

September 3, 2008

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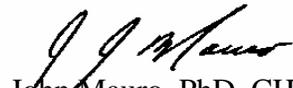
Re: Contract No. 200-2004-03805, Task Order 5: Transmittal of the Draft Report  
SCA-SEC-TASK5-0057-Addendum 2, *A Focused Review of Addendum 2 to the Dow  
Chemical – Madison Plant SEC Petition Evaluation Report (SEC-00079)*

Dear Mr. Staudt:

SC&A is pleased to submit to NIOSH and the Advisory Board its draft report entitled *A Focused Review of Addendum 2 to the Dow Chemical – Madison Plant SEC Petition Evaluation Report (SEC-00079)*.

This report has been reviewed for Privacy Act information and has been cleared for distribution. However, this report is pre-decisional and has not been reviewed by the Advisory Board for factual accuracy or applicability within the requirements of 42 CFR 82. Should you have any questions, please contact me at 732-530-0104.

Sincerely,



John Mauro, PhD, CHP  
Project Manager

cc: P. Ziemer, Board Chairperson  
Advisory Board Members  
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Project File (ANIOS/005/57)

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**DRAFT**

**ADVISORY BOARD ON  
RADIATION AND WORKER HEALTH**

*National Institute for Occupational Safety and Health*

**A FOCUSED REVIEW OF ADDENDUM 2 TO THE  
DOW CHEMICAL – MADISON PLANT  
SEC PETITION EVALUATION REPORT (SEC-00079)**

**Contract No. 200-2004-03805  
Task Order No. 5  
SCA-SEC-TASK5-0057-Addendum 2**

Prepared by

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September 2008

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*Disclaimer*

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| <p>S. COHEN &amp; ASSOCIATES:</p> <p><i>Technical Support for the Advisory Board on Radiation &amp; Worker Health Review of NIOSH Dose Reconstruction Program</i></p> | Document No.<br>SCA-SEC-TASK5-0057-Addendum 2 |
|   | Effective Date:<br>Draft — September 3, 2008  |
|   | Revision No.<br>0 – Draft                     |
| <i>A Focused Review of Addendum 2 to the Dow Chemical – Madison Plant SEC Petition Evaluation Report (SEC-00079)</i>  | Page 2 of 21                                  |
| <p>Task Manager:</p> <p>_____ Date: _____</p> <p>William C. Thurber</p>   | Supersedes:<br><br>N/A                        |
| <p>Project Manager:</p> <p>_____ Date: _____</p> <p>John Mauro, PhD, CHP</p>  |   |

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## EXECUTIVE SUMMARY

This report presents SC&A's review of Addendum 2 to SEC-00079, the Dow Chemical Company SEC Petition Evaluation Report. Addendum 2 extends the period of residual radioactivity to October 2006, and provides the National Institute for Occupational Safety and Health's (NIOSH's) basis for determining that exposures to residual radioactivity from thorium operations during 1957 and 1958 could be reconstructed using bounding calculations for the period January 1, 1961, through October 31, 2006.

While we believe that NIOSH has developed claimant-favorable bounding calculations for thorium exposures during the period of residual radioactivity, we have several findings, including whether the assumptions describe plausible circumstances and whether some of the selected assumptions are scientifically sound.

Specific findings are listed below:

***Finding 1:*** *NIOSH needs to document that its bounding calculations are representative of plausible circumstances, as required under 42 CFR 83.13(c)(1).*

***Finding 2:*** *NIOSH did not consider the fact that Mg-Th alloy production for atomic weapons is a small fraction of total Mg-Th alloy production. This approach is bounding and claimant favorable. However, neglecting this fact can result in overstating exposure to residual radioactivity over the time period under consideration by more than an order of magnitude. NIOSH needs to justify that neglecting the small fractional contribution of materials for weapons production is scientifically sound.*

***Finding 3:*** *While the approach taken by NIOSH clearly bounds the initial inhalation exposure to residual radioactivity, NIOSH needs to explain considerations applied to data selection. NIOSH also needs to justify that use of 2006 air sampling data is relevant for bounding exposures in that year.*

***Finding 4:*** *The NIOSH approach used to quantify the residual radioactivity associated with exposure to Th-containing slag from 1957 and 1958 appears to be unrealistically conservative and may not meet the Part 83 requirement for the exposure scenarios and assumptions to be plausible. Such an approach may be appropriate as an efficiency approach for denial, but not for granting a claim.*

***Finding 5:*** *NIOSH needs to explain why all available general area thoron measurements were not used in calculating thoron exposures. Because not all of the data were used, the potential maximum thoron exposures may have been underestimated.*

***Finding 6:*** *NIOSH needs to provide convincing arguments that an external exposure of 0.7 mr/hr during the period of residual radioactivity is a reasonable estimate of the bounding exposures under plausible circumstances from Mg-Th alloys produced in 1957 and 1958.*

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***Finding 7:*** *On the basis of past reviews of several NIOSH documents, SC&A has questioned the approach to ingestion exposures developed in OCAS-TIB-009. NIOSH is presumably developing a new approach, but the existing model is still used in Addendum 2 to SEC-00079.*

