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Site Profiles for Atomic Weapons Employers that Worked Uranium Metals **Appendix C – Dow Chemical Co. (Madison Site)**	
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
9/8/2008	9/8/2008	0	Appendix to Battelle-TBD-6000 describing the use of the TBD for uranium exposures and presenting information for thorium exposures for claims at Dow Chemical Co. (Madison Site)
03/10/2014	04/03/2014	1	Revised to incorporate changes made during the revision of the base document TBD-6000. Revisions include changes to inhalation values during uranium operations, increased photon dose from contamination (based on 30 day deposition) and added beta dose values based on contamination. Residual period uranium inhalation values increased, OTIB-70 technique used during residual period, The basis for residual period ingestion values changed to use operational period airborne value and TIB-009 for the first year.

DOW CHEMICAL CO. (MADISON SITE)

C.1 Introduction

This document serves as an appendix to Battelle-TBD-6000, Site Profiles for Atomic Weapons Employers that Worked Uranium Metals (Battelle 2011). This Site Profile presents site-specific information for the Dow Chemical Co. Madison, Illinois Site for which sufficient information has been found to provide more appropriate estimates of worker radiation dose than provided for in the technical basis document (TBD). Where specific information is lacking, research into similar facilities described in the body of this Site Profile is used.

C.2 Site Description

From 1954 through 1969, the Dow Madison facility in Madison, Illinois was owned and operated by the Dow Metal Products Division of the Dow Chemical Company. Dow sold this facility in 1969 to Consolidated Aluminum, which continued to operate the facility from 1969 through 1986. Spectrulite subsequently purchased the plant from consolidated Aluminum (DOE web site).

From 1957 through 1960 the Dow Madison site performed several campaigns of work with uranium metal for the Mallinckrodt Chemical Works. The work involved both experimental extrusion of uranium metal and uranium metal rod straightening (DOE, 1991). These rods were for use in the AEC nuclear weapons program. Therefore, in accordance with OCAS-IG-003 (NIOSH 2007a), radiation exposure from these uranium rods is covered during the contract period. Exposure from any residual contamination is also covered exposure in accordance with OCAS-IG-003.

The Madison site produced and commercially sold magnesium alloy during most of its history. Many of these magnesium alloys contained thorium. DOE determined that some of this alloyed magnesium was sold to the AEC in 1957 and 1958. DOE further concluded that the material sold in 1957 and 1958 may have been used in nuclear weapons manufactured between 1956 and 1969 (DOE, 2008). Therefore, in accordance with OCAS-IG-003, the thorium related to the 1957 and 1958 magnesium alloy production is covered radiation exposure during the residual contamination period. Since during the contract period, all sources of radiation are covered exposure, all the thorium work from 1957 to 1960 is covered exposure.

C.2.1 Site Activities

The Dow Madison site performed work with both uranium and thorium metal. The thorium work consisted of manufacturing magnesium alloy materials. The uranium work consisted of experimental extrusion of uranium billets into metal rods for Mallinckrodt Chemical Works. The Madison site also straightened uranium metal rods for Mallinckrodt Chemical Works.

C.2.1.1 Thorium Work

From 1958 until 1992, the Dow Chemical Company and the successor companies held AEC and State of Illinois licenses for the possession and use of thorium materials for the commercial production of magnesium-thorium alloys for various high temperature applications, including aeronautics and space programs. Licensed activities included storage in the waste sludge disposal area, which remained during the post-production period.

Magnesium-thorium alloy production at Dow Madison involved a number of metallurgical and mechanical operations. Activities included high temperature melting and alloying Th pellets or Mg-Th hardener with cell Mg, pouring molten alloy into casting pots and molds, breaking sludge out of crucibles, grinding/gouging/sanding, rolling, and packaging slabs and sheets of metal alloy (AEC, 1960).

