*Draft*

**ADVISORY BOARD ON**
**RADIATION AND WORKER HEALTH**

***National Institute for Occupational Safety and Health***

# FOCUSED REVIEW OF APPENDIX C, REVISION 1 TO TBD-6000, DOW CHEMICAL COMPANY (MADISON SITE)

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*Disclaimer*

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| Advisory Board or ABRWH | Advisory Board on Radiation and Worker Health |
| AEC | Atomic Energy Commission |
| AWE | Atomic Weapons Employer |
| $Bq/m^3$ | becquerel per cubic meter |
| $dpm/m^2$ | disintegration per minute per square meter |
| $dpm/m^3$ | disintegration per minute per cubic meter |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act |
| hr | hour |
| $m^{3/}hr$ | cubic meter per hour |
| m/s | meter per second |
| MAC | maximum allowable concentration |
| Mg-Th | magnesium-thorium |
| mr | milliroentgen |
| mrad | millirad |
| mrem | millirem |
| NIOSH | National Institute for Occupational Safety and Health |
| ORAUT | Oak Ridge Associated Universities Team |
| pCi/L | picocurie per liter |
| $pCi/m^2$ | picocuries per square meter |
| SC&A | S. Cohen and Associates (SC&A, Inc.) |
| SEC | Special Exposure Cohort |
| TBD | technical basis document |
| TIB | technical information bulletin |
| WLM | working level month |

# EXECUTIVE SUMMARY

On November 6, 2014, the Advisory Board on Radiation and Worker Health (Advisory Board) requested that SC&A conduct a focused review of Revision 1 to Appendix C, Dow Chemical Co. (Madison Site) (NIOSH 2014a), a supplement to Battelle-TBD-6000, Revision 1 (NIOSH 2011), hereafter referred to as TBD-6000. Appendix C provides site-specific dose reconstruction guidance to support the generic guidance included in TBD-6000. In its prior reviews as documented in the Special Exposure Cohort (SEC) Petition Evaluation Report for SEC-00079, including Addendums 1 and 2, NIOSH had determined that the operating period for Atomic Weapons Employer (AWE) work at Dow extended from January 1, 1957, through December 31, 1960, and included exposures to both uranium and thorium. NIOSH had also determined that the residual period for uranium extended from January 1, 1961, through July 31, 2000, and through November 30, 2007, for thorium (NIOSH 2007a, 2007b, and 2008a).

SC&A had previously reviewed the site profiles, SEC petitions, and evaluation reports pertaining to what is referred to as the operations period (i.e., 1957 through 1960) and the residual period (post-1960) at the Dow Madison facility (SC&A 2007 and 2008). Subsequent to those SC&A reviews, in September 2008, NIOSH published Revision 0 to Appendix C to TBD-6000 (NIOSH 2008b), which provided updated information and guidance pertaining to the Dow facility. During a conference call with the Advisory Board Work Group on SEC issues held on July 24, 2009, the Work Group requested that SC&A review Revision 0 to Appendix C to determine if there was any new information contained in that report that should be brought to their attention. SC&A issued a draft report in August 2009 that identified five findings (SC&A 2009).

Since then, TBD-6000 was revised in June 2011. Appendix C was revised to incorporate the changes made to TBD-6000 and re-issued in April 2014 (NIOSH 2014b). Revisions to Appendix C included 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. In addition, the residual period uranium inhalation values were increased; ORAUT-OTIB-0070 techniques were used during the residual period, and the basis for residual period ingestion values were changed to use the operational period airborne value and OCAS-TIB-009 (NIOSH 2004) for the first year of the residual period. During a teleconference call of the Advisory Board held on November 6, 2014, the Board requested that SC&A review Revision 1 to Appendix C to determine if there is any new information contained in the report that should be raised to the SEC Work Group and Advisory Board.

Appendix C tabulates and consolidates data and guidance that can be used to calculate internal (inhalation and ingestion) and external doses from uranium exposures during both the operating and residual periods. Appendix C also provides data that can be used to calculate external thorium exposures during the operating period and both external and internal (inhalation, ingestion, and thoron) exposures during the residual period. NIOSH had determined that it was not possible to reconstruct internal thorium doses during the operating period, and NIOSH recommended that SEC status be granted for AWE workers during that period. However, NIOSH concluded that thorium exposures during the residual period could be reconstructed by using the limited data available for the operations and residual period, along with bounding, but plausible, dose reconstruction models.

SC&A's findings from its review of Revision 1 of Appendix C are as follows:

**Finding 1:** The resuspension rate used by NIOSH is reflective of quiescent conditions. According to ORAUT-OTIB-0070, Revision 01 (ORAUT 2012), a resuspension factor of $1\times10^{-5}$ per meter would be reflective of moderate activity, as would be assumed for an operating environment. This greater resuspension factor should be used at least for 1957–1960. This issue was also addressed as a finding in SC&A's review of Appendix C, Revision 0.