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## 1.0 BACKGROUND

On November 27, 2006, the law firm of Simmons-Cooper, LLC, filed a Special Exposure Cohort (SEC) Petition with the National Institute for Occupational Safety and Health (NIOSH), Office of Compensation and Support, on behalf of workers at the Dow Chemical Company plant in Madison, Illinois. On December 14, 2006, the Department of Health and Human Services published a notice in the Federal Register (71 FR 75258) indicating that the federal government had made a decision to evaluate the Dow employees petition to determine if the group should be included in the SEC. The period of employment for the proposed cohort was defined as January 1, 1957, through December 31, 1960. The period was chosen because during that timeframe, Dow did some uranium fabrication work related to Atomic Energy Commission (AEC) programs.<sup>1</sup> For the defined period, it is possible that some Dow workers received exposure to uranium (and daughter products) from the AEC uranium fabrication work, and to thorium from activities originally presumed to be related to the routine commercial melting, casting, and fabrication of Mg-Th alloys. As will be discussed in this report, the latter premise requires re-examination.

As required by both the Energy Employee Occupational Illness Compensation Program Act of 2000 (EEOICPA) and Title 42, Part 83 of the *Code of Federal Regulations* (CFR), NIOSH issued “SEC Petition Evaluation Report for SEC-00079” (NIOSH 2007a) on April 13, 2007. In its evaluation, NIOSH decided that both uranium and thorium doses need to be considered during the time period of January 1, 1957, through December 31, 1960. The evaluation concluded the following:

*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*

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<sup>1</sup> On March 15, 1957, Subcontract No. 25034 was implemented between the Uranium Division of Mallinckrodt Chemical Works and the Madison Division of Dow Chemical Company to do research and development work on gamma phase extrusion of uranium metal. No contractual evidence of prior work has been developed. However, a Record of Contact prepared by Spectrulite Consortium, Inc., quotes a former Dow employee as stating, “The work was done in the plant extrusion department beginning in 1955 for a period of about two years—may have been longer” (Young 1988).

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*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.*

As part of its continuing support to the Advisory Board on Radiation and Worker Health (Advisory Board), SC&A was tasked to review the SEC petition and the NIOSH evaluation of the petition. Subsequently, at the Advisory Board meeting in Denver, Colorado, on May 2, 2007, SC&A was asked to evaluate thorium exposures from 1961 forward at the Dow (Madison) plant, and to review newly available material on the Madison site. This material consisted of approximately 700 pages of information obtained by NIOSH from Dow Chemical Company and made available on the “O” drive on May 1, 2007. SC&A provided its focused review to the Advisory Board on August 24, 2007 (SC&A 2007a).

At about the same time, NIOSH provided to the Advisory Board Addendum 1 to the SEC Petition Evaluation Report. Addendum 1 contains NIOSH’s review of the nearly 700 pages of new material from DOW (NIOSH 2007b). Based on its review, NIOSH concluded that the additional information did not provide sufficient data to change its original conclusion regarding the infeasibility of reconstructing internal Th doses during the operating period. NIOSH further concluded that sufficient information was available to conduct a bounding estimate of external doses from thorium exposure during the operating period.

Based on information available prior to January 2008, a basic assumption in establishing the SEC was that Dow’s Mg-Th alloys were not used in atomic weapons. However, in January 2008, the U.S. Department of Energy (DOE) provided information to the Department of Labor (DOL) that some Mg-Th alloys had been purchased by Mallinckrodt for weapons applications (DOE 2008). Prior to this, it was assumed that exposures to thorium only need be considered during the operational period, since Mg-Th alloys were presumed to be produced for strictly commercial purposes during the operational period when some special uranium fabrication had been done by Dow to support the weapons program (January 1, 1957, through December 31, 1960). Only uranium exposures were considered during the residual radiation period (January 1, 1961, through December 31, 1998).

NIOSH prepared Addendum 2 to the Dow Madison SEC Petition Evaluation Report to address the new DOE information that Mg-Th alloys had been used in weapons (NIOSH 2008a). One consequence of the new DOE information was that thorium exposures from weapons material production would need to be evaluated during the residual radioactivity period. NIOSH updated the end date for the residual radioactivity period to October 31, 2006, and concluded that thorium doses during the residual radioactivity period could be reconstructed with sufficient accuracy. Consequently, NIOSH recommended that no changes be made to the SEC class definition.

During the Advisory Board meeting held in St. Louis, Missouri, on June 24–26, 2008, SC&A was requested by the Board to review the amended SEC Petition Evaluation Report for DOW Madison. This report presents SC&A’s review of Addendum 2 of the SEC Petition Evaluation Report, SEC-00079 (NIOSH 2008a).

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## 2.0 GENERAL COMMENTS

SC&A believes that NIOSH has conducted a claimant-favorable bounding analysis for thorium exposures during the residual radioactivity period from January 1, 1961, through October 31, 2006. However, we have some concerns that, in bounding residual exposures, NIOSH has adequately considered whether the chosen approaches estimate the maximum radiation dose incurred in **plausible circumstances** as required under 42 CFR 83.13(c)(1). In many cases, NIOSH has selected a maximum measure of exposure without fully documenting why they believe that the measure is plausible for the residual radioactivity period.