C.2.1.2 Uranium Work

Two phases of uranium work for the U.S. AEC comprise the AWE covered work period:

C.2.1.2.a Uranium Extrusion

In 1957, Dow Madison was subcontracted by Mallinckrodt Chemical Works (MCW) to perform research and development work involving gamma-phase extrusion of uranium metal. According to the contract (AEC, 1957), the experimental extrusion work consisted of 12 consecutive monthly cycles, each consisting of 28 hours of work. Each monthly cycle was defined as 6 hours for set-up, 16 hours of extrusion, and 6 hours of clean-up. Dow was to provide auxiliary equipment and tool design expertise in addition to the use of its press, labor and plant facilities. Mallinckrodt responsibilities included procurement and installation of the auxiliary equipment designed and specified by Dow, modifications to dust arresting equipment and other protective equipment required by plant surveys ostensibly made during the course of the work, arrangement for a complete survey of breathing-zone air quality to be conducted periodically by the Health and Safety Laboratory, establishment of a program for area clearance after each cycle, supply of the billets allocated for each cycle, and clean up of billets or extruded metal after each cycle. Each work cycle involved the extrusion of 20 billets of Uranium. A total of 240 billets were processed in 12 consecutive months. The contract was signed on March 15th 1957. Giving a few months to startup, this appendix will assume this work occurred in six months of 1957 and six months of 1958 (168 hours each year).

C.2.1.2.b Uranium Rod Straightening

In March 1960, the Uranium Division of Mallinckrodt Chemical Works issued a purchase order (DOE, 1991) with DOW for the straightening of uranium rods supplied by MCW. Mallinckrodt personnel delivered the rods to the Dow Madison plant and picked them up after the straightening operation. Documentation has been found for two rod-straightening campaigns, one in December 1959 and one in January 1960. The quantities of Uranium metal involved in these operations are unknown, however, the total value of the purchase order, and the unit cost identified with lot size indicate that the quantity of metal involved was probably small (DOE, 1991). The two campaigns were completed a month apart (December 1959 and January 1960), therefore, each campaign must have lasted less than a few weeks. It therefore appears using the same 168 hour per year estimate as the extrusion campaigns would be favorable to the claimant.

C.2.2 Job Categories

The uranium extrusion and straightening work was comprised of a few relatively short campaigns during the covered period. Workers from the regular Dow Madison commercial magnesium alloy operations were pulled from those activities to run the uranium extrusion and rod straightening campaigns. It is assumed that the workers in the uranium operations would have fulfilled job functions similar to their regular jobs in magnesium metal and alloy production.

Four job exposure categories similar to the four generic job titles used in TBD-6000 have been determined for assigning radiation dose.

Operators	(Involved directly in operations; includes jobs such as Extrusion Press Operator, Saw Operator, Furnace Worker, Metal Caster)
Laborer	(Involved in support of operations; includes jobs such as Fork Truck Operator, Crane Operator, Janitor Laborer, Pipefitter and other maintenance)
Supervisor	(Assumed to spend time in the production areas but primarily not in a “hands on” job; includes jobs such as Foreman, Supervisor, Inspector, Security)
Others	(Jobs involving little or no time in production areas, primarily office jobs)

The job(s) performed by a claimant should be evaluated during the dose reconstruction process to determine the most appropriate job exposure category. Note that many claimants list more than one job title. If this is the case for a claimant for whom a dose reconstruction is being performed, the assigned dose should be prorated according to the time spent in each job if that information is available. If not, dose should be assigned according to the highest job exposure category applicable to that worker.

C.3 Occupational Medical Dose

No information regarding occupational medical dose specific to the Dow Madison Site was found. Information to be used in dose reconstructions for which no specific information is available is provided in ORAUT-OTIB-0006 (ORAU, 2011), the dose reconstruction project technical information bulletin covering diagnostic x-ray procedures.

C.4 Occupational Internal Dose

C.4.1 Uranium

No air sampling data were available for uranium operations during the period of 1957-1960. Air concentrations from Table 7.2 of TBD-6000 were used to calculate uranium inhalation and ingestion quantities for 1957 and 1958. As described in section C.2.1.2.a, these air concentrations were assumed to be present for 168 hours each year.

