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February 26, 2008

Mr. David Staudt
Center for Disease Control and Prevention
Acquisition and Assistance Field Branch
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626 Cochrans Mill Road – B-140
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Re: Contract No. 200-2004-03805, Task Order 1: Document No. SC&A-TR-TASK1-0026, *Draft Review of Battelle-TBD-6001, Site Profiles for Atomic Weapons Employers That Worked Uranium And Thorium Metals, Revision FO Dated December 13, 2006*

Dear Mr. Staudt:

In accordance with Contract No. 200-2004-03805, Task Order 1, SC&A is pleased to submit the Draft Document No. SC&A-TR-TASK1-0026, *Draft Review of Battelle-TBD-6001, Site Profiles for Atomic Weapons Employers That Worked Uranium And Thorium Metals, Revision FO Dated December 13, 2006*. This document has been reviewed for Privacy Act information, edited accordingly, and is cleared for unrestricted distribution.

If you have any comments or questions, please contact me at 732-530-0104.

Sincerely,

John Mauro, PhD, CHP
Project Manager

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ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

Draft Review of Battelle-TBD-6001, Site Profiles for Atomic Weapons Employers That Worked Uranium And Thorium Metals, Revision FO Dated December 13, 2006

Contract No. 200-2004-03805
Task Order No. 1
SCA-TR-TASK1-0026

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S. COHEN & ASSOCIATES: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-TASK1-0026 Effective Date: Draft — February 26, 2008 Revision No. 0 – (Draft)
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Task Manager: _____ Date: _____ William Thurber	Supersedes: N/A
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ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
Advisory Board	Advisory Board on Radiation and Worker Health
AMAD	Activity Median Aerodynamic Diameter
AWE	Atomic Weapons Employer
BZ	Breathing Zone
DCF	Dose Conversion Factor
dpm	Disintegrations per minute
DWA	Daily Weighted Average
EU	Enriched Uranium
FMPC	Fernald
GA	General Area
GSD	Geometric Standard Deviation
IMBA	Integrated Modules for Bioassay Analysis
MCW	Mallinckrodt Chemical Company
NIOSH	National Institute for Occupational Safety and Health
PL	Preferred Level
RU	Recycled Uranium
SX	Solvent Extraction
TBD	Technical Basis Document
TIB	Technical Information Bulletin
UF_4	Uranium Tetrafluoride
UF_6	Uranium Hexafluoride
WLM	Working Level Month

EXECUTIVE SUMMARY

In accordance with direction provided by the Advisory Board on Radiation and Worker Health (Advisory Board) during the Advisory Board conference call held on November 27, 2007, this report presents a review of Technical Basis Document-6001, *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium* (Battelle-TBD-6001, Revision F0, December 13, 2006), referred to here as TBD-6001. TBD-6001 provides a generic dose reconstruction exposure matrix specifically for workers at Atomic Weapons Employer (AWE) facilities that performed uranium refining operations and have no or limited site-specific external dosimetry, bioassay, or air-sampling data upon which to base site-specific/realistic dose reconstructions. A companion document to TBD-6001 is TBD-6000 (*Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals* [Battelle-TBD-6000, Revision F0, December 13, 2006]), which provides an exposure matrix for workers at AWE facilities that performed uranium metal-working operations. SC&A's draft review of TBD-6000 was delivered to the National Institute for Occupational Safety and Health (NIOSH) and the Advisory Board on September 14, 2007 (SC&A 2007). As will be discussed subsequently, some of the issues raised in our review of TBD-6000 are equally relevant to our review of TBD-6001.

From our review of TBD-6001, we have developed the impression that this document was hastily prepared. The document contains numerous typographical errors and other editing issues that make the logic used in developing the dose rates difficult to follow and may hamper the use of the document by dose reconstructors. The construction of the primary dose summary tables is confusing, and little effort is made to lead the reader through the methodology used in developing these summary tables. The sources of numerous pieces of technical data are not referenced. We have provided a listing of some of these editorial issues separate from our technical findings.

The following technical findings are discussed in subsequent sections of this report.

Finding 1: It is not possible to judge whether the basic approach to developing inhalation doses in TBD-6001 is claimant favorable, based on the information presented in that document. However, based on analyses presented in this review, it appears that the average inhalation doses used in TBD-6001 are not claimant favorable, particularly for the period prior to 1948.

Finding 2: TBD-6001 oversimplifies the process descriptions from Christofano and Harris (1960) and, as a result, may have missed or understated significant pathways for external and internal exposure.

Finding 3: The approach used in TBD-6001 to calculate the contribution to external exposure of contaminated dust settled on workplace surfaces is not appropriate. SC&A addressed the same issue in its review of TBD-6000 (SC&A 2007, Item 5).

Finding 4: Summary Tables 7.1 and 7.3 in Section 7 of TBD-6001 that address external exposures require additional elaboration to understand the sources of the contained data and how the data were derived.

Finding 5: The approach taken by NIOSH to develop year-specific correction factors to inhalation doses does not appear to be claimant favorable. Doses in the early years may be understated.

Finding 6: NIOSH did not consider radon exposures in developing inhalation exposure rates. Since pitchblende ore contains significant quantities of Ra-226 and its progeny, this omission significantly understates inhalation exposure rates for workers involved with operations at the front end (ore processing) of the refining process.

REVIEW OF BATTELLE-TBD-6001, DISCUSSION OF FINDINGS

During the conference call of the Advisory Board on Radiation and Worker Health (Advisory Board) held on November 27, 2007, the Board directed SC&A to perform a review of Technical Basis Document (TBD) 6001, *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium Metals* (Battelle-TBD-6001, Revision F0, December 13, 2006). This report presents our review of TBD-6001. SC&A was not directed to review the appendices to TBD-6001 as part of this review.

An overarching issue that must be considered is the basic approach to reconstructing doses adopted in TBD-6001. The fundamental question that must be asked is this: Is the sampling data in Christofano and Harris 1960, which is the basic source document used to develop the exposure matrix in TBD-6001, adequate to characterize worker exposures over the period 1948–1956 for which data are provided, and can the exposures be extended back in time to 1942? Christofano and Harris note that 60 surveys were made at 7 plants over a 9-year period. This is less than one survey per plant per year on average. Each survey establishes the conditions in the plant over a brief survey period of a few days' duration. This survey is then assumed to be representative of the conditions for the balance of the year or for longer time periods in some locations. Operations, particularly in the early days of the Manhattan Project, could hardly be described as steady state. There was continuing pressure on production staffs to maximize output from plants originally designed for short-term operation, and process excursions were common. We believe that the NIOSH report needs to provide a carefully reasoned basis for accepting this fundamental premise, namely, that relatively short-term surveys performed in a given year in a given facility are representative of the entire year's operation and protective of the claimant's interests.

Regarding such additional justification, we also note that the authors of the Harshaw TBD concluded the following:

> *It has been determined that it is not feasible to perform dose reconstructions from August 14, 1942 through November 30, 1949 due to lack of internal dosimetry data for the radionuclides associated with uranium operations at Harshaw* (ORAUT 2007, p. 23).

If such a conclusion is appropriate for Harshaw, why would it not be equally appropriate for the generic workers covered by TBD-6001? TBD-6001 includes no internal dosimetry data, and relies solely on air sampling to estimate internal exposures.

The discussion that follows is organized according to the major sections that comprise TBD-6001 and uses the same section numbering scheme (in parentheses). We consider this a focused review, because we did not attempt to assess each and every guideline or look-up table. Rather, we limited our review to those analyses, guidelines, and look-up tables that we judged to be potentially important to the dose reconstruction process. In some cases, the TBD discusses different aspects of a given exposure pathway, such as external dosimetry, in separate chapters. As a result, there is some redundancy in presenting the results of the review. Those sections of TBD-6001 for which we have no comments are not listed in the discussions that follow.

1.0 PURPOSE AND SCOPE (SECTION 1.0)

NIOSH states in this section that the report provides the technical basis for reconstructing doses for AWE sites that refined uranium under government contract during the period 1942–1958; however, no basis is provided for selecting 1942–1958 as the relevant time period. We also note that NIOSH refers elsewhere to 1944 as start date (page 4, second paragraph).

2.0 INTRODUCTION (SECTION 2.0)

Section 2.0 of TBD-6001 is a brief introduction to the NIOSH report noting that, in the early days of the Atomic Energy Commission (AEC) program, no one organization had the capability of performing all the steps necessary to process uranium ores and produce uranium metal billets or uranium hexafluoride (UF_6) needed to manufacture fuel for the production reactors. The authors of TBD-6001 state that they relied heavily on a journal article by Christofano and Harris (1960)[1] to develop the exposure matrix. Christofano and Harris, who worked for the AEC Health and Safety Laboratory, accumulated more than 20,000 air-sampling measurements in 60 surveys at 7 AEC plants over the period 1948 through 1956 (C&H 1960, p. 77/441). They also provide some information on external exposures. The uranium refining operations were conducted at Middlesex, Mallinckrodt (MCW), Fernald (FMPC), Harshaw, Linde, Electromet, and Vitro. By 1955, uranium refining was consolidated into two parallel integrated processing plants— MCW and Fernald (with the exception of uranium hexafluoride production, which was moved from Harshaw to Oak Ridge). NIOSH has prepared individual TBDs for MCW, FMPC, Linde, and Harshaw (ORAUT 2004, 2005, 2006, and 2007).

C&H present tabular summaries of air-sampling measurements for the various unit operations involved in uranium refining, including ore sampling, digestion, denitration, oxide conversion, UF_4 production, uranium metal production, uranium metal recasting, UF_6 conversion, scrap recycling, and drum handling, but not for solvent extraction.[2] For each unit operation (except solvent extraction), the tabular summaries provide minimum, maximum, and average air concentrations (dpm/m^3) from breathing zone (BZ) measurements associated with various worker activities required by each of the unit operations and from general area (GA) samples. The tables also provide an "average daily exposure." As an example, Table 3 from C&H 1960, included here as Table 1, summarizes the air sampling results for the digestion operation.[3] In the digestion operation, pitchblende ore or ore concentrates are dissolved in nitric acid, and the uranyl nitrate solution is separated from the gangue by filtration. If the uranium-bearing solution resulted from processing of pitchblende ore, it was further processed to remove radium. A simplified flow diagram for all the uranium refining operations is included as Figure 1.

[1] Since Christofano and Harris (1960) is frequently referenced throughout this review, we have chosen to use the abbreviation C&H or C&H 1960 for simplicity and readability of our review.

[2] Although solvent extraction was discussed, no tabular data summary was provided.

[3] C&H refer to the summary values in Table 3 as "average daily exposure." In other tables in C&H 1960, terms such as "DWA" (Tables 5 and 10), "average weighted exposure" (Table 4), "daily average exposure" (Table 2) and "weighted average exposure" (Tables 6 and 8), "weighted average" (Table 9), "average exposure" (Table 11), and "daily weighted average" (Table 1) are used. We presume these terms are synonymous (and, apparently, they are assumed to be synonymous in TBD-6001), but we are not sure.

Table 1. Air Sampling Results from Digestion Operations
(Source: C&H 1960, Table 3)

Sample Location	Pitchblende Ore (dpm/m^3)		Concentrates (dpm/m^3)	
	Range	Average	Range	Average
BZ reaming ore chute	350–8,000	1,000		
BZ drum dumping – uncontrolled		2,500	1,000–6,000	2,400
BZ drum dumping – ventilated			0–220	90
BZ drum dumping – remote			6–44	30
BZ lidding and delidding drums	600–1,700	1,200		
GA digest area	6 – 330	150	0–75	30
GA ore room	90–2,600	1,000		
Average daily exposure	7–350	110	17–100	40

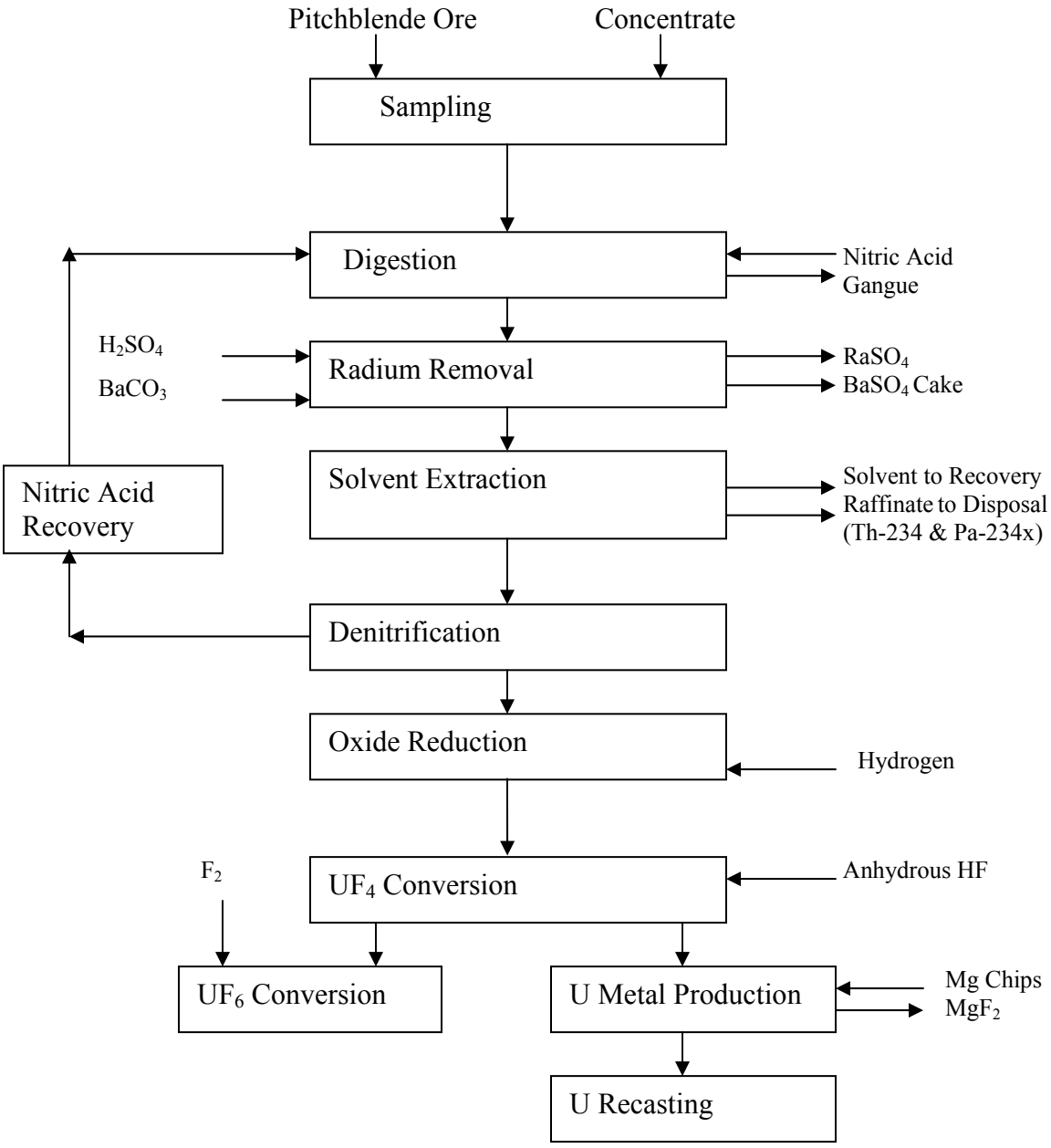

Figure 1. Flow Diagram for Uranium Refining from Ore or Concentrates
(Based on C&H 1960, Figure 3)

No discussion is provided in C&H 1960 as to how the range and the average of the "Average Daily Exposures" reported in their tabular summaries were obtained, and the paper includes no references that would assist the researcher in understanding how these quantities are derived. Presumably, the data are some type of long-term average from 1948 to 1956 of time-weighted daily averages of surveys taken for various operations from the seven plants. Unfortunately, there is no transparency as to how the average of the average daily exposures is derived.

