ORAU Team **NIOSH Dose Reconstruction Project** Technical Information Bulletin: Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities	Document Number: ORAUT-OTIB-0004 Effective Date: 11/25/2003 Revision No.: 01 Controlled Copy No.:_____ Page 1 of 13
Subject Expert: Jeri L. Anderson Approval: Signature on File Date: 11/25/2003 Judson L. Kenoyer, Task 3 Manager Concurrence: Signature on File Date: 11/26/2003 Richard E. Toohey, Project Director Approval: Grady Calhoun Signature on File for Date: 11/26/2003 James W. Neton, OCAS Health Science Administrator	Supersedes: Revision No.: 00

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	Draft	00-A	New Technical Information Bulletin to establish a process for estimating the maximum plausible dose to workers at selected AWE Facilities. Initiated by Jeri L. Anderson.
Draft	11/12/2003	00-B	Incorporates comments from internal and NIOSH review. Initiated by Jeri L. Anderson.
Draft	11/12/2003	00-C	Incorporates comments from NIOSH review received on redline/strikeout version of TIB dated 11/12/2003. Initiated by Jeri L. Anderson.
11/20/2003	11/20/2003	00	First approved issue. Initiated by Jeri L. Anderson.
Draft	11/24/2003	01-A	Incorporates changes to correct errors. Initiated by Jeri L. Anderson.
11/25/2003	11/25/2003	01	Approved issue of revision 01. Initiated by Jeri L. Anderson.

1.0 SCOPE

The purpose of this document is to provide guidance for estimating the maximum plausible dose to workers at Atomic Weapons Employers (AWEs). This document describes an efficiency process that may be used to expedite the processing of claims requiring dose reconstruction under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA). The exposure matrix in this document is designed for estimating the maximum plausible annual dose in all organs with the exception of lung, skin, breast, eye, and testes except when the testes dose is used as an analog for the prostate. Because the current ICRP model does not calculate a dose to the prostate, the dose to the testes is reconstructed and used to determine the probability of causation for prostate cancer. This is considered a claimant-favorable approach.

There were approximately 109 AWE facilities that handled only natural uranium in support of the atomic weapons program. Of these facilities, 88% operated for 10 years or less and 72% operated for 5 years or less (see Figure 1). The maximum time operated was twenty-three years and the minimum time was less than a year.