***Finding 1:*** *NIOSH needs to document that its bounding calculations are representative of plausible circumstances as required under 42 CFR 83.13(c)(1).*

The motivation for preparing Addendum 2 to SEC-00079 was evidence provided to DOE that Dow had supplied Mg-Th alloys to the AEC, and that these alloys were used in atomic weapons production (DOE 2008). DOE stated that such materials were supplied to AEC during 1957 and 1958. Consequently, exposures during the residual radioactivity period should be based on residual contamination from Mg-Th alloy production for atomic weapons use during 1957 and 1958. The period for exposure to residual radioactivity from Mg-Th alloy production does not begin until January 1, 1960, because Mg-Th operational exposures contemporaneous with uranium processing are covered in 1959 and 1960. The evaluation report would benefit from a more thorough description and discussion of these matters, especially the fact that the amount of thorium processed at Dow Madison in 1957 and 1958 in support of the weapons program was a very small fraction of the total amount of thorium processed at the facility over the years in which Mg-Th alloys were produced at Dow Madison..

DOE specifically noted that Mg-Th alloy sheet and plate were shipped to Mallinckrodt Chemical Works in 1957 and 1958. Subsequent to the preparation of the SEC Petition Evaluation Report SEC-00079 (NIOSH 2007a), NIOSH received about 700 pages of additional documentation from Dow. This documentation was reviewed by NIOSH in Addendum 1 to SEC-00079 (NIOSH 2007b) and by SC&A (SC&A 2007a). Included in the documentation were a large number of purchase orders from Mallinckrodt Chemical Works covering the period November 11, 1957, through December 27, 1965. Examination of these purchase orders indicated that the quantities of Mg-Th alloy mill products summarized in Table 2-1 were shipped to Mallinckrodt.

It can be seen from Table 2-1 that 1,847 lb of Mg-Th alloy containing 28 to 46 lb of Th was purchased by Mallinckrodt in 1957 and 1958. Although the total annual production of Mg-Th alloys over that period is not known, an AEC Compliance Report stated that 160,000 lb of Th had been used through July 1960 (AEC 1960). Assuming that this usage was over a 5 ½-year period beginning in 1955, annual usage would have been about 29,000 lb. Thus, an estimate of the fraction of residual activity beginning in 1961 from Mg-Th alloy shipments to Mallinckrodt in 1957 and 1958 would be about 0.07% ( $46/58,000 \times 100$ ).

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**Table 2-1. Mg-Th Mill Products Shipped By Dow to Mallinckrodt from 11/11/57 through 2/27/65**

| Purchase Order | Date    | Quantity (lb) | Alloy <sup>(a)</sup> | Form        |
|----------------|---------|---------------|----------------------|-------------|
| U-51362-L      | 1/23/58 | 55            | HM21XA-T8            | sheet       |
|                |         | 27            | HM21XA               | tubing      |
| U-52990-A      | 3/18/58 | 37            | HM-21XA-T8           | plate       |
|                |         | 10            | HM31A                | welding rod |
| U-3067-L       | 12/5/57 | 471           | HM21XA-T8            | sheet       |
|                |         | 75            | HM21XA-T8            | sheet       |
|                |         | 1028          | HM21XA-T8            | sheet       |
|                |         | 144           | HM21XA-T8            | sheet       |

(a) The alloy designations on the scanned purchase orders were difficult to read, but it is not significant for purposes of this report whether the alloy was HM21A, HM31A, or HK31A. Alloy HM21 contains 1.5 to 2.5% Th.

It is stated on page 6 of NIOSH 2008a, “Potential exposures resulting from clean-up operations were considered as part of this addendum, but consideration was only given to the amount of waste materials resulting from AWE operations.” Based on our review of the evaluation report, it does not appear that NIOSH made an attempt to consider what fraction of residual radioactivity was associated with AWE operations.

***Finding 2:*** NIOSH did not consider the fact that Mg-Th alloy production for atomic weapons is a small fraction of total Mg-Th alloy production. This approach is bounding and claimant favorable. However, neglecting this fact can result in overstating exposure to residual radioactivity by about three orders of magnitude. NIOSH needs to justify that neglecting the fractional contribution of materials for weapons production is scientifically justifiable.

## 2.1 CHRONOLOGY OF EVENTS

In order to assist the reader in understanding the intertwined events that relate to the period of residual radioactivity, a chronology for the Madison Plant was prepared and is presented below:

- 1952: Mg-Th sludge storage begins (Mura 1986).
- 1955: Start of large-scale Mg-Th alloy production (SC&A assumption).
- January 1, 1957–December 31, 1960: Dow Madison AWE operations.
- December 5, 1957–March 18, 1958: Mallinckrodt purchases Mg-Th alloys for use in atomic weapons production. (See Table 2-1 this report).
- January 1, 1961: Period of residual radioactivity begins (NIOSH 2008a).
- 1969: Dow sells Madison Plant via a lease/purchase option to Phelps Dodge Aluminum (NIOSH 2008a, Pangea 2008).
- 1971: CONALCO assumes Madison Plant lease (Pangea 2008).
- 1973: CONALCO purchases Madison Plant.