For example, NIOSH uses the average airborne concentration value of 110 dpm/m^3 from Table 3 of C&H 1960 to establish a median exposure level of 49 dpm/m^3 (Table 8.3) and a median daily inhalation rate for a digester operator in summary Table 8.29 of 145 pCi/calendar day based on a 40-hour work week. In our opinion, the method used to derive this exposure rate is as follows (although the NIOSH document does not make clear the calculational approach):

I (pCi/day) = 49 dis/min-m^3 × 1 min/60 sec × 1 Bq/dps × 27 pCi/Bq × 1.2 m^3/hr × 8 hr/day × 250 work days/365 calendar days = 145 pCi/calendar day.

However, the larger problem is that there is no insight into how the core value of 110 dpm/m^3 was derived originally. Without additional insight into the averaging processes used by C&H, one cannot make any assertions as to whether or not the approach used in TBD-6001 for this inhalation value is reasonable and/or claimant favorable. This issue is further discussed under Section 8.1 of this report.

This lack of transparency as to how C&H manipulated their survey data is also apparent in Figure 16 of their paper. Figure 16 is a plot of weighted exposures (dpm/m^3) by year. The plot contains 137 data points (17 in 1948, 9 in 1949, etc.). C&H provide no information as to how their survey information was composited to obtain the 137 annual data points. The information in Figure 16 was used in TBD-6001 to develop year-specific correction factors (see TDB-6001, Table 8.28). During dose reconstruction, these correction factors are to be used as multipliers of the inhalation intake rates in Table 8.29, depending on the years during which a claimant was employed. Since it is not known how the C&H survey data were composited to obtain annual weighted exposures, it is not possible to judge whether or not the approach used is claimant favorable.

It should also be noted that C&H 1960 covers the period 1948–1956, while the relevant period for dose reconstruction using TBD-6001 is 1942–1958. The ramifications of this will be discussed subsequently in Section 8.3 of this report.

3.0 URANIUM DOSIMETRY (SECTION 3.0)

Section 3 of TBD-6001 presents a generic description of the characteristics of uranium and its emissions, and a general discussion of the types of external and internal exposures that are associated with uranium refining operations; it also treats dose conversion factors (DCFs). Most of the information in Section 3 (i.e., Sections 3.1, 3.2 and 3.3) of TBD-6001 is the same as the information included in Section 3 of TBD-6000, which was previously reviewed by SC&A (SC&A 2007). In its review of TBD-6000, SC&A found the fundamental descriptions of the

isotopic composition of various forms of uranium to be correct. The same conclusion applies to TBD-6001.

3.1 Source Terms for External Doses (Section 3.4)

SC&A provided an extensive critique of the information in Section 3.4.2 of TBD-6000 (SC&A 2007, Section 3.1, Surface Contamination). The same comments are relevant to Section 3.4.2 of TBD-6001. In particular, SC&A questioned the use of a model for developing surface contamination based on settling of 5 micron (AMAD) particles with a terminal settling velocity of 0.00075 m/sec onto external surfaces.

3.2 Internal Dosimetry (Section 3.5)

The only sources of internal exposure considered in TBD-6001 are the various isotopes of uranium and the uranium progeny that exist 100 days after ore processing. The report does not explicitly address exposures to Th-230, Ra-226, or Rn-222 and its progeny. These radionuclides could be important for workers that handled ore. For example, consider an air sample collected in an ore processing area, and it is determined that the sample contains x dpm/m^3 after allowing the short-lived radon progeny to decay away. This sample is likely to contain equal activities of all isotopes that comprise the natural uranium decay series, except radon and its short-lived progeny. By assuming that all the detected alpha emissions are U-234, when in fact the sample likely contains equal amounts of U-234, U-238, Th-230, and Ra-226, is it possible that the derived doses to specific organs might be significantly underestimated? Table 2 presents the default ICRP 50-year committed dose equivalent (Sv/Bq inhaled) to key organs for these radionuclides (ICRP 1968).

Table 2. ICRP Default Dose Conversion Factors (Sv/Bq inhaled for adult workers)

	U-238 Type F	Type M	Type S	U-234 Type S	Th-230 Type M	Th-230 Type S	Ra-226 Type M
Time after intake	**50 years**	**50 years**	**50 years**	**50 years**	**50 years**	**50 years**	**50 years**
Adrenals	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	3.00E-08
Bladder Wall	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Bone Surface	8.70E-06	3.50E-06	4.60E-07	2.70E-07	1.50E-03	1.40E-04	9.00E-06
Brain	3.00E-07	1.20E-07	1.40E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Breast	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Oesophagus	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
St Wall	3.00E-07	1.20E-07	1.50E-08	9.20E-09	1.60E-06	1.50E-07	2.90E-08
SI Wall	3.00E-07	1.20E-07	1.60E-08	1.00E-08	1.60E-06	1.50E-07	3.00E-08
ULI Wall	3.00E-07	1.30E-07	2.10E-08	1.70E-08	1.60E-06	1.50E-07	4.10E-08
LLI Wall	3.00E-07	1.30E-07	3.30E-08	3.20E-08	1.70E-06	1.70E-07	8.00E-08
Colon	3.00E-07	1.30E-07	2.60E-08	2.30E-08	1.60E-06	1.60E-07	5.70E-08
Kidneys	3.10E-06	1.30E-06	1.70E-07	1.00E-07	2.20E-05	2.10E-06	4.30E-08
Liver	1.20E-06	4.80E-07	6.20E-08	3.70E-08	1.90E-05	1.80E-06	1.30E-07
Muscle	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Ovaries	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.20E-05	1.10E-06	2.90E-08
Pancreas	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Red Marrow	9.10E-07	3.70E-07	4.90E-08	2.80E-08	5.20E-05	4.90E-06	6.40E-07
ET Airways	3.00E-07	5.20E-06	3.10E-05	7.50E-05	1.40E-05	7.40E-05	1.30E-05
Lungs	3.10E-07	2.20E-05	6.70E-05	4.10E-05	1.70E-05	4.00E-05	1.70E-05
Skin	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Spleen	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	3.90E-08
Testes	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.20E-05	1.10E-06	2.90E-08
Thymus	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Thyroid	3.00E-07	1.20E-07	1.50E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Uterus	3.00E-07	1.20E-07	1.40E-08	8.70E-09	1.60E-06	1.50E-07	2.90E-08
Remainder	3.30E-07	1.40E-07	3.10E-08	3.80E-05	1.90E-06	2.00E-07	3.50E-08
Effective dose	5.00E-07	2.90E-06	8.00E-06	6.80E-06	2.80E-05	7.20E-06	2.20E-06

As may be noted, for Th-230 and Ra-226, the limiting DCFs for several organs are greater than or comparable to that for U-234. Hence, ignoring the fact that some of the alpha activity observed in an air sample might be Th-230 or Ra-226 could result in a substantial underestimate of the dose to certain organs. TBD-6001 should address possible exposures to Th-230 and Ra-226 for workers handling ore.

The report also does not address exposures to enriched uranium (EU) or recycled uranium (RU). In light of this, Section 1 of the report, titled "Purpose and Scope," should make it clear that this document should only be used for workers involved in the processing of uranium ores and concentrates, and that it does not provide direction regarding exposures to workers who might have handled EU, RU, or ores containing Th-232.

With respect to the possible importance of exposure to radon and its progeny, it is important to recognize that an air particulate sample will not capture radon. In addition, it is likely that the

short-lived progeny that are captured in an air sample will be allowed to decay before alpha counting. In order to assess the possible significance of ignoring radon and its short-lived progeny in TBD-6001, we reviewed a number of source documents, including NYOO 1949, ORAUT 2005, and ORAUT 2007. It is reported on page 8 of NYOO 1949 that radon levels exceeding 1×10^{-10} Ci/L were experienced by workers loading and unloading freight cars. That document further notes that at the Middlesex plant, "For a period of several years employees engaged in this operation [loading and unloading freight cars] were exposed to levels of radon which ranged from 200 to 250 times the 'maximum permissible exposure' of 10^{-10} c per liter" (NYOO 1949, p. 14). C&H 1960 states that radon concentrations in ore cars were as high as 10^{-7} to 10^{-8} Ci/L.

A table of radon exposures at MCW Plant 6, where ore storage and handling, digestion solvent extraction, and denitration operations were conducted, is presented on page 71 of ORAUT 2005. The table, which covers the period 1946–1957, includes radon exposure rates for a variety of job descriptions. The exposure for a production operator is stated to have been 0.138 WLM per month worked, based on an equilibrium factor of 0.25. Based on a breathing rate of 9.6 m^3/day, this translates to an exposure of 5.3×10^5 pCi/day.

As may be noted in Table 8.29 in TBD-6001, uranium intake rates are provided for a broad range of operations, job titles, and years of AEC operations. The table does not address radon. For example, the recommended uranium inhalation rate for an ore digestion operator is 1.45×10^2 pCi/d. This corresponds to a 50-year dose commitment of about 4 mrem per day of exposure (145 pCi/day × 6.8E-06 Sv/Bq [U-234 eff. dose] × 1 Bq/27 pCi × 1E05 mrem/Sv). Assuming the whole-body dose equivalent associated with exposure to radon and its progeny is about 200 mrem/yr per pCi/L of radon,[4] the daily whole-body dose equivalent associated with a radon intake rate of 5.3 x10^5 pCi/work day is about 10 mrem/work day (5.3E05 pCi/day × 1 day/9.6 m^3 × 1 m^3/1000L × 200 mrem/yr per pCi/L × 1 yr/8760 hr × 8 hr/work day). Clearly, failure to consider radon exposure could result in underestimating inhalation exposures for workers involved in ore handling and processing, and residue handling and processing. This may involve not only workers directly involved in those operations, but also nearby workers performing other operations. TBD-6001 should address the issue of radon exposures, or at least caution the dose reconstructor that radon exposures are not included in the TBD.

A review of the exposure matrix prepared by NIOSH in support of dose reconstruction of workers at the Harshaw Chemical Company (ORAUT 2007) reveals that consideration was given to radon exposures, RU, EU, radium, thorium, special isotopic separations, and incidents. Since TBD-6001 is designed as a generic protocol for uranium processing facilities, some mention of these isotopes is warranted.

[4] Tables 2.4 and 2.1 of NCRP Report No. 93 (NCRP 1987) indicate that the typical radon exposure to people in the U.S. of about 1 pCi/L (this includes a collective average for both indoor and outdoor exposure) is associated with a whole-body dose equivalent of about 200 mrem/yr (including progeny). Hence, using this as a rule of thumb, exposure to radon plus progeny is associated with an effective whole-body dose of about 0.5 mrem per full day of exposure per pCi/L of radon in partial equilibrium with its progeny.

4.0 PROCESS DESCRIPTION (SECTION 4.0)

This section of TBD-6001 divides uranium refining into nine unit operations, as follows (see also Figure 1):

- Ore digestion
- Solvent extraction
- Boildown and denitration to produce UO_3
- Oxide conversion to produce UO_2
- Conversion of UO_2 to UF_4 by hydrofluorination
- Reduction of UF_4 to uranium metal in a magnesium thermite bomb
- Recasting of uranium metal into billets for further fabrication
- Conversion of UF_4 to UF_6 by fluorination
- Scrap recovery

Descriptions of the various worker activities are drawn by NIOSH from simplified process descriptions in C&H 1960. We have concerns that this heavy reliance on process descriptions in C&H 1960 may result in understating some worker exposures. Examples are provided here.

Ore Handling

On page 15, Section 4.1 of TBD-6001, NIOSH defines the first refining step as "ore digestion." However, C&H (1960) indicate that an ore sampling step preceded ore digestion. Sampling involved opening welded drums, drying, crushing, screening, and other handling operations. Per Table 1 of C&H 1960, the daily weighted average for manual sampling of pitchblende ores was 800 dpm/m^3, and 140 dpm/m^3 for automatic sampling. Cleaning ore drums resulted in BZ exposures averaging 30,000 dpm/m^3.

In addition, in Table 33 of ORAUT 2005, NIOSH notes that external exposures related to ore handling in Plant 6 of MCW ranged from 7 to 200 mR/hr, based on measurements made in 1947 and 1948. C&H also commented on external exposures experienced by sampling plant operators handling pitchblende ores. These authors note that exposures in areas where drums of high-grade ore were stored were 10 to 100 mR/hr at 10 feet (C&H 1960, p. 77/441). High external exposures could also be experienced by truck drivers moving drums of ore between locations. Depending on the details of the plant layout, workers in other operations might also be affected by stored drums. The authors of TBD-6001 should explain why ore sampling exposures were not included in that document.

Digestion

The authors of TBD-6001 note in Section 4.1 (page 15, second paragraph) that removal of radium from the digester liquor by co-precipitation with barium sulfate produced drums of waste with high gamma radiation. C&H (1960, p. 81/445) indicate that exposures of 100 to 300 mR/hr were measured at the surface of a 55-gallon drum of radium cake, and exposures of 50 to 100 mR/hr were measured at a distance of 10 ft from a stack of radium cake drums.

The process used for radium removal at MCW is described somewhat differently in ORAUT 2005 (Section 4.1). At MCW, sulfuric acid was added to the uranyl nitrate solution from the digester to precipitate out radium sulfate (called K-65 residue) that was then removed via a string-discharge rotary vacuum filter. Residual sulfate from the uranium-bearing solution was then removed by the addition of barium carbonate that precipitated barium sulfate. The barium sulfate was separated by centrifugation. According to Table 32 of ORAUT 2005, exposures from an array of 95 drums containing K-65 residue ranged from 95 mR/hr at 1 foot to 9.4 mR/hr at 30 feet. Additionally, both types of residues (K-65 and barium sulfate cake) were reworked for uranium recovery by MCW—an additional source of exposure (SC&A 2005, Finding 7, p. 25).

Drums of K-65 residue produced at locations such as MCW were often stored at Middlesex. Thus, workers at Middlesex received external exposures from both radium-bearing pitchblende ores and K-65 residues. For the 3-month period from November 1948 through January 1949, the average beta/gamma exposure (65% gamma) was 330 mrep/week, but 10 employees had exposures exceeding 50 R, and the highest exposure for the period was 110 R (NYOO 1949, p. 13). Workers involved in ore digestion could experience comparable external exposures. Workers at MCW were exposed to 100 g/month of radium in ores and residues (NYOO 1949, p. 19).

Measurements of external exposure of workers around ore digestion tanks at MCW Plant 6 were frequently above tolerance (100 mR/8 hr or 12.4 mR/hr) (ORAUT 2005, Table 33). However, the authors of TBD-6001 assume an exposure to penetrating radiation of 6.1 mR/hr (Table 7.1) for a digestion worker, based on proximity to a single drum of pitchblende concentrate.

Based on this type of information, NIOSH should re-examine the basis for estimating external exposures at the front end of the ore refining process.