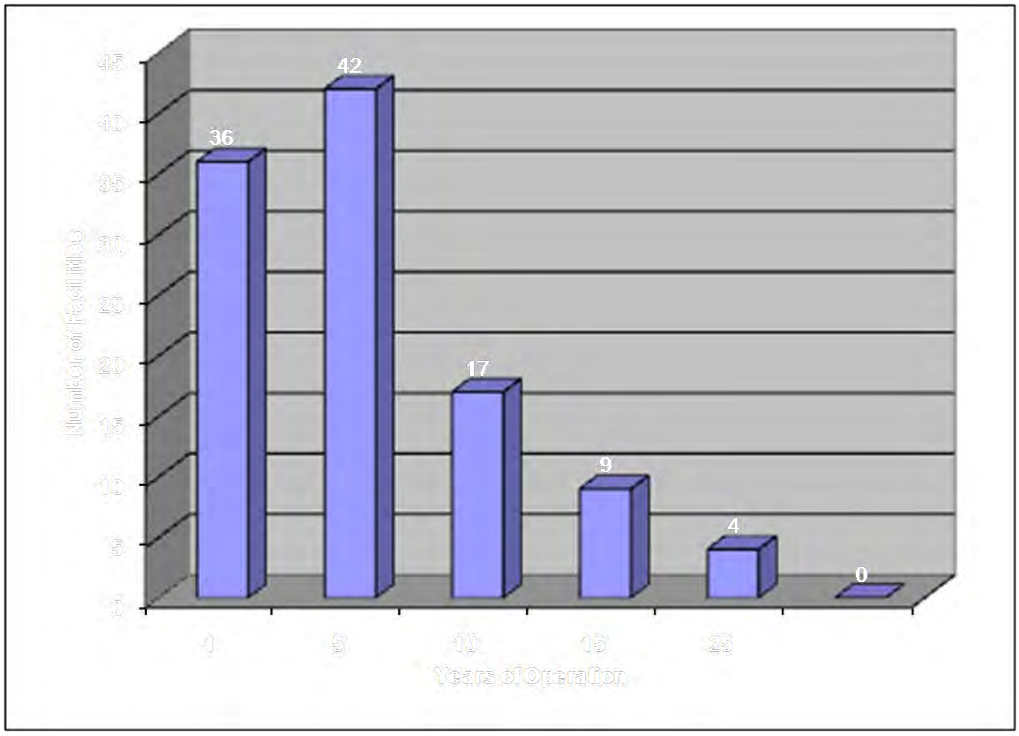

Figure 1. Number of AWE facilities versus years of operation.

The processes at these facilities included reduction and recasting, rolling, machining, and extruding of uranium, fuel element fabrication, scrap recovery, and recovery of uranium from phosphoric acid. A large number of the facilities handled uranium metal. The facilities relevant to this document were privately-owned and the AEC work was done on a part-time basis or in addition to their normal commercial operations.

This document applies only to facilities that handled uranium metal and is not to be used for facilities that processed thorium, radium, or uranium ores. The intake and dose rates in this exposure matrix are to be used in conjunction with the individual worker's covered employment dates, date of birth, and date of cancer diagnosis. If it is necessary to pro-rate intake and dose rates, it is acceptable to

use values for a full year as this is an over-estimation and, thus, claimant-favorable. Because worker bioassay and dosimetry data cannot be ignored, the worker's data, if available, should be reviewed and it should be ensured that a dose reconstruction based on this exposure matrix is an overestimate and is, therefore, a claimant-favorable approach.

2.0 ESTIMATION OF INTERNAL DOSE

During World War II and the time of the Manhattan Engineer District, the permissible level for uranium air dust concentration was set at 500 $\mu g/m^3$ for insoluble uranium compounds and 150 $\mu g/m^3$ for soluble uranium compounds. After the war, the University of Rochester (Rochester, NY) recommended lowering the permissible level to 50 $\mu g/m^3$ for all uranium compounds on the basis of chemical toxicity. This level is equivalent to 70 disintegrations per minute per cubic meter (70 dpm/m^3) and is based primarily on animal studies. The Medical Division of the AEC New York Operations Office (NYOO) thought that the "maximum permissible level" should be based on human data and was thus unknown. Therefore, the level of 50 $\mu g/m^3$ was generally referred to as the "preferred level" (US AEC 1949). Oftentimes the contractors of the Atomic Energy Commission (AEC) used the term "Maximum Allowable (air) Concentration" or "MAC" interchangeably with the "preferred level" and reported air-sampling results as multiples of the MAC (NLO 1952, US AEC 1953).

In 1949, the Medical Division of the NYOO published a report on the health hazards at seven facilities that produced and/or processed uranium for the AEC. These facilities included Mallinckrodt Chemical Works, Harshaw Chemical Company, Linde Air Products, Electrometallurgical Company, Simonds Saw and Steel Company, Vulcan Crucible Company, and Vitro Manufacturing Company. These facilities were the earliest of those constructed by the Manhattan Engineer District and, with the exception of Vulcan Crucible, were very large operations in comparison to the facilities for which this document is relevant. Up until the time of this report, surveys by the NYOO indicated that out of 648 exposed workers at these plants, 9% were exposed to uranium air concentrations greater than 125 MAC (> 6250 $\mu g/m^3$), 9% were exposed at 25-125 MAC (1250-6250 $\mu g/m^3$), and 82% were exposed to less than 25 MAC (< 1250 $\mu g/m^3$). As a result of this report, significant improvements were made in the operational conditions such as re-design of ventilation systems, enclosing some operations, and using remote control (US AEC 1949). By the end of 1949, exposure levels were significantly reduced at these larger plants even though production levels increased (Mason 1958).

