. Workers were to be instructed to not eat or smoke with gloved hands, and to wash hands thoroughly before smoking, eating, or leaving the shift. The AEC also recommended showering at the end of the shift. No later reports were found to indicate that the company supplied clothing, but there was indication that some workers showered and changed at the end of the shift. The available records indicate contamination controls were not strictly implemented.

The air samples taken during the September 1948 visit indicated one sample (during the third pass in back of the mill) showing an air concentration as high as 1,800 times the preferred level. Although peak values need to be considered, the fact that work tasks and worker locations were constantly changing resulted in time-weighted exposures that were typically much lower than the peak values. The other air sampling results for September 1 and 2, 1948, showed concentrations in the range of 2.6 to 510 times the preferred level, with 15 of the 22 results less than or equal to 50 times the preferred level.

A NYOO report of an AEC visit to Vulcan Crucible on February 15 and 16, 1949, describes time-weighted radioactive dust exposures between 2.7 and 5300 times the preferred level depending on the type of job (AEC 1949b). A review of the February 1949 report and calculations shows that February report was in error and overstated the maximum exposure by about a factor of 10. When discussing the higher concentration, the report states:

> *It was noted during the sampling that relatively large flakes of scale were being thrown from the rods at this operation. The above concentrations may therefore represent some number of large, non-respirable particles, and not be a true indication of exposure.*

A later summary report (AEC 1949c) stated that four people directly involved in the rolling were exposed to as much as 530 times the preferred level. The summary report mentioned that the

recommended ventilation system upgrade had not been installed, but was on order and that a temporary although inadequate system was in place.

The AEC visit of March 30, 1949, occurred after the installation of a new exhaust fan with twice the capacity of the previous fan. During this visit, the largest calculated time-weighted uranium exposure was 21 times the preferred level. A reevaluation of one worker's exposure based on a statement that one sample appeared to be unreasonably low indicates that the largest exposure might have been 57 times the preferred level. This is still indicative of a reduction of uranium air concentrations due to the improved ventilation. The AEC noted during this visit that rather than rolling 112 "small" billets during a 9-hour shift, 70 "larger" billets were rolled in an 8-hour shift, which might also have contributed to the lower uranium dust concentrations (Breslin 1949). The AEC record indicates that there were no rolling operations after March 1949 and that only cleanup operations were taking place (AEC 1949a).

The purpose of the April 24, 1949, AEC visit was to survey the contamination resulting from previous rolling. The visit resulted in recommendations for the cleanup of the mill. The visit of July 21, 1949, evaluated the effectiveness of the recommended decontamination. During these two visits (Belmore 1949b, Klevin 1949), AEC took direct measurements of surface contamination using a Zeuto, but collected no smear samples. (A Zeuto is a portable ionization chamber. The early models were used to measure alpha contamination; some models also measured beta and gamma radiation.)

Based on the time-motion information collected on February 15-16, 1949 (AEC 1949b) and March 30, 1949 (Breslin 1949), this evaluation assumed 10-hour workdays prior to March 30, 1949, and 8-hour workdays thereafter. Table 2 lists the assumed number of workdays and uranium rolling days in each period.

Table 2. Number of assumed workdays and uranium rolling-days.

Start	End	Non-uranium rolling workdays	Rolling days	Calendar days
7/23/1948	12/31/1948	116	50	162
1/1/1949	3/29/1949	63	30	88
3/30/1949	12/31/1949	198	90	277
1/1/1950	2/28/1950	42	20	58

The analyses in this Technical Basis Document divide the workers into three categories, as listed in Table 3. While different tasks in the mill resulted in differences in exposures (AEC 1949b), it is not known if each worker always performed the same task within a group, or if workers temporarily worked in locations where higher or lower exposures occurred. Workgroup exposure assignments are based on data that are suggestive of workers' 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 ancillary data on a specific claim, additional considerations might be appropriate.

- Group I workers were assumed to have been involved primarily with heating, rolling, finishing, and quenching of uranium. They spent the largest part of their time in the general mill area near the furnace and rollers.

- Group II workers were assumed to have worked primarily with the finished uranium rods and to have spent the largest part of their time in the rod storage area and boxcar.

- Group III workers were not engaged directly in the processing of uranium. They probably had lower internal and external exposures than the other groups, with the possible exception of the guards, who might have spent time near the boxcar and the uranium storage areas.

Table 3. Job titles involved in uranium rolling.

Group I	Group II	Group III
Hook Man (Front Hooker, Back Hooker)	Shipping and Receiving	Guard
Drag-down Operator (Buggy Man)	Checker	Technical Supervisor
Rougher	Rod Weigher	Office Workers
Finisher		
Shear Man		
Shear Man Helper		
Heater (Furnace Man)		
Heater Helper (Furnace Man Helper)		
Mill Roller		
Catcher		
Hot Sawyer		
Hot Sawyer Helper		
Rod Stamper		
Quencher		

Table 3 categorizes Vulcan Crucible uranium rolling job titles in the designated groups. Exposures to workers who do not fit in the groups are designated to an "unknown" category, which is included in the internal and external exposure sections of this Technical Basis Document.