Solvent Extraction

In the solvent extraction process (Section 4.2, p. 16), the authors of TBD-6001 note that, after the uranium is stripped from the aqueous phase, the aqueous raffinate contains nitrates of all undesirable metals, including Th-234 and Pa-234m. According to C&H (1960), this raffinate may be concentrated and calcined to recover nitric acid with the residue stored in drums at the plant or discarded directly to lagoons. It is likely that the concentrated raffinate would be a strong source of beta emitters. It is not apparent that this exposure source was considered in TBD-6001. Table 7.1 lists no non-penetrating exposure to the hands for solvent extraction operators.

C&H 1960 (p. 80) notes that overhead process piping in operating areas had an internal coating that caused an exposure of about 300 mrem/week. Based on a 48-hr work week, this source would contribute an additional 6 mrem/hr, presumably in the ore digestion and solvent extraction (SX) areas. It is not apparent that this external radiation source was considered in developing Table 7.1.

Oxide Reduction

The oxide reduction process is outlined in Section 4.4. As noted there and in C&H 1960, the orange oxide (UO_3) produced in the denitration step was a coarse, lumpy material requiring size reduction prior to conversion to UO_2. To accomplish this, operators dumped material from drums into a mill, where a fine powder was produced. In all likelihood, this was a very dusty operation, but C&H 1960 does not provide air-sampling data for this operation. However, air-sampling data for milling at MCW include weighted average concentrations of 12,600 dpm/m^3 and 46,200 dpm/m^3 for measurements made in 1948 (ORAUT 2005, Table 13). In Section 8.2.4 (pp. 40–41), NIOSH discusses internal exposures from the oxide reduction operations. The oxide reduction operations assume average weighted exposures or daily weighted averages (DWAs) of 20,000, 700, and 140 dpm/m^3 for tray furnace, multiple hearth, and horizontal reactor operations, respectively (TBD-6001, Table 8.9). While it is possible that dust exposure from the milling operations would be captured by the statistical distribution of DWAs for tray furnace operations, the same cannot be said for using multiple hearth and horizontal reactor DWAs to capture dust exposures from the milling operations.

Hydrofluorination

The hydrofluorination process is described in Section 4.5. The hydrofluorination of UO_2 to green salt at Harshaw produced about 2,000 grams per day of residue containing 2.5 curies of Th-234 and Pa-234m. This resulted in whole-body beta radiation exposures of about 1 R/week for as long as 3 years (NYOO 1949, p. 58). The exposure of 1 R/week (200 mR/day) can be compared with the exposure to a hydrofluorination operator with a median non-penetrating radiation exposure to the body (other than hands) of 122 mrem/day (or a 95th percentile exposure of 1,722 mrem/day), based on a 40-hr work week (TBD-6001, Table 7.3). It thus appears that the approach in TBD-6001 adequately captures the exposure effects of Th-234 and Pa-234m in green salt residues for the Harshaw plant through early 1949.

Uranium Recasting

In reviewing this section, we used a general rule of thumb that the external beta/gamma exposure rate at contact with pure uranium metal is about 200 mR/hr, and the penetrating exposure rate at 1 foot from the surface of a large piece of pure natural uranium metal is about 2 mR/hr. We obtained these values from previous MCNP calculations performed by SC&A. In addition, the rule of thumb for contact exposure rate is consistent with the values in Table 3.4 of TBD-6001.

Recasting of uranium metal into billets is described in Section 4.7. Recasting is done in vacuum furnaces and, during the melting process, Th-234 and Pa-234m (which are in approximate equilibrium with the U-238) volatilize and are condensed on the cooler surfaces of the furnaces. Workers involved in furnace charging, discharging, cleaning, and maintenance were subject to high levels of beta radiation (NYOO 1949, p. 12). NIOSH has selected a value 665 mrem/hr for non-penetrating radiation (to body parts other than skin) for a recasting furnace tender (TBD-6001, Table 7.1). This value was reportedly taken from ORAUT 2005 (Table 33, p. 234), which lists the beta exposure for “recasting, furnace tending” as 665 mrep/wk (not per hour). Other exposures reported in Table 33 for recasting workers in Plant 4 at MCW include the following:

- Recasting, top furnace tending – 1,220 mrep/wk
- Recasting, bottom furnace tending – 800 mrep/wk

Apparently, the value of 665 mrem/hr is a typo. This typo also appears to be present in Table 7.1 of the TBD.

NIOSH used a value of 665 mR/hr (Table 7.1, p. 29) for exposure of the uranium recasting furnace tender to penetrating radiation, citing the same reference as for non-penetrating radiation discussed above (i.e., ORAUT 2005, Table 33, p. 234). A careful re-examination of this value and whether the temporal basis is hours or weeks is particularly important, since the use of 665 mR/hr results in the highest exposure from materials handling for any operator listed in Table 7.3 (i.e., 816 mR/day for a 40-hour work week). A dose reconstructor faced with the need to select a value for exposure to penetrating radiation for a worker with no clear cut job description might chose this maximum value as claimant favorable. While such a selection would indeed be claimant favorable, it appears to be erroneously high.

Fluorination

The fluorination process is outlined in Section 4.8. Air concentrations for fluorination (UF_6) production are presented in Table 8.21 of TBD-6001. The **maximum** value of the DWA entries in this table is 7,300 dpm/m^3 (for hex loaders). Both hydrofluorination and fluorination operations were conducted at the Harshaw Chemical Co. It is noted in Table 8 of NYOO 1949 that average daily exposures measured at Harshaw exceeded 8,750 dpm/m^3 (125 PL × 70 dpm/m^3 per PL)[5] in 34% of the measurements. Based on Figure 11 of NYOO 1949, it can be presumed that this included worker(s) with exposure(s) of 9,800 dpm/m^3 (140 PL), worker(s) with exposure(s) of 13,160 dpm/m^3 (188 PL), worker(s) with an exposure(s) of 15,120 dpm/m^3 (216 PL), and worker(s) with exposure(s) of 26,180 dpm/m^3 (374 PL). The 24 workers with the highest exposure (26,180 dpm/m^3) were hex area loaders. Thus, it does not appear that the data used by NIOSH adequately capture the range of exposures for operators working in the production of UF_6.

5.0 OCCUPATIONAL MEDICAL DOSE (SECTION 5.0)

The approach to occupational medical dose is the same as provided in TBD-6000 (Battelle 2006). This approach had been previously reviewed by SC&A and found to be scientifically sound and claimant favorable (SC&A 2007).

6.0 OCCUPATIONAL ENVIRONMENTAL DOSE (SECTION 6.0)

This section of TBD-6001 discusses occupational exposures to workers away from the main operating areas.

[5] PL is the preferred level for alpha-emitting dust averaged over an 8-hr work day. At that time the PL was 70 dpm/m^3.

6.1 Environmental External Radiation (Section 6.1)

As described in Section 6.1.1 (page 23, second paragraph), NIOSH assumes that the ambient dust level is 7 dpm/m^3 for non-operational work areas while the plant is operating, and that uranium particles with a 5-µm AMAD fall from this dust for a full year at a terminal settling velocity of 7.5E-04 m/s to floors in the workplace. This surface contamination then remains with no cleanup. The same general methodology is used in Section 7.1.2 to calculate occupational exposures, except that work place air concentrations are used rather than the default value of 7 dpm/m^3 for non-operational areas. Some of our concerns with the approach used to develop surface contamination levels were presented previously in our review of TBD-6000 (SC&A 2007, Item 5).

While the assumption of a 5-µm AMAD is often used for calculating inhalation doses, it is of questionable relevance when calculating surface contamination levels. In Section 4.1 of TBD-6001 (page 15, third paragraph), NIOSH states the following:

> *The uranium ore was a powder, often 20 mesh (Christofano and Harris (1960)). Twenty mesh powder has a diameter of 840 µm (Lide 1995, pp. 15–37). If 840 µm is assumed to be the upper 99%ile of the aerosol particle size distribution, the equations of ICRP-66 (ICRP 1994) would imply that the actual AMAD of the aerosol is about 54 µm.*

Alternatively, if one assumes that the geometric standard deviation (GSD) for the particle size distribution is 5, as suggested in Section 2.1.2.5 of Strom (2007), then the median particle size for the distribution would be about 20 µm. From Figure 5-80 of Perry and Green (1984), the terminal settling velocity for a 20-µm particle with a density of 10 g/cc is 0.12 m/sec. This would cause the deposition factor used in TBD-6001 to calculate surface contamination to be low by more than 2 orders of magnitude.

In its review of TBD-6000, SC&A raised some concerns about the use of an air concentration of 7 dpm/m^3 for non-operational areas of a plant (SC&A 2007, Section 5). We further note here that exposures to workers in non-operational areas may be higher than that. For example, the following weighted average values have been reported (ORAUT 2005, Table 20):

- Dispensary: Nurse/Medic/Other (personnel) – 1.5 to 175 dpm/m^3
- Office: MCW – Clerk/Maintenance/Messenger/Porter/Expediter – 15 to 50 dpm/m^3
- Office: MCW – Other, AEC-all AEC except Engineer – 0 to 50 dpm/m^3

Any use of a default air concentration for non-operational areas should provide some guidance as to what should be considered "non-operational areas of the plant." Use of a value of 7 dpm/m^3 would not be appropriate for the types of locations cited above.

6.2 Environmental Internal Dose due to Inhalation and Ingestion of Radioactive Material (Section 6.2)

In its review of TBD-6000, SC&A questioned the general approach to calculating ingestion exposures (SC&A 2007, Finding 7). SC&A noted the following:

> *Internal doses associated with the inadvertent ingestion of uranium are derived in the TBD using models and assumptions that have been discussed with NIOSH in the past as part of the review of numerous site profiles and exposure matrices. Based on these discussions, it is our understanding that NIOSH would agree that the basic methodology described in the TBD is deficient and should be revised when the revised methodology is developed.*

Assuming that the revised methodology is developed, the following discussion would become irrelevant. NIOSH states the following in Section 6.2 (pp. 23–24):

> *At several DOE facilities, radioactive emissions from plant stacks have been known to significantly increase the 'background' radiation levels on the plant site. The estimate of 7 dpm/m3 used in Section 6.1.1 can be assumed for the contamination level. Ingestion intakes were found using the equation* $I_{IMBA} = 3.062 \times 10{-}5\ Ah$ *as discussed in Section 8.5.3.*

In this equation, I_{IMBA} is the IMBA chronic intake in pCi/d, A is the air concentration (pCi/m^3), and h is the number of working hours in a year. If the measured air concentration has units of dpm/m^3, then one must divide the constant in the above equation by 2.22 (dpm/pCi).

However, according to Section 8.5.3, the daily ingestion rate is given by the equation $I_{IMBA} = 3.373 \times 10^{-5}\ Ah$, and the incidental hand-to-mouth ingestion rate is given by the equation $I_{IMBA} = 3.425 \times 10^{-5}\ Ah$, and the total ingestion rate by the equation $I_{IMBA} = 6.798 \times 10^{-5}\ Ah$. In spite of what the text in Section 6.2 says, the equation $I_{IMBA} = 6.798 \times 10^{-5}\ Ah$ apparently was used to calculate the inhalation doses in Table 6.2. The direction provided in TBD-6001 appears contradictory and should be corrected.

6.3 During Operations (Section 6.2.1)

Further confusion as to the intent of Section 6.2 is created by the second paragraph in Section 6.2.1, where NIOSH states the following:

> *An estimate of the intake from the inhalation pathway can be estimated assuming an airborne contamination level, a breathing rate, and daily exposure period. The estimate of 1 dpm/m^3 can be assumed for the contamination level. A breathing rate of 9.6 m^3/d includes an exposure period of 8 hours per day. A conversion factor of 2.22 dpm/pCi must also be employed, to give a daily intake of 4.4 pCi/d of uranium.*

Why is a contamination level of 1 dpm/m^3 used when the reader had previously been advised that the contamination level was 7 dpm/m^3 and 7 dpm/m^3 was used to develop Table 6.2? Additionally, the cited intake 4.4 pCi/d is for one 8-hr working day, while the exposures in Table 6.2 are adjusted for calendar days. This paragraph seems to be irrelevant.

7.0 OCCUPATIONAL EXTERNAL DOSE (SECTION 7.0)

Section 7.0 of TBD-6001 presents guidance in the form of default exposure rates for reconstructing external doses to workers from several exposure pathways, including submersion in contaminated air, standing on contaminated surfaces, and standing in the vicinity of, or handling drums containing uranium product produced during, uranium refining operations. The default exposure rates are provided in three tables, Tables 7.1, 7.2, and 7.3, all of which were compiled based on film badge data and process knowledge taken from actual uranium processing facilities, and also external dosimetry computer codes. In developing these tables, the data cited in C&H 1960 and ORAUT 2005 were used. The dose rates are cited in the TBD as representative of "typical" conditions in the workplace at uranium refining facilities.

7.1 Submersion in Contaminated Air (Section 7.1.1)

The external exposure submersion dose rates provided in Table 7.3 are apparently based on a combination of assumed airborne dust loading (dpm/m^3) of alpha emitters and the DCFs in Table 3.9 of the TBD. Some explanation is needed regarding the airborne dust loadings employed and the rationale for their use. In Section 7.2 of the TBD, reference is made to C&H 1960 as the source of the airborne dust loading data. However, it is not apparent what data was specifically used and where that data came from. The TBD appears to be rushed, making it difficult to review. For example, for ore handling operations, was any consideration given to the contribution of Ra-226 and other gamma emitters, other than uranium (and its short-lived progeny), in developing the recommended exposure rates to submersion?

7.2 Exposure from Contaminated Surfaces (Section 7.1.2)

We do not understand the following discussion in Section 7.1.2: "The floor contamination level is then estimated as Floor Concentration (dpm/m^2) = Air Concentration (dpm/m^3) × 2.37E4 meters. This method calculates the surface contamination over 1 m^2, and the dose factors in Table 6.1 should be used." The reference to Table 6.1 is inappropriate. Table 6.1 provides doses for environmental exposure, based on an air concentration of 7 dpm/m^3 for workers in areas **away from the main operations area**.

In addition, we have concerns regarding the methods used to derive the buildup of contamination on surfaces using the deposition velocity approach. This issue is discussed extensively in our review of TBD-6000, and is not repeated here.

Another concern is external exposures to deposited radioactivity in ore handling areas. In ore handling areas, it would appear that consideration needs to be given to the radionuclides that comprise the entire uranium decay series, not just separated uranium. In addition, surface contamination in ore handling areas may have come about from spills. As a result, the

deposition velocity approach may underestimate the external doses from surface contamination in areas where surface contamination was dominated by spills.

7.3 Process Specific Dose Rates (Section 7.2)

Table 7.1 presents external exposure rates (mR/hr and mrem/hr) by major step in the uranium refining operation, and by tasks associated with each step. The number of work hours per day for each task in each refining step is provided, along with the external dose rate to penetrating and non-penetrating radiation. Non-penetrating exposure rates are provided for hands and also for other organs. Table 7.2 presents generic external exposure rates as a function of distance from different size drums and for drums containing recently separated uranium and drums containing pitchblende ore. Based on the information provided in Tables 7.1 and 7.2, Table 7.3 presents the recommended weekly median dose rate and its GSD for each uranium refinery operation, each job title, each external exposure pathway, and each exposure geometry. Table 7.3 is the most important table, because it is intended to be used by dose reconstructors to derive external exposures.

