ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, Lackawanna, New York; Period of Operation: 1949-1952	Document Number: ORAUT-TKBS-0001 Effective Date: 06/29/2004 Revision No.: 01 Controlled Copy No.: _____ Page 1 of 13

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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	12/17/2002	0-A	New document to establish the technical basis for the development of a radiation exposure matrix for Bethlehem Steel Corporation. Initiated by Jeri L. Anderson.
Draft	12/17/2002	0-B	Changes in response to internal and NIOSH review comments.
Draft	12/17/2002	0-C	Changes in response to NIOSH review comments.
Draft	12/17/2002	0-D	Changes in response to NIOSH review comments.
Draft	12/17/2002	0-E	Changes in response to NIOSH review comments.
03/31/2003	03/31/2003	00	First approved issue.
Draft	02/19/2004	01-A	Revision to incorporate occupational X-ray doses from the OTIB-0006 and to incorporate estimates of ingestion intakes. Initiated by Jeri L. Anderson.
Draft	04/27/2004	01-B	Revision to incorporate additional OCAS comments. Initiated by Jeri L. Anderson.
06/29/2004	06/29/2004	01	Approved issue of Revision 01. Initiated by Jeri L. Anderson.

1.0   SITE DESCRIPTION AND OPERATIONAL HISTORY

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy facility" as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l (5) and (12)).

In 1949, the U.S. Atomic Energy Commission (AEC) contracted with Bethlehem Steel Corporation (BSC) to develop improved rolling mill pass schedules. BSC conducted this work under contracts AT(30-1)-1279 and AT(30-1)-1156, which were subcontracts with National Lead of Ohio (DOE 1985). The pass schedules were for the rolling of 5-in. natural uranium billets into 1.5-in. rods for use in nuclear reactors (LaMastra 1976; DOE 1985) for production of plutonium. The billets were prepared by Mallinckrodt Chemical in St. Louis, Missouri, and shipped to Lackawanna in freight cars. The freight cars, which were spotted at the BSC plant, served as storage for the uranium billets during the week (Range 1976; ORNL 1980; DOE 1985). The rolling experiments generally took place on weekends because the mills were in full use 5 days per week. The work only involved the 10-in. bar mill and associated billet preparation and handling equipment (LaMastra 1976; Range 1976; Thornton 1977; ORNL 1980; DOE 1985).

Because of material accountability procedures, scale, residue and cropped ends were collected and fine debris was vacuumed, packaged, and returned to the AEC (LaMastra 1976; Range 1976; ORNL 1980; DOE 1985). Radiological surveys in 1976 and 1980 of the original facility and equipment, which were still in existence, identified no residual contamination above natural background levels (LaMastra 1976; ORNL 1980; DOE 1985).

Some references indicate that all work occurred between 1949 and 1951 (Summary 1951; LaMastra 1976; ORNL 1980). However, other reports indicate that eight additional rollings occurred in 1952 (Bowman et al. 1952; Hershman 1952; NLO 1952a; DOE 1985), although they were reported to be production rollings. A letter from a labor representative in October 1979 claims that six to eight rollings took place in 1955 although no verification of these dates has been found (Kosanovich 1979). The work was supposedly transferred to the Fernald Plant around September 1952 (NLO 1952a; LaMastra 1976; Range 1976). Information obtained from the rolling experiments at BSC was used in the design of a rolling mill at the National Lead Company plant in Fernald, Ohio, which began production in 1953 (LaMastra 1976; Range 1976). Table 1 lists the dates of rollings at BSC for which documentation has been found.

Table 1. Documented rollings at Bethlehem Steel Corporation, Lackawanna, New York.

Date	Day	Type	Billets rolled	Bath type
April 26-27, 1951	Thurs., Fri.	Experimental	26	Lead/salt
July 29, 1951	Sun.	Experimental	24	Lead/salt
August 26, 1951	Sun.	Experimental	32	Lead/salt
September 30, 1951	Sun.	Experimental	43	Lead/salt
October 28, 1951	Sun.		93	Salt
January 26, 1952	Sat.	Production		Salt

March 15, 1952	Sat.	Production	218	Salt
April 12, 1952	Sat.	Production	220	Salt
August 17, 1952	Sun.	Production	157	Salt
August 31, 1952	Sunday	Production	219	Salt
September 14, 1952	Sunday	Production	303	Salt
September 22, 1952	Monday	Production	302	Salt
October 19, 1952	Sunday	Production	~300	

Several documents report that AEC personnel were present during all rolling operations. These personnel conducted air and surface radioactivity monitoring and checked personnel involved in the rolling for contamination (LaMastra 1976; ORNL 1980; DOE 1985). Documents also report that no records are available of these monitoring activities (LaMastra 1976; Range 1976; ORNL 1980). If monitoring records ever existed, they were not retained (LaMastra 1976). Uranium metal accountability records apparently were destroyed (Range 1976).