In July of 1949, a survey was performed to determine Vulcan Crucible cleanup requirements (Belmore 1949a). Additional AEC assessments/surveys were made throughout the cleanup process; and although it was noted that the cleanup personnel had no monitoring equipment, AEC assessments concluded that a sufficient job of cleanup had been done (Author unknown 1950; Belmore 1950).

The Formerly Utilized Sites Remedial Action Program (FUSRAP) began in 1976.

> *A radiological survey in 1978 identified contamination (primarily uranium-238) 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 may refer to it 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.] The site was designated for further remediation under FUSRAP, and the small operation was shut down and the building evacuated* (Perry 1993).

Radioactive contamination was found during the survey of May 2-8, 1978, on the dirt floor, concrete floor, steel floor plates, and the overhead beams above the furnaces used in the uranium processing (Wynveen et al. 1982). The actual date of building evacuation is unknown and is assumed to have occurred on May 31, 1978, after the FUSRAP survey.

In August 1983, the Aliquippa Forge site was designated for remedial action under FUSRAP (DOE 1996). In December 1987, storage activities began in Building 3. Interim remedial actions were taken from October to December 1988 to enable additional restricted use of Building 3 for expansion of a small forging operation (Baublitz 1988, Harbert 1989, DOE 1996). Controlled areas were established to prevent access to contamination (Seay 1988, DOE 1996). The exact date of reoccupation is

unknown, but is assumed to have occurred as early as December 1, 1987. As of May 17, 1993, the buildings were no longer in use, although the date that use ended is not clear. This analysis assumed that a second period of residual exposure occurred from December 1, 1987, to May 17, 1993. Final remedial activities occurred from about June 1993 to September 1994 (Abelquist 1995, DOE 1996). A final survey and decontamination were performed in 1995 (DOE 1996). A Department of Energy notice of certification was published in October 1996 in the *Federal Register* (61 *FR* 211, pp. 55981-55982).

Because recycled uranium was not available to contracted AEC facilities until after March 1952 (DOE 2001), the Vulcan Crucible exposure analysis did not consider it.

3.0 ESTIMATION OF INTERNAL EXPOSURE

The primary source of internal radiation exposure at Vulcan Crucible was uranium dust produced from the manipulation and oxidation of uranium metal during the rolling and related processes. There is no indication that uranium rolled at Vulcan Crucible was enriched, so the analysis assumed natural uranium enrichment.

Human and animal studies have indicated that oxides of uranium can be very insoluble (ICRP 1995), indicating absorption type S. 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. *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 at Vulcan Crucible, this analysis assumed that both types M and S were available. The selection of absorption type should depend on the organ of interest. Dose reconstructions should assume International Commission on Radiological Protection (ICRP) Publication 66 default parameters for particle deposition (ICRP 1994).

The uranium fusion photofluorimetry urinalyses performed by the University of Rochester and the AEC NYOO were similar to those performed at the Fernald Plant. The default detection threshold for uranium urinalysis is 14 µg/L, based on the Fernald reevaluation of its uranium fluorimetry urinalysis minimum detectable activity (MDA) in 1993 (Blalock 1993).

Individual uranium urinalysis data are available for some Vulcan Crucible workers (AEC 1949d). For unmonitored workers or unmonitored periods, this Technical Basis Document analyzes air monitoring data for use in reconstructing internal doses.

3.1 URANIUM AIR SAMPLING

Air sampling was performed at Vulcan Crucible during some of the uranium rolling (AEC 1949c; Breslin 1949). The air samples consisted of collection on filters of radioactive particulate from breathing zones (BZs), general areas (GAs), processes, and effluents. 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.

The AEC used the information on work tasks with the measured air concentration to determine an average air concentration weighted by time, and summed these weighted average air concentrations

to determine a daily weighted average air concentration for specified job categories. These air concentration results are further analyzed here to determine group geometric means. The daily weighted average air concentrations were weighted further by the AEC-reported number of workers exposed at a given concentration. The geometric means of the workgroups' daily weighted average air concentrations were calculated. The geometric standard deviations (GSDs) of both the job category concentrations and the workgroup concentrations (this latter GSD includes consideration of the number of people included in each category in the AEC study) were determined to provide an indication of the distribution of the data. This analysis assumed that, because 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.

The report on the February 1949 rolling shows time-weighted air concentrations measured at the plant before the upgrade of the ventilation system. The report on the March 1949 rolling (Breslin 1949) shows the time-weighted air concentrations measured at the plant after the upgrade of the ventilation system. During spot-checks of the February 1949 air concentrations, this analysis revealed a mathematical error for the Hook Man's daily weighted air concentration, which resulted in a change from the 36,800 dpm/m^3 to 38,200 dpm/m^3. An error was also found for the Roughers February result, but the change was small and correction of the error would have slightly reduced the exposure, so it was ignored. The March report noted that "one unsubstantiated sample of unusually low concentration" probably resulted in an "erroneous" daily weighted average air concentration for the Hook Man. To remedy this, the March 30 average ratio of the second-to-first rolling pass air concentrations was determined. This ratio, 19.2, was used to modify the low air concentration result. The two sets of data from February and March 1949 were then used to estimate the air concentrations to determine internal exposures by workgroup. Table 4 lists the geometric means and GSDs for the job category and the workgroups' daily time-weighted average air concentrations.