Exposure from airborne uranium resuspended from surface contamination is also estimated. This exposure was assumed for the entire year, not just the uranium operational time. The resuspension was calculated by assuming the uranium airborne contamination during operations settled to horizontal surfaces and was later resuspended. The contamination was assumed to accumulate for an entire period of time of uranium work with no removal mechanisms. Values necessary for this calculation are described in the body of TBD-6000. As a favorable assumption, the contamination value calculated at the end of this period was used to estimate the resuspended airborne value for the entire time period.

For 1959 and 1960, air concentrations from Table 7.7 were used. The air concentrations in this table are driven by rod straightening and therefore appear to be a good representation of this work. As described in section C.2.1.2.b, these air concentrations were assumed to be present for 168 hours each year. Exposure from airborne uranium resuspended from surface contamination was again estimated using the same techniques as described above. However, for this period, the contamination was added to that already assumed present from the first two years. Again, the airborne value calculated from the contamination present at the end of this period was used for the entire period.

Ingestion doses were calculated using OCAS-TIB-009 (NIOSH 2004) and the operational airborne levels discussed above. This produces an ingestion rate equivalent to continuous work rather than intermittent work with uranium. Table C.1 contains inhalation and ingestion intakes in terms of dpm per day for each job category and each year. Contaminates from recycled uranium should be added to the uranium intakes based on Table 3.2 in TBD-6000.

C.4.2 Thorium

Data from a number of work area and breathing zone air samples taken during alloy production operations involving thorium were found, but NIOSH has determined (NIOSH, 2007b) that the data are not sufficient to adequately determine the potential intake of thorium, making reconstruction of internal thorium doses infeasible.

C.5 Occupational External Dose

C.5.1 Uranium

No data were found related to occupational external dose from the uranium work at the Dow Madison site. The work performed at Dow Madison involved extruding uranium ingots and uranium rod straightening; therefore, the external dose values for the appropriate job category in Table 6.4 of TBD 6000 were used. The values associated with working directly with the metal were prorated to 168 hours per year. The values associated with submersion in a cloud and surface contamination were assumed to be present for the full year.

Table C.2 presents the values for whole body and skin dose to be used for each calendar year listed.

C.5.2 Thorium

Dow conducted an estimate of the external radiation dose received while working in the pot room (Levy, 1957). The resulting estimate was 250 to 380 mr/yr when working with 26% thorium hardener and 100 to 160 mr/yr when working with thorium pellets. Addendum 2 of the NIOSH SEC Evaluation Report for the Dow Madison site, estimated a bounding exposure of 1400 mr/yr. This estimate was based on 100% occupancy 1 foot from the highest area dose rate. TBD-6000 assumes an operator is one foot from the material 50% of the time. This adjustment provides an estimate of 700 mr/yr.

Some film badge data is available from Dow's Bay City plant (Silverstein, 1957). Dow's Bay City plant performed similar operations with similar material. This data was collected for a 13 day period during HK31 casting production. When a lognormal distribution of this data is assumed, the 95th percentile results in a dose of 1,095 mr/yr. This dose will be considered a bounding dose for the operator category. The Laborer category will be assumed to be half of this and the Supervisor category will be assumed to be half of the Laborer category. That results in an estimate of 274 mr/yr for the Supervisor category. This appears to be reasonably bounding since the geometric mean of the distribution is 254 mr/yr. The supervisor estimate is therefore higher than half of those monitored. For the "others" category, the 5th percentile of the distribution was used. The photon engery distribution assumed for thorium is 25% 30 kev – 250 kev and 75% > 250 kev (General Electric, 1964).

Various contact and surface measurements for the different materials used in the alloying process showed the measured beta component to be slightly less than the gamma component and falling to zero with distance (AEC, 1960; Saunders, 1960). Even though the beta component falls off with distance, this estimate will assume the beta dose is equal to the photon dose at all distances.