**Finding 2:** NIOSH should review the derivation of the resuspended concentration of $1.47 \times 10^8$ dpm/m$^2$ in TBD-6000 to determine if it is correct and update Appendix C, if necessary.

In addition, SC&A identified five observations, as follows:

**Observation 1:** The air sampling data in TBD-6000 are empirical values and can be assumed to account for any resuspended particles. Separate calculations for resuspended particles in the operational period are not necessary.

**Observation 2:** Appendix C should show the specific assumptions made in determining the uranium intake rates for the labor categories and correct the first year of the residual period in Table C.4 if incorrect assumptions were made for the laborer.

**Observation 3**: The header for Table C.5 should be updated to state that the contents of the table are ingestion rates, not inhalation rates.

**Observation 4:** NIOSH needs to clarify how the 1961 thoron air concentration in Table C.8 was reached. Appendix C, Revision 1, currently refers to Addendum 2 to SEC-00079, in which the 95$^{th}$ percentile thoron concentration is documented as 0.182 pCi/L in Section 3.2. This value has been updated as documented in SC&A's review of Addendum 2 to SEC-00079 and subsequent review of Revision 0 to Appendix C (SC&A 2008, 2009); therefore, Appendix C needs to be updated to cite the origin of the thoron air concentration value in Appendix C that is used in Table C.8.

**Observation 5:** Section C.6 needs to be revised to correctly refer to Tables C.7, C.8 and C.9 in the text.

# 1.0 INTRODUCTION

SC&A had previously performed three investigations pertaining to the Dow Madison facility. These include the following:

- *A Focused Review of Operations and Thorium Exposures at the Dow Chemical Company Madison Plant*, August 2007 (SC&A 2007). This report presents SC&A's review of NIOSH's Evaluation Report for SEC-00079 (April 13, 2007), which is concerned with the reconstruction of doses to workers at the Dow Madison facility during the uranium operations performed from 1957 through 1960.
- *A Focused Review of Addendum 2 to the Dow Chemical-Madison Plant SEC Petition Evaluation Report (SEC-00079)*, September 2008 (SC&A 2008). This report presents SC&A's review of NIOSH Addendum 2 to its evaluation report, which deals with the reconstruction of thorium doses during the residual period.
- *Focused Review of Appendix C to TBD-6000, Dow Chemical Company (Madison Site)* - Draft, August 2009 (SC&A 2009). This report describes SC&A's review of Revision 0 of Appendix C, which presents data that can be used to reconstruct internal and external doses during the operational and residual periods.

During the November 6, 2014, teleconference of the Advisory Board, SC&A was requested to conduct a focused review of Revision 1 of Appendix C, Dow Chemical Co. (Madison Site), of TBD-6000 (NIOSH 2011). The primary intent of the review is to determine if Appendix C contains any new material that is relevant to the Work Group's consideration of exposures at Dow. This report is provided in response to that request.

## 1.1 SYNOPSIS OF SITE PROFILE AND SEC ISSUES

During 1957 and 1958, Dow Madison performed uranium extrusion work related to the Atomic Energy Commission (AEC) weapons program under contract from Mallinckrodt Chemical Company. Subsequently, in 1959 and 1960, again under contract to Mallinckrodt, Dow performed uranium rod straightening for the weapons program. These activities established the operating period for uranium dose reconstruction as 1957 through 1960. During this period, the major activity at Dow Madison was the production of magnesium alloys, many of which contained thorium. These alloys were sold commercially for use in applications involving missiles and spacecraft, for example. Workers at Dow were subject to radiation exposures from both thorium and uranium during the operating period and the residual period.

The following was noted by NIOSH in its SEC Petition Evaluation Report, Petition SEC-00079 (NIOSH 2007a):

> *For dose reconstructions under EEOICPA, all sources of radiation exposure must be considered in the assessment of dose received during AWE operational periods. However, exposures due to non-AEC radioactive materials are not included in the assessment of dose received during an AWE residual radiation*

> *period if they can be distinguished from exposures resulting from AEC residual contamination. [See 42 U.S.C. 7384 n (c)(4)(b)].*

Thus, exposures to both thorium and uranium must be considered during the operating period, but thorium exposures can be excluded during the residual period if they can be separated from uranium exposures. With regard to reconstructing doses from thorium exposures during the operating period, NIOSH concluded the following (NIOSH 2007a):

> *NIOSH has documented herein that it cannot complete the dose reconstructions related to this petition where doses resulted from exposure to thorium-containing materials. The basis of this finding is specified in this report, which demonstrates that NIOSH does not have access to sufficient information to estimate with sufficient accuracy either the maximum radiation dose incurred by any member of the class or to estimate such radiation doses more precisely than a maximum dose estimate. Members of this class at the Dow Chemical Company site in Madison, Illinois, may have received unmonitored internal and external radiological exposures from thorium radionuclides at the plant. NIOSH lacks sufficient information, which includes sufficient personnel and workplace monitoring data and radiological source term information, to allow NIOSH to estimate the potential total internal thorium exposures to which the proposed class may have been exposed.*
>
> *With the data currently available to NIOSH, it is feasible to reconstruct with sufficient accuracy the external and internal doses resulting from exposure to uranium metal during the Dow Madison AWE operational period (January 1, 1957 through December 31, 1960), and during the residual radiation period (January 1, 1961 through December 31, 1998). NIOSH also considers the reconstruction of medical dose for Dow Madison workers to be feasible.*