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- 1986: CONALCO sells Madison Plant to Spectrulite but retains ownership of 40-acre waste disposal yard (NIOSH 2008a).
- March 1989: ORNL performs radiological survey of Building 6 where uranium AWE operations were performed in the late 1950s (ORNL 1990).
- 1992: Based on ORNL survey, a portion of Building 6 added to FUSRAP list of sites slated for cleanup (NIOSH 2008a).
- 1989–1992: Cleanup of CONALCO waste disposal yard conducted. 100,614 tons of slag, soil, and debris containing 11.4 Ci of Th-230 and 5.7 Ci of Th-232 shipped to Envirocare (Baker 1992).
- January 1993: CONALCO’s NRC license terminated (NIOSH 2008a, p. 6).
- January–June 1998: Spectrulite removes soils contaminated with Th-232 related to CONALCO commercial operations (NIOSH 2008a, p. 6).
- June–July 1999: Corps of Engineers decontaminates Building 6. (NIOSH 2008a, p. 6).
- 2002: Pangea scoping study indicates horizontal surfaces of rafters in Buildings 4, 5, 6, 7, and 8 had sufficient accumulated contaminated to require cleanup (Cushman 2008).
- August 2003: Spectrulite declares bankruptcy and Mg assets sold to Magnesium Electron North America, but responsibility for radioactive materials license remained with Spectrulite (Pangea 2008).
- 2004: Pangea conducts radiological characterization study of the Madison Plant (Pangea 2008).
- June–October 2006: Pangea conducts additional cleanup of Madison Plant (Cushman 2008).
- October 31, 2006: Period of residual radioactivity ends (NIOSH 2008a).
- April 2007–November 2007: Secondary remediation of Madison Plant conducted (Pangea 2008).

This chronology of events is fundamental to developing an understanding of the plausibility of the dose reconstruction methodology adopted by NIOSH in the evaluation report, as discussed in Sections 3 and 4 below. It should also be noted that melting and casting operations were done in Building 7 while fabrication operations such as extrusion and rolling were done in Building 6. Different exposure levels are likely dependent on the type of operation.

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### **3.0 THORIUM INTERNAL EXPOSURES DURING RESIDUAL RADIOACTIVITY PERIOD**

#### **3.1 INHALATION EXPOSURES IN PRODUCTION AREAS**

To bound thorium internal exposures during the period of residual radioactivity (i.e., after January 1, 1961), NIOSH considered four sources of data:

- General area air sampling during the operational period from January 1, 1957, through December 31, 1960 (Dow 1959, Shrader 1959)
- Dust samples taken by ORNL during a Building 6 site survey in 1989 (ORNL 1990)
- Dust samples taken by ERG in 1992 related to waste yard remediation (Baker 1992)
- Air sampling during final site cleanup by Pangea from June through October 2006 (Cushman 2008).

NIOSH also notes the following (SEC-00079, Addendum 2, Section 2.0):

*Empirical data and process descriptions of arc-melting of thorium metals are provided in a formal study (Lowery, 1962). Arc-melting was used at Dow Madison. While the Lowery data are not used directly in determining intake in the bounding analysis, the study is important to demonstrate expected air concentrations of thorium and thorium progeny. The study also measured airborne activity (breathing zone and general area) in the major task areas involved with arc-melting thorium.*

SC&A is not aware of the use of arc melting at Dow Madison. Melting of Mg-Th alloys was done in pot furnaces. Arc melting as described in Lowery (1962) involves melting of thorium metal ingots in closed consumable-electrode furnaces. The processes are not comparable. We therefore question the relevance of the reference.

NIOSH bounded the airborne activity during the residual period using what they deemed to be the highest general area air sample collected from 1957 through 1959. NIOSH stated the following:

*Process and breathing zone samples were excluded, the rationale being that general area air samples collected during operations would adequately represent contributions from both resuspension of surface contamination and dispersion of process releases and, as such, would bound the contribution from re-suspension of surface activity alone during the residual contamination period.*

SC&A believes that this premise is scientifically sound and is an appropriate basis for conducting a bounding analysis. However, we do not believe that the manner in which NIOSH implemented their approach is scientifically sound. Table 3-1 (Table 2-1 in NIOSH 2008a) describes the 13 general area air samples considered by NIOSH in selecting the highest general

area air sample. NIOSH provides no explanation as to why samples from 1955 and 1956 were not included in the dataset. It would seem that the general area air samples collected in 1955 and 1956 are also representative of the general airborne dust loading of thorium during 1957 and 1958 and, therefore, should be included as part of the dataset of interest to this analysis. We also suspect that the first two samples in Table 3-1 are breathing zone samples.<sup>2</sup> Assuming that this premise is correct, all of the remaining samples in Table 3-1 are less than the limit of detection. The highest reported limit of detection is 0.076 mg/m<sup>3</sup> for Sample 4. This sample was obtained by passing 0.471 m<sup>3</sup> of air through a Millipore filter (Shrader 1959). The air volumes for the other samples in SRBD Ref ID 39914 ranged from 1.18 to 1.54 m<sup>3</sup>. The low sample volume is a significant contributor to the high detection limit for Sample 4. Had the sampled air volume been comparable to the other samples in Table 3-1, it is likely that the detection limit would have been on the order of 0.010 to 0.015 mg/m<sup>3</sup>. While the selection of Sample 4 for a bounding calculation is certainly conservative, it should be recognized that the true value could range between 0 and 0.076 mg/m<sup>3</sup>. It should also be noted that use of the uncertain value of a general area sample (0.076 mg/m<sup>3</sup>) results in selecting a bounding value that is higher than breathing zone samples in Table 3-1 (0.018 and 0.036 mg/m<sup>3</sup>).

