ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation	Document Number: ORAUT-TKBS-0001 Effective Date: 03/31/2003 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 14
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Basis for Development of an Exposure Matrix for
BETHLEHEM STEEL CORPORATION
Lackawanna, New York
Period of Operation: 1949-1952

Site Description and Operational History

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

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

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

Table 1. Documented rollings at Bethlehem Steel Corporation, Lackawanna, NY.

Date of Rolling	Day of Week	Type	No. of 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

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, US DOE 1985). Documents also indicate 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). It appears that the uranium metal accountability records 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 uranium compounds. After the war, the University of Rochester lowered their 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. This level was based 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, the level 50 $\mu g/m^3$ was referred to as the "preferred level" (U.S. AEC 1949b). Many of the AEC contractors used the term Maximum Allowable (air) Concentration (MAC) interchangeably with the "preferred level" and often reported air-sampling results as multiples of the MAC (NLO 1952c, U.S. AEC 1953).

A New York Operations Office (NYOO) report of a visit to Simonds Saw and Steel 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 (US AEC 1948a). This report indicates a 10-hour workday. The report also 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" (US AEC 1948a). This survey was done during a production rolling. During experimental rollings, generally less than 50 billets were

rolled. It appears from the job analysis sheets that around 180 billets were rolled that day.

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

One of the many purposes of the 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 was done on April 17, 1951 at Simonds Saw and Steel Company in Lockport, NY using 18" bar mills. This rolling was also considered part of Experimental Rolling #1 (Summary 1951). A NYOO report showed results from a survey done during rolling operations on a 16" 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 (US AEC 1953). The same report gives the results of another survey done on December 9, 1952 at Simonds showing exposure levels between 0.93 and 4.2 MAC (US AEC 1953). The average exposures were 1.48 MAC for August 20, 1951 and 2.1 MAC for December 9, 1952. This report also indicates that workdays were generally eight hours (US AEC 1953).

Air dust data reports from rollings done 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 0 and 4900 dpm/m^3 (70 MAC) in 1952 (NLO 1952a, US AEC 1951-1952). All data were collected by the AEC New York Operations Office Medical Division with the exception of data obtained on September 14, 1952, which was collected by National Lead Company of Ohio Health and Safety Division.

Estimation of Internal Exposure

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

Tables 2a and 2b below show the internal exposure matrix for the Bethlehem Steel site. Table 2a is considered to be a lower bound for estimation of internal exposure and Table 2b is considered to be 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 takes into account the possibility that there was no exposure. The maximum value for the lower bound matrix was assumed to be 4900 dpm/m^3 (70 MAC), which is the maximum reading found in the Bethlehem Steel air

monitoring data (U.S. AEC 1951-1952). The maximum value for the upper bound matrix was assumed to be 70,000 dpm/m^3 (1000 MAC) because of the reported maximum levels during rolling operations in 1948 at the Simonds facility (US AEC 1948a). Although the exposure levels in 1948 were reportedly higher than the mode value of 2 MAC used in the matrices, it was assumed that several recommended improvements were made to the process in the interim (US AEC 1948a), which is evident in the 1951 and 1952 Bethlehem Steel data. Another factor in the difference in air concentration levels is the fact that the rollings at Simonds were production runs as opposed to experimental runs that involved much less material.

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 that there is no documentation that indicates any rollings actually took place during those years. If there were any rollings, it is assumed they only took place 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) rollings, only one weekend day per month was utilized. 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 seven documented rollings, it was assumed that one rolling each took place in February, March, June, and July resulting in 11 10-hour workdays. It is assumed that no rollings took place after September 1952 because the work was transferred to the Fernald Plant around that time (NLO 1952a, LaMastra 1976, Range 1976).

The breathing rate was calculated from the volume of air breathed for an adult light worker shown in ICRP Publication 66, Table 6 on pg. 23 (ICRP 1994). This category assumes an activity distribution of 1/3 sitting and 2/3 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. The maximum intakes were calculated using the same method but substituting the breathing rate for an adult heavy worker, which assumes an activity distribution of 7/8 light exercise and 1/8 heavy exercise.

Table 2a. Internal Exposure Matrix-Lower Bound

Work Period	**Air Concentration (dpm/m^3)**			**Breathing Rate (m^3/h)***	**Hours (h)**	**Annual Intake (pCi)**		
	min.	mode	max	Light/heavy		min.	mode	max.
1949	0	140	4900	1.2/1.7	120	0.00E+00	9.16E+03	4.54E+05
1950	0	140	4900	1.2/1.7	120	0.00E+00	9.16E+03	4.54E+05
1951	0	140	4900	1.2/1.7	130	0.00E+00	9.93E+03	4.92E+05
1952	0	140	4900	1.2/1.7	110	0.00E+00	8.40E+03	4.17E+05

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

Table 2b. Internal Exposure Matrix-Upper Bound

Work Period	**Air Concentration (dpm/m^3)**			**Breathing Rate (m^3/h)***	**Hours (h)**	**Annual 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

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

In order to make use of the information in Tables 2a and 2b for estimation of internal dose, the annual doses for the organ of interest should be calculated in the IMBA NIOSH program for the minimum, mode, and maximum intake of natural uranium assuming a chronic exposure. If the claimant has a likely compensable cancer, the exposure should be calculated using the lower bound matrix (Table 2a). If the claimant has a likely non-compensable cancer, the exposure should be calculated using the upper bound matrix. The three sets of annual organ doses can then be entered into the NIOSH IREP program 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 lower bound matrix was used to calculate exposure, and the probability of causation is determined to be less than 50%, then the exposure should be recalculated using the upper bound matrix.