During the war, permissible levels for uranium dust in air were set at 500 $\mu g/m^3$ for insoluble uranium compounds and 150 $\mu g/m^3$ for soluble compounds. After the war, the University of Rochester lowered its recommendation for soluble uranium compounds to 50 $\mu g/m^3$ on the basis of chemical toxicity, which is equivalent to 70 disintegrations per minute per cubic meter. The University based this level primarily on animal studies. The Medical Division of the New York Operations Office felt that a "maximum permissible level" was really unknown and should be based on human data. Therefore, 50 g/m^3 level was referred to as the "preferred level" (AEC 1949b). Many AEC contractors used the term Maximum Allowable (air) Concentration (MAC) interchangeably with "preferred level" and often reported air-sampling results as multiples of the MAC (NLO 1952b; AEC 1953).

An AEC New York Operations Office (NYOO) report of a visit to Simonds Saw and Steel Company in Lockport, New York, on October 27, 1948, describes occupational radioactive dust exposures between 8 and 190 times the MAC depending on the type of job performed (AEC 1948a). This report indicates a 10-hour workday. In addition, it states "…where the maximum amount of alpha was present, a concentration of more than 1000 times the preferred level, the beta activity of the same sample was less than 0.5 times the tolerance (40,000 beta disintegrations per cubic meter). For this reason it is felt that the exposure to beta emitting dust is of negligible consequence as compared to any concomitant alpha dust exposure" (AEC 1948a). This survey occurred during a production rolling. During experimental rollings, generally less than 50 billets were rolled. From the job analysis sheets, apparently180 billets were rolled that day.

After the October 1948 visit to Simonds Saw and Steel, recommendations were made for the implementation of procedures to reduce the dust hazard. Surveys to determine the effectiveness of implemented control procedures were performed. A survey in December 1948 showed reduction of air concentration to levels between 4 and 28 MAC. A survey in January 1949 showed further reduction of air concentration to levels between 1.4 and 28 MAC (AEC 1949a).

One of the many purposes of Experimental Rolling 1 at BSC on April 26-27, 1951, was to explore the feasibility of using fused salt as a protective medium during rolling to prevent oxidation and minimize the health hazard (Summary 1951). An additional rolling occurred on April 17, 1951 at Simonds Saw and Steel using 18-in. bar mills. This rolling was part of Experimental Rolling 1 (Summary 1951). An NYOO report showed results from a survey performed during rolling operations on a 16-in. bar mill at Simonds on August 20, 1951. The survey indicated exposures between 0.81 MAC to 2.5 MAC depending on the type of job performed (AEC 1953). The same report contains results of a survey performed on December 9, 1952, at Simonds that indicated exposure levels between 0.93 and 4.2

MAC. The average exposures were 1.48 MAC for August 20, 1951, and 2.1 MAC for December 9, 1952. In addition, this report also indicates that workdays were generally 8 hours.

Air dust data reports from rollings in 1951 and 1952 at BSC were found in documents submitted by a claimant. Alpha air concentration values ranged from 0 to 130 dpm/m^3 (1.9 MAC) in 1951 and from 0 to 4,900 dpm/m^3 (70 MAC) in 1952 (NLO 1952c; AEC 1951-1952). The NYOO Medical Division collected all data with the exception of data obtained on September 14, 1952, which the National Lead Company of Ohio Health and Safety Division collected.

2.0   ESTIMATION OF INTERNAL EXPOSURE

Triangular distribution is used to represent subjective judgments about uncertainty when an upper and lower bound and a most likely value for a quantity can be estimated (Frey and Cullen 1995). Because there were few records of air monitoring at BSC, a triangular distribution is used to represent the distribution of possible air concentration values during operations.

Tables 2 and 3 list the internal exposure matrix for the Bethlehem Steel site. Table 2 is a lower bound for estimating internal exposure and Table 3 is an upper bound. For 1949 through 1952, the most likely value, or mode, was assumed to be 140 dpm/m^3, which corresponds to 2 MAC. The minimum value was assumed to be 0 dpm/m^3, which considers the possibility that there was no exposure. The maximum value for the lower bound matrix was assumed to be 4,900 dpm/m^3 (70 MAC), which is the maximum reading found in Bethlehem Steel air monitoring data (AEC 1951-1952). The maximum value for the upper bound table was assumed to be 70,000 dpm/m^3 (1,000 MAC) because of the reported maximum levels during rolling operations in 1948 at the Simonds facility (AEC 1948a). Although exposure levels in 1948 were reportedly higher than the mode value of 2 MAC used in the tables, it was assumed that several recommended improvements were made to the process in the interim (AEC 1948a), which is evident in 1951 and 1952 Bethlehem Steel data. Another factor in the difference in air concentration levels is the fact that the Simonds rollings were production runs rather than experimental runs, which involved much less material.