C.6 Dose from Residual Contamination

After the contract period, employees could still be exposed to residual contamination left over from the AEC related materials. Uranium contamination was discovered in the overhead structures and as a result, in 1992 the site was designated as part of the Formerly Utilized Site Remediation Action Program (FUSRAP). This program was transferred to the Army Corps of Engineers (ACE) in 1997. The ACE completed a remediation by mid-July 2000 (USACE web site). Therefore, this appendix will provide an estimate of uranium residual contamination dose until the end of July 2000. This estimate can then be used for any employees for whom DOL has verified employment through July 2000. The dose from residual uranium contamination after July 2000 is considered to be zero.

For the first year of the residual period, the estimate for inhalation and ingestion of uranium uses the same estimate as the last year of the operational period. After that, the intakes are reduced by 9.87% per year. This rate was derived in Addendum 2 of the SEC Evaluation Report for the Dow Madison site. The rate was derived for thorium but it is site specific and more favorable than the default rate found in ORAUT-OTIB-0070 (ORAU, 2012). These values are contained in Tables C.4 and C.5.

The external dose from residual uranium contamination utilizes the Battelle-TBD-6000 Table 6.4 for contamination. The scrape recovery task was used because it included rod straightening and was more favorable than extrusion. These values were used for the first year of the residual period and decreased each year after that the same as the intakes discussed above.

Residual thorium contamination was not part of the FUSRAP cleanup because DOE determined it was part of the commercial operations at the site (DOE, 1991). However, in January 2008, the DOE notified DOL and NIOSH that after additional research, DOE had concluded that Dow Madison did use thorium in AWE operations (DOE, 2008). DOE stated that in 1957 and 1958 Dow Madison supplied the AEC (via Mallinckrodt) with Mg-Th plates and sheets. DOE further concluded that this alloy may have been used to make components for nuclear weapons manufactured between 1956 and 1969. In accordance with OCAS-IG-003, all radiation exposure is considered during the AEC contract work. Therefore, thorium dose from operations is covered during the entire covered period (1957 through 1960). After 1960, only residual thorium contamination related to the weapons work is considered. Since reliable documentation is not available to distinguish between thorium related to weapons work and that related to commercial work, a bounding estimate based on all the thorium work between 1957 and 1958 is used. The residual thorium contamination is considered through the last day of the thorium cleanup. That date was reported to be October 31, 2006 (Cushman, 2008, NIOSH, 2007). However, the Project Closure Report indicated that the last thorium contamination was shipped off site in November, 2007 (Pangea, 2008). Therefore, this estimate will be applied to any DOL verified covered employment through November 30, 2007.

The thorium and thoron intakes during the residual contamination period are estimated using the technique described in Addendum 2 of the SEC Evaluation Report for the Dow Madison site (NIOSH, 2007b). That technique assumes the airborne concentrations during the first year of the residual period is equal to the airborne concentrations during thorium operations. This is considered a bounding estimate because much of the airborne contamination during operations is caused by the operation itself and not the resuspension of contamination remaining from previous operations.

It was determined that intakes during the contract period could not be estimated because the airborne concentrations available could not be shown to be representative of most of the operational period. However, this does not prevent using the assumption that the intakes during the operational period bound the intakes caused by the resuspension of residual contamination. This is particularly true since some of the operational airborne concentration would be caused by the resuspension of contamination from previous operations. Also, incidents such as fires or explosions occurring in the residual contamination period do not affect this estimate. This is due to the fact that while such incidents may have occurred, it is highly unlikely they occurred due to the residual thorium contamination. It is much more likely they would have involved the material in process at the time. Table C.7 presents these values as thorium intakes to be used for each calendar year of the residual contamination period. These values should be assigned as intakes of Thorium-232, Thorium-228, and Radium-228 each receiving a value equal to the values in Table C.7. An intake of Thorium-230 should be assigned that is two times the values of Table C.7 in accordance with page 30 of Addendum 2 of the SEC Evaluation Report for the Dow Madison site (NIOSH, 2007b).