**Table 3-1. Thorium Air Monitoring Data**

| Task, Area, or Process                                    | Time Frame | SRDB Ref ID      | Sample ID | Reported Thorium (mg/m <sup>3</sup> ) | Calculated Conc. (pCi/m <sup>3</sup> ) |
|---|------------|------------------|-----------|---------------------------------------|--|
| R. M. Salvage (range of results)                          | Dec-57     | 39912, pdf pg. 7 |           | 0.018                                 | 2.00                                   |
| R. M. Salvage (range of results)                          | Dec-57     | 39912, pdf pg. 7 |           | 0.036                                 | 4.00                                   |
| Rolling steam annealed HK31 in #2 Mill (range of results) | Mar-59     | 39912, pdf pg. 7 |           | <0.009                                | 1.00                                   |
| Rolling steam annealed HK31 in #2 Mill (range of results) | Mar-59     | 39912, pdf pg. 7 |           | <0.015                                | 1.70                                   |
| Centrifuge – HK31 sludge                                  | Dec-59     | 39914, pdf pg. 7 | 10        | <0.010                                | 1.11                                   |
| Centrifuge – HK31 sludge                                  | Dec-59     | 39914, pdf pg. 7 | 12        | <0.011                                | 1.22                                   |
| Near instrument panel                                     | Dec-59     | 39914, pdf pg. 7 | 9         | <0.011                                | 1.22                                   |
| Next to drums in sludge recovery                          | Dec-59     | 39914, pdf pg. 7 | 14        | <0.011                                | 1.22                                   |
| Sludge recovery   | Dec-59     | 39914, pdf pg. 7 | 6         | <0.011                                | 1.22                                   |
| Sludge recovery   | Dec-59     | 39914, pdf pg. 7 | 8         | <0.011                                | 1.22                                   |
| Control panel   | Dec-59     | 39914, pdf pg. 7 | 11        | <0.013                                | 1.44                                   |
| Near control panel  | Dec-59     | 39914, pdf pg. 7 | 2         | <0.023                                | 2.56                                   |
| Near control panel  | Dec-59     | 39914, pdf pg. 7 | 4         | <0.076                                | 8.44                                   |

Source: NIOSH 2008a, Table 2-1

<sup>2</sup> Mitchell 1957 notes that samples were collected on December 2, 1957, from the breathing zones of two workers using vibratory hand sanders on alloy HK31 and submitted for Th analysis.

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NIOSH used the specific activity of Th-232 to convert measured thorium dust loadings to inhalation exposures. From the data in Table 3-1, NIOSH selected the maximum cited value of 8.44 pCi/m<sup>3</sup> to bound the exposure level to be used in calculating internal thorium exposures during the residual radioactivity period. It is not clear how NIOSH selected the samples for inclusion in Table 3-1. For example, SRDB REF ID 33914.pdf (Shrader 1959, p. 7) lists data on samples 1, 3, 5, and 7, in addition to those in Table 3-1 (sample 13 was a blank). Reference SRDB REF ID 33912.pdf (Dow 1959) lists several samples in addition to those provided in Table 3-1 (Pot Room, By #1 Slab Oven, #7 Mill, etc.). Sample 3 in Shrader 1959, which was not included in the NIOSH data set, was conceivably higher than Sample 4 which was selected as the bounding value. Sample 3 had a thorium content of <0.084 mg/m<sup>3</sup>.

Air-sample measurements taken during the melting of Alloy HM21 in July 1956 have also been reported by Dow (Silverstein 1956). A more complete listing of Dow air-sampling results is provided in Attachment F of SCA-SEC-TASK5-0057 (SC&A 2007a; Tables F-1, F-2, and F-3). The highest reported value above the limit of detection was 0.020 mg/m<sup>3</sup> (Table F-1, Sample M-6). Thus, the selection of 0.076 (or 0.084) mg/m<sup>3</sup> is clearly bounding and claimant favorable; however, it appears that 0.020 mg/m<sup>3</sup> is a more scientifically defensible bounding concentration.