Table 2. Internal exposure matrix – lower bound.

Work period	Air concentration (dpm/m^3)			Breathing rate (m^3/h)[a]	Hours (h)	Annual inhalation intake (pCi)		
	Min.	Mode	Max	Light/heavy		Min.	Mode	Max.
1949	0	140	4,900	1.2/1.7	120	0.00E+00	9.16E+03	4.54E+05
1950	0	140	4,900	1.2/1.7	120	0.00E+00	9.16E+03	4.54E+05
1951	0	140	4,900	1.2/1.7	130	0.00E+00	9.93E+03	4.92E+05
1952	0	140	4,900	1.2/1.7	110	0.00E+00	8.40E+03	4.17E+05

a.   The breathing rate of 1.2 m^3/h was used to calculate the minimum and mode intake. The rate of 1.7 m^3/h was used to calculate the maximum intake.

Table 3. Internal exposure matrix – upper bound.

Work period	Air concentration (dpm/m^3)			Breathing rate (m^3/h)[a]	Hours (h)	Annual inhalation intake (pCi)		
	Min.	Mode	Max	Light/heavy		Min.	Mode	Max.
1949	0	140	70,000	1.2/1.7	120	0.00E+00	9.16E+03	6.49E+06
1950	0	140	70,000	1.2/1.7	120	0.00E+00	9.16E+03	6.49E+06
1951	0	140	70,000	1.2/1.7	130	0.00E+00	9.93E+03	7.03E+06
1952	0	140	70,000	1.2/1.7	110	0.00E+00	8.40E+03	5.95E+06

a.   The breathing rate of 1.2 m3/h was used to calculate the minimum and mode intake. The breathing rate of 1.7 m3/h was used to calculate the maximum intake.

The number of exposure hours per year was determined by assuming 12 10-hour workdays per year for 1949 and 1950. This assumption is conservative considering no documentation indicates any rollings took place during those years. If there were rollings, it is assumed they took place only on weekends. Reports from 1951 and 1952 indicate that, with the exception of the April 1951 (Summary

1951), August 1952 (Bowman et al. 1952), and September 1952 (Schneider and Yocce no date) rollings, rollings occurred on only one weekend day per month. For 1951, an additional 10 hours was added to account for the additional weekday in April, resulting in 13 10-hour workdays. For 1952, in addition to the eight documented rollings, it was assumed that one rolling each took place in February, May, and June, resulting in 11 10-hour workdays.

The breathing rate was calculated from the volume of air breathed for an adult light worker listed in International Commission on Radiological Protection (ICRP) Publication 66 (ICRP 1994, Table 6, p. 23). This category assumes an activity distribution of one-third sitting and two-thirds light exercise. The minimum and mode intakes, in pCi, were calculated by multiplying the appropriate air concentration by the breathing rate and the hours worked, and dividing by 2.2 dpm/pCi. Maximum intakes calculations used the same method but substituted the breathing rate for an adult heavy worker, which assumes an activity distribution of seven-eighths light exercise and one-eighth heavy exercise.

To make use of the information in Tables 2 and 3 for estimation of internal dose, annual doses for the organ of interest should be calculated by applying current ICRP models for the minimum, mode, and maximum intake of natural uranium assuming a chronic inhalation exposure. Assume that the exposure began on January 1, 1949, or the worker's first day of work, whichever is later, and ended on December 31, 1952, or the worker's last day of work, whichever is earlier. The three sets of annual organ doses can then be entered into the National Institute for Occupational Safety and Health (NIOSH) Interactive RadioEpidemiological Program (IREP) as the annual dose due to alpha radiation using a triangular distribution and the minimum, mode, and maximum doses as parameters 1, 2, and 3, respectively.

If the claimant has a PC likely to be > 50%, the exposure should be calculated using the lower bound (Table 2). If the claimant has a PC likely to be < 50 % , the exposure should be calculated using the upper bound (Table 3). If Table 2 was used to calculate exposure, and the probability of causation is less than 50%, the exposure should be recalculated using Table 3.

Human and animal studies have indicated that oxides of uranium can be very insoluble (ICRP 1995). However, to be claimant-favorable, the selection of absorption type should depend on the organ of interest. For example, Absorption Type S should be selected for respiratory tract dose calculations and Absorption Type M for all other organ dose calculations. ICRP (1994) default parameters should be used for particle deposition parameters.