Table 4. Daily time-weighted average air concentration information.

		Group I		Group II and III
	Air samples collection date	**2/15/1949**	**3/30/1949**	**2/15/1949**
Job categories	Number of categories	9	9	6
	Geometric means (dpm/m3)	2,210	545	484
	GSD	5	3.2	2
Workgroup	Number of workers	15	9	10
	Geometric means (dpm/m3)	2,610	479	608
	GSD	5.3	3	1.8

This analysis of intakes based on air concentrations made the claimant-favorable assumption that uranium rolling took place between July 23, 1948, and February 28, 1950. It also assumed that 10 days of every month were spent rolling uranium because the AEC required Vulcan Crucible to be prepared to spend 2 consecutive weeks of every 5 consecutive weeks performing AEC work (AEC 1948a). Although rolling did not actually occur after March 1949, data to estimate exposure directly from cleanup operations were not available. The analysis assumed that the internal exposure rates during cleanup would not have exceeded the internal exposure rates during continued rolling operations with the improved ventilation.

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 geometric mean of a workgroup's time-weighted 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. Vulcan Crucible internal organ doses are assumed to be lognormally distributed and the GSDs for the calculated internal organ

doses are assumed to be 5.3. The primary bases for selecting a GSD of 5.3 for all Vulcan Crucible internal organ dose calculation is to simplify and expedite dose reconstructions, and to encompass the largest distribution from the air sampling data. Several assumptions included in the intake/dose reconstruction are likely to be overestimating assumptions, which increase the estimate of the median intakes. This overestimation of the median, combined with the assumed GSD of 5.3, is believed to be sufficiently large to describe the organ dose distributions.

Tables 5 and 6 list estimated annual inhalation intakes during rolling assigned to workers in each category. Because air concentrations were not available for Groups II and III in March, the March-to-February ratio of the Group I job category geometric mean air concentration, 4, was used to estimate a Group II and III March 30, 1949, air concentration.

Table 5. Inhalation exposures during rolling operations for Group I workers.

Work period	Number of months	Number of potential AEC workdays	Air concentration (pCi/m^3)	Breathing rate (m^3/h)	Hours worked per day	Intake (pCi)
7/23/1948-3/29/1949	8	80	1,180	1.2	10	1.13E+6
3/30/1949-2/28/1950	11	110	216	1.2	8	2.28E+5
Total						**1.36E+6**

Table 6. Inhalation exposures during rolling operations for Group II and III workers.

Work period	Number of months	Number of potential AEC workdays	Air concentration (pCi/m^3)	Breathing rate (m^3/h)	Hours worked per day	Intake (pCi)
7/23/1948-3/29/1949	8	80	274	1.2	10	2.63E+5
3/30/1949-2/28/1950	11	110	68.5	1.2	8	7.23E+4
Total						**3.35E+5**

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 largest air concentrations, listed in Table 5, 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 1994). 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 July 23, 1948, to February 28, 1950, was 5.35×10^{6} pCi/m^2 (119,000 dpm/100 cm2). 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 5.35 pCi/m^3. Table 7 lists the assumed annual inhalation intake received from resuspension of deposited material. The intakes listed in Table 7 are added to the intakes listed in Table 5 or 6 before calculation of annual organ dose: this is done in Table 9.

Table 7. Annual inhalation exposure during non-AEC operations due to resuspension of deposited uranium dust.

Work period	Hours per day	Workdays per work period	Breathing rate (m^3/h)	Resuspended air concentration (pCi/m^3)	Intake (pCi)
7/23/1948-3/29/1949	10	179	1.2	5.35	1.15E+4
3/30/1949-2/28/1950	8	240	1.2	5.35	1.23E+4
Total					**2.38E+4**

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. For a 10-hour workday, the multiplier would be 0.223. The daily ingestion rates during AEC uranium work are estimated from the air concentrations in Table 5, which are larger than the concentrations in Table 6. The daily ingestion intakes from resuspended uranium are estimated from Table 7. The ingestion intake rates are multiplied by the number of workdays exposed at the calculated levels and summed. The ingestion intakes listed in Table 8 apply to workers in Groups I, II, and III.

Table 8. Estimated amount of uranium ingested (pCi) (based on Tables 5 and 7).

Work period	Days of uranium rolling	Uranium ingestion rate (during uranium rolling) pCi/d	Non-uranium rolling workdays	Uranium ingestion rate (during normal operation) pCi/d	Intake pCi
7/23/1948-3/29/1949	80	2.62E+02	99	1.19	2.12E+4
3/30/1949-2/28/1950	110	4.32E+01	130	1.07	4.89E+3
Total					**2.62E+4**

3.2 OCCUPATIONAL INTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

The assumed uranium photofluorimetry urinalysis MDA is 14 µg/L.