External dose from residual thorium contamination is accounted for by starting with the values indicated in section C.5.2. These are bounding estimates based on film badge data from similar operations with similar material. The values presented in section C.5.2 are used for the first year of the residual contamination period. For subsequent years, the values are decreased at the same rate as the internal intakes. The rate and the derivation of that rate are contained in Addendum 2 of the SEC Evaluation Report for the Dow Madison site. This effectively assumes that residual thorium is removed (due to fugitive emissions, tracking, housekeeping, etc) at the same rate for the internal and the external dose estimates. The external estimate is considered a bounding estimate because the majority of the external dose recorded on the film badges likely came from the in-process thorium material itself rather than residual contamination. Table C.8 presents whole body doses to be used for each calendar year of the residual contamination period. As with the operational period, the dose to the skin of the whole body will be added at a rate equal to the photon dose.

C.7 References

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Silverstein, 1957, Memo from Lawrence G. Silverstein, Dow Chemical Company to H. L. Price U. S. Atomic Energy Commission, June 26, 1957 (TDCC 000362)

USACE web site, U. S. Army Corps of Engineers, St. Louis District, FUSRAP website, http://www.mvs.usace.army.mil/Missions/CentersofExpertise/FormerlyUtilizedSitesRemedialActionProgram.aspx

Table C.1 INTERNAL DOSE PATHWAYS - Inhalation of Airborne Uranium

All intakes and doses assume full-time employment for the given year.
Recycled uranium contaminates should also be assigned based on Table 3.2 of Battelle-TBD-6000

Job Category	Year	Operation Phase	Inhalation (dpm/d)	Ingestion (dpm/d)	GSD	TBD Reference or Research Justification
Operators	1957-1958	Operations	553	136	5	Based on Metal TBD for Extrusion
Operators	1959-1960	Operations	948	232	5	Based on Metal TBD for Scrap Recovery
Laborers	1957-1958	Operations	87	20	5	Based on Metal TBD for Extrusion
Laborers	1959-1960	Operations	481	116	5	Based on Metal TBD for Scrap Recovery
Supervisors	1957-1958	Operations	46	10	5	Based on Metal TBD for Extrusion
Supervisors	1959-1960	Operations	248	58	5	Based on Metal TBD for Scrap Recovery
Others	1957-1958	Operations	9	1	5	Based on Metal TBD for Extrusion
Others	1959-1960	Operations	38	6	5	Based on Metal TBD for Scrap Recovery

Table C.2 EXTERNAL DOSE PATHWAYS - Uranium

Doses assume full-time employment for the given year.
Geometric Standard Deviation of 5 applies to all doses

Job Category	Year	Operation Phase	Photon (mr/yr)	Skin-Whole Body (mrem/yr)	Skin-Hands and Forarms (mrem/yr)	TBD Reference or Research Justification
Operators	1957-1960	Operations	177	1998	19571	TBD Table 6.4
Laborers	1957-1960	Operations	33	1000	9786	TBD Table 6.4
Supervisors	1957-1960	Operations	16	150	1029	TBD Table 6.4
Others	1957-1960	Operations	2	6	6	TBD Table 6.4

Table C.3 EXTERNAL DOSE PATHWAYS - Thorium

Doses assume full-time employment for the given year.
Values are bounding and used as a constant distribution

Job Category	Year	Operation Phase	Photon (mr/yr)	Skin-Whole Body (mrem/yr)	TBD Reference or Research Justification
Operators	1957-1960	Operations	1095	1095	Bay City film badge data (ln distrib.)
Laborers	1957-1960	Operations	548	548	Bay City film badge data (ln distrib.)
Supervisors	1957-1960	Operations	274	274	Bay City film badge data (ln distrib.)
Others	1957-1960	Operations	59	59	Bay City film badge data (ln distrib.)