Vulcan Crucible (Aliquippa Forge) was a steel mill that contracted with the AEC to roll uranium billets into rods on a part-time basis from 1948 to 1949. The contract (AEC Contract No. AT-(30-1)-407) stated that the plant was to arrange to spend "at least two consecutive weeks out of every five consecutive weeks" performing the AEC contract work. Four of the most exposed workers in the 1949 study were from this plant and the report stated that discussions were under way to shut down this operation (US AEC 1949). Operations were shut down in late 1949 and the plant was decontaminated to 1950 standards (Adams and Payne 1992).

It is important to note that these early exposure studies were not very selective in terms of particle size (Stannard 1988). Also, the air concentration measurements represented the amount uranium in the air where the workers were located but not necessarily what was taken into the lung or the body.

For the purpose of estimating maximum plausible dose, it is assumed that a worker receives a constant exposure to a maximum level of 5000 ug/m^3 (100 MAC) during the entire period of operation. This means that it is assumed that the worker is exposed at this level for eight hours per day, five days per week, 50 weeks per year, whereas time-weighted average studies of even the larger plants

like Mallinckrodt show that the majority of time workers were exposed at lower levels this. It is assumed the worker is exposed at this level during lunches, breaks, and when working at tasks that are not AEC-related. This is considered claimant-favorable because the operations at the facilities for which this document is applicable were smaller, mostly part-time operations. This maximum exposure level is converted to pCi/m^3 by multiplying by 0.677 pCi/μg, which is the specific activity of natural uranium.

The annual amount inhaled due to chronic exposure is determined by multiplying the maximum air concentration of 3400 pCi/m^3 (5000 μg/m^3) by the ICRP 66 recommended breathing rate of 1.2 m^3/h and by an assumed 2000-hour work year. This results in an annual intake of 8.1E+06 pCi (1.2E+07 μg). This value for the cumulative annual intake is assumed to result from a chronic exposure and is used to determine the annual internal organ dose by applying the current ICRP models. The Absorption Type is assigned to Type M as recommended by the ICRP in Publication 71 (ICRP 1995b) for uranium compounds for which there is no specific information on solubility and absorption. Although human and animal studies have indicated that uranium oxides can be relatively insoluble, the selection of Type M results in greater organ uptake and is thus considered claimant favorable. ICRP Publication 66 default values (ICRP 1994) should be selected for particle deposition parameters. The annual organ doses are entered into the NIOSH IREP program assuming a chronic exposure and a constant distribution. The dose is attributed to alpha radiation.

Internal exposure can also be caused by individuals ingesting material by smoking or eating while their hands are contaminated with uranium. To estimate the quantity of this ingested material, several claimant favorable assumptions have been made.

1. The individual's hands have become contaminated from contact with the most highly contaminated surfaces in the facility, the floor. The individual's hand is assumed to become contaminated at a level equal to 10% of the level of contamination on the floor.
2. A study was done at the Oak Ridge Gaseous Diffusion Plant (ORGDP) to determine the intake of uranium from hand contamination. The study indicated that the amount of uranium that is transferred from the hand to the cigarette while smoking was approximately 1% of the material on the surface of the hand (Bailey 1958). For this estimate, 10% was used as a bounding estimate to include all forms of consumption.
3. The individuals hand is to be approximated by an area of 4" by 6" and is evenly contaminated.

When the estimated surface contamination level of 8.1E+7 pCi/m^2 (see section 3.0 below) is multiplied by the surface area of the hand (0.0155 m^2) and the 10% transfer factor is applied, the total activity on the individual's hand is equal to 1.26E+5 pCi. If 10% of this is ingested on a daily basis, 5 days per week for 50 weeks, the total annual ingestion of uranium can be calculated to be 3.14E+6 pCi annually.

