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RADIATION AND WORKER HEALTH

National Institute of Occupational Safety and Health

Review of NIOSH Site Profile

for

Mallinckrodt Chemical Company, St. Louis Downtown Site

St. Louis, MO

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EXECUTIVE SUMMARY

Under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) and Federal regulations defined in 42 CFR Part 82, the Advisory Board on Radiation and Worker Health is mandated to conduct an independent review of the methods and procedures used by the National Institute of Occupational Safety and Health (NIOSH) and its contractors for dose reconstruction.

As a contractor to the Advisory Board, S. Cohen & Associates (SC&A, Inc.) has been charged under Task 1 to support the Board in this effort by independently evaluating a select number of site profiles that correspond to specific facilities at which energy employees worked and were exposed to ionizing radiation.

This report presents SC&A's evaluation of the site profile ORAUT-TKBS-0005, *Technical Basis Document: Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company, St. Louis Downtown Site, St. Louis, Missouri, Period of Operation 1942-1958*. This document is also commonly called the Mallinckrodt Chemical Works (MCW) site profile or the MCW technical basis document (TBD). Our review of the site profile focused largely on the quality of available data that characterized the facility and its operations, and the methods prescribed by NIOSH for the use of those data in dose reconstruction. Our review of ORAUT-TKBS-0005 was conducted in accordance with the objectives stated in SC&A's *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004a).

It should be noted that SC&A's review in this report reflects information and data contained in Revision 00 of the MCW site profile. NIOSH informed SC&A on October 13, 2004 that the agency was currently in the process of revising the MCW TBD as a result of new information that had been gathered in behalf of the Mallinckrodt facility (see Attachment 2). Furthermore, NIOSH is currently also evaluating a Special Exposure Cohort (SEC) petition in behalf of the Mallinckrodt facility. Since neither the revised TBD nor recent decisions pertaining to the SEC petition were made available to SC&A, comments contained in this report should be judged accordingly. (During a recent informal exchange with NIOSH, SC&A was informed that numerous concerns raised herein are currently being addressed in the revised TBD).

SUMMARY FINDINGS

Critical to dose reconstruction are personnel monitoring data that define both internal and external exposure measurements for a given individual. However, even when personnel monitoring records are complete, a credible dose reconstruction must rely on a host of supportive data that are generally referred to as site-specific data, which are provided in a TBD. Examples of site-specific data are a thorough description of (1) the physical design of a facility, (2) the type and quantities of materials processed, (3) prevailing work practices, (4) job descriptions, (5) dosimeters and bioassay used for monitoring.

The value of a TBD in dose reconstruction becomes even more important when personnel monitoring was not performed or when monitoring records for specific individuals are missing.

Under these circumstances, dose reconstruction must rely on TBD data for the purpose of extrapolation/interpolation and/or the use of surrogate values, such as co-worker data.

In our review of ORAUT-TKBS-0005, SC&A fully recognizes that a comprehensive characterization of the Mallinckrodt facility for the purpose of dose reconstruction represents a difficult and complex task. This difficulty is readily apparent from information presented in Sections 1 through 5, and numerous references cited in the TBD.

To summarize, uranium refining began in 1942 in Plant 2 at a rate of about 1 ton per day of uranium oxide (UO_2). It is estimated that between 1942 and 1957, Mallinckrodt processed in excess of 50,000 tons of natural uranium products from a variety of feed materials. While early ores of black oxides (U_3O_3) were free of radium (Ra-226) and its decay products, in about 1944, Mallinckrodt began processing high-grade pitchblende ores from the Belgian Congo. Pitchblende from so-called "Congo-ore" had an **average** concentration of 25% uranium by weight, with maximum values of up to 65% to 70%. Such unprocessed ores had the undesirable radiological property of containing Ra-226 in near-equilibrium with the parent U-238. For average pitchblende (ore with 25% U by weight), this resulted in 100 milligrams (or about 100 millicuries) of Ra-226 per ton of ore. The decay of radium to radon gas and its short-lived daughters created unique radiological hazards, from external sources of radiation as well as inhalation/internal hazards. A 1949 Atomic Energy Commission (AEC) report stated that as much as 200 grams of Ra-226 (representing ~200 curies of Ra-226) were produced in a single month and stored at the Mallinckrodt facility. In select confined spaces, radon levels in air as high as 10^{-7} Ci/l (100,000 pCi/l) were found.

At the height of facility operations, uranium refining took place in about 60 separate buildings on the St. Louis Downtown Site (SLDS). A factor that further enhanced early worker exposure is the fact that initial operations in 1942 began in three Mallinckrodt plants (1, 2, and 4) that had not been built or designed for the purpose of uranium refining. Structural and engineering deficiencies included inadequate ventilation and failure to shield, isolate, or confine materials.