The assumed operational exposure period ran from July 23, 1948, to February 23, 1950. The uranium-rolling period was over by March 31, 1949, and the analysis assumed that the exposure after that time was due to cleanup activities, which might have resulted in changing uranium intake rates by some workers. If the limited bioassay data are used to calculate intakes, the assignment of the exposure period needs to be considered carefully, because assuming that bioassay results are collected during periods of elevated exposure, when the result is actually collected days or months after the period of elevated exposure, could result in underestimation of intake. For individuals unlikely to have been involved in cleanup, but who have positive bioassay results, it would be reasonable to set the intake period to the period of uranium rolling operations (July 23, 1948, through March 30, 1949) and to add an additional intake based on the Table 9 intakes for the period after the last bioassay.

For **unmonitored workers or unmonitored periods**, Table 9 lists intake rate assumptions for natural uranium. The intake mode is chronic. The dose distribution is assumed to be lognormal with a GSD of 5.3.

Table 9. Internal exposure summary for operational period July 23, 1948, to February 28, 1950.

	Start	End	Intake route	Absorption type	Intake (pCi/day)
Group I and unknown	7/23/1948	3/29/1949	Inhalation	M, S	4,610
	7/23/1948	3/29/1949	Ingestion	(a)	85.1
	3/30/1949	2/28/1950	Inhalation	M,S	731
	3/30/1949	2/28/1950	Ingestion	(a)	14.6
Group II and III	7/23/1948	3/29/1949	Inhalation	M, S	1,120
	7/23/1948	3/29/1949	Ingestion	(a)	85.0
	3/30/1949	2/28/1950	Inhalation	M,S	267
	3/30/1949	2/28/1950	Ingestion	(a)	14.6

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

4.0 ESTIMATION OF EXTERNAL EXPOSURE

Individual external dosimetry results for Vulcan Crucible are not available. If Vulcan Crucible individual external dosimetry results are found, dose reconstructors should consider those results in the evaluation of external dose.

For dose reconstruction, this analysis assumed 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, and
- Exposure to an annual diagnostic X-ray.

The majority of photons from natural uranium metals are in the 30 to 250 keV 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 billet or a rod, 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. The claimant favorable assumption for this analysis is workers were exposed to photon energies in the 30 to 250 keV range. Nonpenetrating dose from natural uranium consists primarily of electrons with energies >15 keV. For consistent presentation, exposure or dose is reported as either penetrating or nonpenetrating and is assumed to be associated with photons of energies 30 keV or greater, and with photons of energies less than 30 keV or with electrons, respectively.

4.1 SUBMERSION AND CONTAMINATION 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” (Author unknown 1949). 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/h beta and 0.34 mR/h gamma. The results of these measurements are assumed to be representative of the general levels of external exposure from submersion in air and contaminated surfaces at Vulcan Crucible. 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. This assumption does not appear to be inconsistent with the reported Zeuto (portable ionization chamber) beta and gamma readings at Simonds Saw and Steel of 2 mR/h or less for most areas (Author unknown 1949), some of which appear to be contact readings. 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 Vulcan Crucible during operational years are listed in Table 12. This analysis assumed that all workers were exposed to penetrating and nonpenetrating radiation from submersion in air and contamination for each workday for 10 hours/day prior to March 30, 1949, and 8 hours thereafter.

4.2 URANIUM BILLET AND ROD EXPOSURES

Another assumption was that workers received a deep dose due to photon exposure from the uranium billets and rods. According to reports, the AEC work involved rolling uranium billets 4 to 5 in. in diameter and 15 to 28 in. long. The billets were rolled into rods approximately 1.5 in. in diameter and 20 ft long. 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 10 lists calculated photon dose rates for the uranium billet and rod.

Table 10. Calculated photon dose rate for uranium billet and uranium rod.

Distance from source	Billet dose rate (mrem/h)	Rod dose rate (mrem/h)
Surface	7.74	5.09
1 ft	0.703	0.285
1 m	0.108	0.0883

This analysis assumed that Group I workers were exposed primarily to the billet dose rate and that Group II workers were exposed primarily to the rod dose rate. 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 12 were calculated by multiplying the median photon dose rates by the number of rolling days per year and the number of work-hours, 10 hours/day prior to March 30, 1949, and 8 hours thereafter.

Shallow dose from the uranium billets and rods were estimated using the measurements in Table 11. These measurements were taken during an AEC survey in September 1948 (Belmore 1948).

Table 11. Direct radiation measurements from September 1948.[a]

Location of measurement	Dose rate (mrep/h)[b]
GROUP I	
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
GROUP II	
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.

This analysis estimated the shallow dose for Group I by assuming that the median dose rate was 5 mrem/h and that the upper 95th percentile dose rate was 10 mrem/h, giving a GSD of 1.5. For Group II, the assumed median dose rate was 5 mrem/h, and the assumed upper 95th percentile dose rate was 20 mrem/h, giving a GSD of 2.3. These exposure rates were multiplied by the assumed number of uranium rolling hours in the period. Table 12 lists these doses for Group I and II workers. The analysis assumed that Group III workers were unlikely to be in close contact with the rods and billets for extended periods; it also assumed that air and surface external exposures account for their external exposure.