NIOSH determined that workers exposed to thorium during the period January 1, 1957, through December 31, 1960, should be defined as an SEC. Uranium exposures could be estimated using tools, such as the NIOSH guidance document, *Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities*, ORAUT-OTIB-0004 (ORAUT 2006).[1] However, no estimates of uranium exposures were reported by NIOSH until Revision 0 of Appendix C of TBD-6000 was published in September 2008.

At about the time that the initial petition evaluation report was published, NIOSH received 676 pages of additional documentation from Dow. Results of the NIOSH review of this additional material were presented in Addendum 1 to SEC-00079 (NIOSH 2007b). The new material did not alter NIOSH's conclusion about the inability to reconstruct internal thorium doses during the operating period. However, NIOSH did observe that bounding of external thorium doses was possible. The Addendum 1 report states the following (NIOSH 2007b, p. 3):

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[1] It is important to note that this procedure is used as a maximizing efficiency approach only under circumstances where a claim in being denied.

> *NIOSH has reviewed the additional documentation provided by Dow and concluded that the documentation does not provide sufficient additional information regarding potential internal thorium dose to workers at the Madison site during the covered period of the SEC, which would result in a change to the initial conclusion that it is not feasible to reconstruct those doses. The additional documentation does include sufficient information to provide a bounding reconstruction of external dose resulting from thorium.*

It was subsequently learned by NIOSH that some Mg-Th alloys sold to AEC contractors (i.e., Mallinckrodt) by Dow may have been used in nuclear weapons (DOE 2008). This new information means that exposure to thorium must also be considered during the residual period. Prior to the availability of the information in DOE 2008, thorium exposures during the residual period were excluded from consideration. In response to this new requirement, NIOSH prepared Addendum 2 to SEC-00079, in which the feasibility of reconstructing thorium doses during the residual period was presented (NIOSH 2008a). NIOSH concluded that, "…potential radiation doses received from exposure to residual thorium at Dow Madison from January 1, 1961 through October 31, 2006 can be reconstructed with sufficient accuracy."

SC&A's review of Appendix C, Revision 1, is presented in the next section.

# 2.0 REVIEW OF APPENDIX C, REVISION 1 – DOW (MADISON SITE)

In April 2014, NIOSH published Revision 1 of Appendix C to TBD-6000 (NIOSH 2014b). The purpose of Appendix C is to provide site-specific dose reconstruction information to supplement the generic information provided in TBD-6000. Key topics addressed in Appendix C include the following:

- Occupational internal dose from uranium
- Occupational external dose from thorium and uranium
- Dose from residual contamination by thorium and uranium

Since Dow Madison AWE employees who worked with thorium during the occupational period are part of an SEC, no dose reconstruction is required for any of these workers who develop one of the 22 types of cancer specified in Energy Employees Occupational Illness Compensation Program Act (EEOICPA), and who worked for at least 250 days during the period from January 1, 1957, through December 31, 1960. In all probability, workers who handled uranium also handled thorium. Consequently, uranium dose reconstruction during the operational period would not be required, unless one needed to consider probability of causation for a cancer that was not one of the 22 types specified in the EEOICPA. For claimants with non-specified cancers, a partial dose reconstruction would be performed that would include occupational internal and external doses from uranium and medical doses.

Subsequent sections of this review discuss the exposure modeling guidance and related data in Appendix C in greater detail. Note that SC&A reviewed Revision 0 of Appendix C (SC&A 2009) previously. This review of Revision 1 builds on the previous review and only examines new information contained in Revision 1, unless findings from the original review were not addressed.

## 2.1 URANIUM EXPOSURES

### 2.1.1 Internal Uranium Exposures

Table C.1 presents calculation results for determining uranium intakes associated with occupational internal dose. Tables 7.2 (for 1957 and 1958) and 7.7 (for 1959 and 1960) from TBD-6000 (NIOSH 2011) were used to obtain generic air sampling data for determining the intakes.

The calculations are based on the individuals working 168 hours per year[2] on these activities. An example calculation follows for an operator for 1957–1958.