The cumulative annual ingestion intake is assumed to result from a chronic exposure for the entire time the individual was employed at the facility during the uranium contract period and is used to calculate the annual internal organ doses by applying the current ICRP models. The f1 value is assigned to 0.02 in Publication 69 (ICRP 1995a) for uranium compounds for which there is no specific information on solubility. The annual organ doses are entered into the NIOSH IREP program assuming a chronic exposure and a constant distribution. The dose is attributed to alpha radiation.

If eating or drinking occurred in the production portions of a facility, airborne radioactivity can settle out on food or drink. This causes an ingestion mode that is not specifically associated with transferring the material from the hand. A realistic estimate of this would have to involve the settling

rate of the airborne contamination onto the food or drink. The surface contamination estimate (see section 3.0) used this settling rate and accumulated material over the course of a year with no removal mechanisms factored in. Since the surface contamination level was the starting point for the ingestion estimate, it inherently accounts for an entire years worth of settling. Assuming food and drink are consumed at some point during the day that they are brought into the area, the amount of material ingested would be a fraction of one days worth of settling. Since a fraction of one years worth of settling is already accounted for, it is believed that this ingestion estimate accounts for ingestion from all modes.

3.0 ESTIMATION OF EXTERNAL DOSE

The maximum size of the uranium ingots used in the atomic weapons program was used to estimate external exposure during processing. The dimensions of the two larger ingots are shown below in Table 1.

Table 1. Most probable dimensions of the uranium ingots used in processing (Bonfer 2003).

Shape	Dimensions (inches)
Rectangular	24 L × 16 W × 4 H
Cylindrical	20 L × 13 Dia.

It was assumed that the most exposed workers were the machinists and general laborers so the exposure geometry was assumed to be 75% anterior-posterior (AP) and 25% isotropic (ISO) as recommended in the NIOSH External Dose Reconstruction Implementation Guideline (US DHHS 2002a). The workers were assumed to spend 7 hours per day performing their duties and 1 hour per day at lunch and on breaks. Although during performance of the job, the worker could have been any distance from the source (the ingots), to be claimant-favorable, it was assumed the worker spent the entire 7 hours 1 foot from the source. Also, to be claimant-favorable, it was assumed that the worker spent his/her lunch and breaks in close proximity to an ingot.

For the calculations of exposure rate, it was assumed that the ingots were composed entirely of natural uranium metal that had been allowed to decay for 100 days resulting in significant dose contribution from the Bremsstrahlung radiations created by the Pa-234m and Th-234 beta emissions. A large percentage of the exposure is from Bremsstrahlung photons with energy between 0.8 and 1 MeV. The exposure rate at various distances from the ingots was calculated using MicroShield™ (Grove Engineering 2003) and MCNP (LANL 2003). The calculated values are shown in Table 2.

The MCNP calculated dose rates were higher than the MicroShield dose rates for both the rectangular and the cylindrical ingot. It was assumed that the majority of the worker's time was spent at 1 foot from the surface of the ingot. The calculated dose rates at 1 foot and 1 meter from the rectangular ingot were the highest so those values were used in the dose estimation. The MCNP-calculated dose rate was multiplied by the number of hours spent in the appropriate exposure geometry, and then multiplied by 250 days per year (8 hours per day for a total of 2000 hours per year). The organ doses

Table 2. Calculated exposure rates from uranium metal ingots.

Shape of ingot	Distance from surface	MicroShield™ exposure rate (mR/hr)	MCNP dose rate (mrem/hr)
Rectangular	1 cm	7.90	8.18
	1 ft	1.91	2.04
	1 m	0.29	0.36
Cylindrical	1 cm	8.27	8.30
	1 ft	1.13	1.14
	1 m	0.17	0.18

were calculated by multiplying the calculated annual dose rate by the "Ambient Dose Equivalent (H*(10)) to Organ Dose (H_T)" photon dose conversion factors found in Appendix B of the NIOSH External Dose Reconstruction Implementation Guideline (DHHS 2002a). The annual dose rate was divided evenly between the photons with energy between 30 and 250 keV and photons with energy greater than 250 keV. Table 3 shows the calculated annual organ doses due to exposure to a natural uranium ingot.