4.3 OCCUPATIONALLY REQUIRED MEDICAL X-RAY

X-ray machine characteristics, beam measurements, and example films for Vulcan Crucible were unavailable. The analysis assumed that workers received a preemployment occupationally related diagnostic PA chest X-ray. The specification for a preemployment X-ray was a "standard 14" x 17" film." X-rays of the chest were to be repeated annually (Belmore 1948). 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* (ORAU 2003) for these pre-1970 examinations. Although the earliest report of uranium work was in July 1948, this document assumes that a preemployment X-ray examination could have occurred as early as January 1, 1947.

4.4 MISCELLANEOUS INFORMATION RELATED TO EXTERNAL DOSE

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

In September 1948, AEC (1948b) noted that some workers were smoking while wearing dirty gloves and one worker was observed sitting on billets during a break. These activities are not directly considered in the external dose evaluations. They were observed early in the Vulcan Crucible uranium rolling operations and might have been limited occurrences.

During the 1949 decontamination activities, an AEC inspector noted:

There were 15 pairs of shoes in two steel drums in the storeroom of the plant. The soles of the shoes gave an average reading of 14,000 alpha d/m and 1.3 mr/hr. beta-gamma. The leather tops of the shoes showed an average reading of 5,000 alpha d/m and less than [0].4 mr/hr. beta-gamma. Inside the shoes there were negligible alpha and beta-gamma readings. (Klevin 1949)

4.5 OCCUPATIONAL EXTERNAL DOSE RECONSTRUCTION ASSUMPTIONS AND SUMMARY

Table 12 summarizes occupational external doses during uranium operations at Vulcan Crucible.

Table 12. External exposure summary for operational period July 23, 1948, to February 28, 1950.

Workers	Exposure mode	Exposure type	Exposure or dose rate	Basis	Exposure time assumption	Year	Annual exposure	IREP distribution
All	Submersion/ area contamination	Penetrating	0.26 mR/h	Film badge	2000 work-h/y	1948 1949 1950	0.302 R 0.576 R 0.087 R	Lognormal GSD 1.2
		Non-penetrating	1.3 mR/h	Film badge	2000 work-h/y	1948 1949 1950	1.508 R 2.878 R 0.437 R	Lognormal GSD 2.3
	Medical X-ray	Pre-1970 PA	Initial plus one exam per year			1947 1948 1949 1950	See ORAUT-OTIB-0006, (ORAUT 2003)	
Group I	U billets	Penetrating	0.703 mrem/h	MCNP calculation	3 h/rolling-day	1948 1949 1950	0.105 rem 0.253 rem 0.042 rem	Lognormal GSD 4.2
		Non-penetrating	5 mrep/h	Instrument measurement	3 h/rolling-day	1948 1949 1950	0.750 rem 1.800 rem 0.300 rem	Lognormal GSD 2.7
Group II and unknown	U rods	Penetrating	0.285 mrem/h	MCNP calculation	7 h/rolling-day	1948 1949 1950	0.100 rem 0.239 rem 0.040 rem	Lognormal GSD 5.7
		Non-penetrating	5 mrem/h	Instrument measurement	7 h/rolling-day	1948 1949 1950	1.750 rem 4.200 rem 0.700 rem	Lognormal GSD 2.3

5.0 ESTIMATION OF RESIDUAL EXPOSURE

After the shutdown of AEC rolling operations, an AEC September 1949 letter described a July 1949 survey, which identified areas that needed cleaning, but did not report quantifiable results (Belmore 1949a). A survey of the site on December 30, 1949, identified areas that still needed cleanup, but again provided no numbers (Author unknown 1950). This analysis assumed that the residual exposure period began on March 1, 1950. A May 1978 survey by Argonne National Laboratory reported 14 areas where the contamination exceeded the criterion of 5,000 dpm/100 cm^2, of which 1,000 dpm/100 cm^2 can be classified as removable. In general, the areas were between 500 and 2,000 cm^2 with one area as large as 5,000 cm^2. The greatest contamination was found on a small patch of dirt floor of about 100 cm^2; the activity levels in this area were 2.2×10^5 dpm/100 cm^2 beta-gamma and 1.1×10^4 dpm/100 cm^2 alpha, and were due to natural uranium. The contact Geiger-Muller end window detector reading at this location was 2.0 mR/h, and the reading at 1 m was at the background level (0.03 to 0.05 mR/h). Contact beta-gamma exposure rates throughout the facility varied between 0.1 and 2 mR/h with a median of 0.4 mR/h. Beta-gamma exposure rates at 1 m were reported as background, which ranged from 0.03 to 0.05 mR/h (Wynveen et al. 1982).