Contamination of uranium metal by fission products and transuranics is not an issue at Bethlehem Steel Corporation because recycling of uranium in the weapons complex did not begin until after March 1952 (DOE 2001b).

Ingestion intakes were estimated using NIOSH (2004) guidance. The amount of uranium ingested daily is based on the concentration of activity in the air. To be claimant-favorable, the air concentrations in the upper bound inhalation exposure matrix (Table 2) were used to estimate ingestion intakes. Table 4 lists estimated ingestion intakes for 1949 to 1952.

Table 4. Estimated ingestion exposures.

Work period	Daily ingestion intake (dpm/m^3)			Days (h)	Annual ingestion intake (pCi)		
	Min.	Mode	Max		Min.	Mode	Max.
1949	0	28	14,000	12	0.0E+00	3.4E+02	1.7E+05
1950	0	28	14,000	12	0.0E+00	3.4E+02	1.7E+05
1951	0	28	14,000	13	0.0E+00	3.6E+02	1.8E+05

| 1952 | 0 | 28 | 14,000 | 11 | 0.0E+00 | 3.0E+02 | 1.5E+05 |

The annual ingestion intakes in Table 4 are used to calculate annual organ doses due to a chronic ingestion of natural uranium. The f_1 value is assumed to be 0.02 (ICRP 1995). These values are entered into the NIOSH IREP program assuming a chronic exposure to alpha radiation using a triangular distribution.

3.0   ESTIMATION OF EXTERNAL EXPOSURE

For estimating maximum external exposure due to submersion in air contaminated with uranium dust, the maximum air concentration value and work times per year in Table 3 (upper bound) were combined with Dose Conversion Factors for [238]U and the daughter radionuclides [234]Th and [234m]Pa from Federal Guidance Report No. 12 (EPA 1993). Table 5 lists external dose estimates for 1949 to 1952. With the exception of dose to the skin, the cumulative 4-year dose for each organ is less than 1 mrem and is, therefore, not included in the dose estimation. The maximum annual dose to the skin listed in Table 5 is applied to both the electron (E > 15 keV) and photon (E = 30 - 250 keV) annual dose in IREP using a constant distribution and assuming a chronic exposure.

Table 5. Estimated maximum annual external dose due to submersion in air contaminated with natural uranium dust.

Organ	Maximum annual organ dose (rem)			
	1949	1950	1951	1952
Adrenals	3.98E-05	3.98E-05	4.31E-05	3.65E-05
U bladder	4.09E-05	4.09E-05	4.43E-05	3.75E-05
Bone surface	1.19E-04	1.19E-04	1.29E-04	1.09E-04
Brain	5.18E-05	5.18E-05	5.61E-05	4.75E-05
Breast	6.13E-05	6.13E-05	6.64E-05	5.62E-05
Esophagus	3.89E-05	3.89E-05	4.22E-05	3.57E-05
Stomach wall	4.39E-05	4.39E-05	4.75E-05	4.02E-05
Small intestine wall	3.83E-05	3.83E-05	4.15E-05	3.51E-05
Upper large intestine wall	4.01E-05	4.01E-05	4.34E-05	3.68E-05
Lower large intestine wall	3.90E-05	3.90E-05	4.22E-05	3.57E-05
Kidney	4.48E-05	4.48E-05	4.85E-05	4.11E-05
Liver	4.46E-05	4.46E-05	4.83E-05	4.09E-05
Lung	5.02E-05	5.02E-05	5.44E-05	4.60E-05
Muscle	4.97E-05	4.97E-05	5.39E-05	4.56E-05
Ovaries	3.81E-05	3.81E-05	4.12E-05	3.49E-05
Pancreas	3.76E-05	3.76E-05	4.07E-05	3.44E-05
Red bone marrow	4.64E-05	4.64E-05	5.02E-05	4.25E-05
Skin	2.80E-03	2.80E-03	3.03E-03	2.57E-03
Spleen	4.47E-05	4.47E-05	4.84E-05	4.10E-05
Testes	5.28E-05	5.28E-05	5.72E-05	4.84E-05
Thymus	4.73E-05	4.73E-05	5.13E-05	4.34E-05
Thyroid	5.27E-05	5.27E-05	5.71E-05	4.83E-05
Uterus	3.72E-05	3.72E-05	4.03E-05	3.41E-05

For estimating external exposure to a uranium source, the source was assumed to be an extended (semi-infinite plane) natural uranium source. Estimated surface dose rates of 230 mrad/hr at a depth of 7 mg/cm^{2} and 2 mrad/hr at a depth of 1000 mg/cm^{2} were obtained from a search of the literature (Coleman, Hudson, and Plato 1983; U.S. Army 1989). Claimant-friendly values for the time workers were located relative to the source were based on descriptions of processes and different job types (AEC 1948b).