A second deficiency and contributing factor to early worker exposure was the lack of process automation, which not only required workers to manually handle materials, but resulted in airborne releases and inhalation of these materials, as described in Section 5.2.2 of the TBD. The following description provides an understanding of processes, working conditions, and prevailing attitudes toward radiological safety:

From pages 28-29 of TBD:

> *Once the Ra-226 was removed following the digestion step and the vessel(s) had been vented, the gamma dose rates were much lower and the radon (which arose from the radium) was no longer an issue. Radium and radon would again build up from the uranium parent, but this took more time than the apparent typical digestion-to-shipout time at Mallinckrodt.*

> *The main hazard after the radium-bearing residue was removed was dust, since a fraction of the uranium salts and oxides tended to aerosolize when dry and when handled. Initially, somewhat* ***crude precautions*** *were taken to control dust during handling and there was* ***extensive manual handling of uranium salts and oxides in the dry form*** *(Eisenbud 1975). For example, in Plant 6 (****and presumably in its predecessor plants 1 and 2****), the UO_3 dry powder was unloaded from the reaction pots into drums by* ***hand-scooping*** *(Mason 1958a), i.e.,* ***manually using handheld scoops.*** *The UO_3 was then moved to the furnace loading area, where it was* ***hand-scooped into trays****, which after weighing were placed into the furnaces to be reduced to UO_2 (Mason 1958a). The trays of UO_2 were then* ***unloaded by hand into drums*** *for transport to other areas or sites. The major handling improvement of 1949, installation of pneumatic unloading and conveying systems, was* ***supposed to have eliminated all hand-scooping of UO_2 and UO_3. However, AEC inspectors repeatedly noted hand-scooping going on until the end of operations at the plant, often due to the failure of equipment such as the vacuum-type UO_3 "gulpers" (AEC 1954d; AEC 1956c)****.*
>
> *UO_2 produced at Plant 6 was trucked over to Plant 4 in "small fiber containers" (AEC 1949); no information is given as to how this affected containment of the dust. In Plant 4, there was again* ***extensive hand-scooping*** *and* ***other manual handling of the uranium materials*** *(UO_2, UF_4, and uranium metal) (Mason 1958a).* ***This was reduced by mechanization in 1948 and 1949, but even so dust levels were considered too high (Mason 1958a)****. AEC agreed to have Mallinckrodt construct Plants 6E and 7 to replace it. These plants were even more mechanized and were said to require little (if any) manual handling (Mason 1958a);* ***however, as various AEC air dust study reports indicate (e.g., AEC 1954g; AEC 1955b), this was not so. AEC (1955c) even reported in 1955 that a Plant 7 operator used a piece of cardboard in lieu of a conventional metal scoop to make up UF_4, with the operator's (presumably gloved) fingers dipping into the material frequently.*** [Emphasis added.]

Observations of those reported above provide clear indications that in spite of efforts that began in the late 1940s to reduce worker exposure, safe work practices appear to have been poorly enforced and openly ignored throughout the 16-year period of facility operations.

However, of particular concern to dose reconstruction is the absence of even the most basic radiological control measures in the first several years of facility operation. The first attempt to monitor a limited number of workers by means of film badge dosimeters started only in late 1945, followed by the first bioassay samples taken in 1948.

Thus, the first available external dose records for dose reconstruction are those of 1946; for internal exposures, limited records of bioassay data are available only from 1948 forward.
In spite of these deficiencies in the early data, SC&A believes NIOSH's review of available data was sufficiently comprehensive. In total, NIOSH analyzed an impressive body of information

(representing more than 150 separate reports) and has collated this information in the TBD in a structured, coherent, and understandable manner.

Given SC&A's appreciation of the comprehensive effort NIOSH put forth in the assembly of available data, SC&A directed its audit of the TBD to the interpretation of the data and resultant prescriptive use of these data in the form of guidance to the dose reconstruction process. SC&A's assessment, therefore, focused on the stated objectives of the TBD and its ability to fulfill those objectives. Section 1.0 of the TBD provides the following:

> *The two principal purposes of this technical basis document are (1) to provide information* ***sufficient to enable dose reconstructors to estimate claimant-favorable doses*** *for these workers on an* **individual basis** *under the provisions of the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) and (2) to allow claimants, federal assessors, and others to understand the information sources and assumptions on which the dose estimations are based.* [Emphasis added.]

To determine if the TBD can meet the above-stated objectives, it is important to briefly review key elements of the dose reconstruction process, as specified in 42 CFR Part 82. Federal regulations specify that a dose reconstruction can be broadly placed into one of three discrete categories. These three categories differ greatly in terms of their dependence on and the completeness of available dose data, as well as on the accuracy/uncertainty of data.

Category 1. Least challenged by any deficiencies in available dose/monitoring data are dose reconstructions for which even a partial assessment (or minimized dose(s)) corresponds to a probability of causation (POC) value in excess of 50%, and assures compensability to the claimant. Such partial/incomplete dose reconstructions with a POC >50% may, in some cases, involve only a limited amount of external or internal data. In extreme cases, even a total absence of a **positive** measurement may suffice for an assigned organ dose that results in a POC >50%. For this reason, dose reconstructions in behalf of this category may only be marginally affected by incomplete/missing data or uncertainty of the measurements. In fact, regulatory guidelines recommend the use of a partial/incomplete dose reconstruction, the minimization of dose, and the exclusion of uncertainty for reasons of process efficiency, as long as this limited effort produces a POC of ≥50%.