Vulcan Crucible received essentially pure uranium metal (no radium) for processing. This is confirmed by the 1978 Argonne National Laboratory survey (Wynveen et al. 1982), which showed radon levels varying between 0.11 and 0.27 pCi/L (0.0.0011 to 0.0027 Working Level assuming 100% equilibrium), which are within the normal range of atmospheric radon content of 0.1 to 0.5 pCi/L (Eisenbud 1987). The building was reportedly evacuated in 1978 (Perry 1993); this is assumed to have occurred on May 31, 1978, after the Argonne National Laboratory survey.

The Aliquippa Forge site was included in the DOE FUSRAP in August 1983. In December 1987, Bechtel National, Inc. surveyed Aliquippa Forge for the purpose of allowing the use of portions of Building 3 for storage. Additional remediation in the fall of 1988 to allow expansion of the forging program resulted in removal of contaminated materials and equipment and barricading of the remaining Building 3 contamination. This analysis assumed that the second exposure period to residual contamination started on December 1, 1987. DOE noted that access to the contaminated areas was not allowed (Seay 1988).

In 1992 and 1993, areas in and adjacent to Buildings 3 and 8 were further characterized (Abelquist 1994, Adams 1992, DOE 1996). It was reported that as of May 17, 1993, the building was no longer in use, however this analysis assumed that date to be the end of the second residual contamination continued until December 31, 1994. In 1992, the maximum reported exposure rate at 1 meter was equal to 0.014 mR/h (Adams et al 1992a). A few spots of contamination were found to approach 1,000,000 dpm/100 cm^2, but most areas of contamination were less than 5,000 dpm/100 cm^2. The greatest removable contamination was 410 dpm/100 cm^2, but the majority of areas checked for removable contamination showed beta results less than 16 dpm/100 cm^2 and alpha results less than 12 dpm/100 cm^2. The largest grid-block-average was a floor area having 230,000 dpm/100 cm^2 (Adams and Payne 1992b, p. 37-40). Most of the contamination results were less than this amount by an order of magnitude or more. In addition, not all areas of the buildings were contaminated.

To calculate internal exposure from residual activity this analysis assumed that the building was uniformly contaminated to 5% of the largest grid-block-average value, which would be 11,500 dpm/100 cm^2. 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 annual inhalation intake was 1,240 pCi. Using the method described in Section 3.0, the calculated annual ingestion intake was 25.9 pCi. Table 13 summarizes the intake rates.

To reconstruct external exposure to residual radioactivity after the end of AEC operations, this analysis assumed that the upper 95th percentile worker penetrating exposure was 0.05 mR/h, which was the upper end of the exposure rate readings at 1 m in 1978 (this reading could be interpreted as the minimum recording level for this type of measurement). The median penetrating exposure rate was assumed to be 0.025 mR/h, one-half of the 95th percentile. A GSD of 1.5 was calculated for the assumed lognormal distribution. This exposure bounds the 1-m exposure rate measurements, 0.007 to 0.014 mR/h, reported by Adams (1992a) in 1992, which were measured after limited remedial activities in 1988.

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 0.125 mR/h. A GSD of 2.6 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 1.5) 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 13, 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 13. Annual internal and external exposure to residual radioactivity.

Exposure	Start	End	Exposure	Absorption type	Intake (pCi/d)	IREP distribution
	3/1/1950	5/31/1978	Inhalation	M, S	3.40	Lognormal GSD 3
	3/1/1950	5/31/1978	Ingestion	(a)	0.071	Lognormal GSD 3
	12/1/1987	12/31/1994	Inhalation	M,S	3.40	Lognormal GSD 3
Internal	12/1/1987	12/31/1994	Ingestion	(a)	0.071	Lognormal GSD 3
	Start	**End**	**Exposure**	**Basis**	**R/y**	
External	3/1/1950	5/31/1978	Penetrating	Survey Instrument	0.050	Lognormal GSD 1.5
	12/1/1987	12/31/1994	Penetrating	Survey Instrument	0.050	Lognormal GSD 1.5
	3/1/1950	5/31/1978	Non-Penetrating	Survey Instrument	0.250	Lognormal GSD 2.6
	12/1/1987	12/31/1994	Non-Penetrating	Survey Instrument	0.250	Lognormal GSD 2.6

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

REFERENCES

Abelquist, E. W., 1994, *Additional Characterization Survey of Buildings 3 and 8, Aliquippa Forge Site West Aliquippa, Pennsylvania*, February, ORISE 94/B-77, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee. [Aliquippa Forge Additional Characterization.pdf].

Abelquist, E. W., 1995, Verification *Survey of Buildings 3 and 8, Aliquippa Forge Site West Aliquippa, Pennsylvania*, July, ORISE 95/G-92, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee. [Aliquippa Forge Additional Characterization.pdf].

Adams, W. C., and Payne, J. L., 1992a, *Radiological Survey of the Aliquippa Forge Site West Aliquippa, Pennsylvania*, December, ORISE 93/A-5, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee. [Aliquippa Forge Rad. Survey.pdf].

Adams, W. C., and Payne, J. L., 1992b, *Characterization Survey of Portions of Aliquippa Forge Site West Aliquippa, Pennsylvania*, December, ORISE 93/A-6, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee. [Aliquippa Forge Characterization.pdf].