A triangular distribution for electron exposure from uranium was determined in the following manner:

- The minimum was estimated by assuming the worker was 1 meter from an extended uranium source for 1 hour (per 10-hour shift). The estimated dose rate for this scenario was 90 mrad/hr (US Army 1989).

- Survey data of the Simonds facility were used to estimate the mode. The highest value measured during those surveys was 15 mrad/hr (AEC 1949b). To be claimant-favorable, this dose rate was assumed for an entire 10-hour shift.

- A maximum value was estimated by assuming the worker was 0.3 meter (1 foot) from an extended uranium source for 6 hours (150 mrad/hr) and 1 meter away for 4 hours (90 mrad/hr).

Table 6 summarizes annual values for estimated external shallow dose due to electron exposure from uranium. The target organs for this type of exposure are the skin, male genitals, and breast. In the case of cancer of the male genitals or female breast cancer, additional evaluation might be needed to consider shielding and attenuation provided by clothing.

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

Work period	Organ annual dose (rem)		
	Min.	Mode	Max.
1949	1.08	1.80	15.12
1950	1.08	1.80	15.12
1951	1.17	1.95	16.38
1952	0.99	1.65	13.86

For cases where the target organ is the skin, male genitals, or breast, the values in Table 6 are entered in IREP as the annual dose due to electrons (E > 15 keV) using a triangular distribution and assuming a chronic exposure.

The assumption was made that workers received an annual occupationally related diagnostic chest X-ray (Simonds 1948). The exposure geometry was assumed to be posterior-anterior (PA) (NIOSH 2002). Table 7 lists annual organ doses due to the assumed annual diagnostic chest X-ray (Kathren et al. 2003). The values in Table 7 are entered into IREP as an acute annual dose due to photons with energies between 30 and 250 keV. A normal distribution should be assumed with a standard deviation of ±30%.

The deep dose rate due to photon exposure (dose rate at 1,000 mg/cm^2) from natural uranium was estimated to be 2 mrad/hr (U.S. Army 1989). Table 8 lists annual organ doses due to photons from the natural uranium source. A triangular distribution for these doses was determined by applying the minimum and maximum dose conversion factors (DCF_{min} and DCF_{max}) for 30 - 250 keV photons (NIOSH 2002) to the estimated 2-mrad/hr deep dose rate multiplied by the estimated work times listed in Tables 2 and 3. To calculate the mode value, the dose conversion factor for AP geometry (DCF_{AP}) was used.

For claims likely to yield a PC < 50%, the values in Table 8 are entered in IREP as the annual organ dose due to photons with energy between 30 and 250 keV using a triangular distribution and assuming a chronic exposure.

Table 7. Annual organ doses due to assumed annual diagnostic chest X-ray.

Organ	Annual organ dose (rem)
Thyroid	3.48E-02
Eye/brain	6.40E-03
Ovaries	2.5E-02
Liver/gall bladder/spleen	9.02E-02
Urinary bladder	2.5E-02
Colon/rectum	2.5E-02
Testes	5.0E-03
Lungs (male)	8.38E-02
Lungs (female)	9.02E-02
Thymus	9.02E-02
Esophagus	9.02E-02
Stomach	9.02E-02
Bone surfaces	9.02E-02
Remainder	9.02E-02
Breast	9.80E-03
Uterus (embryo)	2.5E-02
Bone marrow (male)	1.84E-02
Bone marrow (female)	1.72E-02
Skin	2.70E-01

Table 8. Annual organ doses due to photons from a natural uranium source.