Table 7.1 appears to have a number of typos, and it is difficult to understand what the various values in the table mean and how they were derived. On first inspection, column 2 titled "duration (h/d)" would seem to provide the typical number of hours per day a worker employed in a given refinery operation was involved in a given task. For example, for "Ore Digestion" operations, column 2 seems to indicate that a typical worker involved in this job category spent 6 hours per day at 45 inches from a drum of high grade pitchblende ore, 2 hours per day at 6 inches from a drum of high grade pitchblende ore, and 2 hours per day in direct contact with a drum of high grade pitchblende ore. This results in total of 10 hours of exposure per day. However, for the "Boildown and Denitration" step, there are 4 tasks that add up to 15 hours per work day. This does not seem reasonable, unless the worker is multitasking. If so, the TBD should provide some explanation in this regard.

The source for the data in the Ore Digestion section of Table 7.1 is ORAUT 2005 (Table A-33), where the units for these particular measurements are mR/hr, not mrem/hr. Presumably, NIOSH has assumed that exposures in mR/hr are equivalent to skin doses in mrem/hr, which is reasonable. Nevertheless, NIOSH should provide a listing and discussion of the assumptions used in developing Table 7.1.

In the same section of Table 7.1, the "Non-penetrating (other)" dose is listed as 100 mrem/hr. However, in Section 3.3.1 (p. 7), the authors state that the non-penetrating dose to the skin other than hands and arms is 20.8 mrem/hr, and the exposure duration is 50% of the work day. While the dose rate in Table 7.1 is claimant favorable, the differences between the two sections should be reconciled. Similarly, Table 7.1 lists the non-penetrating exposure to the hands as 66 mrem/hr, while Section 3.3.1 quotes a value of 233 mrad/hr. Again, the differences between Section 3.3.1 and Table 7.1 should be explained. Why include the information in Section 3.3.1 if it is not used? Furthermore, it is not apparent why, in Table 7.1, the contact dose to the hands from non-penetrating radiation should be less than the non-penetrating dose to other parts of the body. Based on the methodology proposed in Section 3.3.1, the non-penetrating dose to other parts of the body can be assumed to be 10 times the photon dose at 1 foot. Applying this model

to the source data used in constructing the Ore Digestion section of Table 7.1 would result in a dose of about 30 mrem/hr. This value appears to be more consistent with a non-penetrating dose to the hands of 66 mrem/hr.

In Table 7.1 (p. 28) under "Boildown and Denitration" penetrating radiation (mR/hr), the table lists the exposure from a 55-gallon drum with 100-day progeny at a distance of 100 cm as 3.10 mR/hr, citing Table 7.2 as the reference. Similarly, the table lists the exposure at 1 cm as 0.28 mR/hr. Referring to Table 7.2, one sees that the exposure at 100 cm is 0.3 mR/hr, and 4.5 mR/hr at 1 cm. A non-penetrating dose based on exposure to a 55-gallon drum at 30 cm is quoted as 4.5 mrem/hr. This is actually the exposure (in mR/h) at 1 cm per Table 7.2. We do not know whether these are typographical errors or systematic errors that were propagated into the Table 7.3 calculations.

In Table 7.1 (p. 29) under "Fluorination" penetrating radiation (mR/hr), NIOSH quotes a value of 0.28, based on exposure to ore. The relevance of using ore as a surrogate for the exposure source in fluorination operations is not apparent. C&H 1960 (p. 92/456) notes that workers involved in the fluorination of UF_4 received doses of 4 to 12 R per month (or up to 70 mR/hr) over extended periods, based on personal film badge monitoring. This suggests that exposures of this class of workers to penetrating radiation may be understated significantly.

7.4 Drum Doses (Section 7.3)

Table 7.2 of the TBD presents external exposure rates (mR/hr) as a function of distance from various size drums. The exposure rates appear to be reasonable.

7.5 Summary of External Doses Received by Workers During Operations (Section 7.4)

Table 7.3 in the TBD is a large summary table where external doses from five sources are presented for work weeks of varying length for various unit operations. No explanation is provided as to how the median and GSD values in Table 7.3 are derived. Consider again the Ore Digestion operator. According to Table 7.3, this worker receives a daily external exposure from contaminated surfaces of 0.206 mR/day based on a 40-hr work week. It should be noted that exposures in Table 7.3 are adjusted for annual calendar days, rather than work days. From Section 7.1.2, the deposition factor is 2.37E4 m, and from Table 3.10, the conversion factor for surface contamination is 4.49E-09 mR/d per dpm/m^2. One also needs the air concentration (dpm/m^3) to calculate the daily exposures. Section 7 is silent on what air concentrations to use, but we presume that they are the dust concentrations subsequently presented in Section 8 of TBD-6001. According to Table 8.3, the median air concentration for the Ore Digestion operator (handling pitchblende ore) is 49 dpm/m^3. From this information, one can calculate that daily exposure is 5.21E-03 mR/day (2.37E04 m × 49 dpm/m^3 × 4.49E-09 mR/day per dpm/m^2). Since this exposure is based on a working day and, for a 40-hr work week, there are 250 work days per 365 calendar days, the exposure adjusted to calendar days would be 3.57E-03 mR/calendar-day. This is lower than the value of 0.206 reported in Table 7.3 by about a factor of 60. We considered the possibility that NIOSH had used 95th percentile values rather than median values for the air concentrations. Using a GSD of 4.949 from Table 8.3, one would estimate the 95th

percentile air concentration to be 678 dpm/m3 (49x $4.939^{1.645}$). We do not understand the basis for this discrepancy.

Given that the objective of the TBD is to provide a default method for reconstructing doses that are claimant favorable to all workers, the 95th percentile values would seem to be more appropriate than the median values of the full distribution. We also recognize that using the upper 95th percentile values for the same worker week after week might be overly conservative. However, such an approach might not be overly conservative if the nature of a given worker's job placed him or her at a high end location week after week. These issues need to be discussed in the TBD, with appropriate guidance provided to the dose reconstructor on how to use the information in the TBD.

Finally, very little information is provided in the TBD as to how the relative exposures to the various classes of workers (Job Titles) in Table 7.3 were developed. This is presumably covered later in Section 8, but should be cross-referenced here.

8.0 OCCUPATIONAL INTERNAL DOSE (SECTION 8)

In the introductory material for Section 8 (page 38), the authors state the following:

> *For each process, there is a table of internal dosimetry parameters – particle size and solubility information. The tabulated values are for reference only, the ICRP (1994) default values are to be used for all internal dose calculations (see Section 3.5).*

The meaning here is not clear. Where are the tabulated internal dosimetry parameters that are for reference only and not to be used?

8.1 Process Specific Uranium Air Sampling Data (Section 8.2)

This section of TBD-6001 reviews the process-specific, airborne uranium exposure summary data reported in C&H 1960. The range and average reported by C&H are used to estimate lognormal distributions for use in dose reconstruction for the job categories reported in the C&H 1960 exposure tables. Tables are included for each of seven unit operations involved in uranium refining—digestion, denitration, oxide reduction, hydrofluorination, metal reduction, metal recasting, and UF_6 fluorination. Tables 8.2, 8.6, 8.9, 8.12, 8.15, 8.18, and 8.21 in Section 8.2 of TBD-6001 repeat the process-specific airborne uranium exposure summary data for the seven operations reported in C&H 1960 Tables 3, 4, 5, 6, 8, 9, and 10, respectively. (The ore sampling stage is not included in the TBD-6001 tables, but was included in C&H 1960 Tables 1 and 2.)

In Tables 8.3, 8.7, 8.10, 8.13, 8.16, 8.19, and 8.22 of Section 8.2 of TBD-6001, the median and GSD of 114 lognormal distributions are reported for various tasks within the C&H unit operations. The lognormal distributions are estimated from the set of summary statistics reported in C&H 1960—the mean and range—using the method reported in Section 2.1.22 of TIB-5000 (Strom 2007). (The procedures advised in TIB-5000 were not part of this review. It should be noted that in several of the TBD-6001 lognormal tables, the reported GSD is less than 1,

although the GSD for a lognormal distribution must be greater than 1. Hence, there appears to be an error here that needs to be corrected.)

Breathing zone (BZ), General Area (GA), and time-weighted daily average (DWA) exposures are included in all these sets of tables. Although lognormal distributions are fitted to all three types of measurements in TBD-6001, only the DWA measurements are used to develop the uranium dust intake rates reported in Section 8.5 of TBD-6001.

The C&H data are the underlying source of information for the lognormal distributions and exposure estimates presented in TBD-6001. The data presented in TBD-6001 faithfully reproduce the values in the original C&H tables. However, only anecdotal information is provided in the 1960 C&H journal article on the details of data processing, and no references are provided for the sources of the original data. Details of the sampling plan for selecting plants and workers for monitoring, the sample sizes at various facilities, the details of the weighting procedures, or the representativeness of the data as a whole are not provided. These shortcomings are inadequately addressed in TBD-6001. One goal of this review of Section 8.2 is to validate the C&H data to the degree possible. A second goal is to review the use of these data in TBD-6001 in estimating the lognormal distributions that are the basis for reconstruction of inhalation intakes.

Validation of C&H 1960 Exposure Data

The most complete set of occupational exposures available for validating the C&H study are the MCW airborne exposure data reported in ORAUT 2005. Tables 12 and 13 of ORAUT 2005 contain detailed data that were available for the C&H study, which also included information from other sites. Tables 12 (Plant 4) and 13 (Plant 6) from ORAUT 2005 are included in this review as Appendix A for inspection.

At first glance, the fact that Figure 16 in the C&H report covers exactly the same span of years as the data contained in Tables 12 and 13 of ORAUT 2005 supports the hypothesis that the MCW data are a very important component of the data available to the C&H study. Figure A-1 contains a scatter plot of the MCW Plant 6 exposures contained in Table 13 of ORAUT 2005, and provides a comparison of the 95th percentile from Table 13 to the yearly 95th percentile estimates reported in Table 8.27 of TBD-6001. The close agreement in the 95th percentiles and the fact that the TBD-6001 95th percentile exceeds the MCW 95th percentile support the premise that the C&H data set contained the MCW data plus additional observations from other facilities.

In order to assess the representativeness of the C&H 1960 data and the TDB-6001 exposure estimates, SC&A analyzed the combined MCW data for Plants 4 and 6. Our goal was to validate the summary statistics for the job categories reported in C&H 1960 (and repeated in TBD-6001) and the lognormal distributions reported in TDB-6001 using only the MCW data. Due to the large number of lognormal distributions presented in the seven tables in Section 8.2 of TBD-6001, only the distributions for the DWA exposures were validated in this review. We selected one C&H job sub-category, generally the earliest in time, within each job (i.e., unit operations) category, and only the MCW data for the appropriate years were included in the comparison.

Table 3 contains the results of our analysis. The range and average reported in each C&H table are shown with the corresponding MCW Plants 4 and 6 statistics. The Plants 4 and 6 values are also expressed as a percentage of the corresponding C&H table entry, with 100% indicating equality of the two values. The results for the lower end of the range (minimums) are plotted in Figure 2 and results for the upper end of the range (maximums) are plotted in Figure 3. In Figure 2, the minimums at Plants 4 and 6 are smaller than those reported in C&H 1960. Examination of Table 3 shows that in all but one case, the minimum of the MCW data for Plants 4 and 6 is smaller (<100%). Although the two data sets appear to have a close correspondence when the upper end of exposures are viewed on this log scale, examination of Table 3 shows that in all cases, the MCW data for Plants 4 and 6 exhibit larger maximums (>100%). In two cases, ore sampling and ore digestion, the Plants 4 and 6 exposures exceed the C&H upper end of range by factors of 4 to 7. This is an unexpected result, since the larger C&H data set would be expected to have a lower minimum exposure than the included MCW data set.

The larger maximums and smaller minimums from the Plants 4 and 6 data indicate that the ranges reported by C&H are narrower than the MCW Plants 4 and 6 exposures would suggest. However, as seen in Figure 4 and Table 3, the average exposures reported in C&H and the Plants 4 and 6 data show no clear pattern of differences. The Plants 4 and 6 data are significantly higher for one operation (ore digestion), and about the same as C&H in the others.

The mean and standard deviation of the logarithms of the MCW exposure data were also calculated for the selected job subcategories in C&H Tables 3, 4, 5, 6, 8, and 9. The data in the last six tables were used to estimate the lognormal distributions found in TBD-6001 Tables 8.3, 8.7, 8.10, 8.13, 8.16, and 8.19, respectively. Note that the ore sampling stage (C&H Tables 1 and 2) is not addressed in the Section 8.2 tables in TBD-6001. The lognormal distribution was used to estimate the median, GSD, and 95th percentiles for each category. The TBD-6001 lognormal median, GSD, and 95th percentiles are compared with the corresponding statistics derived from the Plants 4 and 6 data in Table 4. The medians are compared in a bar chart in Figure 5. The medians show no clear pattern of differences. However, for denitration, oxide reduction, and hydrofluorination, the TBD-6001 medians are higher than the Plants 4 and 6 medians by factors of 3 to 9. This unusual discrepancy may be connected to other anomalies discussed below.

The GSDs of the Plants 4 and 6 data are compared with the GSDs reported in the TBD-6001 tables in Figure 6. Note that the lognormal distributions presented in TDB-6001 have GSDs that often are significantly lower than those for the MCW exposures. In particular, the TBD-6001 estimates of the GSD for denitration and oxide reduction in Plants 4 and 6 are more than a factor of 6 higher than the TBD-6001 estimates. These large differences occur in two of the three categories with high estimates for the median. This discrepancy may indicate a systemic problem in the application of methods prescribed in Section 2.1.22 of Strom 2007 for estimating lognormal distributions from the minimum, average, and maximum. These job categories also have high values in C&H 1960 for the lower end of the range, when compared to the MCW data. This may be another possible explanation for the large differences in the GSD estimates. In this case, overestimation of the lower end of the range of exposures is not necessarily claimant favorable, because this may lead to underestimation of the GSD.

The estimated 95th percentiles of exposure are compared in the chart in Figure 7. Four of the lognormal distributions derived from the MCW exposures have 95th percentiles that are higher than those presented in TDB-6001. As shown in Table 4, the 95th percentiles for digestion, denitration, oxide reduction, and recasting at MCW are higher than those in TDB-6001 by factors of 2 to 5. Anomalies of this magnitude raise questions concerning the weighting procedures in general, and the relative weight assigned to the MCW data in the C&H study.

Use of C&H 1948 to 1956 Averages

Although TBD-6001 addresses exposures over the entire period from 1942 to 1958, the C&H data cover only the period from 1948 to 1956. Hence, the mean exposures reported by C&H are averages over the years 1948 to 1956 only. To address exposures to workers in the pre-1948 time period, TBD-6001 assumes that the 1948 exposures are applicable to the earlier years. However, the average exposures reported by C&H do not give any weight to exposures in the years before 1948, and exposures in 1948 are among the highest exposures reported by C&H. A more appropriate time-weighted mean exposure would account for each year from 1942 to 1958. To see the effect of the missing years, new averages were calculated here by extrapolating the 1948–1956 data to the years 1942–1947 and 1957–1958. Claimant-favorable estimates of exposures in the years 1942–1947 were constructed for each job category by assigning either the upper end of the C&H range or the 95th percentile of the estimated lognormal distributions in TDB-6001 to each year before 1948. For the years 1957 and 1958, the average exposure was used.