AEC (U.S. Atomic Energy Commission), 1948a, contract AT-(30-1)-407, August 16 [pp. 2-8 of Aliquippa Forge-Vulcan AEC Contract.pdf].

AEC (U.S. Atomic Energy Commission), 1948b, *Health Physics Survey of Vulcan Crucible Steel Co., September 20, 1948* [260000127.pdf].

AEC (U.S. Atomic Energy Commission), 1949a, *Monthly Status and Progress Report for April 1949*, May 10, New York Operations Office, New York, New York [NYOO – Brookhaven and AWE Reports - 1949.pdf].

AEC (U.S. Atomic Energy Commission), 1949b, *Vulcan Crucible Steel Co. Occupational Exposure to Radioactive Dust Visit of February 15-16, 1949*, [EmlBx17VulcanCrucSteelCoOccExpRadDustFeb1949-A.pdf].

AEC (U.S. Atomic Energy Commission), 1949c, *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.

AEC (U.S. Atomic Energy Commission), 1949d, untitled, June 24, New York Operations Office, Medical Division, New York, New York [Eml2Bx24VulcanUrine&Feces1949.pdf].

Author unknown, 1948, letter to T. W. Hauff (Metallurgy and Control Division), “Uranium Rolling by Vulcan Crucible Steel Company August 21 to September 2, 1948,” September 13 [p. 3 of Aliquippa Forge-Uranium Rolling.pdf].

Author Unknown, 1949, “Simonds Saw & Steel Co. Summary Report of Three Surveys,” [pp 250-254 of Simonds Saw and Steel Company.pdf]

Author unknown, 1950, “Contamination at Vulcan Following First Cleanup,” letter to F. M. Belmore (U.S. Atomic Energy Commission), January 12 [p. 6 of Aliquippa Forge-Vulcan Crucible.pdf].

Baublitz, J. E., 1988, “NEPA Review of the Interim Review of the Cleanup of Contaminated Materials within Building 3 at the Universal Cyclops Pennsylvania Site,” November 15 letter to file, NE-

20, Office of Remedial Action and Waste Technology, U.S. Department of Energy [page II-32 of http://csd.apps.em.doe.gov/PDFs/PA.07-4.pdf]

Belmore, F. M., 1948, letter to J. O. Flower (Vulcan Crucible Steel Company), October 22, no subject, U.S. Atomic Energy Commission, New York Operations Office, New York, New York [260000126.pdf]

Belmore, F. M., 1949a, letter to J. O. Flower (Vulcan Crucible Steel), September 12, U.S. Atomic Energy Commission [pp. 10-12 of Aliquippa Forge-Vulcan AEC Contract.pdf].

Belmore, F. M., 1949b, *Decontamination of Vulcan Crucible Steel Co. at West Aliquippa, Penna.*, July 28, U.S. Atomic Energy Commission [pp 9-10 of 260000123.pdf].

Belmore, F. M., 1950, letter to J. O. Flower (Vulcan Crucible Steel Company), January 19, U.S. Atomic Energy Commission [p. 5 of Aliquippa Forge-Vulcan Crucible.pdf].

Blalock, W. O., 1993, no title, Corrective Action Report, 93:0008, January 26, Fernald Environmental Restoration Management Corporation, Fernald, Ohio.

Breslin, A. J., 1949, *Vulcan Crucible Steel Co. Occupational Exposure to Radioactive Dust Visit of March 30, 1949,* U.S. Atomic Energy Commission, New York Operations Office, May 13 [EML.pdf].

DOE (U.S. Department of Energy), 1996, *Certification Docket for Remedial Action Performed at the Aliquippa Forge Site in Aliquippa Pennsylvania*, Former Sites Restoration Division, Oak Ridge Operations Office, Oak Ridge, Tennessee, November [http://csd.apps.em.doe.gov/PDFs/PA.07-4.pdf]

DOE (U.S. Department of Energy), 2001, *Preliminary Review of the Flow and Characteristics of Recycled Uranium throughout the DOE Complex 1952-1999, Vol. 1, Project Overview*, Washington, D.C.

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, M., 1987, *Environmental Radioactivity from Natural, Industrial, and Military Sources*, Third Edition, p. 417, Academic Press, Inc., San Diego, California.

61 *FR* 211, 1996, *Certification of the Radiological Condition of the Aliquippa Forge Site in Aliquippa Pennsylvania, 1995*, October 30, Volume 61, Number 211, Notices, *Federal Register*, pp. 55981-55982 [pp. 164-165, 0300001182.pdf]

Harbert, R. R., 1989, letter to W. M. Seay (Oak Ridge Operations Office), "Bechtel Job No. 14501, FUSRAP Project, DOE Contract No. DE-AC05-81OR20722, Post-Remedial Action Summary on the Aliquippa Forge 1988 Decontamination of Building 3, Code: 7330/126," Bechtel National Inc., Oak Ridge, Tennessee, May 16 [pp. 130-142 of 030001182.pdf]

Hauff, T. W., 1948, letter to F. C. Schlemmer (U.S. Atomic Energy Commission), HW-11853, December 15, General Electric [Aliquippa Forge- GE Uranium Forging.pdf].