***Finding 3:*** *While the approach taken by NIOSH clearly bounds the initial inhalation exposure to residual radioactivity, NIOSH needs to explain considerations applied to data selection.*

After selecting the apparent maximum general area air sampling concentration (8.44 pCi/m<sup>3</sup>), NIOSH estimated that the annual exposure in 1961 (the first year of the residual radioactivity period) was 20,256 pCi, based a breathing rate of 1.2 m<sup>3</sup>/hr and a 2,000-hour work year. Implicit in this calculation are the assumptions that (1) the airborne concentration is the result of resuspension of residual radioactivity, and (2) all the residual radioactivity is the result of production of Mg-Th alloys for weapons purposes. The preceding discussion supported the reasonableness of the first assumption for a bounding calculation and, as discussed in Section 2 above, production of Mg-Th alloys for atomic weapons was only about 0.07% of total production in 1957 and 1958 indicative of the large measure of conservatism in the second assumption. NIOSH further noted that the maximum air concentration in 2006 during final site cleanup was 9.947% of the Derived Air Concentration (DAC) at a perimeter monitoring station. Since the DAC for Class Y Th-232 is 1 pCi/m<sup>3</sup>, the maximum air concentration was 0.0994 pCi/m<sup>3</sup>, which translates to an inhalation rate of 239 pCi/yr (NIOSH 2008a, pp. 25–26). The 2006 measurements were made during cleanup of the horizontal surfaces of overhead beams which involved vacuuming and, to a limited degree in Building 7, manual removal of contamination (Cushman 2008). Cleanup of the dross storage area in Building 7 required the use of a concrete scabber on the floor and a shrouded grinder on the walls (Pangea 2008). Thus measurements taken during that period are likely to be reflective of disturbed contamination and elevated dust levels. Since the measurements do not take into account the fact that residual radioactivity from 1957 and 1958 Mg-Th alloy production for atomic weapons use was a very small fraction of total alloy production and since the measurements were made during cleanup activities, they are bounding and claimant favorable but they do not appear to be scientifically valid or plausible (as discussed below).

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Based on the methodology developed in ORAUT-OTIB-0070 (NIOSH 2008b), NIOSH assumed that the annual inhalation rate declined exponentially from 20,256 pCi in 1961 to 239 pCi in 2006. Calculations are summarized in Table 3-2 of NIOSH 2008a. The general appropriateness of this exponential approach will be examined in the separate review of OTIB-0070 currently being prepared by SC&A, as directed by the Advisory Board.

While the chosen approach appears to bound inhalation exposures from residual radioactivity, we have some concerns about the relevance of the 2006 air sampling data as a measure of residual radioactivity from operations prior to 1960. For example, cleanup of Building 6 was done in 1999 and involved removal of residual radioactivity that was deposited over a 40-year time period, only a very small fraction of which could possibly have been due to thorium production in the 1950s (i.e., associated with the fabrication of weapons components). Also, the airborne thorium measured in 2006 is associated with decommissioning activities and is not representative of on-going exposures to residual radioactivity. NIOSH might wish to examine alternative approaches, such as that outlined in Section 2.6 of ORAUT-OTIB-0070 (NIOSH 2008b). Another possibility is to model annual deposition and dilution of pre-1960 residues based on annual production assumptions (i.e., each year after 1960, the residual thorium due to pre-1960 thorium operations will be diluted due to post-1960 thorium operations). Still another strategy might be to develop a plausible but bounding model of the rate at which the airborne thorium observed during the covered time period would have declined as a function of time (i.e., deposition, resuspension, and depletion as a result of the building air turnover rate). Such strategies would represent a more scientifically valid approach to bounding the rate at which the residual radioactivity associated with pre-1960 alloy production declined with time.

### 3.2 INHALATION EXPOSURE FROM THORIUM IN SLAG

NIOSH presumed that workers could receive inhalation exposures from dust generated by materials in the waste yard during the period of residual radioactivity. They concluded that such exposures were less than those based on inhalation exposure within buildings in the plant, and thus were bounded by in-plant exposures.

Although apparently not used in its analyses, NIOSH states that Dow put solid slag waste in the disposal yard from 1957 through 1969 (SEC-00079, Addendum 2, Section 3.1). However, as indicated by Mura (1986, p. 16), magnesium-thorium sludge had been stored on the site since 1952, and was presumably still being stored in 1984 when CONALCO updated the decommissioning plan for NRC License STB-1097. In fact, NIOSH assumed that 1,844 kg of Th from the slag pile was released annually into the environment from 1961 through 1992. Thus, reference to the 1957–1969 time period is confusing and probably unnecessary. Presumably, it refers to the time period when Dow owned the Madison Plant.

In its amendment to NRC license STB-1097 dated August 21, 1986, CONALCO stated that no new material would be brought on site (Mura 1986, p. 7, Item 11). At the time the decommissioning plan was updated (April 26, 1984), the site contained 3,300,000 lb of Mg-Th alloy sludge with an assumed Th content of 4%, which equates to 130,000 lb of Th (Mura 1986, p. 18). Assuming this material had been uniformly accumulated from 1955–1983, the annual

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accumulation rate would be 4,482 lb of Th in sludge.<sup>3, 4</sup> Thorium accumulated in sludges during 1957 and 1958, when material was produced for use in atomic weapons, would be 8,965 lb. According to Stein (1982), 1 lb of sludge is generated for every 5 lb of Mg-Th alloy produced. Thus, based on the data in Table 2-1 above, about 369 lb of sludge containing about 9 lb of Th would have been created during the production of mill products sold to Mallinckrodt in 1957 and 1958 for use in atomic weapons (1,847 lb alloy × 2.5% Th × 0.2 lb sludge/lb alloy). Of the 130,000 lb of Th contained in sludges, 0.007% would be from Mg-Th alloy production for atomic weapons. This suggests that residual radioactivity exposure to Th in slag could be orders of magnitude lower than proposed by NIOSH. Though the NIOSH approach is bounding, it is likely to be implausibly high.