For the years 1957–1958, the air concentration (992 dpm/$m^3$) is taken from Table 7.2 of TBD-6000 because the work performed in this time period is more associated with uranium extrusions. The total intake is a function of the work performed in a given operating year and the dust

[2] SC&A reviewed the assumption of 168 hours per year in its review of Revision 0 of Appendix C and concurred with the approach (SC&A 2009).

resuspended from dust deposited during prior year operations. For current-year operations (i.e., 1957 or 1958), the average daily intake would be:

$$992 \text{ dpm/m}^3 \times 1.2 \text{ m}^3\text{/hr} \times 168 \text{ hr/work-year} \times 1 \text{ work-year/365 calendar-days} = 548 \text{ dpm/calendar-day}$$

Based on Appendix C, Section C.4.1, resuspension of particles from deposition from previous years is taken into account:

> *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.*

The determination of the contamination surface concentration from settlement of dust over the course of the first 2-year period would be:

$$992 \text{ dpm/m}^3 \times 7.5 \times 10^{-4} \text{ meters/second} \times 3{,}600 \text{ seconds/hour} \times 2 \text{ years} \times 168 \text{ hour/year} = 8.99 \times 10^5 \text{ dpm/m}^2$$

The air concentration from resuspension would then be:

$$8.99 \times 10^5 \text{ dpm/m}^2 \times 1 \times 10^{-6}\text{/m} = 0.899 \text{ dpm/m}^3$$

And the inhalation intake would be:

$$0.899 \text{ dpm/m}^3 \times 1.2 \text{ m}^3\text{/hour} \times 8 \text{ hour/work-day} \times 250 \text{ work-days/365 calendar-days} = 6 \text{ dpm/calendar-day}$$

The total intake for the first 2-year period would therefore be:

$$548 \text{ (operations)} + 6 \text{ (resuspension)} = 554 \text{ dpm/m}^3$$

For the second year period of 1959–1960, the above calculations are repeated, substituting 1,690 dpm/m$^3$ from TBD-6000, Table 7.7 for 992 dpm/m$^3$.

$$1{,}690 \text{ dpm/m}^3 \times 1.2 \text{ m}^3\text{/hr} \times 168 \text{ hr/work-year} \times 1 \text{ work-year/365 calendar-days} = 933 \text{ dpm/calendarday}$$

Resuspension is again addressed by NIOSH, but in a different manner. According to Appendix C, Revision 1, Section C.4.1:

> *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.*

SC&A interprets this to mean that for the period 1959–1960, 4 years of deposition with no removal should be assumed (deposition during 1957, 1958, 1959, and 1960) to account for deposition up to the end of the AWE period; therefore, the amount of inhalation due to resuspension from the first 2-year period (6 dpm/calendar-day) should be added to inhalation of resuspended particles from the second 2-year period.

The determination of the contamination surface concentration from settlement of dust over the course of the second 2-year period would be:

$$1{,}690 \text{ dpm/m}^3 \times 7.5 \times 10^{-4} \text{ meters/second} \times 3{,}600 \text{ seconds/hour} \times 2 \text{ years} \times 168 \text{ hour/year} = 1.53 \times 10^6 \text{ dpm/m}^2$$

The air concentration from resuspension would then be:

$$1.53 \times 10^6 \text{ dpm/m}^2 \times 1{\times}10^{-6}\text{/m} = 1.53 \text{ dpm/m}^3$$

And the inhalation intake would be:

$$1.53 \text{ dpm/m}^3 \times 1.2 \text{ m}^3\text{/hour} \times 8 \text{ hour/work-day} \times 250 \text{ work-days/365 calendar-days} = 10 \text{ dpm/calendar-day}$$

The total intake for the second-year period (1959–1960) would therefore be:

$$933 \text{ (operations)} + 6 \text{ (resuspension in 1957–1958)} + 10 \text{ (resuspension in 1959–1960)} = 949 \text{ dpm/m}^3$$

Table 1 shows the results of using this approach when determining how Table C.1 values were obtained. SC&A would like to note that the air sampling data in TBD-6000 was determined assuming no ventilation and little dust mitigation. The values in TBD-6000 are empirical values that should include any resuspended particles; therefore, it was not necessary for NIOSH to account for resuspended particles as a separate inhalation calculation as shown above. However, inhalation of resuspended particles is a small contributor to the total inhalation, and SC&A therefore agrees with the values in Table C.1.

**Table 1. Comparison of Appendix C, Revision 1, Table C.1 Values with SC&A-Calculated Values[a]**

| Job Category | Year | App C, Table C.1 Inhalation (dpm/day) | Check Inhalation (dpm/day) | App C, Table C.1 Ingestion (dpm/day) | Check Ingestion (dpm/day) |
|---|---|---|---|---|---|
| Operators | 1957–1958 | 553 | 554 | 136 | 136 |
| Operators | 1959–1960 | 948 | 949 | 232 | 232 |
| Laborers | 1957–1958 | 87 | 87 | 20 | 20 |
| Laborers | 1959–1960 | 481 | 483 | 116 | 116 |
| Supervisors | 1957–1958 | 46 | 46 | 10 | 10 |
| Supervisors | 1959–1960 | 248 | 250 | 58 | 58 |
| Others | 1957–1958 | 9 | 10 | 1 | 1 |
| Others | 1959–1960 | 38 | 39 | 6 | 6 |

[a] When determining inhalation and ingestion values due to deposition and resuspension, 3 years of deposition was assumed for 1959–1960.