	Annual organ dose (rem)											
	1949			1950			1951			1952		
Organ	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
Bladder	0.01	0.23	0.24	0.01	0.23	0.24	0.01	0.24	0.26	0.01	0.21	0.22
Red bone marrow	0.02	0.11	0.20	0.02	0.11	0.20	0.02	0.12	0.22	0.01	0.11	0.19
Bone surface	0.09	0.22	0.36	0.09	0.22	0.36	0.10	0.24	0.39	0.08	0.20	0.33
Breast	0.01	0.23	0.23	0.01	0.23	0.23	0.01	0.25	0.25	0.01	0.21	0.21
Colon	0.01	0.19	0.21	0.01	0.19	0.21	0.01	0.21	0.22	0.01	0.18	0.19
Esophagus	0.01	0.13	0.17	0.01	0.13	0.17	0.01	0.14	0.19	0.01	0.12	0.16
Eye	0.00	0.23	0.26	0.00	0.23	0.26	0.00	0.25	0.28	0.00	0.21	0.24
Ovaries	0.01	0.17	0.19	0.01	0.17	0.19	0.01	0.19	0.21	0.01	0.16	0.17
Testes	0.01	0.26	0.27	0.01	0.26	0.27	0.01	0.28	0.30	0.01	0.24	0.25
Liver	0.02	0.19	0.20	0.02	0.19	0.20	0.03	0.21	0.22	0.02	0.18	0.19
Lung	0.03	0.18	0.21	0.03	0.18	0.21	0.03	0.19	0.22	0.03	0.16	0.19
Remainder organs	0.02	0.16	0.17	0.02	0.16	0.17	0.02	0.17	0.19	0.02	0.15	0.16
Skin	0.11	0.16	0.18	0.11	0.16	0.18	0.12	0.18	0.19	0.10	0.15	0.16
Stomach	0.01	0.23	0.24	0.01	0.23	0.24	0.01	0.25	0.26	0.01	0.21	0.22
Thymus	0.00	0.26	0.27	0.00	0.26	0.27	0.00	0.28	0.29	0.00	0.23	0.25
Thyroid	0.00	0.26	0.27	0.00	0.26	0.27	0.00	0.28	0.30	0.00	0.24	0.25
Uterus	0.01	0.18	0.20	0.01	0.18	0.20	0.01	0.20	0.22	0.01	0.17	0.18

For cases likely to yield a PC> 50 %, the estimated 2-mrad/hr deep dose rate from the uranium source is evenly divided between photons with energies E = 30-250 keV and E > 250 keV. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for 30-250 keV photons were used to calculate the doses listed in Table 9. Dose conversion factors DCF_{min}, DCF_{max}, and DCF_{AP}, for E > 250 keV photons were used to calculate the doses in Table 10. The values in Tables 9 and 10 are entered into IREP as organ doses due to the appropriate energy photons, using a triangular distribution and assuming a chronic exposure.

Table 9. Annual organ doses due to photons (30-250 keV) from natural uranium source.

Organ	Annual organ dose (rem)											
	1949			1950			1951			1952		
	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
Bladder	0.00	0.11	0.12	0.00	0.11	0.12	0.00	0.12	0.13	0.00	0.10	0.11
Red bone marrow	0.01	0.06	0.10	0.01	0.06	0.10	0.01	0.06	0.11	0.01	0.05	0.09
Bone surface	0.05	0.11	0.18	0.05	0.11	0.18	0.05	0.12	0.20	0.04	0.10	0.17
Breast	0.01	0.12	0.12	0.01	0.12	0.12	0.01	0.12	0.13	0.00	0.11	0.11
Colon	0.01	0.10	0.10	0.01	0.10	0.10	0.01	0.10	0.11	0.01	0.09	0.09
Esophagus	0.00	0.06	0.09	0.00	0.06	0.09	0.00	0.07	0.09	0.00	0.06	0.08
Eye	0.00	0.11	0.13	0.00	0.11	0.13	0.00	0.12	0.14	0.00	0.10	0.12
Ovaries	0.00	0.09	0.10	0.00	0.09	0.10	0.00	0.09	0.10	0.00	0.08	0.09
Testes	0.00	0.13	0.14	0.00	0.13	0.14	0.00	0.14	0.15	0.00	0.12	0.12
Liver	0.01	0.10	0.10	0.01	0.10	0.10	0.01	0.10	0.11	0.01	0.09	0.09
Lung	0.02	0.09	0.10	0.02	0.09	0.10	0.02	0.10	0.11	0.01	0.08	0.09
Remainder organs	0.01	0.08	0.09	0.01	0.08	0.09	0.01	0.09	0.09	0.01	0.07	0.08
Skin	0.05	0.08	0.09	0.05	0.08	0.09	0.06	0.09	0.10	0.05	0.07	0.08
Stomach	0.01	0.11	0.12	0.01	0.11	0.12	0.01	0.12	0.13	0.00	0.10	0.11
Thymus	0.00	0.13	0.14	0.00	0.13	0.14	0.00	0.14	0.15	0.00	0.12	0.12
Thyroid	0.00	0.13	0.14	0.00	0.13	0.14	0.00	0.14	0.15	0.00	0.12	0.12
Uterus	0.01	0.09	0.10	0.01	0.09	0.10	0.01	0.10	0.11	0.00	0.08	0.09

Table 10. Annual organ doses due to photons (>250 keV) from natural uranium source.