It is further noted in Mura 1986 that the sludge was stored in drums on a curbed asphalt pad and the drums were covered with Hypalon® sheets. It is not clear whether drum storage represented only a then-current practice or was a practice that had been used for several years. The assumption that 3.1 % of the Th in the sludge was released each year from 1961 through 1992 is extremely conservative. Presumably, all of the sludge in drums was shipped to waste disposal sites prior to soil removal by CONALCO from the waste yard in 1992. Their NRC license was terminated in January 1993 (NIOSH 2008a, p. 6). Thus sludge in the waste yard would not be a source of residual radioactivity after 1992.

***Finding 4:*** *The NIOSH approach used to quantify the residual radioactivity associated with exposure to Th-containing slag from 1957 and 1958 appears to be unrealistically conservative and may not meet the Part 83 requirement for the exposure scenarios and assumption to be plausible. Such an approach may be appropriate as an efficiency approach for denial, but not for granting a claim.*

### 3.3 EXPOSURE TO THORON

To bound thoron exposures for the period of residual radioactivity, NIOSH used the data from 13 measurements of short-lived alpha activity made during the melting of alloy HK31 during 1959 (NIOSH 2008a, Table 3-4). Using a z-score analysis, NIOSH determined that the 95<sup>th</sup> percentile value was 0.182 pCi/L (NIOSH 2008a, Table 3-5). SC&A attempted to verify the 95<sup>th</sup> percentile value by performing a z-score analysis with the same dataset. While we were able to reproduce the median, geometric standard deviation, and 84<sup>th</sup> percentile values, we could not duplicate the 95<sup>th</sup> percentile values. Our analysis resulted in a 95<sup>th</sup> percentile value of 0.247 pCi/L, about 35% higher than that calculated by NIOSH. The reason for this difference is not apparent.

The NIOSH approach did not utilize the full range of measurements reported by Dow. Referring to Attachment F of SCA-SEC-TASK5-0057 (SC&A 2007a), additional data are included in Tables F-1, F-2, and F-8. The dataset used by NIOSH is included in Table F-3. SC&A

<sup>3</sup> Based on annual production estimates of alloy containing 29,000 lb Th for 1957 and 1958 presented in Section 2, the Th contained in sludge generated in those years would be estimated to be 5,800 lb, a value in reasonable agreement with 4,482 lb estimated here.

<sup>4</sup> Although Mg-Th sludges were apparently stored onsite from 1952, we have assumed here that significant production did not begin until 1955. Exposure data from 1955 are included in Dow 1959.

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conducted a z-score analysis using the expanded dataset derived from these four tables. Breathing zone samples were excluded. Use of the expanded distribution resulted in median, mean, and 95<sup>th</sup> percentile values of 0.152, 0.156, and 1.99 pCi/L, respectively. Thus, the 95<sup>th</sup> percentile for the full dataset is an order of magnitude higher than for the limited dataset used by NIOSH.

***Finding 5:** NIOSH needs to explain why all available general area thoron measurements were not used in calculating thoron exposures. This may understate the maximum thoron exposure.*

### 3.4 INGESTION EXPOSURES

To estimate ingestion exposures, NIOSH used a modeling approach developed in OCAS-TIB-009 (NIOSH 2004), which assumed that the total daily ingestion is 0.2 times the air concentration. Using this formulation, NIOSH derived the ingestion rate for 1961 of 422 pCi/yr of Th-232 as the product of the maximum air concentration of 8.44 pCi/m<sup>3</sup>, a 250-day work year, and the 0.2 ingestion factor. Using the same methodology, the ingestion rate in 2006 was calculated to be 5 pCi/yr based on a measured air concentration of 0.0994 pCi/m<sup>3</sup>. As shown in Table 3-3 of NIOSH 2008a, the ingestion rates were assumed to decline exponentially from 422 pCi/yr in 1961 to 5 pCi/yr in 2006.

SC&A has frequently questioned the validity of the approach outlined in OCAS-TIB-009. In its 2007 review of NIOSH Procedures (SC&A 2007b), SC&A noted that the ingestion model suffers from the following deficiencies:

- Surface contamination levels are likely to be orders of magnitude higher than predicted by the settling velocity of airborne contaminants assumed at 5 microns. For example, at uranium rolling mills, airborne particulates are likely to represent a distribution of particles that range from a few microns to large/visible particles. For larger particles, settling velocities increase dramatically, and while large particles limit internalization by inhalation, there are no limitations for their ingestion.
- Surface contamination is likely to build up over time that may extend to weeks/months or longer before reaching equilibrium. NIOSH's assumption that this equilibrium is reached in a 24-hour period is without scientific basis and highly unconservative.
- For select processes, surface contamination may not be the result of settling, but may include liquid spills or result from milling, grinding, cutting, welding, etc.
- The modeled transfer of surface contaminations to the mouth that assumes a 10% transfer from the surface area of one hand during a full workday appears unrealistic. In a hot/dusty work environment, a "radiologically uninformed/untrained" worker is likely to contact/wipe his/her face with both hands repeatedly over the course of a full workday.
- Ingestion may involve other modes, such as direct deposition on lips, smoking of cigarettes, etc.