**Finding 1:** The resuspension rate used by NIOSH is reflective of quiescent conditions. According to ORAUT-OTIB-0070, Revision 01 (ORAUT 2012), a resuspension factor of $1\times10^{-5}$ per meter would be reflective of moderate activity, as would be assumed for an operating environment. This greater resuspension factor should be used at least for 1957–1960. This issue was also addressed as a finding in SC&A's review of Appendix C, Revision 0.

**Observation 1:** The air sampling data in TBD-6000 are empirical values and can be assumed to account for any resuspended particles. Separate calculations for resuspended particles in the operational period are not necessary.

For ingestion, Appendix C refers to OCAS-TIB-009 (NIOSH 2004) for the methodology. In the conclusions for OCAS-TIB-009, the following is stated:

> *The amount of activity ingested on a daily basis can be approximated by assuming it to be 0.2 times the activity per cubic meter of air. The fl value for the ingestion should be the same as that used for inhalation.*

Therefore, to calculate the ingestion rate, the air concentration (which would include resuspended particles) is multiplied by 0.2, as follows (using the example above):

$$1{,}690 \text{ dpm/m}^3 \times 0.2 \times 250 \text{ work-days}/365 \text{ calendar-days} = 232 \text{ dpm/calendar-day}$$

SC&A would like to note that, while researching the assumptions in TBD-6000 that led to the values in Table C.1, the calculation of surface concentrations in TBD-6000 Section 7.1.5 appears to be incorrect. According to Section 7.1.5, surface contamination is based on an air concentration of 7,000 dpm/m$^3$ (100 MAC). Using NIOSH's assumptions, SC&A calculates the surface concentration as being:

$$7{,}000 \text{ dpm/m}^3 \times 7.5 \times 10^{-4} \text{ m/s} \times 30 \text{ days} \times 24 \text{ hours/day} \times 3{,}600 \text{ seconds/hour} \times 1 \text{ pCi}/2.22 \text{ dpm} = 6.1\times10^6 \text{ dpm/m}^2$$

This value would need to be multiplied by 24 to obtain the $1.47 \times 10^8$ pCi/m$^2$ that was derived in TBD-6000.

**Finding 2:** NIOSH should review the derivation of the resuspended concentration of $1.47 \times 10^8$ dpm/m$^2$ in TBD-6000 to determine if it is correct and update Appendix C, if necessary.

### 2.1.2 External Uranium Exposures

Table C.2 presents the external uranium dose associated with full-time employment for a given year for operators, laborers, supervisors, and others. Appendix C states the following as to how Table C.2 was developed:

> *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.*

According to Table 6.1 of TBD-6000, the modeled photon dose rate at 1 foot for handling a rectangular ingot is 2.08 mrem/hr. An operator is assumed to spend 50% of his time near the ingot, so his dose rate is 1.04 mrem/hr. Per Table 6.2 of TBD-6000, the annual operator dose is 2,080 mrem (1.04 mrem/hour × 2,000 hour/year). This same value can be found for the extrusion operator in Table 6.4, except that units are cited in mrad that are assumed to be equal to mrem. According to Table C.2 in Appendix C, the operator photon exposure for 168 hours is 176 mrem (168 × 1.04 = 174.7). According to Table 6.4, the photon exposure from contaminated floors was assumed for the full year to be 1.52 mrem. If this value is added to the operator photon exposure of 174.7 mrem, then this rounds to 177 mrem, which is essentially equivalent to the Table C.2 value of 176 mr. The external dose from submersion in a dust cloud was negligible.

For the skin whole-body dose, the scrap recovery operator dose in Table 6.4 is 20,800 mrad/year (other skin non-penetrating dose in Table 6.4). For a work-year of 2,000 hours, this equates to 10.4 mrad/hour. Multiplying this dose rate by 168 hours gives 1,747 mrem. Adding the beta dose from the contaminated floor from Table 6.4 (251 mrad/year), the total dose rate for the skin whole-body dose is 1,747 + 251 = 1,998 mrem. This is identical to the value of 1,998 mrem/year in Table C.2.

For the hands/forearm, Table C.2 shows 19,571 mrem/year. Table 6.4 shows the annual dose to the skin/forearm to an operator as 230,000 mrad/year. For 2,000 hours, this equates to a dose rate of 115 mrad/hr. For a work-year of 168 hours, the dose to the hands and forearms is 19,320 mrem/year, to which must be added 251 mrad/yr from the contaminated floor to account for all of the beta dose.

The results calculated for the operator shown in Table C.2 can be prorated to obtain the exposure rates to the other labor categories. Unlike the operator (who stands 1 foot from the source), the laborer is assumed to spend 50% of his time at a distance of 1 meter from the source so his annual dose would be 373 mr for a 2,000 hour work year (TBD-6000, Table 6.2). For example, for calculating the photon dose rate for a laborer, the photon dose rate would be 176(373/2,080) = 31.6 mrem/year. When added to the floor photon dose (0.224 mrem/year), the total photon dose would be 31.8 mrem/year. Table 2 shows SC&A's calculated results versus the Table C.2 values. The values compare well.