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.

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.

Jones, T. S., 1948, memorandum to T. W. Hauff (300 Technical Division), "Trial Rolling at Vulcan-Crucible Steel Company, Aliquippa, PA – July 23, 1948," HW-10764, 300 Area Plant Assistance Group, Technical Divisions, August 18 [010002520.pdf].

Klevin, P.B. , 1949, memorandum to F. M. Belmore (Production Division) and B. S. Wolf (Medical), "April 26 Visit to Vulcan Crucible Steel Co., West Aliquippa, Pa.," U.S. Atomic Energy Commission, May 9 [260000124.pdf].

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

NRC (U.S. Nuclear Regulatory Commission), 2002a, *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.

NRC (U.S. Nuclear Regulatory Commission), 2002b, *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, Washington, D.C.

ORAUT (Oak Ridge Associated Universities Team), 2003, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, ORAUT-OTIB-0006, Revision 2, December 29, Oak Ridge Associated Universities, Oak Ridge, Tennessee.

OSTI (Office of Scientific and Technical Information), 2002, list of Vulcan Crucible report titles downloaded February 7, http://www.osti.gov/cgi-bin/opennetnewgate/198.125.128.130=apollo2=210=/wais/indexes/op 2/7/2002 [p. 31, Aliquippa Forge. pdf]

Padden, R. M., 1949, letter to T. W. Hauff (Metallurgy and Control Division, 300 Area), "Production Rolling of Uranium Rods by Vulcan Crucible Steel Company, Jan. 3 to Jan. 15, 1949.," 300 Area Plant Assistance, January 31 [00253.pdf]

Perry, T. C., 1993, "Aliquippa Forge Site - Notification of Uranium Guidelines to Be Used in Uranium Remediation Activities," letter to J. G. Yusko (Pennsylvania Department of Environmental Resources), Former Sites Restoration, Field Office, Oak Ridge, U.S. Department of Energy, Oak Ridge, Tennessee, May 17 [pp. II-88 to 89 of http://csd.apps.em.doe.gov/PDFs/PA.07-4.pdf].

Reichard, H. E., 1948a, memorandum to files, “October Rolling Operations,” United States Government, November 2 [pp. 36-38 Aliquippa Forge.pdf].

Reichard, H. E. 1948b, memorandum to N. Williams (Oak Ridge Operations Office, AEC) and J. P. Morgan (New York, AEC), “Y-12 Uranium Metal Requirements for 1949,” United States Government, December 22 [p. 40 Aliquippa Forge.pdf].

Schier, R. J., 1948, letter to T. W. Hauff (Metallurgy and Control Division), 300 Area Plant Assistance Group, September 22 [p. 1 of Aliquippa Forge-Uranium Rolling.pdf].

Seay, W.M., 1988, “Additional Information Regarding Cleanup of the Universal Cyclops Site,” letter to J. Wagoner, NE-23, GTN-HQ, Technical Services Division, Oak Ridge Operations Office, U.S. Department of Energy, November 10 [pp. II-34 to II-35 of http://csd.apps.em.doe.gov/PDFs/PA.07-4.pdf]

Stroke, F. G., 1949a, memorandum to files (Thu: J. G. Beckerley), “Uranium Metal Production,” March 4, Division of Technical Advisors, United States Government, location unknown. [p. 45. Aliquippa Forge.pdf].

Stroke, F. G., 1949b, memorandum to files, “Report of Visit to Vulcan Crucible Steel Co., West Aliquippa, PA., January 3, ” Division of Technical Advisors, United States Government, March 1. [pp. 42-43, Aliquippa Forge.pdf]

Tabershaw, I. R., 1949, memorandum to B. S. Wolf, Medical Director, “Vulcan Crucible Steel Co., Aliquippa, Pa.,” United States Government, March 29 [260000125.pdf].

VCSC (Vulcan Crucible Steel Company), c. 1949, *Specification and Procedure for Rolling Uranium Ingots at Vulcan Crucible Steel Co.*, VC-1, Jan. 21 [pp. 22-25 Aliquippa Forge.pdf].

Wallo III, A., 1981, letter to Dr. W. E. Mott (Director, Environmental & Safety Engineering Division, U.S. Department of Energy), 7963-02.81.aw.05, The Aerospace Corporation, January 20 [pp. 1-2 of Aliquippa Forge-Vulcan Crucible.pdf].

Wynveen, R. A., W. H. Smith, R. L. Mundis, C. Boggs Mayes, 1982, *Formerly Utilized MED/AEC Sites Remedial Action Program Radiological Survey of Universal Cyclops, Inc. Titusville Plant (Formerly Vulcan Crucible Steel Company) Aliquippa, Pennsylvania May 2-8, 1978*, DOE/EV-0005/33, ANL-OHS/HP-82-104, U.S. Department of Energy, Argonne National Laboratory, Argonne, Illinois [Aliquippa Forge-Vulcan FUSRAP.pdf].