Table C.4 INHALATION INTAKES – Uranium

All intakes and doses assume full-time employment for the given year.
Recycled uranium contaminates should also be assigned based on Table 3.2 of Battelle-TBD-6000
Geometric Standard Deviation of 5 applies to all doses

Inhalation (dpm/day)									
Year	**Operators**	**Laborers**	**Supervisor**	**Others**	**Year**	**Operators**	**Laborers**	**Supervisor**	**Others**
1961	16.00	5.92	2.96	0.29	1984	1.65	0.61	0.31	0.03
1962	14.49	5.36	2.68	0.26	1985	1.50	0.55	0.28	0.03
1963	13.13	4.86	2.43	0.24	1986	1.36	0.50	0.25	0.02
1964	11.90	4.40	2.20	0.22	1987	1.23	0.45	0.23	0.02
1965	10.78	3.99	1.99	0.20	1988	1.11	0.41	0.21	0.02
1966	9.77	3.61	1.81	0.18	1989	1.01	0.37	0.19	0.02
1967	8.85	3.27	1.64	0.16	1990	0.91	0.34	0.17	0.02
1968	8.02	2.97	1.48	0.15	1991	0.83	0.31	0.15	0.02
1969	7.26	2.69	1.34	0.13	1992	0.75	0.28	0.14	0.01
1970	6.58	2.43	1.22	0.12	1993	0.68	0.25	0.13	0.01
1971	5.96	2.21	1.10	0.11	1994	0.62	0.23	0.11	0.01
1972	5.40	2.00	1.00	0.10	1995	0.56	0.21	0.10	0.01
1973	4.89	1.81	0.91	0.09	1996	0.51	0.19	0.09	0.01
1974	4.43	1.64	0.82	0.08	1997	0.46	0.17	0.08	0.01
1975	4.02	1.49	0.74	0.07	1998	0.42	0.15	0.08	0.01
1976	3.64	1.35	0.67	0.07	1999	0.38	0.14	0.07	0.01
1977	3.30	1.22	0.61	0.06	2000	0.34	0.13	0.06	0.01
1978	2.99	1.11	0.55	0.05					
1979	2.71	1.00	0.50	0.05					
1980	2.45	0.91	0.45	0.04					
1981	2.22	0.82	0.41	0.04					
1982	2.01	0.74	0.37	0.04					
1983	1.82	0.67	0.34	0.03					

Table C.5 INGESTION INTAKES – Uranium

All intakes and doses assume full-time employment for the given year.
Recycled uranium contaminates should also be assigned based on Table 3.2 of Battelle-TBD-6000
Geometric Standard Deviation of 5 applies to all doses

Inhalation (dpm/day)									
Year	**Operators**	**Laborers**	**Supervisor**	**Others**	**Year**	**Operators**	**Laborers**	**Supervisor**	**Others**
1961	232	116	57.9	5.75	1984	23.9	12.0	5.99	0.59
1962	210	105	52.5	5.21	1985	21.7	10.8	5.42	0.54
1963	190	95.02	47.6	4.72	1986	19.6	9.82	4.91	0.49
1964	172	86.09	43.1	4.28	1987	17.8	8.89	4.45	0.44
1965	156	78.00	39.0	3.88	1988	16.1	8.06	4.03	0.40
1966	141	70.67	35.4	3.51	1989	14.6	7.30	3.65	0.36
1967	128	64.02	32.1	3.18	1990	13.2	6.61	3.31	0.33
1968	116	58.01	29.0	2.88	1991	12.0	5.99	3.00	0.30
1969	105	52.56	26.3	2.61	1992	10.9	5.43	2.72	0.27
1970	95.2	47.6	23.8	2.37	1993	9.84	4.92	2.46	0.24
1971	86.3	43.1	21.6	2.14	1994	8.91	4.46	2.23	0.22
1972	78.2	39.1	19.6	1.94	1995	8.08	4.04	2.02	0.20
1973	70.8	35.4	17.7	1.76	1996	7.32	3.66	1.83	0.18
1974	64.2	32.1	16.1	1.59	1997	6.63	3.31	1.66	0.16
1975	58.1	29.1	14.6	1.44	1998	6.01	3.00	1.50	0.15
1976	52.7	26.3	13.2	1.31	1999	5.44	2.72	1.36	0.14
1977	47.7	23.9	11.9	1.19	2000	4.93	2.46	1.23	0.12
1978	43.2	21.6	10.8	1.07					
1979	39.2	19.6	9.81	0.97					
1980	35.5	17.7	8.88	0.88					
1981	32.2	16.1	8.05	0.80					
1982	29.1	14.6	7.29	0.72					
1983	26.4	13.2	6.61	0.66					