Organ	Annual organ dose (rem)											
	1949			1950			1951			1952		
	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
Bladder	0.05	0.11	0.11	0.05	0.11	0.11	0.06	0.12	0.12	0.05	0.10	0.10
Red bone marrow	0.06	0.09	0.11	0.06	0.09	0.11	0.07	0.10	0.12	0.06	0.08	0.10
Bone surface	0.07	0.09	0.11	0.07	0.09	0.11	0.07	0.10	0.12	0.06	0.09	0.10
Breast	0.06	0.12	0.12	0.06	0.12	0.12	0.06	0.13	0.13	0.05	0.11	0.11
Colon	0.05	0.10	0.11	0.05	0.10	0.11	0.06	0.11	0.12	0.05	0.10	0.10
Esophagus	0.05	0.09	0.10	0.05	0.09	0.10	0.06	0.10	0.11	0.05	0.08	0.10
Eye	0.02	0.11	0.12	0.02	0.11	0.12	0.03	0.12	0.13	0.02	0.10	0.11
Ovaries	0.05	0.10	0.12	0.05	0.10	0.12	0.06	0.11	0.12	0.05	0.09	0.11
Testes	0.06	0.12	0.13	0.06	0.12	0.13	0.06	0.13	0.14	0.05	0.11	0.12
Liver	0.06	0.11	0.11	0.06	0.11	0.11	0.06	0.11	0.12	0.05	0.10	0.10
Lung	0.06	0.10	0.11	0.06	0.10	0.11	0.07	0.11	0.12	0.06	0.10	0.10
Remainder organs	0.06	0.10	0.10	0.06	0.10	0.10	0.06	0.11	0.11	0.05	0.09	0.09
Skin	0.07	0.10	0.11	0.07	0.10	0.11	0.08	0.11	0.12	0.07	0.09	0.10
Stomach	0.06	0.11	0.11	0.06	0.11	0.11	0.06	0.12	0.12	0.05	0.10	0.11
Thymus	0.04	0.11	0.13	0.04	0.11	0.13	0.05	0.12	0.14	0.04	0.10	0.12
Thyroid	0.05	0.12	0.13	0.05	0.12	0.13	0.05	0.13	0.14	0.04	0.11	0.12
Uterus	0.05	0.10	0.10	0.05	0.10	0.10	0.06	0.11	0.11	0.05	0.09	0.09

REFERENCES

AEC (U.S. Atomic Energy Commission), 1953, *Simonds Saw and Steel Company, Occupational Exposure to Uranium*, New York Operations Office, Health and Safety Division, February 18 [p. 54, Simonds Saw and Steel Company.pdf].

AEC (U.S. Atomic Energy Commission), 1948a, *Simonds Saw and Steel Company, Occupational Exposure to Radioactive Dust: Visit of October 27, 1948*, New York Operations Office [p. 138, Simonds Saw and Steel Company.pdf].

AEC (U.S. Atomic Energy Commission), 1948b, *Simonds Saw and Steel Company, Occupational Exposure to Radioactive Dust: Visit of October 27, 1948*, New York Operations Office [pp. 139-153, Simonds Saw and Steel Company.pdf].

AEC (U.S. Atomic Energy Commission), 1949a, *Health Hazards in NYOO Facilities Producing and Processing Uranium: A Status Report- April 1, 1949*, New York Operations Office, Medical Division, April 18.

AEC (U.S. Atomic Energy Commission), 1949b, *Simonds Saw and Steel Company, Summary Report of Three Surveys, (October 27, 1948-February 15, 1949)*, New York Operations Office, Medical Division [p9. 250-252, Simonds Saw and Steel Company.pdf].

AEC (U.S. Atomic Energy Commission), 1951-1952, "Air dust data from Bethlehem Steel Corporation's Lackawanna Plant," New York Operations Office, Medical Division, [pp. 4-11, Bethlehem Steel Site Profile.pdf].

Bowman, H. T., Merrill, P. E., Schneider, C. A., and Yocco, A. S., 1952, *Report on Trips to Bethlehem Steel Corporation, Lackawanna Plant, Buffalo, N.Y.*, Production Division of National Lead Company of Ohio, September 4 [p. 23, NY-Bethlehem Steel.pdf].

Coleman, R. L., Hudson, C. G., and Plato, P. A., 1983, "Depth-dose curves for ^{90}Sr and natural and depleted uranium in mylar," *Health Physics*, 44(4): 395-402.

DOE (U.S. Department of Energy), 1985, *FUSRAP Elimination Report for Bethlehem Steel Corporation, Lackawanna, New York* [p. 64, Bethlehem Steel.pdf].

DOE (U.S. Department of Energy), 2001a, *DOE Standard: Health Physics Manual of Good Practices for Uranium Facilities*, DOE-STD-1136-2000, Change Notice No. 3, December http://tis.eh.doe.gov/techstds/standard/std1136/STD11362000.pdf.