Table 3. Annual organ doses due to external exposure to a natural uranium ingot.

Organ	Annual organ dose (rem)		
	Photons with E=30-250 keV	Photons with E>250 keV	Total
Urinary bladder	1.9	2.3	4.2
Bone (red marrow)	1.6	2.2	3.8
Bone (surfaces)	2.6	2.2	4.8
Colon	1.8	2.3	4.1
Esophagus	1.5	2.2	3.7
Gonads (ovaries)	1.8	2.2	4.1
Gonads (testes)	2.1	2.4	4.4
Liver	1.9	2.3	4.2
Remainder	1.8	2.2	4.0
Stomach	1.9	2.3	4.2
Thymus	1.9	2.2	4.1
Thyroid	2.0	2.4	4.4
Uterus	1.8	2.1	3.9

The doses in Table 3 are entered into the NIOSH IREP program assuming a chronic exposure and a constant distribution. The doses in the second column of Table 3 are attributed to photons with energy between 30 and 250 keV and the doses in the third column are attributed to photons with energy greater than 250 keV.

It was also assumed that workers were exposed to contaminated surfaces during their entire work period. The level of surface contamination was determined by first calculating a terminal settling velocity for 5-μm activity mean aerodynamic diameter (AMAD) particles. The calculated terminal settling velocity of 0.00075 meters per second is multiplied by the assumed maximum air concentration of 3400 pCi/m^3. It was assumed that due to the constant air concentration, the surface contamination level was due to 365 days of constant deposition. This is considered claimant-favorable as facility housekeeping practices most likely kept levels lower than this. At the assumed air concentration level with the calculated terminal settling velocity, a 365-day buildup will result in a contamination level of 8.1E+07 pCi/m^2. The annual organ dose due to exposure to contaminated surfaces was determined by multiplying the surface contamination level by the dose coefficients for contaminated ground surfaces for U-238 and daughters Pa-234m and Th-234 from Federal Guidance

Report No. 12 (US EPA 1993). These dose conversion factors were modeled using an anthropomorphic phantom standing on an isotropic plane source in air. Table 4 shows the annual external organ dose estimates.

Table 4. Annual organ doses due to external exposure to ground surfaces contaminated with natural uranium dust.

Organ	Annual dose (rem)
Adrenals	4.0E-02
Urinary bladder	4.4E-02
Bone surface	1.1E-01
Brain	4.2E-02
Esophagus	3.7E-02
Stomach wall	4.4E-02
Small intestine wall	4.1E-02
Upper large intestine wall	4.2E-02
Lower large intestine wall	4.3E-02
Kidney	4.4E-02
Liver	4.4E-02
Muscle	5.4E-02
Ovaries	4.1E-02
Pancreas	3.9E-02
Red Marrow	4.5E-02
Spleen	4.4E-02
Testes	5.6E-02
Thymus	4.3E-02
Thyroid	4.8E-02
Uterus	4.1E-02

The doses in Table 4 are entered into the NIOSH IREP program assuming a chronic exposure and a constant distribution. The dose is divided equally between photons with energy between 30 and 250 keV and photons with energy greater than 250 keV.

The assumption was also made that workers received an annual occupationally related diagnostic x-ray. The exposure geometry was assumed to be posterior-anterior (PA) (DHHS 2002). The air kerma at skin entrance for the diagnostic chest x-ray was estimated to be 0.108 R (Scalsky 2003). The organ doses were calculated by multiplying the air kerma by the "Kerma (K_a) to Organ Dose (H_T)" photon dose conversion factors for 30-250 keV photons found in Appendix B of the NIOSH External Dose Reconstruction Implementation Guideline (DHHS 2002). Table 5 below shows the annual organ doses due to the assumed annual diagnostic chest x-ray. The values in Table 5 are entered into the NIOSH-IREP program as the annual dose due to an acute exposure to photons (E=30-250 keV) and a constant distribution is assumed.

Table 5. Annual organ doses due to the assumed annual diagnostic chest x-ray.