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The maximum ingestion exposure assumed by NIOSH for Dow workers is 0.015 mg/day (0.076 mg/m<sup>3</sup> × 0.2), or 412 pCi/yr. Since this value is linked to the maximum inhalation exposure, any changes in the inhalation calculations would need to be reflected for ingestion exposures.

***Finding 6:*** *On the basis of past reviews of several NIOSH documents, SC&A has questioned the approach to ingestion exposures developed in OCAS-TIB-009. NIOSH is presumably developing a new approach, but the existing model is still used in Addendum 2 to SEC-00079.*

### 3.5 INTERNAL EXPOSURE SUMMARY

NIOSH notes that equal ingestion and inhalation intakes should be assumed for Th-232, Ra-228, and Th-228. This assumption is appropriate and claimant favorable, since it takes about 55 years after chemical purification for the activity of Ra-228 and Th-228 to build up to the activity level of Th-232 (Albert 1966, Figure 2.5).<sup>5</sup>

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<sup>5</sup> Immediately after purification, Th-228 and Th-232 have equal activities, but Th-228 then begins a period of initial decay relative to Th-232. After about 6 years, the in-growth of Th-228 from its progenitor, Ra-228, is sufficient to cause the total activity of Th-228 to begin to increase again, reaching secular equilibrium with Th-232 after about 55 years (Albert 1966).

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#### **4.0 THORIUM EXTERNAL EXPOSURES DURING RESIDUAL RADIOACTIVITY PERIOD**

NIOSH used data from CONALCO to establish a limit for external exposure during the residual radioactivity period (NIOSH 2008a, Section 3.4). Based on 1981 measurements, the “highest recorded exposure rate” was 0.7 mr/hr measured at 1 ft from the source in an area where thorium storage and scrap bins for Atomic Weapons Employer-era materials were located. This translates into an annual exposure of 1.4 rem. Although a reference to the CONALCO data was not provided in Attachment 2 of their report, NIOSH confirmed that the appropriate reference is Stein 1982 (Rutherford 2008a). Examination of Table 1 in Stein 1982 shows that the exposure rate of 0.7mr/hr was associated with a worker standing 12 inches from HM scrap slabs for alloying. Higher exposure rates are also reported in Table 1 of Stein 1982, such as 19–20 mr/hr at a barrel of 38% Th hardener, but NIOSH eliminated such exposures as not representative of exposures from residual radioactivity (Rutherford 2008b). We agree that it is appropriate to disregard these higher exposures. NIOSH further notes in Section 3.4 of NIOSH 2008a that exposure rates in all areas except near the thorium scrap bins and storage annex ranged from 0.01 to 0.05 mr/hr. However, we believe that NIOSH needs to justify why exposure to scrap slabs in 1981 is representative of external exposures to residual radioactivity from operations conducted in 1957 and 1958.

It is stated in Stein 1982 (p. 16) that film badges were worn during the casting of alloy on HM21A on August 10, 1981 (the operation that provided the basis for the data in the previous paragraph), but results had not been returned at the time the report was written. NIOSH has unsuccessfully tried to locate the film badge data (Rutherford 2008b). Some film badge data were reported by Dow for casting of HK31 at the Bay City plant in 1957 (Silverstein 1957). Although this is surrogate data, we have no reason to believe that operations at Madison and Bay City were not comparable. The maximum measured exposure over a 13-day period was 75 mr or 0.72 mr/hr, in close agreement with the maximum value selected by NIOSH. Most of the film badge exposures were about 10 mr (0.096 mr/hr), which is the lower limit of detection for film badges. However, it must be emphasized that, in both Stein 1982 and Silverstein 1957, the data are representative of the operational period, not the period of residual radioactivity. Only some unestimated fraction of the radioactivity reported in Stein 1982 is attributable to operations prior to December 31, 1960.

To provide additional perspective on the selection of 0.7 mr/hr as the bounding value for external exposure, we note that this is the exposure that a worker would receive if he stood full-time about 48 in from a 108-in thick source of alloy HK31 slabs, each 26 inch by 76 inch (Dow 1956). It is difficult to conceive of a physical situation during the period of residual radioactivity that would approach continuous exposure to a large mass of Mg-Th alloy. We also note that values of 3 to 7  $\mu$ r/hr were obtained from near- surface gamma scans of the concrete floor in Building 6 during a 1989 survey (ORNL 1990).

While we believe that the use of an exposure rate of 0.7 mr/hr for external exposure during the residual radioactivity period is bounding, we are not convinced that selection of an external exposure measurement taken adjacent to a large source during 1981 operations is representative of the residual radioactivity from operations during 1957 and 1958.

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***Finding 7:*** *NIOSH needs to provide convincing arguments that an external exposure of 0.7 mr/hr during the period of residual radioactivity is representative of exposures under plausible circumstances from Mg-Th alloys produced in 1957 and 1958.*

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