Table 5 shows a comparison of the average exposures over the entire 1942–1958 period with the C&H average exposure when the 95th percentile is used as a claimant-favorable estimate of exposures in the years before 1948. The ratio of the 1942–1958 average to the C&H 1948–1956 average is also shown in the table. A graph of the ratios is shown in Figure 8. As expected, the ratios for the 10 job categories, which only apply to years after 1949, are equal to 1, since these categories are not affected by assumptions regarding the early years. However, the job categories that existed in 1948 have ratios as high as a factor of 3.5, indicating that the 1948–1956 averages reported in C&H are not claimant favorable if used for the entire 1942–1958 time period without adjustment to account for exposures in the earlier years. Over all categories, the 1942–1958 average exceeds the C&H 1948–1956 average by a factor of 1.63.

Table 6 shows a similar comparison of the average exposures over the two time periods when the upper end of the C&H range is used as a claimant-favorable estimate for exposures in the years before 1948. The categories that were most affected by giving weight to the early years using the 95th percentile show smaller ratios, in general, when the upper end of the range is used, because the 95th percentiles of the TBD-6001 lognormals often exceed the upper end of the C&H range. When using the upper end of the C&H exposures, the ratios range up to a factor of approximately 2.5. Over all categories, the 1942–1958 average exceeds the C&H 1948–1956 average by a factor of 1.68. A graph of the ratios in Table 6 is shown in Figure 9.

Clearly, use of the average uranium dust exposure data from C&H 1960 is not claimant favorable to those workers whose exposures began prior to 1948.

Table 3. Comparison of MCW Plants 4 and 6 Average Exposure and Range Values with those Reported in C&H 1960

C&H Table No.	Unit Operation	Sub-category	Lower End of Range			Average			Upper End of Range		
			C&H (dpm/m^3)	Plants 4 & 6 (dpm/m^3)	% of C&H	C&H (dpm/m^3)	Plants 4 & 6 (dpm/m^3)	% of C&H	C&H (dpm/m^3)	Plants 4 & 6 (dpm/m^3)	% of C&H
1	Ore Sampling	Manual	140	3	2.1%	800	762	177%	3,000	13,720	457%
3	Digestion	Ore	7	6	86%	110	249	443%	350	2,520	720%
4	Denitration	Up to 1949	4,200	46	1.1%	15,000	8,230	64%	32,000	32,200	101%
5	Oxide Reduction	Tray Furnace	9,800	686	7.0%	20,000	12,168	44%	32,000	46,200	144%
6	Hydrofluorination	UO_2 Loaders	260	35	13%	3,300	2,031	97%	8,900	13,020	146%
8	Reduction to Metal	Bomb Preparation	300	35	12%	875	694	122%	2,300	3,640	158%
9	Metal Recasting	Recasting Furnace	110	189	172%	1,100	2,414	216%	4,100	5,110	125%

Table 4. Comparison of Lognormal Distribution Parameters for MCW Plants 4 and 6 with TBD-6001 Lognormal Parameters

TBD-6001 Table No.	Unit Operation	Sub-category	Median			GSD			95th Percentile		
			TBD-6001 (dpm/m^3)	Plants 4 & 6 (dpm/m^3)	% of TDB-6001	TBD-6001	Plants 4 & 6	% of TDB-6001	TBD-6001 (dpm/m^3)	Plants 4 & 6 (dpm/m^3)	% of TDB-6001
--	Ore Sampling	Manual	--	101	--	--	6.6	--	--	2,272	--
8.3	Digestion	Ore	49.0	109	223%	4.9	3.9	80%	678	1,048	155%
8.7	Denitration	Up to 1949	11,593	1,264	11%	1.7	10.9	651%	27,055	87,556	324%
8.10	Oxide Reduction	Tray Furnace	17,709	6,125	35%	1.3	8.6	675%	26,443	46,999	178%
8.13	Hydrofluorination	UO_2 Loaders	1,334	500	37%	6.1	5.0	81%	26,243	8,465	32%
8.16	Reduction to Metal	Bomb Preparation	240	301	125%	5.0	3.4	68%	3,388	2,602	77%
8.19	Metal Recasting	Recasting Furnace	672	1,145	170%	2.7	7.8	292%	3,407	17,368	510%

Table 5. Comparison of Estimated Average Exposure from 1942 to 1958 with C&H 1948 to 1956 Average Exposure
(Assumes 95th Percentile Estimate for Years 1942 to 1947)

Job Category	Average 1942–1958 (dpm/m^3)	C&H Average 1948–1956 (dpm/m^3)	Ratio of Averages 1942–1958/ 1948–1956
Ore Sampling-Manual	1,576	800	1.97
Ore Sampling-Automatic	158	140	1.13
Sampling-Concentrate	158	140	1.13
Digestion-Ore	310	110	2.82
Digestion-Concentrate	61	40	1.53
Denitration-Up to 1949	24,041	15,000	1.60
Denitration-After 1949	130	130	1.00
Oxide Reduction-Tray Furnace	25,522	20,000	1.28
Oxide Reduction-Multiple Hearth	700	700	1.00
Oxide Reduction-Horizontal Reactor	140	140	1.00
Hydrofluorination-UO2 Loaders	11,398	3,300	3.45
Hydrofluorination-Furnace Operator	1,228	500	2.46
Hydrofluorination-UF4 Packagers	2,762	1,300	2.12
Reduction to Metal-Bomb Preparation up to 1951	2,383	875	2.72
Reduction to Metal-Reduction Operations up to 1951	814	300	2.71
Reduction to Metal-Bomb Preparation after 1951	30	30	1.00
Reduction to Metal-Reduction Operations after 1951	11	11	1.00
Metal Recasting-Crucible Loading up to 1951	64	51	1.25
Metal Recasting-Recasting Furnace up to 1951	2,484	1,100	2.26
Metal Recasting-Crucible Burnout up to 1951	139	50	2.77
Metal Recasting-Billet Cleaning up to 1951	79	47	1.69
Metal Recasting-Crucible Assembly up to 1951	732	360	2.03
Metal Recasting-Crucible Loading after 1951	36	36	1.00
Metal Recasting-Recasting Furnace after 1951	47	47	1.00
Metal Recasting-Crucible Burnout after 1951	70	70	1.00
Metal Recasting-Billet Cleaning after 1951	28	28	1.00
Metal Recasting-Crucible Assembly after 1951	55	55	1.00
UF6 Fluorination-Hex Loaders	3,012	2,600	1.16
UF6 Fluorination-Fluorination Operators	2,130	1,100	1.94
UF6 Fluorination-Still Operators	511	350	1.46
UF6 Fluorination-Central Loaders	635	550	1.16
All Categories	2,627	1,612	1.63

Table 6. Comparison of Estimated Average Exposure from 1942 to 1958 with C&H 1948 to 1956 Average Exposure
(Assumes Upper End of Range Estimate for Years 1942 to 1947)

Job Category	Average 1942–1958 (dpm/m^3)	C&H Average 1948–1956 (dpm/m^3)	Ratio of Averages 1942–1958/ 1948–1956
Ore Sampling-Manual	1,576	800	1.97
Ore Sampling-Automatic	158	140	1.13
Sampling-Concentrate	158	140	1.13
Digestion-Ore	195	110	1.77
Digestion-Concentrate	61	40	1.53
Denitration-Up to 1949	27,750	15,000	1.85
Denitration-After 1949	130	130	1.00
Oxide Reduction-Tray Furnace	30,286	20,000	1.51
Oxide Reduction-Multiple Hearth	700	700	1.00
Oxide Reduction-Horizontal Reactor	140	140	1.00
Hydrofluorination-UO2 Loaders	5,276	3,300	1.60
Hydrofluorination-Furnace Operator	747	500	1.49
Hydrofluorination-UF4 Packagers	2,394	1,300	1.84
Reduction to Metal-Bomb Preparation up to 1951	1,730	875	1.98
Reduction to Metal-Reduction Operations up to 1951	702	300	2.34
Reduction to Metal-Bomb Preparation after 1951	30	30	1.00
Reduction to Metal-Reduction Operations after 1951	11	11	1.00
Metal Recasting-Crucible Loading up to 1951	67	51	1.31
Metal Recasting-Recasting Furnace up to 1951	2,900	1,100	2.64
Metal Recasting-Crucible Burnout up to 1951	80	50	1.60
Metal Recasting-Billet Cleaning up to 1951	67	47	1.42
Metal Recasting-Crucible Assembly up to 1951	468	360	1.30
Metal Recasting-Crucible Loading after 1951	36	36	1.00
Metal Recasting-Recasting Furnace after 1951	47	47	1.00
Metal Recasting-Crucible Burnout after 1951	70	70	1.00
Metal Recasting-Billet Cleaning after 1951	28	28	1.00
Metal Recasting-Crucible Assembly after 1951	55	55	1.00
UF6 Fluorination-Hex Loaders	4,259	2,600	1.64
UF6 Fluorination-Fluorination Operators	2,688	1,100	2.44
UF6 Fluorination-Still Operators	548	350	1.56
UF6 Fluorination-Central Loaders	744	550	1.35
All Categories	2,713	1,612	1.68

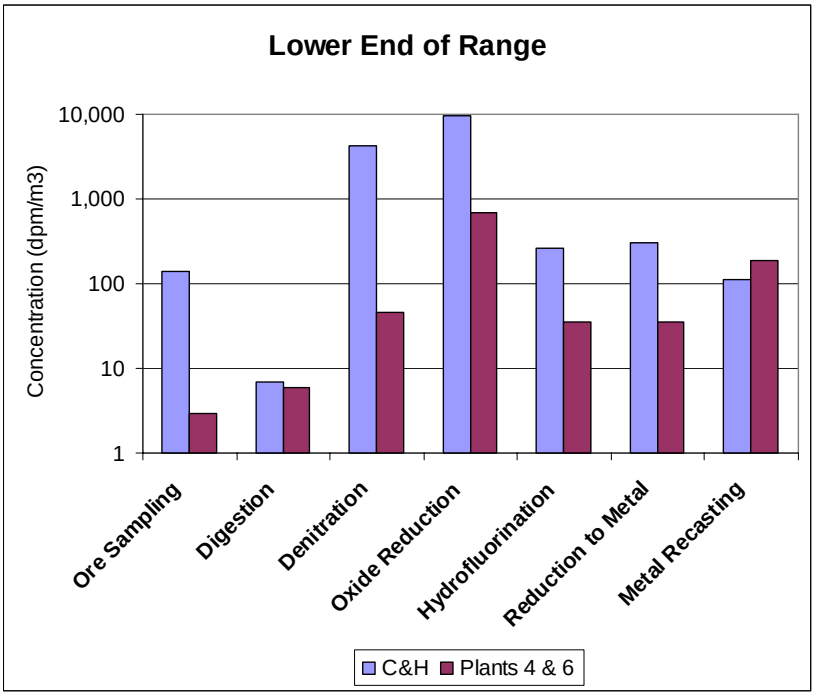

Figure 2. Comparison of C&H Tabulated Lower End of Range with Mallinckrodt Plants 4 and 6 Lower End of Range

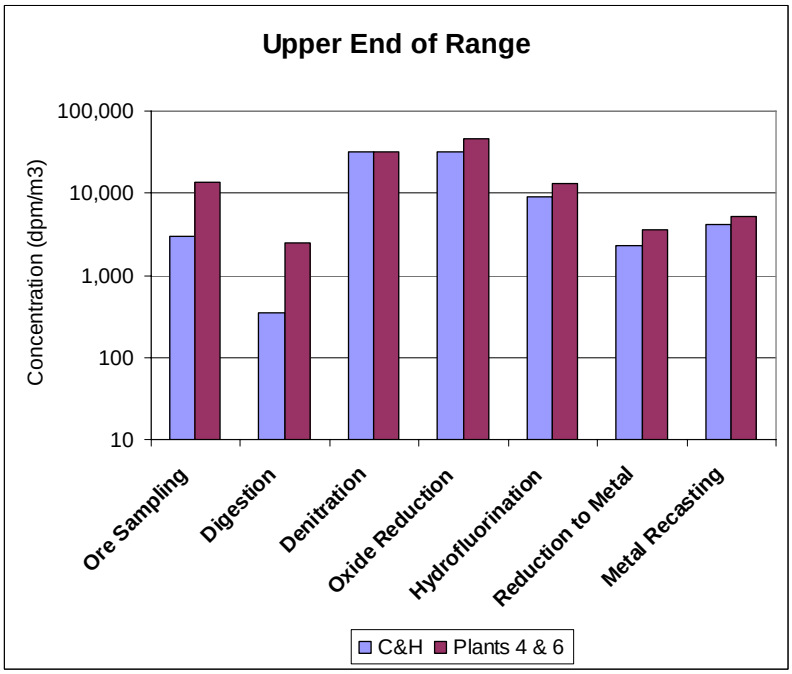

Figure 3. Comparison of C&H Tabulated Upper End of Range with Mallinckrodt Plants 4 and 6 Upper End of Range

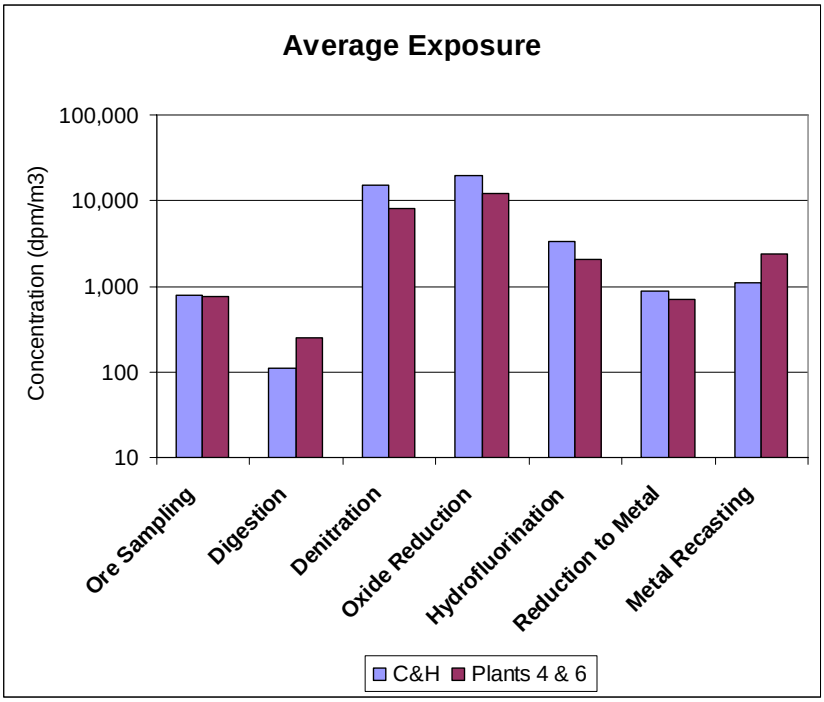

Figure 4. Comparison of C&H Tabulated Average Exposure with Mallinckrodt Plants 4 and 6 Average Exposure