Organ	Annual dose (rem)
Bladder	0.074
Red bone marrow	0.124
Bone Surface	0.178
Breast	0.059
Colon	0.095
Esophagus	0.105
Eye	0.022
Ovaries	0.110
Testes	0.061
Liver	0.101
Lung	0.133
Remainder organs	0.110
Skin	0.110
Stomach	0.077
Thymus	0.048
Thyroid	0.052
Uterus	0.096

4.0 ESTIMATION OF EXPOSURE TO RESIDUAL RADIOACTIVITY

During operations with uranium, airborne contamination can be caused directly from operations with uranium bearing materials as well as by the resuspension of surface contamination. This airborne contamination can be removed by settling on floors or other surfaces or by ventilation (both engineered and natural building ventilation). The surface contamination levels can be increased by the airborne contamination settling or directly by operations with uranium. This level is decreased by various incidental means such as general housekeeping or tracking of contamination out of the area on equipment or personnel.

For the purpose of estimating the airborne contamination from residual contamination, it is assumed that during uranium operations, these factors reached an equilibrium that caused the airborne concentration and surface contamination to remain at a constant level. Once the generation source from uranium operation was removed, the other factors then caused the over mass of uranium to decrease at some rate due to the remaining removal factors.

This analysis assumes that 1) uranium operations directly accounted for half the airborne concentration in the facility during operations and 2) all the remaining removal mechanisms eliminated only 1% of the uranium mass per day. With these assumptions in place, an equation can be written for the airborne concentration as a function of time.

$$A(t) = 50MAC * e^{-0.01*t}$$

Where:
A(t) = Airborne activity at time t (pCi/m^3)
t = time since uranium operations ended (days)
MAC = Maximum Allowed Concentration (34 pCi/m^3)

When this is multiplied by the breathing rate of 9.6 m^3 per day, the daily intake is calculated. This equation can then be integrated from the end of uranium operations to infinity to determine the total amount of uranium that could be inhaled from residual contamination. This integration results in:

$$I = 9.6 * 50MAC / 0.01$$

Where:
I = total intake from inhalation of residual activity (pCi)
MAC = Maximum allowed concentration (34 pCi/m^3)
9.6 = daily breathing rate (m^3/day)
0.01 = fraction of material removed per day

The results of this equation indicate a total of 1.63×10^6 pCi would be inhaled. This equates to approximately 20% of the 8.1×10^6 pCi annual intake during operations. Therefore, the total inhalation intake from residual contamination can be overestimated by assuming one additional year of inhalation exposure at the operational level of 100 MAC.

The external radiation caused by residual contamination can be overestimated by assuming the contamination levels that existed during operations continued to exist after operations ceased. The annual dose from this source of radiation has already been estimated and can be found in Table 4. This dose should be added to an individuals estimate for each year the individual worked at the facility following the end of uranium operations.

Ingestion of material is most closely related to removable surface contamination rather than fixed surface contamination. Airborne concentrations are also related to removable surface contamination. Therefore, the removable contamination levels are assumed to decrease as the same rate as the airborne concentrations. For this reason, the same approach will be taken for ingestion estimates following periods of operations. That is, the ingestion intakes from residual contamination will be estimated by assuming one additional year of ingestion at the same rate it occurred during operation.

5.0 REFERENCES

Adams, W.C., and Payne, J.L., "Characterization Survey of Portions of the Aliquippa Forge Site, West Aliquippa, Pennsylvania," prepared for the Office of Environmental Restoration, U.S. Department of Energy, ORISE 93/A-6, December 1992

Bailey, J.C., "Personnel Contamination as a Uranium Hazard," in Symposium on Occupational Health Experience and Practices in the Uranium Industry, HASL-58, Health and Safety Laboratory, U.S. Atomic Energy Commission, New York Operations Office, October 15-17, 1958

Bonfer, D., Personal Communication, 2003

Grove Engineering, MicroShield Software Program, Version 6.01, Copyright 1992-2003