DOE (U.S. Department of Energy), 2001b, *Preliminary Review of the Flow and Characteristics of Recycled Uranium Throughout the DOE Complex 1952-1999*, Vol. 1, *Project Overview*, March http://tis.eh.doe.gov/legacy/reports/reports.html.

EPA (U.S. Environmental Protection Agency), 1993, *External Exposure to Radionuclides in Air, Water, and Soil*; Federal Guidance Report No. 12, Washington, D.C., September.

Frey, H. C., and A. C. Cullen, 1995, "Distribution Development for Probabilistic Exposure Assessment," Paper No. 95-94.02, *Proceedings of the 88th Annual Meeting of the Air & Waste Management Association*, San Antonio, Texas, June 18-23.

Hershman, H.J., 1952, "Transmittal of the Monthly Progress Report for October, Monthly progress report for October 1952 covering activities at the Tonawanda Sub Office," memorandum to R.J. Smith, October 21.

ICRP (International Commission on Radiological Protection), 1994, *Human Respiratory Tract Model for Radiological Protection*, Publication 66, Pergamon Press, Oxford, England, p. 198.

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, p. 299.

Kathren, R. L., V. E. Shockley, E. M. Thomas, and T. D. Taulbee, 2003, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, Revision 2, ORAUT-OTIB-0006, NIOSH Dose Reconstruction Project, Cincinnati, Ohio.

Kosanovich, P. (Compensation Agent, L.U. 2603), 1979, letter to Robert Anderson (Bethlehem Steel Corporation), October 19 [p. 36, Bethlehem Steel Site Profile.pdf].

LaMastra, A., 1976, "Investigation Report: Uranium Metal Rolling, 10" Bar Mill, Lackawanna Plant," report to D. L. Webster, Bethlehem Steel Corporation, June 29. [p. 16, Bethlehem Steel.pdf].

NIOSH (National Institute for Occupational Safety and Health), 2002, *External Dose Reconstruction Implementation Guideline*, Revision 1, OCAS-IG-001, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NIOSH (National Institute for Occupational Safety and Health), 2004, *Estimation of Ingestion Intakes*, Revision 0, Technical Information Bulletin, OCAS-TIB-00?, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NLO (National Lead Company of Ohio), 1952a, *Production Report on the Rolling of Two Hundred and Twenty-two Uranium Billets at Bethlehem Steel Corporation's Lackawanna Plant on Saturday, April 12, 1952*, Contract No. AT(30-1)-1156, April 28 [p. 1, NY-Bethlehem Steel.pdf].

NLO (National Lead Company of Ohio), 1952b, Production Report on the Rolling of Two Hundred an Eighteen Uranium Billets at Bethlehem Steel Corporation's Lackawanna Plant on March 15, 1952, Contract No. AT(30-1)-1156, March 21 [p. 37, Bethlehem Steel Site Profile.pdf].

NLO (National Lead Company of Ohio), 1952c, *Air dust data from last rolling on September 14, 1952 at Bethlehem Steel Corporation's Lackawanna Plant*, Health and Safety Division, September 17 [pp. 12-15, Bethlehem Steel Site Profile.pdf].

ORNL (Oak Ridge National Laboratory), 1980, *Preliminary Survey of Bethlehem Steel, Lackawanna, New York*, March [p. 79, Bethlehem Steel.pdf].

Range, W., 1976, letter to David M. Anderson (Bethlehem Steel Corporation), Energy Research and Development Administration, June 7 [p. 71, Bethlehem Steel.pdf].

Schneider, C. A., and A. S. Yocce, no date, *Report on Rollings and Bethlehem Steel Corporation, Lackawanna Plant, Buffalo, New York*, Abstract, FMPC-79, [p. 35, Bethlehem Steel Site Profile.pdf].

Simonds (Simonds Saw & Steel Company), 1948, *Hazard Identification, Evaluation, and Mitigation*, [pp. 461-464, Simonds Saw and Steel Company.pdf].

Summary (Summary of Experimental Rollings Relating to Fernald Operations), 1951 [p. 20, Bethlehem Steel.pdf].

Thornton, W. T., 1977, "ERDA Resurvey Program – Bethlehem Steel, Lackawanna, NY," report to R. H. Kennedy, Energy Research and Development Administration, March 16 [p. 75, Bethlehem Steel.pdf].

U.S. Army, 1989, Handbook *of Safety Procedures for Processing Depleted Uranium*, Chapter 3, *Safety Considerations for Processing, Handling, and Testing of DU Components*, AMC HDBK 385-1.1-89, Department