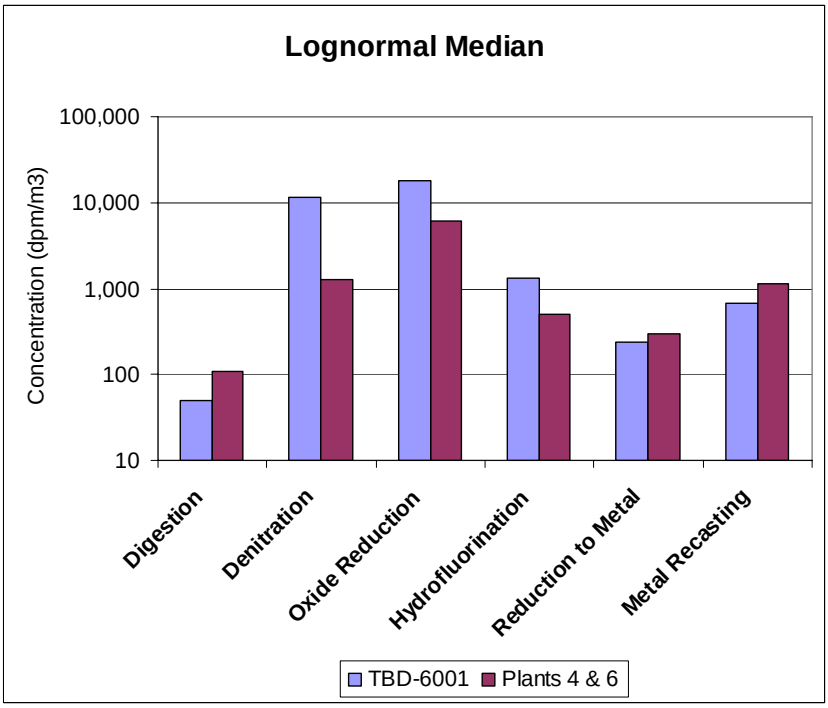

Figure 5. Comparison of TBD-6001 Lognormal Median with Mallinckrodt Plants 4 and 6 Lognormal Median

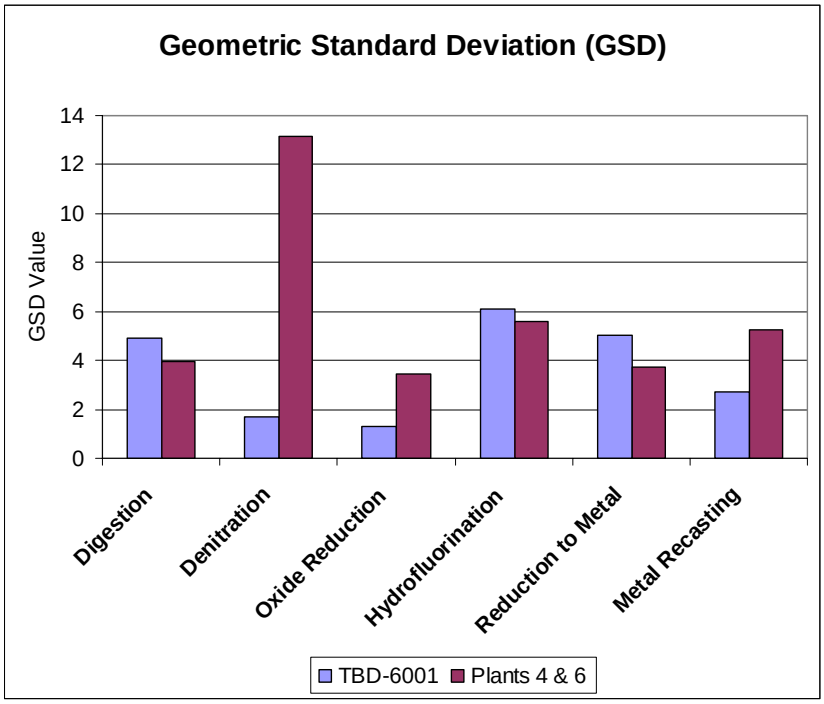

Figure 6. Comparison of TBD-6001 Lognormal GSD with Mallinckrodt Plants 4 and 6 Lognormal GSD

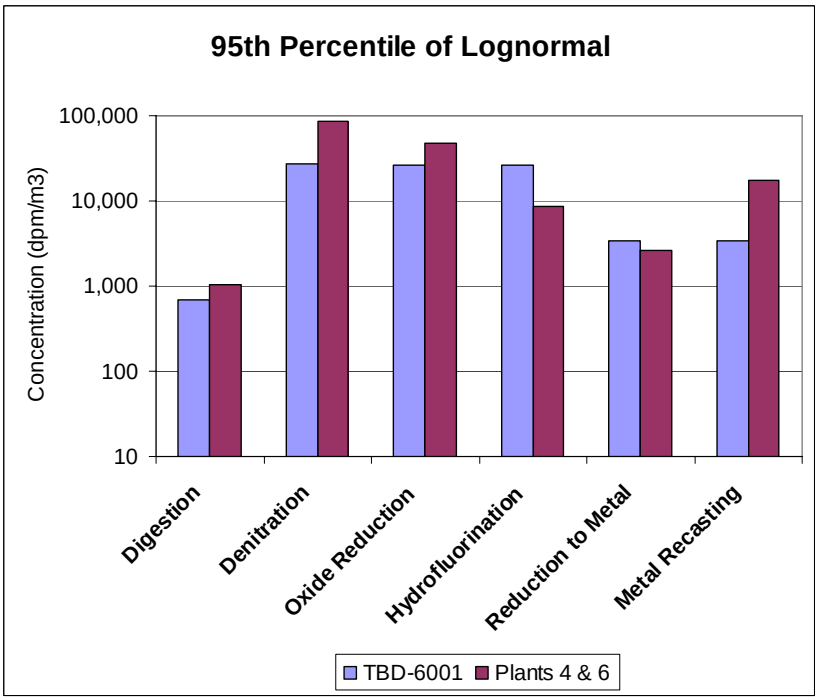

Figure 7. Comparison of TBD-6001 Lognormal 95th Percentile with Mallinckrodt Plants 4 and 6 Lognormal 95th Percentile

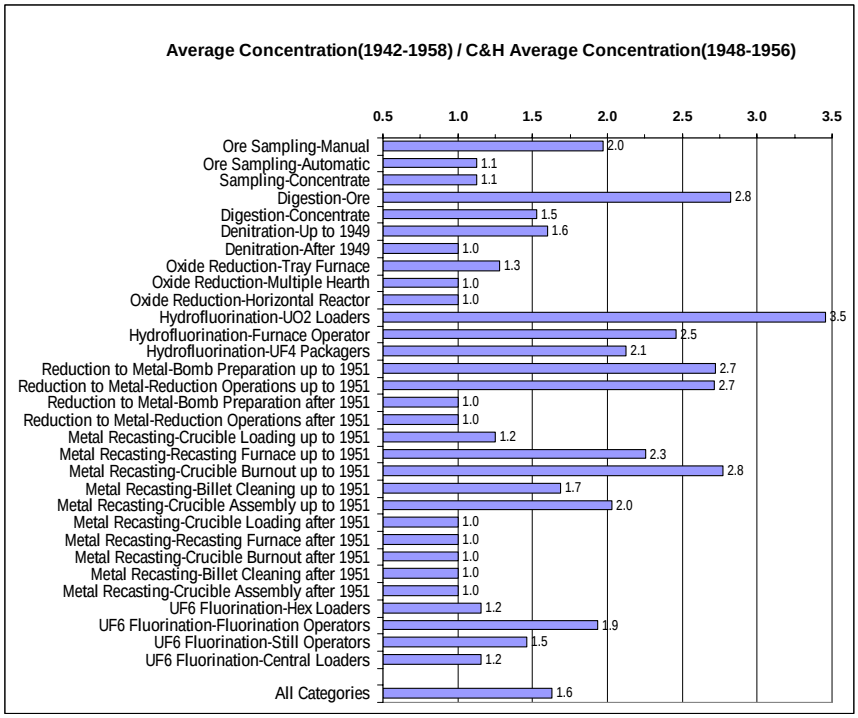

Figure 8. Comparison of Estimated Average Exposure (dpm/m^3) from 1942 to 1958 with C&H 1948 to 1956 Average Exposure (dpm/m^3)
(Assumes 95th Percentile Estimate for Years 1942 to 1947)

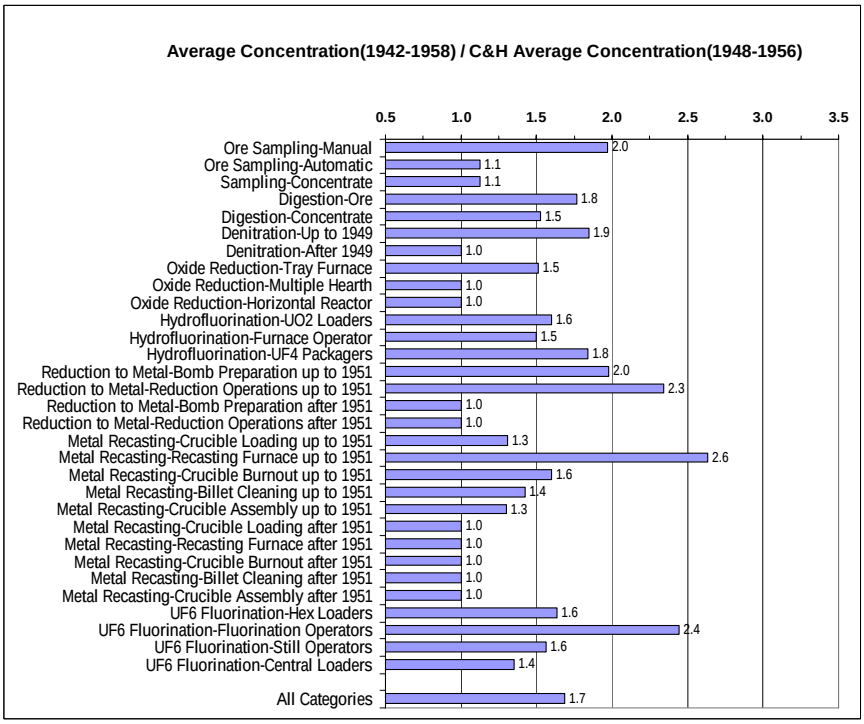

Figure 9. Comparison of Estimated Average Exposure (dpm/m^3) from 1942 to 1958 with C&H 1948 to 1956 Average Exposure (dpm/m^3)
(Assumes Upper End of Range Estimate for Years 1942 to 1947)

8.2 Resuspension during Periods with No Uranium Operations (Section 8.3)

Resuspension of radioactive dust during periods of non-operation is discussed in Section 8.3 (p. 48). This same material is duplicated under the same title in Section 8.5.2 (p. 58). The methodology presented relies on a prior analysis of uranium **metal-working** operations. The methodology assumes that particles with a 5-µm AMAD in a dust cloud containing 7,000 dpm/m^3 settle at a terminal velocity of 7.5E-04 m/s. Settling occurs during 20 hours of daily operation for a 1-year period. The calculated surface contamination is 3.44E07 pCi/m^2. (About 202 work days per year are implicit in this contamination level, i.e., 7,000dpm/m^3 × 7.5E-04 m/s × 1/2.22 pCi/dpm × 3.6E03 sec/hr × 20 hr/day × 202 day/yr = 3.44E07 pCi/m^2). However, in Section 3.4.2, exposures from contaminated surfaces are based on continuous deposition for 365 days. We do not understand why calculations in Section 8.4.2 are not done on the same basis as those in 3.4.2.

We have already described elsewhere in this review (see Section 6.1.1) and in SC&A 2007 our concerns with using terminal velocity for 5-µm AMAD particles to estimate surface contamination levels. TBD-6001 (Section 8.3) assumes a resuspension factor 1×10^{-6}/m. SC&A had previously questioned the use of this parameter value in SC&A 2007, indicating that a higher value would be consistent with available information. In addition, review of the average exposure data in C&H 1960 suggests that the use of 7,000 dpm/m^3 as the air concentration estimate may be low for certain unit operations. Average values of daily weighted exposures for denitration operations up to 1949 were 15,000 dpm/m^3 (C&H 1960, Table 4), and 20,000 dpm/m^3 for oxide reduction in trays (C&H 1960, Table 5). These are average values for all surveys for those operations over the relevant time periods. On the other hand, an air concentration of 7,000 dpm/m^3 is probably claimant favorable for the other unit operations considered in TBD-6001.

8.3 Time-Dependent Air Concentration Data (Section 8.4)

NIOSH states that the relevant evaluation period for TBD-6001 is 1942 through 1958; however, the C&H 1960 report covers only the period 1948 through 1956. To address this difference in time periods, it is assumed in Table 8.28 (p. 53) that the year-specific correction factor of 6.89 be used for the years prior to 1948, and the year-specific correction factor of 0.0792 be used after 1956. Use of the 6.89 factor does not appear to be claimant favorable for the period 1942 through 1947. As shown in Figure 16 of C&H 1960, reproduced as Figure 1 in TBD-6001, there was a rapid decline (greater than an order of magnitude) in the weighted dust exposures over the period 1948–1950, as process improvements were implemented. This suggests that dust levels prior to 1948 could be substantially higher than implied by the year-specific correction factor. For example, NIOSH estimates a mean air concentration of 7,398 dpm/m^3 for 1948 (see Table 8.27). Values of daily weighted average exposures reported at MCW for the period 1946–1948 include the following:

- TA unloader (operator) – 13,000 dpm/m^3 (ORAUT 2005, Table 19)
- Furnace operator – 24,780 dpm/m^3 (ORAUT 2005, Table 20)
- LF-9/brown/UO_2/packager/unloader – 38,990 dpm/m^3 (ORAUT 2005, Table 20)
- Miller (UO3QM-2) – 12,600 dpm/m^3 (ORAUT 2005, Table 20)

- Ore room operator – 13,720 dpm/m^3 (ORAUT 2005, Table 20)

These values are significantly higher than the mean value of 7,398 dpm/m^3 calculated by NIOSH for 1948.

Given the fact that correction factors proposed by NIOSH for the period prior to 1948 may lead to understated inhalation exposures, SC&A developed an alternative methodology to calculate year-specific correction factors. This alternative methodology is presented below.

Alternative Methodology to Calculate Year-Specific Correction Factors

The mean exposure concentrations in each year from 1948 to 1956 (derived by digitizing Figure 16 in C&H 1960) are presented in Table 8.27 of TBD-6001. Figure 2 of TBD-6001 shows a plot of the mean concentrations using a logarithmic scale. A similar plot is shown here in Figure 10, where the mean concentrations are plotted by year from 1948 to 1956. Due to the wide range of mean values, the natural logarithms of the mean concentrations are plotted on the vertical axis. The horizontal dashed lines extending from each end of the plot represent the NIOSH extrapolation of the 1948 and 1956 values to the earlier and later time periods, respectively. The least squares trend line which best fits the data is also shown in the figure. The trend line has a relatively high R^2 of 0.78 and a significantly negative trend coefficient of -.51. (The t-statistic for the slope of the trend line is -5.02. A t-statistic that is lower than -2.3 indicates that the trend coefficient is significantly negative.). Given the relatively good fit of the trend line, it is not unreasonable to use the trend line for estimating the dose to workers exposed during time periods before 1948 and after 1956.

Table 8.28 of TBD-6001 presents a table of ratios (correction factors) prescribed for adjusting claimant exposures to airborne uranium in individual years 1942–1958. The ratios are derived from the 1948 to 1956 mean concentrations shown in Figure 10. The tabulated correction factor for 1948 is prescribed by NIOSH for use in the years from 1942 to 1947, and the tabulated correction factor for 1956 is prescribed for use in the years 1957 and 1958. Figure 11 shows a comparison of the TBD-6001 Table 8.28 correction factors with factors derived from the trend line in Figure 10. Both sets of ratios are scaled, so that a worker who is employed during the entire period from 1948 to 1956 would have an unchanged total dose using these ratios (i.e., the average correction factor over these years is equal to 1). For those workers who did not work for the entire period or those who worked in the years before 1948 and after 1956, these ratios are used to adjust their dose estimates in the years they worked. As shown in Figure 11, the TDB-6001 correction factors based on backward extrapolation of the 1948 value are not as claimant favorable as the factors derived from trend line extrapolation to the earlier years.