**Table 2. Comparison of Appendix C, Table C.2 Values with SC&A-Calculated Values**

| | App C, Table C.2[a] | Check | App C, Table C.2[b] | Check | App C, Table C.2[b] | Check |
|---|---|---|---|---|---|---|
| **Job Category** | **Photon (mrem/year)** | **Photon (mrem/year)** | **Skin – Whole body (mrem/year)** | **Skin – Whole body (mrem/year)** | **Skin – Hands and Forearms (mrem/year)** | **Skin – Hands and Forearms (mrem/year)** |
| Operators | 177 | 176 | 1,998 | 1,998 | 19,571 | 19,571 |
| Laborers | 33 | 32 | 1,000 | 1,000 | 9,786 | 9,786 |
| Supervisors | 16 | 16 | 150 | 150 | 1,029 | 1,029 |
| Others | 2 | 2 | 6 | 6 | 6 | 6 |

[a] Includes photon dose from contaminated floor.
[b] Includes beta dose from contaminated floor.

### 2.1.3 Inhalation of Uranium during the Residual Period

Table C.4 provides the estimated inhalation rates for the residual period of 1961 to 2000. Appendix C states, "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." Because the first year of 1961 begins the residual period, it is assumed that the intakes do not include any airborne concentrations related to operations, and that intakes are strictly limited to resuspended particles. In the discussion above for Table C.1, SC&A calculated the intake for an operator to be about 5 dpm/day based on 1 year's worth of particle settlement and resuspension. If NIOSH assumed that 3 years' worth of buildup of contamination and ultimate resuspension occurred (SC&A believes this should be 4 years, assuming work occurred from 1957 through 1960, but the difference is small and NIOSH's calculations are sufficient), then about 15 dpm/day of intake would occur in the first year of the residual period, which is very close to NIOSH's estimate of 16 dpm/day for an operator in Table C.4.

TBD-6000, Table 7.7, shows that the air sampling data for scrap recovery for a laborer are 50% of that for the operator. The geometric mean air concentration for the supervisor is 50% of the laborer, and clerical is 10% of the supervisor. The intake would be proportional to the air concentration, so the laborer's intake should be 8 dpm/day, the supervisor's intake should be 4 dpm/day, and the "others" labor category would be 0.4 dpm/day. Table C.4 follows this pattern of assumptions for the first year of the residual period, except for the laborer. The laborer's uranium intake in Table C.4 is 37% of the operator's intake (5.92/16 = 0.37). If NIOSH meant to assume the air concentrations associated with the extrusion process, then according to Table 7.2 in TBD-6000, the air concentration associated with the laborer would be about 15% of the air concentration associated with the operator (from Table 7.2 in TBD-6000, the geometric mean in dpm/m$^3$ of a laborer versus an operator would be 147/992 = 0.15).

**Observation 2:** Appendix C should show the specific assumptions made in determining the uranium intake rates for the labor categories and correct the first year of the residual period in Table C.4 if incorrect assumptions were made for the laborer. It would appear that the laborer's intake rate would be 50% of the operator's intake rate.

NIOSH reduces the intake by 9.87% per year. In ORAUT-OTIB-0070 (ORAUT 2012), Table 4-1 shows a source term depletion rate specific to Dow Madison of 0.00027/day, which is equivalent to 0.0986/year, or 9.86% per year. This rate does not appear to be specific to a particular radionuclide. In Addendum 2 to SEC-00079, a decay constant is derived for thorium for the residual period at Dow Madison. In Section 3 of Addendum 2, a decay constant of 9.87% per year is determined using air concentrations from 1961 and air sampling data obtained in 2006. This is essentially the same as the decay constant determined in Addendum 2 to SEC-00079. SC&A concurs with this approach. The year-to-year decreases in Table C.4 for all labor categories range from 9% to 10% per year, which is close to 9.87%; therefore, SC&A concurs with this approach.

### 2.1.4 Ingestion of Uranium during the Residual Period

Table C.5 provides the estimated uranium ingestion rates for the residual period of 1961 to 2000. The same approach and assumptions used for Table C.4, which does not appear to include air contamination associated with operations since this is the first year of the residual period, should have also been applied to determine the ingestion rates in Table C.5 by NIOSH. For the 1961 ingestion rate for an operator, the total of 232 dpm/day ingested matches the calculated ingestion rate in Table C.1, which includes air contamination associated with operations. This estimate for the first year of the residual period is conservative and would otherwise be negligible if only resuspended particles are considered. SC&A therefore concurs with the approach to assume 232 dpm/day for the first year for an operator.

The determination of the ingestion rates for the labor categories of laborers, supervisors, and others follows the assumptions that the ingestion rate for a laborer is 50% of an operator, the supervisor's ingestion rate is 50% of the laborer, and "others" is 10% of the supervisor.

In regards to the year-to-year decrease in ingestion rate, the same assumptions apply to ingestion as to inhalation (Table C.4). SC&A notes that, similar to Table C.4, the year-to-year decrease in ingestion rate ranges from 9% to 10% per year; therefore, SC&A concurs with this approach.