Heatherton, R.C., and Quigley, J.A., AEC Radiation Exposure Report-1959, February 11, 1960 [found on pg. 34 of O:\DOE Site Images\FEMP\09-17-03 Data Capture\010001640.pdf]

International Commission on Radiological Protection (ICRP), "Human Respiratory Tract Model for Radiological Protection," ICRP Publication 66, pg. 198, 1994

International Commission on Radiological Protection (ICRP), "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3 Ingestion Dose Coefficients, ICRP Publication 69, pg. 65, 1995a

International Commission on Radiological Protection (ICRP), "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients, ICRP Publication 71, pg. 299, 1995b

LANL, X-5 Monte Carlo Team, "MCNP—A General Monte Carlo N-Particle Transport Code, Version 5," LA-UR-03-1987, Los Alamos National Laboratory, April 24, 2003

Mason, M.G., "A Summary of Fifteen Years of Experience With Dust Problems in Refining and Fabrication of Uranium," in proceedings of the Symposium on Occupational Health Experience and Practices in the Uranium Industry, HASL-58, October 15-17, 1958

National Council on Radiation Protection and Measurements (NCRP), Permissible Dose from External Sources of Ionizing Radiation, Including Maximum Permissible Exposure to Man, NCRP Report No. 17, National Bureau of Standards Handbook 59, 1954

National Lead Company of Ohio (NLO), Production Report on the Rolling of Two Hundred and Eighteen Uranium Billets at Bethlehem Steel Corporation's Lackawanna Plant on March 15, 1952, Contract No. AT(30-1)-1156, March 21, 1952

Scalsky, E.D., Technical Basis Document for the Savannah River Site To be Used for EEOICPA Dose Reconstructions, ORAUT-TKBS-003, Effective Date August 21, 2003

Stannard, J.N., Radioactivity and Health: A History, Volume 1, Laboratory Research, prepared for the U.S. Department of Energy, Office of Health and Environmental Research, DOE/RL/01830-T59, October 1988

US AEC, "Health Hazards in NYOO Facilities Producing and Processing Uranium: A Status Report-April 1, 1949," Prepared by the New York Operations Office Medical Division, Issued April 18, 1949

US AEC, "Simonds Saw and Steel Company, Occupational Exposure to Uranium," New York Operations Office Health and Safety Division, February 18, 1953

US DHHS, External Dose Reconstruction Implementation Guideline, Rev. 1, National Institute for Occupational Safety and Health, August 2002 (2002a)

US DHHS, Progress Report on Residual Radioactive and Beryllium Contamination at Atomic Weapons Employer Facilities and Beryllium Vendor Facilities, Prepared by the National Institute for Occupational Safety and Health, November 2002 (2002b)

US EPA, External Exposure to Radionuclides in Air, Water, and Soil; Federal Guidance Report No. 12, September 1993

Appendix
List of Applicable Facilities

Site Name	Years of Operation
Ajax Magnethermic Corp.	1958–1962
Alba Craft	1952–1957
Aliquippa Forge	1947–1950
Allegheny-Ludlum Steel	1950–1952
Allied Chemical and Dye Corp.	1951–1969
Allis-Chalmers Co.	1943–1944
Aluminum Co. of America (NJ)	1944
Aluminum Co. of America (PA)	1944–1945
AMCOT	1961–1962
American Bearing Corp.	1954–1959
American Chain and Cable Co.	1944
American Peddinghaus Corp.	1978
American Potash & Chemical	1959–1961
Anaconda Co.	1942, 1956–1959
Armco-Rustless Iron & Steel	1948
Armour Fertilizer Works	1951–1955
Associated Aircraft Tool and Manufacturing	1956
B&T Metals	1943
Baker and Williams Co.	1957–1962
Baker and Williams Warehouses	1940–1950
Baker Brothers	1943–1944
Baker-Perkins Co.	1956
Bell Telephone Laboratories	1943–1944
Bendix Aviation (Pioneer Division)	1960
Besley-Wells	1953
Bethlehem Steel	1949–1952
Birdsboro Steel & Foundry	1951–1952, 1962
Bliss & Laughlin Steel	1948–1952
Blockson Chemical Co. (Bldg. 55)	1952–1962
Bloomfield Tool Co.	1947, 1951
Bridgeport Brass Co., Havens Laboratory	1952–1962
Brush Beryllium Co. (Detroit)	1940–1955
BWX Technologies (Virginia)	1959, 1969–1972, 1985–2001
C.H. Schnoor	1943–1951
C.I. Hayes, Inc.	1964
Callite Tungsten Co.	1944
Carboloy Co.	1956
Carpenter Steel Co.	1943–1944
Chambersburg Engineering Co.	1957
Chapman Valve	1948–1949
Cincinnati Milling Machine Co.	1963
Combustion Engineering	1965–1972
Copperweld Steel	1943–1946
Dow Chemical Co. (Madison Site)	1957–1960
Electro Circuits, Inc.	1952–1953
Fenn Machinery Co.	1950