The TDB-6001 mean concentrations and the trend line estimates of the mean concentration plotted in Figure 10 are detailed in Table 7. The exposure correction factors derived from each set of mean concentrations are also shown in the table. The correction factors derived from the trend line exceed the factors derived in TBD-6001 by the horizontal extrapolation method by as much as a factor of 10 in the earlier years. The correction factors derived from the trend line also appear to be more claimant favorable in the years with data (1948–1956). The sole exception is 1948, when the trend line falls appreciably below the data. This is an important exception,

because the highest recorded doses (from C&H 1960) occur in this year. For this year, the data-based correction factor in TBD-6001 should be retained in order to remain claimant favorable.

In the period from 1957 to 1958, the trend line leads to less claimant favorable correction factors than horizontal extrapolation. The TBD-6001, Table 8.28 factors also should be retained in these years to be claimant favorable.

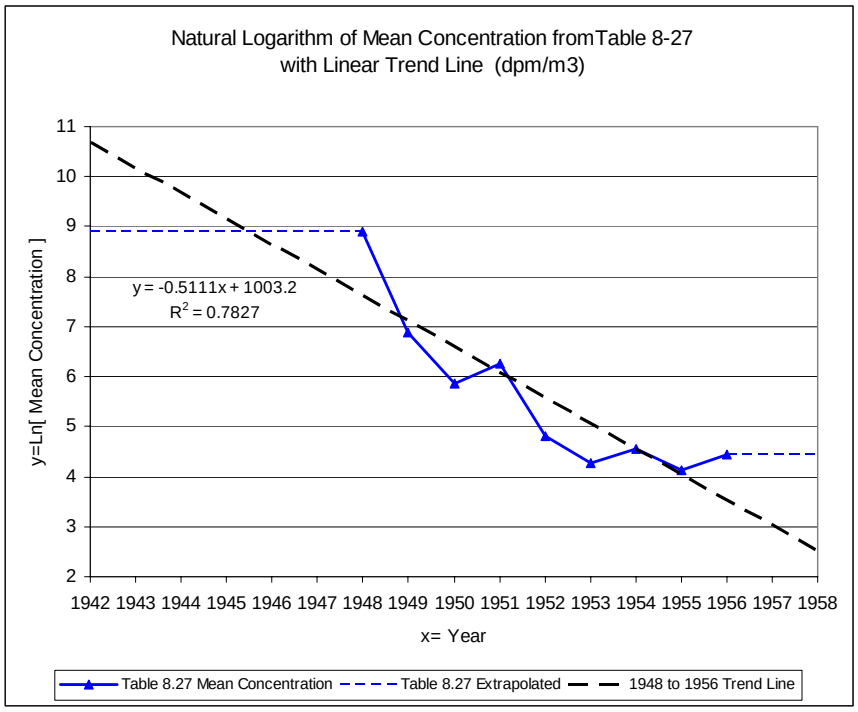

Figure 10. TBD-6001 Table 8.27 Mean Air Concentrations from 1948 to 1956, with Extrapolation to Earlier and Later Years and Regression Trend Line (n=9, R^2=0.78)

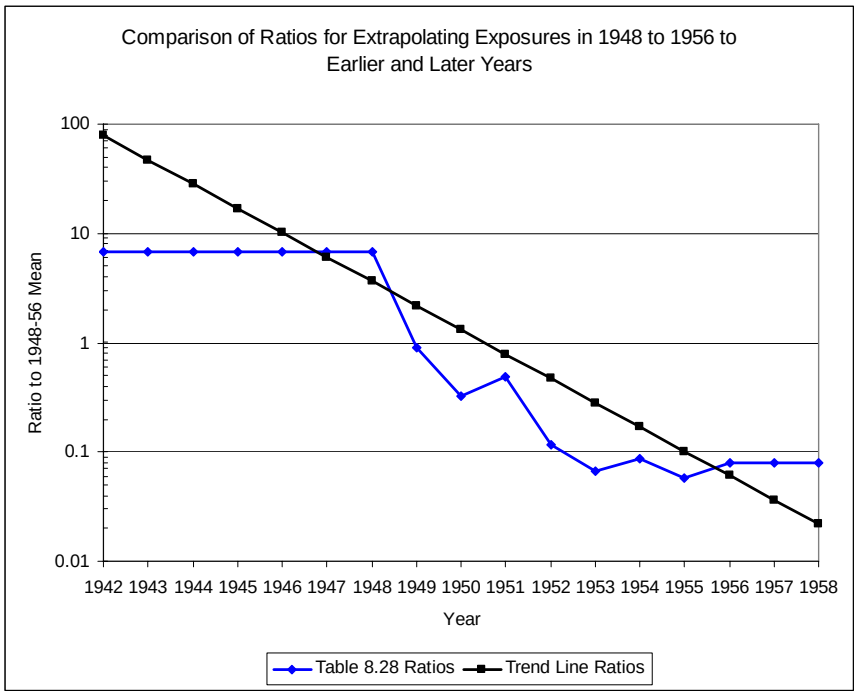

Figure 11. Comparison of TBD-6001 Table 8.28 Year-Specific Correction Factors with Factors Derived from 1948 to 1956 Trend Line

Table 7. Comparison of Year-Specific Correction Factors from TBD-6001 Table 8.28 with Correction Factors Derived from 1948 to 1956 Trend Line

	Mean Concentration (dpm/m^3)		Correction Factor Ratio to 1948–1956 Average		
Year	TBD-6001 (Table 8.27)	Trend Line	TBD-6001 (Table 8.28)	Trend Line	Percent Difference
1942		43,388	6.89	78.10	1034%
1943		26,026	6.89	46.85	580%
1944		15,611	6.89	28.10	308%
1945		9,364	6.89	16.86	145%
1946		5,617	6.89	10.11	47%
1947		3,369	6.89	6.07	-12%
1948	7,398	2,021	6.89	3.64	-47%
1949	964	1,212	0.897	2.18	143%
1950	349	727	0.325	1.31	303%
1951	521	436	0.485	0.785	62%
1952	124	262	0.1154	0.471	308%
1953	71	157	0.0661	0.283	327%
1954	94	94.1	0.0875	0.169	94%
1955	63	56.5	0.0586	0.102	73%
1956	85	33.9	0.0791	0.061	-23%
1957		20.3	0.0791	0.037	-54%
1958		12.2	0.0791	0.022	-72%
Mean (1948–1956)	1,074	556	1.00	1.00	0%

8.4 Summary (Section 8.5)

In TBD-6000, NIOSH provided the following guidance with regard to uranium air-sampling data:

> *For the air sampling data presented in this section, data are presented for individual worker positions, as listed in the Harris and Kingsley (1959) tables. When a claimant's job category is known, the air sampling data for the corresponding job category can be used for the dose reconstruction. Where the claimant's job category is unknown or does not correspond to a listed category, the maximum air sampling data should be used* (Battelle 2006, pp. 43–44).

In its review of TBD-6000, SC&A commended NIOSH on providing this guidance (SC&A 2007). We did not find similar guidance in TBD-6001 and believe it should be provided there as well. We believe that this is particularly important since, as early as 1949, health physicists judged that it would be impossible to estimate dust exposures based on job descriptions, because the men were transferred from one department to another and no records were made of the transfers (NYOO 1949, p. 53).

Table 8.29 (p. 54) provides intake rates for uranium dust from various operations. It may be noted in the table that an ore digestion operator working a 40-hr week would have a median

inhalation exposure of 145 pCi/day. We presume that this value is calculated per Section 8.5.1as follows:

$$I_{IMBA} = 3.288 \times 10^{-3} Ah,$$

where

I_{IMBA} is the IMBA chronic intake in pCi/d,
A is the air concentration (pCi/m^3) and
h is the number of working hours in a year.

If the measured air concentration has units of dpm/m^3, then divide the constant by 2.22 (dpm/pCi).

For a 40-hr work week, h is 2,000 hours and A from Table 8.3 is 49 dpm/m^3. ($I_{IMBA} = 3.288 \times 10^{-3} \times 2{,}000 \times 49/2.22 = 145$ pCi/d.) This is the median average daily exposure for an operator handling pitchblende ore. Choice of an operator handling ore rather than concentrates is claimant favorable, since the comparable number for handling concentrates is 41 dpm/m^3. The median average exposure in Table 8.3 is derived from data in Table 8.2, which were taken directly from Table 3 of C&H (1960). C&H 1960 refers to the summary values in Table 3 as "average daily exposure." In other tables in C&H 1960, terms such as "DWA" (Tables 5 and 10), "average weighted exposure" (Table 4), "daily average exposure" (Table 2), "weighted average exposure" (Tables 6 and 8), "weighted average" (Table 9), "average exposure" (Table 11), and "daily weighted average" (Table 1) are used. We presume these terms are synonymous (and, apparently, they are assumed to be synonymous in TBD-6001), but we are not sure. NIOSH should clarify this.

9.0 MINOR COMMENTS AND TYPOGRAPHICAL ERRORS

Page viii. In ICRP documents, AMAD is defined as "activity median aerodynamic diameter." See also pages 11 and 27.

Page 3, line 2. Why is Th refining mentioned when it is not discussed in the TBD?

Page 3, Section 3.1, third paragraph. Typo: pitchblende (sp.).

Page 4, third paragraph. The document indicates that uranium recycling occurred "after 1953." According to DOE 2003, Hanford supplied recycled U to ORGDP in 1952.

Page 6, Section 3.3, first bullet. Typo: "photons" duplicated.

Page 7, third paragraph. Is there a basis for assuming that the workers' hands are in contact with uranium 50% of the day? The assumption is probably claimant favorable, but if there is support for the assumption, it should be provided.

Page 8, Section 3.3.2. The meaning and intent of the sentence "A quick check…." is not obvious.

Page 8, Section 3.3.3. This section references ORAUT-OTIB-0004 Revision 3 as the source of the statement that natural uranium photon energies range from 30 to 250 keV. ORAUT-OTIB-0004 iterates the same range, but provides no indication as to the source of the values.

Page 8, Table 3.5. Typo: We believe that the reference should read "DOE-STD-1136-2004."

Page 9. Table 3.7. "and doses" should be eliminated from the table title. It only presents dose rates.

Page 10, Section 3.4, last line. Typo: We believe that this should be Sections 3.4 not 3.3.

Page 10, Section 3.4.1. This section deals only with Exposure from Submersion. Exposure from Contaminated Surfaces is discussed in Section 3.4.2. The authors should discuss why different photon energy distributions are used in Sections 3.4.1 and 3.4.2.

Page 11, Table 3.9. The source of the data for this table is not apparent.

Page 12, Section 3.4.3. The source of the data in Table 3.11 is not apparent.

Page 15, Section 4.1, first sentence. "Hot" uranium ore should be defined, as should the phrase "concentrate (without processing)." Concentrate generally implies a product resulting from a processing operation. Presumably "hot' ore is high-grade pitchblende containing 20% to 50% U_3O_8.

Page 18. Section 4.10. What is "purified uranium ore?" This is not common terminology. The referenced figure seems irrelevant; it shows a rail car modified to handle shipment of hot ore. Typo: Ore is singular.

Page 18, Section 4.10. The authors state that, "The dose rates due to neutrons from spontaneous fission are about 0.09% of the photon dose rates." What is the source of this information?

Page 18, first line. Typo: Eisenbud (sp.).

Page 23, Table 6.1. External exposures from submersion are presented here in units of mrem/day, while comparable exposures in Table 7.3 are presented in units of mR/day. It would facilitate comparison of environmental and occupational doses if the units were consistent.

Page 26, Section 7.1.2. The table citation should be Table 3.10, not Table 3.9.

Page 29, Table 7.1. Table entries for hydrofluorination list Tables 1.3 and 5.6 as references. There are no such tables in TBD-6001.

Page 31, Section 7.4. The text notes that "skin" pathways are at a skin depth of 0.07 mg/cm^2, while page 7, second paragraph, states that skin doses are based on 7 mg/cm^2.

Page 32, Table 7.3. It would be helpful if the abbreviations in the "Geometry" column were defined in a table footnote.

Page 40, Section 8.2.4, third sentence. The term "Method 3" is not used elsewhere in TBD-6001. For connectivity with Tables 8.9 and 8.10, use "horizontal reactor operations" instead.

Page 47, Table 8.24. Presumably the heading for the last two columns should be "calciner," not "trays."

Page 53, Table 8.28. Christofano and Harris reference is confusing. The figure in question is Figure 16 in C&H and Figure 1 in TBD-6001. The same comment applies to Footnote 2 on page 54.

Page 54, Table 8.29. The terminology "three work week durations" is confusing.

10.0 REFERENCES

Battelle 2006. *Site Profiles for Atomic Weapons Employers that Worked Thorium and Uranium Metals*. Battelle-TBD-2006. PNWD-3758, Rev. 0.

Christofano E. and W.B. Harris. 1960. *The Industrial Hygiene of Uranium Refining*. Env Health 1(5):74-96.

DOE (U.S. Department of Energy) 2003. *Recycled Uranium: United States Production, Enrichment,and Utilization*. DOE/SO-0003. Available on the web at: http://www.ssa.doe.gov/sp70/documents/Recycled%20Uranium%20May%202003.pdf .

Harris, W.B., and I. Kingsley, 1959. *The Industrial Hygiene of Uranium Fabrication*, Table 5, Archives of Industrial Health, Volume 19, reprint, American Medical Association, New York, New York. May. [SRDB Ref. ID: 15779]

ICRP (International Commission on Radiation Protection) 1994. Human Respiratory Tract Model for Radiological Protection. Publication 66. Ann. ICRP 24(3-1). Oxford: Pergamon Press.

ICRP (International Commission on Radiation Protection) 1968. "ICRP Database of Dose Coefficients: Workers and Members of the Public." V. 2.01. DOCAL Task Group Committee 2 of the International Commission on Radiation Protection. October 1998.

Lide, D.R., 1995. *CRC Handbook of Chemistry and Physics*, 75th edition. CRC Press, Boca Raton, Florida.

NCRP (National Council on Radiation Protection and Measurements) 1987. *Ionizing Radiation Exposure of the Population of the United States*. NCRP Report No. 93.

NYOO 1949. *Health Hazards in NYOO Facilities Producing and Processing Uranium*. (A Status Report – April 1, 1949), New York Operations Office, U.S. Atomic Energy Commission.

ORAUT (Oak Ridge Associated Universities Team) 2004. *Technical Basis Document for Fernald Environmental Management Project*. ORAUT-TKBS-0017, Revision 01. ORAU Team. Cincinnati, Ohio.

ORAUT (Oak Ridge Associated Universities Team) 2005. *Basis for development of an exposure matrix for the Mallinckrodt Chemical Company St. Lewis downtown site and the St. Lewis airport site, St. Louis, Missouri, period of operation: 1942–1958*. ORAUT-TKBS-0005, Revision 01. ORAU Team. Cincinnati, Ohio.

ORAUT (Oak Ridge Associated Universities Team) 2006. *An Exposure Matrix for Linde Ceramics Plant (Including Tonawanda Laboratory)*. QRAUT-TKBS-0025, Rev. 00 PC-1. ORAU Team. Cincinnati, Ohio.