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 be dependent 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 66 default parameters should be selected for particle deposition parameters in the IMBA NIOSH program.

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

Although the values shown above in Tables 2a and 2b may seem to be excessive overestimates, they are consistent with NIOSH's approach of making claimant favorable assumptions when monitoring data are lacking or incomplete.

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 2b (upper bound) were combined with Dose Conversion Factors for U-238 and the daughter radionuclides Th-234 and Pa-234m from Federal Guidance Report No. 12 (US EPA 1993). Table 3 shows external dose estimates for 1949-1952. With the exception of dose to the skin, the cumulative four-year dose for each of the organs is less than 1 mrem and

is therefore not included in the dose estimation. The maximum annual dose to the skin shown in Table 3 is applied to both the electron (E>15 kev) and photon (E = 30-250 keV) annual dose in the NIOSH-IREP program using a constant distribution and assuming a chronic exposure.

Table 3. Estimated maximum annual external dose due to submersion in air contaminated with natural uranium dust.

	Maximum AnnualOrgan Dose (rem)			
Organ	**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 et al. 1983, US Army 1989). Claimant-friendly values for the time that workers were located relative to the source were based on descriptions of processes and different job types (US 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 away 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 (US AEC 1949a). 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 meters (1 foot) away from an extended uranium source for 6 hours (150 mrad/hr) and 1 meter away for 4 hours (90mrad/hr).

Table 4 is a summary of the 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 may be needed to consider shielding and attenuation provided by clothing.

Table 4. Estimated external shallow dose due to electron exposure from a natural uranium source.

	Organ Annual Dose (rem)		
Work Period	**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 4 above are entered into the NIOSH-IREP program as the annual dose due to electrons (E>15 keV) using a triangular distribution and assuming a chronic exposure.

The assumption was also made that workers received an annual occupationally related diagnostic x-ray (Simonds 1948). The exposure geometry was assumed to be posterior-anterior (PA) (DHHS 2002). The entrance skin exposure from the diagnostic chest x-ray was estimated to be 0.027 R (range 0-0.090 R) (NCRP 1989). The organ doses were calculated by multiplying the entrance skin exposure by the "Exposure (R) 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 lower and upper bounds of the entrance skin exposure range were multiplied by the lower and upper bounds of the dose conversion factor to produce a minimum and maximum dose. The values in Table 5 are entered into the NIOSH-IREP program as the annual dose due to photons with energies between 30 and 250 keV using a triangular distribution and assuming an acute exposure.

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

	Organ Dose (rem)		
Organ	**Minimum**	**Mode**	**Maximum**
Bladder	0.000	0.016	0.062
Red Bone Marrow	0.000	0.027	0.105
Bone Surface	0.000	0.039	0.210
Breast	0.000	0.013	0.050
Colon	0.000	0.021	0.081
Esophagus	0.000	0.023	0.089
Eye	0.000	0.005	0.022
Ovaries	0.000	0.024	0.096
Testes	0.000	0.013	0.051
Liver	0.000	0.022	0.086
Lung	0.000	0.029	0.113
Remainder organs	0.000	0.024	0.093
Skin	0.000	0.024	0.087
Stomach	0.000	0.017	0.064
Thymus	0.000	0.010	0.040
Thyroid	0.000	0.011	0.043
Uterus	0.000	0.021	0.082

The deep dose rate due to photon exposure (dose rate at 1000 mg/cm^2) from natural uranium was estimated to be 2 mrad/hr (US Army 1989). Table 6 shows the 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 (US DHHS 2002) to the estimated 2 mrad/hr deep dose rate multiplied by the estimated work times shown in Tables 2a and 2b. To calculate the mode value, the dose conversion factor for anterior-posterior geometry (DCF_{AP}) was used.

Table 6. 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 likely non-compensable cases, the values in Table 6 above are entered into the NIOSH-IREP program as the annual organ dose due to photons with energy between 30 and 250 keV using a triangular distribution and assuming a chronic exposure.

For likely compensable cases, 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. The dose conversion factors, DCF_{min}, DCF_{max}, and DCF_{AP}, for 30-350 keV photons were used to calculate the doses in Table 7a. The dose conversion factors, DCF_{min}, DCF_{max}, and DCF_{AP}, for E>250 keV photons were used to calculate the doses in Table 7b. The values in Tables 7a and 7b are entered into the NIOSH-IREP program as organ doses due to the appropriate energy photons, using a triangular distribution and assuming a chronic exposure.

Table 7a. Annual organ doses due to photons (30-250 keV) 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	0.00	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 7b. Annual organ doses due to photons (>250 keV) 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	0.05	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

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