Table C.6 EXTERNAL PHOTON DOSE – Uranium

Doses assume full-time employment for the given year.
Geometric Standard Deviation of 5 applies to all doses

Annual Photon Dose (mr/yr)									
Year	**Operators**	**Laborers**	**Supervisor**	**Others**	**Year**	**Operators**	**Laborers**	**Supervisor**	**Others**
1961	2.59	1.29	0.65	0.06	1984	0.27	0.13	0.07	0.01
1962	2.35	1.17	0.59	0.06	1985	0.24	0.12	0.06	0.01
1963	2.13	1.06	0.53	0.05	1986	0.22	0.11	0.05	0.01
1964	1.93	0.96	0.48	0.05	1987	0.20	0.10	0.05	0.00
1965	1.75	0.87	0.44	0.04	1988	0.18	0.09	0.05	0.00
1966	1.58	0.79	0.39	0.04	1989	0.16	0.08	0.04	0.00
1967	1.43	0.71	0.36	0.04	1990	0.15	0.07	0.04	0.00
1968	1.30	0.65	0.32	0.03	1991	0.13	0.07	0.03	0.00
1969	1.18	0.59	0.29	0.03	1992	0.12	0.06	0.03	0.00
1970	1.07	0.53	0.27	0.03	1993	0.11	0.05	0.03	0.00
1971	0.97	0.48	0.24	0.02	1994	0.10	0.05	0.02	0.00
1972	0.87	0.44	0.22	0.02	1995	0.09	0.04	0.02	0.00
1973	0.79	0.39	0.20	0.02	1996	0.08	0.04	0.02	0.00
1974	0.72	0.36	0.18	0.02	1997	0.07	0.04	0.02	0.00
1975	0.65	0.32	0.16	0.02	1998	0.07	0.03	0.02	0.00
1976	0.59	0.29	0.15	0.01	1999	0.06	0.03	0.02	0.00
1977	0.53	0.27	0.13	0.01	2000	0.06	0.03	0.01	0.00
1978	0.48	0.24	0.12	0.01					
1979	0.44	0.22	0.11	0.01					
1980	0.40	0.20	0.10	0.01					
1981	0.36	0.18	0.09	0.01					
1982	0.33	0.16	0.08	0.01					
1983	0.30	0.15	0.07	0.01					

Table C.7 EXTERNAL BETA DOSE – Uranium

Doses assume full-time employment for the given year.
Geometric Standard Deviation of 5 applies to all doses

Annual Beta Dose (mrad/yr)									
Year	**Operators**	**Laborers**	**Supervisor**	**Others**	**Year**	**Operators**	**Laborers**	**Supervisor**	**Others**
1961	251	126	63	6	1984	26	13	6	1
1962	227	114	57	6	1985	23	12	6	1
1963	206	103	52	5	1986	21	11	5	1
1964	187	94	47	5	1987	19	10	5	0
1965	169	85	42	4	1988	17	9	4	0
1966	153	77	38	4	1989	16	8	4	0
1967	139	70	35	3	1990	14	7	4	0
1968	126	63	31	3	1991	13	7	3	0
1969	114	57	29	3	1992	12	6	3	0
1970	103	52	26	3	1993	11	5	3	0
1971	94	47	23	2	1994	10	5	2	0
1972	85	43	21	2	1995	9	4	2	0
1973	77	39	19	2	1996	8	4	2	0
1974	70	35	17	2	1997	7	4	2	0
1975	63	32	16	2	1998	7	3	2	0
1976	57	29	14	1	1999	6	3	1	0
1977	52	26	13	1	2000	5	3	1	0
1978	47	24	12	1					
1979	42	21	11	1					
1980	38	19	10	1					
1981	35	18	9	1					
1982	32	16	8	1					
1983	29	14	7	1					

Table C.8 INTERNAL DOSE PATHWAYS - Thorium

Thorium intakes should be assigned for Th-232, Th-228, and Ra-228. Two times these values for Th-230.
Values are bounding and used as a constant distribution