ORAUT (Oak Ridge Associated Universities Team) 2007. *An Exposure Matrix for Harshaw Chemical Company, Cleveland Ohio.* ORAUT-TKBS-0022, Rev. 00. ORAU Team. Cincinnati, Ohio.

Perry, Robert H. and Don W. Green 1984. *Perry's Chemical Enginees' Handbook*, Sixth Edition. McGraw-Hill Inc., New York NY.

SC&A 2005. *Review of NIOSH Site Profile for Mallinckrodt Chemical Company, St. Louis Downtown Site, St. Louis, MO*. SCA-TR-Task1-0002, SC&A, Inc., Vienna, Virginia. January 31, 2005.

SC&A 2007. *Draft Review of Technical Basis Document 6000*, SC&A, Inc., Vienna, Virginia. September 12, 2007.

Strom, Daniel F. 2007. *Default Assumptions and Methods for Atomic Weapons Employer Dose Reconstructions*. Battelle-TIB-5000, Rev. 00, Effective date: April 2, 2007.

APPENDIX A: TABLES 12 AND 13 FROM ORAUT 2005

Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St. Louis Airport Site, St. Louis, Missouri, Period of Operation: 1942–1958

Table 12. Plant 4 Measured Daily Weighted Average Exposure Concentrations

Occupation	Weighted Average Concentration, Alpha dpm/m^3								
	May-56	**Nov-53**	**Mar-53**	**Jun-50**	**Oct-49**	**Sep-48**	**May-48**	**AEC 1949b**	**AEC 1951a**
Magnesium operator				35	70				
Lime blender				35	70				
Slag man				70	105	210	140		
Cage man (handler)				190		3640	189	2940	
Derby unloader				175	245	1,260	280		
Bomb topper				210	280	2,310	840		
Charge firing				140	350	980	910		
Derby chipper				140	350	910	1,890		
Jolter				70	140	490	3,500		
Bomb charger				210	490	3,010	3,640		
Green lead man				70	140				
Cleanup man				140	140				
Furnace tender				70	70	350	560		
Furnace box puller				35	140	560	630		
TA-7 Pilot Plant				980	175				
Brown loader				280	350	2,240	3,360		
Green packer				245	210	1,750	3,990		7,210
Green miller and mixer				70	140	980	4,690		
Green unloader				210	490	1,540	13,020		
Plant superintendent	7.3								
Technical supervisor	6.6								
Engineers	7.3	9.8	14						
Chief chemist	5.9								
Vacuum fusion chemist	39								
Vacuum fusion technician	59								
Microscopist	18.4								
Chemist	10								
Chemical technician	10	4.6	7						
Foreman	22.5	6.7	12	35	70	175			
Shift foremen	12.4			56	98	175			
Lead operator	25	8.2	19	119	63	---			
Dingot/bomb, slag grinding oper	85	33	64	X	X	X		X	
Furnace and saw man	17.5			X	X	X		X	
Casting furnace operator	10.8	110	480					5110	
Furnace operator (UF4-derby?)				91	70	570			
HF operator				91	70	570			
UO3 & Brown packer				217	322	2,730		4200	2,730
Green packing operator				196	315	7,210		4,000; 13,000	
Asst green packing operator				112	133	2,800			
Residue	27.4								
Ceramic	14.8								
Vertical lathe	28.5								
Forge press lead operator	22								
Forge press salt bath man	21.5								
Forge press manipulator (oper)	22.6								

Table 12. Plant 4 Measured Daily Weighted Average Exposure Concentrations

Occupation	Weighted Average Concentration, Alpha dpm/m^3								
	May-56	**Nov-53**	**Mar-53**	**Jun-50**	**Oct-49**	**Sep-48**	**May-48**	**AEC 1949b**	**AEC 1951a**
Forge press operator	21.9								
Clerk	5							42	
Guard	7.1							28	
Porter	40	2.7	5.8					56	
Area mechanic	---	22	15	84	112	350		350	

Data from the surveys of 6/50, 10/49, 9/48, and 5/48 is from AEC 1950c; data from the surveys of 3/53 and 11/53 is from AEC1954b; and data from the survey of 5/56 is from AEC 1956a. Other data are from the references given in the column headings.

Table 13. Plant 6 Measured Daily Weighted Average Exposure Concentrations

Occupation	Weighted Average Concentration, Alpha dpm/m^3								
	May-56	**May-54**	**Oct-53**	**Jan-53**	**Jan-52**	**Aug-50**	**1949**	**Oct–Nov 1948**	**May-48**
Digest area lead operator	6	60	36	62	140	84		686	280
Digest operator	7.3	37	41	52	370	77		399	490
U-Con man #1	7.3								
U-Con man #2	14								
Feinc operator	6.2	96	38	110	175	154		980	840
Barium operator			38	130	144	126			280
Feed operator	40.8	23	100	150	110	126		910	476
C-3 wash filter operator		79	32	48	120	116		497	476
C-3 adjustments operator			22	420	120			497	476
C-3 centrifuge operator		42	630	52		140		567	476
Ore Room operator			140	170	370	392	350	13,720	4970
Extraction area lead operator	34	5.4	4						
Ether House operator	11					40		46	
Ether House lead operator						66		154	
Sump recovery operator			8.5	100	76	126		273	364
Raffinate operator	216	11	8	170	68	154		273	364
QM-2 (Orange) packager	268	1,961	120	130	130				
Furnace operator	12	33	55	96	150	1,400		5320	24500
Furnace room sampler								3150	
Reduction area (furn room) lead oper'r	22	25	28	69	54	147		686	
LF-9 (Brown) packager						364		11270	39200
Nitric acid recovery operator	20	9.6	19	44	35	99		46	364
Pot Room operator	234	113	45	190	100	336	770	7,770	32200
Metal dissolver #1	204								
Metal dissolver #2	21								
MGX operator		29	68	52	94				
Utility operator	88	129	94	97					
Miller (Mill Room)						X	X	12,600	46200
Pilot Plant group leader	7.5	6.9	3.1			105		91	245
Pilot Plant lead operator	7.7	8.8	6.1	77	116	105		91	245
Pilot Plant technician	1,940	9.2	6	77	116	105		91	245
Production superintendent	7.7	8.8	56	25					
Experimental continuous furnace						8,540	X	X	X
Asst. production superintendent	18	21	26						
General/Asst foreman	14	18	30	50					
Foreman	17	21	29	58				161	
Technical supervisor	18	21	25	33		52		161	
Production Office clerk	9.1	12	18	17		27		161	
Production Office secretary	3.4	3.4				27			
Shift foreman	19	25	27	81	96			161	
Cloth & Training Grp Lead Operator			23	25				2520	
Cloth operator		18	19	92		245		665	
Trainers						231		2,520	
Decontamination man	17	22	19	60	99				
Decontamination man	3.5	2.7	2.8	29					
Receiving clerk	5.2	19	4.5	10	99	28			

Table 13. Plant 6 Measured Daily Weighted Average Exposure Concentrations

Occupation	Weighted Average Concentration, Alpha dpm/m^3								
	May-56	May-54	Oct-53	Jan-53	Jan-52	Aug-50	1949	Oct–Nov 1948	May-48
Cleanup man	22								
Production Research Lab personnel	3.7	2	5	13	30	12		30	245
Ledoux Lab asst technician (raffinate)	15.2	8.1	39						
Ledoux Lab technician (raffinate)	12.9	8.1	39	140	420	91		189	
Ledoux Lab technician (K-65)	21	7.5	27	440	1,900	1,400		2,100	
Ledoux Lab technician (MgF2)	21	7.5	27						
Shotgun Lab analyst	24.1	10	27	23	25	239		24 (239)	
Laboratory personnel	42	2.9	30	23	21				
MCW Laboratory west section						21		30	245
MCW Laboratory east section						13		30	245
Powder sample technician	56.5					217?		448	
Metal room sampler	420								
Outside sampling man	22.5								
Sample Room supervisor	41					245		448	
Laboratory Office personnel	42	2	5.6						
Truck operator	16	19	20	63	75				
Truck operator	20	19	20	63	75				
Warehouse foreman & Asst Foreman	4.2	2.9	6.2	17		70		161	
Warehouse man -- K-65 sampler			350	270	230	84		189	196
Warehouse man	5.8	10	20	38	46	84		189	196
Boiler House operator	9.3	7.3	7.5	8.9	2	36		44	
Laundry operator	6.2	19	11	19	4.5	13			
Porter	3.9	17	14			39			
General cleanup						39			
Change room						48			
Lunch room						5.6			
Clothes issue man	18	19	9.4	92					
Chief guard	1.7	14	16	14	1.8				
Security Office						6.3			
Guard	10	13	15	22	1.8	32			
Health Office - personnel (office)	1.6	6.7	15	14	0	11			
Health Office - personnel	8.1	11	15	14	0			7	14
Health Office personnel (plant monitor/health surveyor)		10	15	15	14	0	46		
Health Office person'l (plant monitor)	15	16	15	14	0				
Medic	1.3	3.5	6.3						
Nurse		3.5	6.3	42	99				
Dispensary & Safety						56		56	175
Instrument Shop technician	12	33	17	40	60	51			252
Instrument Shop machinist	5.5	44	17	27	60	51			252
Maintenance/mechanical supervisor	140	13	10	42	38	50			
Maintenance Office clerk	6.5	12	7.7	39					
Area mechanic	24	29	28						
Ore & Furnace Room AM						189			
Digest & feed AM						133			
Raffinate and C-3 AM						161			
Ether & NA House AM						77			
Welders, pipefitters, etc.						98		128	

Table 13. Plant 6 Measured Daily Weighted Average Exposure Concentrations

Occupation	Weighted Average Concentration, Alpha dpm/m^3								
	May-56	May-54	Oct-53	Jan-53	Jan-52	Aug-50	1949	Oct–Nov 1948	May-48
Carpenters						66			
Stock Room (Storeroom) foreman	3.7	14	22	13	33	21			
Stock Room clerk	2.6	9	34	15	33	21			
AEC Office personnel		2.2	1.8	6.7	0	Non-det		7.7	33
AEC Engineer		19	9.9	31	7				
MCW Office personnel	1.5	2	2.9	0.7	0			7	50
MCW engineer	4.2	4.5	5.4	10	7	15			
MCW Office messenger	15	14	15	40					
MCW Office maintenance	7.5	12	20	10					
MCW Office construction expeditor			9.6	29					
Overall average weighted exposure	41	24	25	56	63				

Notes: The first set of 1948 data (Oct–Nov 1948) is from MCW (MCW 1949d (repeated in AEC 1949b and MCW 1950s), the second set (May 1948). The 1949 and 1950 data are from MCW (MCW 1950q) and AEC(AEC 1953); the May 1952, January 1953, and the October 1953 sets of survey data are from AEC (AEC 1954c); the May 1954 survey data are from AEC (AEC 1954d); and the May 1956 survey data are from AEC (AEC 1956b). For some occupations (mostly office types), the May 1948 concentration was the average in the work area, not a DWE, so that the level shown would be higher than what the worker actually experienced.

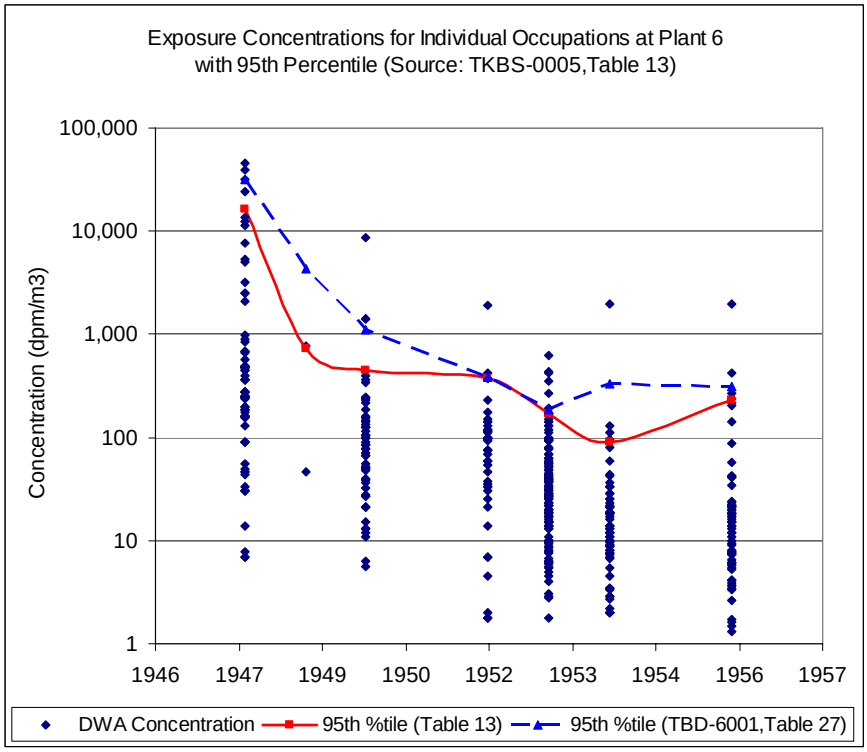

Figure A-1. ORAUT 2005 Table 13 DWA Air Concentrations for Job Categories in Plant 6 from 1948 to 1956

The 95th Percentile from Table 13 is compared with 95th Percentile from TBD-6001 Table 8.27.

Appendix A References:

AEC (Atomic Energy Commission) 1949b. Health Hazards in NYOO Facilities Producing and Processing Uranium. Report by the New York Operations Office Medical Division.18 April 1949.

AEC (Atomic Energy Commission) 1950c. Mallinckrodt Chemical Works Plant 4 Occupational Exposure to Radioactive Dust. Mallinckrodt-3; 26 July 1950.

AEC (Atomic Energy Commission) 1953. Mallinckrodt Chemical Works Plant 6 – Ore Room Addition – Occupational Exposure to Airborne Contamination. 22 May 1953.

AEC (Atomic Energy Commission) 1954a. Mallinckrodt Chemical Works Plant 4 Occupational Exposure to Airborne Contamination. [HASL-]MCW-17; 11 February 1954.

AEC (Atomic Energy Commission) 1954b. Mallinckrodt Chemical Works Plant 6 Occupational Exposure to Airborne Contamination. [HASL-]MCW-15; January 1954.
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AEC (Atomic Energy Commission) 1954c. Mallinckrodt Chemical Works Plant 6 Occupational Exposure to Airborne Contaminants. HASL-MCW-19; 13 August 1954.

AEC (Atomic Energy Commission) 1954d. Mallinckrodt Chemical Works Plant 6E Occupational Exposure to Airborne Contamination. [HASL-]MCW-18; February 1954.

AEC (Atomic Energy Commission) 1956a. Mallinckrodt Chemical Works Plant 4 Occupational Exposure to Airborne Contamination. HASL-MCW-26; 24 September 1956.

AEC (Atomic Energy Commission) 1956b. Mallinckrodt Chemical Works Plant 6 Occupational Exposure to Airborne Contamination. HASL-MCW-27; 12 October 1956.

MCW (Mallinckrodt Chemical Works) 1949d. Dust Study of Plant Six, October-November 1948. Memo and report to H. E. Thayer from K. J. Caplan; 21 April 1949.

MCW (Mallinckrodt Chemical Works) 1950q. No subject. Letter to M. Eisenbud of AEC from K. J. Caplan of Mallinckrodt. 4 October 1950.

MCW (Mallinckrodt Chemical Works) 1950s. Plant Six Dust Study, August 1950. Report; 21 August 1950.