One minor comment is that the title of Table C.5 should be corrected to state that the table shows ingestion rates, not inhalation rates.

**Observation 3**: The header for Table C.5 should be updated to state that the contents of the table are ingestion rates, not inhalation rates.

### 2.1.5 External Photon Exposure due to Uranium in the Residual Period

Table C.6 provides the estimated annual external photon dose for the residual period. The 1961 photon dose to the operator (2.59 mr/year) is the basis for establishing the first-year photon dose to the laborer, supervisor, and other workers. This photon dose is taken from TBD-6000, Table 6.4, for uranium scrap recovery, and is the estimated photon dose from the contaminated floor for 1956 to 2000.

The determination of the external photon dose rate for the labor categories of laborers, supervisors, and others follows the assumptions that the photon dose for a laborer is 50% of an operator, the supervisor's ingestion rate is 50% of the laborer, and "others" is 10% of the supervisor.

In regards to the year-to-year decrease in the photon dose rate, the decrease should be 9.87%, as established in Appendix C for Table C.4. SC&A notes that, similar to Table C.4, the year-to-year decrease in the photon dose rate is not exactly 9.87% per year, but varies between 9% to 10%. Hence, we concur with NIOSH's estimate.

### 2.1.6 External Beta Exposure due to Uranium in the Residual Period

Table C.7 provides the estimated annual external beta dose for the residual period. The 1961 beta dose to the operator (251 mrad/year) is the basis for establishing the first-year beta photon dose to the laborer, supervisor, and other workers. This beta dose is taken from TBD-6000, Table 6.4, for uranium scrap recovery, and is the estimated beta dose from the contaminated floor for 1956 to 2000.

The determination of the external beta dose rate for the labor categories of laborers, supervisors, and others follows the assumptions that the beta dose for a laborer is 50% of an operator, the supervisor's ingestion rate is 50% of the laborer, and "others" is 10% of the supervisor.

In regards to the year-to-year decrease in the beta dose rate, the decrease should be 9.87%, as established in Appendix C for Table C.4. SC&A notes that the year-to-year decrease in beta dose rate varies between 9% and 10%. Hence, SC&A agrees with NIOSH's estimate.

## 2.2 THORIUM EXPOSURES

### 2.2.1 External Exposure to Thorium

Table C.3 shows the photon and whole-body external annual dose estimated for operators, laborers, supervisors, and others due to exposure to thorium. NIOSH examined three different sets of data and used the data that provided the most claimant-favorable dose. The first set of data used was developed by Dow Chemical Company and is representative of radiation exposures in the pot room. The referenced document (Levy 1957) shows an annualized exposure of 250 to 380 mr/year when working with 26% thorium hardener, and 100 to 160 mr/year when working with thorium pellets.

The second set of data is taken from Addendum 2 of the Petition Evaluation Report (NIOSH 2008a). In Section 3.4 of Addendum 2, Attachment 2, a worker's external exposure to thorium is stated as being bounded at 1.4 rem/year (1,400 mrem/year). This bounding exposure is based on all workers being continuously exposed to the maximum recorded exposure rate (0.7 mr/hour at 1 foot) during a 40-hour work week. Dose rate measurements are from 1982, with 0.7 mr/hour being the maximum rate measured. TBD-6000 assumes an operator is 1 foot from the material 50% of the time. This measurement was taken near the thorium storage area and scrap bins. All other areas ranged from 0.01 to 0.05 mr/hour between 1 and 10 feet. When taking into consideration ingrowth of daughters, the photon and electron dose rates were estimated to be in an approximately 1:1 ratio. SC&A believes 1,400 mrem/year is extremely claimant favorable because it is unlikely that an operator would be present 1 foot from material containing thorium in the thorium storage area and scrap bins for 1,000 hours per year. A more realistic estimate would be someone in the general area within the facility exposed to 0.05 mr/hour 100% of the time (2,000 hours per year), for an annual dose of 100 mr/year. In any event, NIOSH did not use this second set of data for its estimate.

The third set of data was obtained from Dow Chemical Company's Bay City Plant. Similar operations and materials to the Dow Madison Plant were used at the Bay City Plant. Data consisting of film badge readings related to casting operations were taken over a 13 working-day period in 1957. The data that were obtained are shown in Table 3.