Year	Inhalation (dpm/d)	Ingestion (dpm/d)	Thoron (pCi/L)	Thoron (WLM)	Year	Inhalation (dpm/d)	Ingestion (dpm/d)	Thoron (pCi/L)	Thoron (WLM)
1961	123	2.57	0.247	0.391	1984	12.7	0.265	0.026	0.040
1962	112	2.33	0.224	0.354	1985	11.5	0.240	0.023	0.037
1963	101	2.11	0.203	0.321	1986	10.4	0.218	0.021	0.033
1964	91.6	1.91	0.184	0.291	1987	9.47	0.197	0.019	0.030
1965	83.0	1.73	0.166	0.264	1988	8.58	0.179	0.017	0.027
1966	75.2	1.57	0.151	0.239	1989	7.77	0.162	0.016	0.025
1967	68.1	1.42	0.137	0.216	1990	7.04	0.147	0.014	0.022
1968	61.7	1.29	0.124	0.196	1991	6.38	0.133	0.013	0.020
1969	55.9	1.17	0.112	0.178	1992	5.78	0.120	0.012	0.018
1970	50.7	1.06	0.102	0.161	1993	5.24	0.109	0.010	0.017
1971	45.9	0.957	0.092	0.146	1994	4.74	0.099	0.010	0.015
1972	41.6	0.867	0.083	0.132	1995	4.30	0.090	0.009	0.014
1973	37.7	0.785	0.076	0.120	1996	3.89	0.081	0.008	0.012
1974	34.1	0.711	0.068	0.108	1997	3.53	0.073	0.007	0.011
1975	30.9	0.645	0.062	0.098	1998	3.20	0.067	0.006	0.010
1976	28.0	0.584	0.056	0.089	1999	2.90	0.060	0.006	0.009
1977	25.4	0.529	0.051	0.081	2000	2.62	0.055	0.005	0.008
1978	23.0	0.479	0.046	0.073	2001	2.38	0.050	0.005	0.008
1979	20.8	0.434	0.042	0.066	2002	2.15	0.045	0.004	0.007
1980	18.9	0.393	0.038	0.060	2003	1.95	0.041	0.004	0.006
1981	17.1	0.357	0.034	0.054	2004	1.77	0.037	0.004	0.006
1982	15.5	0.323	0.031	0.049	2005	1.60	0.033	0.003	0.005
1983	14.0	0.293	0.028	0.045	2006	1.45	0.030	0.003	0.005

Table C.9 EXTERNAL DOSE PATHWAYS – Thorium – Residual period

Values are bounding and used as a constant distribution

	Photon (mr/yr)					Photon (mr/yr)			
Year	Operators	Laborers	Supervisor	Others	Year	Operators	Laborers	Supervisor	Others
1961	1095	548	274	59	1984	113	57	28	6
1962	992	496	248	54	1985	103	51	26	6
1963	899	450	225	49	1986	93	46	23	5
1964	815	407	204	44	1987	84	42	21	5
1965	738	369	185	40	1988	76	38	19	4
1966	669	334	167	36	1989	69	35	17	4
1967	606	303	151	33	1990	63	31	16	3
1968	549	274	137	30	1991	57	28	14	3
1969	497	249	124	27	1992	51	26	13	3
1970	451	225	113	24	1993	47	23	12	3
1971	408	204	102	22	1994	42	21	11	2
1972	370	185	92	20	1995	38	19	10	2
1973	335	168	84	18	1996	35	17	9	2
1974	304	152	76	16	1997	31	16	8	2
1975	275	138	69	15	1998	28	14	7	2
1976	249	125	62	13	1999	26	13	6	1
1977	226	113	56	12	2000	23	12	6	1
1978	205	102	51	11	2001	21	11	5	1
1979	185	93	46	10	2002	19	10	5	1
1980	168	84	42	9	2003	17	9	4	1
1981	152	76	38	8	2004	16	8	4	1
1982	138	69	34	7	2005	14	7	4	1
1983	125	62	31	7	2006	13	6	3	1