List of Applicable Facilities (Continued)

Site Name	Years of Operation
Fenwal, Inc.	1967–1968
Frankford Arsenal	1952–1954
Gardinier Inc.	1951–1954, 1956–1961
Granite City Steel	19581966
Gruen Watch	1956
Heald Machine Co.	1960
Heppenstall Co.	1955
Herring-Hall Marvin Safe Co.	1943–1951
Hunter Douglas Aluminum Corp.	1959–1963
Huntington Pilot Plant	1951–1963
International Minerals and Chemical Corp.	1951–1961
International Nickel Co., Bayonne Laboratories	1951–1952
International Register	1943
Ithaca Gun Co.	1961–1962
J.T. Baker Chemical Co.	1948, 1957–1958
Jessop Steel Co.	1950–1954
Joslyn Manufacturing and Supply Co.	1944–1952
Kaiser Aluminum Corp.	1959
Kerr-McGee	1962–1973
La Pointe Machine and Tool Co.	1956
Landis Machine Tool Co.	1952
Magnus Brass Co.	1954–1957
Mathieson Chemical Co.	1951–1953
Medart Co.	1951–1952
Metals and Controls Corp.	1952–1967
Mitchell Steel Co.	1954
National Research Corp.	1944–1952
New England Lime Co.	1963
New York University	1946–1952
Oliver Corp.	1956–1957, 1961–1962
Picatinny Arsenal	1947–1948
Podbeliniac Corp.	1957
Precision Extrusion Co.	1949–1950, 1956–1959
Quality Hardware and Machine Co.	1944–1945
R.W. Leblond Machine Tool Co.	1961
Revere Copper and Brass	1943–1955
Roger Iron Co.	1956
Sciaky Brothers, Inc.	1953
Seymour Specialty Wire	1962–1964
Southern Research Institute	1955–1958, 1962, 1976
Spencer Chemical Co., Jayhawks Works	1958–1963
Sperry Products, Inc.	1952–1953
Star Cutter Corp.	1956
Stauffer Metals, Inc.	1961
Superior Steel Co.	1952–1957
Tennessee Valley Authority	1951–1955
Texas City Chemicals	1952–1956
Titus Metals	1956

List of Applicable Facilities (Continued)

Site Name	Years of Operation
Tocco Induction Heating Div.	1968–1969
Torrington Co.	1951–1953
Tube Reducing Co.	1952, 1957
U.S. Steel Co., National Tube Division	1959–1960
United Nuclear Corp.	1958–1969
University of Michigan	1944
Ventron Corporation	1942–1948
Virginia-Carolina Chemical Corp	1952–1957
Vulcan Tool Co.	1959
W.E. Pratt Manufacturing Co.	1943–1946
W.R. Grace (Tennessee)	1958–1970
W.R. Grace Co., Agricultural Chemical Div.	1954
Westinghouse Atomic Power Development Plant	1941–1944
Wyckoff Drawn Steel Co.	1943
Wyckoff Steel Co.	1950