**Table 3. Film Badge Readings from Casting Operations at the Bay City Plant**

| Job | Exposure Over 13 Days (mr) | Exposure (mr/year) |
|---|---:|---:|
| Pour Off #1 | 10 | 192 |
| Pour Off #2 | 75 | 1442 |
| Pour Off #3 | 10 | 192 |
| Knockout #1 | 10 | 192 |
| Knockout #2 | <10 | <192.31 |
| Sandblast #1 | 10 | 192 |
| Sandblast #2 | <10 | <192.31 |
| Bandsaw #1 | 10 | 192 |
| Bandsaw #2 | 50 | 962 |
| Chipper #1 | <10 | <192.31 |
| Chipper #2 | 10 | 192 |
| Machine trim | 10 | 192 |
| Inspection | 10 | 192 |
| Pickler | <10 | <192.31 |
| Rotary file #1 | 50 | 962 |
| Rotary file #2 | 10 | 192 |
| Buffer | 10 | 192 |
| Heat treat | 10 | 192 |
| Wheelabrator | <10 | <192.31 |
| Pickler | <10 | <192.31 |
| Inspection | 10 | 192 |
| Touchup | <10 | <192.31 |
| X--ray | <10 | <192.31 |
| Fixture | <10 | <192.31 |

**Table 3. Film Badge Readings from Casting Operations at the Bay City Plant**

| Job | Exposure Over 13 Days (mr) | Exposure (mr/year) |
|---|---|---|
| Shipping | 50 | 962 |
| Metal reclamation | 10 | 192 |
| Control Badge | 10 | 192 |

Source: SC&A 2007, Appendix F, Table F-5

NIOSH took a lognormal distribution of the data in Table 3 and found the 95th percentile result, which was 1,095 mr/year. NIOSH considered this result a bounding dose for an operator. To check this value, SC&A used the PERCENTILE.INC function in MS Excel for the array of annualized doses. This resulted in a 95th percentile value of 1,058 mr/year.

SC&A then performed a more detailed calculation using the methodology described in Battelle-TIB-5000 (Battelle 2007), *Default Assumptions and Methods for Atomic Weapons Employer Dose Reconstructions*, for left-censored data (Section 2.1.3.1 of Battelle-TIB-5000). The dataset shown in Table 3 above can be described as being left-censored in that there are a number of data described as "less than" a number (9 of 27 values, or 33%). In evaluating a dataset considered left-censored, Battelle-TIB-5000 provides a graphical approach that uses a linear regression of the logarithmic non-zero values to determine the slope-intercept. SC&A used this approach to obtain the following equation:

$$y = 0.8577x + 5.2782$$

The slope-intercept can then be used to calculate the 95th percentile (and 5th percentile). Using this methodology, SC&A obtained a 95th percentile value of 804 mr/year for operators. This approach is likely more realistic than the bounding approach that results in 1,095 mr/year. However, SC&A accepts NIOSH's use of the bounding approach.

### 2.2.2 Internal Exposures to Thorium and Thoron during the Residual Period

Table C.8 provides calculated inhalation and ingestion rates related to residual thorium contamination. The table also provides estimated exposures to thoron.

The 1961 inhalation rate for thorium (123 dpm/day) was determined from information in Addendum 2 to SEC-00079, Section 2.0. In Table 2-1 of Addendum 2 to SEC-00079, Attachment 2, reported and calculated thorium concentrations are provided for different tasks/areas/processes in 1957–1960 time period. The maximum thorium air concentration was determined to be 8.44 pCi/m$^3$. To convert to dpm/day, the following calculation is performed:

$$8.44 \text{ pCi/m}^3 \times 2.22 \text{ dpm/pCi} \times 1.2 \text{ m}^3\text{/hr} \times 2{,}000 \text{ hr/year} / 365 \text{ calendar-days/year} = 123 \text{ dpm/calendar-days}$$

This value matches the 1961 inhalation value in Table C.8. To determine the 1961 ingestion value, the ingestion rate shown in Table 3-3 of Addendum 2 to SEC-00079 is converted to a calendar-day basis as follows:

$$422 \text{ pCi/year} \times 2.22 \text{ dpm/pCi} / 365 \text{ calendar-days} = 2.57 \text{ dpm/calendar-day}$$

This ingestion value matches the 1961 ingestion rate in Table C.8.

Table C.8 shows an air concentration of 0.247 pCi/L of thoron for 1961. This value is a corrected value determined by SC&A in its review of Addendum 2 to SEC-00079 (SC&A 2008), as documented in our review of Revision 0 to Appendix C (SC&A 2009).

SC&A concurs with the calculation of WLM. Finally, references to Table C.7 in Appendix C, Section C.6, should be changed to Table C.8.

**Observation 4:** NIOSH needs to clarify how the 1961 thoron air concentration in Table C.8 was reached. Appendix C, Revision 1, currently refers to Addendum 2 to SEC-00079, in which the 95$^{th}$ percentile thoron concentration is documented as 0.182 pCi/L in Section 3.2. This value has been updated as documented in SC&A's review of Addendum 2 to SEC-00079 and subsequent review of Revision 0 to Appendix C (SC&A 2008, 2009); therefore, Appendix C needs to be updated to cite the origin of the thoron air concentration value in Appendix C that is used in Table C.8.

**Observation 5:** Section C.6 needs to be revised to correctly refer to Tables C.7, C.8 and C.9 in the text.

### 2.2.3 External Thorium Exposure due to Thoron during the Residual Period

Table C.9 provides external photon dose associated with thorium exposure during the residual period. The table is based on the values in Table C.3 for the first year (1961) of the residual period. SC&A concurs with the values in Table C.9.

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