Category 2. A second category of dose reconstruction is defined by Federal guidance, which recommends the use of "worst-case" assumptions. The purpose of "worst-case" assumptions in dose reconstruction is to derive **maximal** or highly improbable dose assignments. For example, a "worst-case" assumption may place a worker at a given work location 24 hours per day and 365 days per year. The use of such maximized (or upper-bound) values, however, is limited to those instances where the resultant maximized doses yield POC values below 50%, which are **not** compensated. For this second category, the dose reconstructor needs only to ensure that **all potential** internal and external exposure pathways have been considered.

The obvious benefit of worst-case assumptions and the use of maximized doses in dose reconstruction is "efficiency." Efficiency is achieved by the fact that maximized doses **avoid** the need for **precise** data and eliminates consideration for the uncertainty of the dose. Lastly, the use of bounding values in dose reconstruction minimizes any controversy regarding the decision not to compensate a claim.

Although simplistic in design, to satisfy this type of a dose reconstruction, the TBD must, at a minimum, provide information and data that clearly identify (1) all potential radionuclides, (2) all potential modes of exposure, and (3) upper limits for each contaminant and mode of exposure. Thus, for external exposures, maximum dose rates must be identified in time and space that correspond to a worker's employment period and work locations; similarly, to maximize internal exposures, highest air concentrations and surface contaminations must be identified.

Category 3. The most complex and challenging dose reconstruction represents cases in which the projected outcome of a dose reconstruction yields a POC value that may be close, but uncertain, relative to the critical 50% value, which segregates the compensability of a claim. It is for this category of dose reconstruction that the TBD is essential but most vulnerable. For Category 3 dose reconstruction, dose estimates are generally defined by central or **best** estimates, along with a quantitative understanding of the uncertainty of each measurement. Central dose estimates and their uncertainties require a detailed understanding of multiple variables that include detection limits, instrument/dosimeter limitations, physical and chemical properties of contaminants (i.e., particle size, solubility), and physiological parameters, such as breathing rates, urine excretion volumes, etc.

Within limits, dose reconstruction may proceed in the absence of such knowledge. In such instances, reasonable and claimant-favorable **assumptions** may be substituted for empirical data.

SUMMARY OF SPECIFIC ISSUES OF CONCERN

Specific issues of concern that were identified in our review and which may affect each of the above-cited categories of dose reconstruction are summarized briefly below. A full explanation of these issues is provided in the main text of the report.

Time-weighted averages contain significant uncertainties and frequently fail to capture dose to workers in areas of high uranium dust concentration. The time-weighted averages do not represent maximized values and may have limitations when used for denial of claims; nor do they give claimants the benefit of the doubt in the face of uncertainties. Individual doses could be far greater than these averages, even when the job description is known. Procedures for estimating 95^{th} percentile values, for instance, would need to be developed in which the claimant is given the benefit of the doubt in the face of significant uncertainties. Revision 00 of the TBD lacks the needed procedures for dealing with these uncertainties. Other issues include uncertainties about the length of a workday, as well as overtime, that need to be addressed when considering time-weighting.

The dose consequences of raffinate trace radionuclides have not been adequately addressed. Specifically, raffinate contained Ac-227 and Pa-231, which are in the U-235 decay chain, as well as Th-230. Possible doses from raffinate-related exposures have not been sufficiently evaluated. Inhalation of even small quantities of some raffinates, such as Sperry cake, could result in significant doses. The issue of potential airborne contamination of raffinates, therefore, needs to be more carefully assessed.

Early external dose assignments are not appropriate for MCW. The lack of film badge data for the period **1942 to 1945** represents a period for which the potential for unaccounted external dose is greatest. The use of **Table 36**, which contains median weekly photon doses and weekly median electron doses for use of unmonitored workers from April 1943 to December 1945 is not likely to capture the full range of external exposures during that time period. Table 36 is based on only **32 average worker readings**, which is hardly a representative sampling of the many facilities and job functions that define MCW-facility operations/processes.

The methodology used in the interpretation and application of co-worker data is incomplete. Co-worker data, presented in Table 31, are insufficiently explained to allow for an understanding of their use in dose reconstruction. Most of the geometric standard deviations (GSDs) in Table 31 are in error and need to be revised. NIOSH should disclose more fully how the data are to be utilized, including the high air-concentration measurements that were made at MCW. Technical criteria for definition of the term “co-worker” and the uncertainties associated with using co-worker data for individual claimant dose calculations are not characterized in the TBD.

NIOSH assumed non-conservative breathing rate and breathing type. The TBD assumed a breathing rate of **1.4 m^3/hour**. This value implies that workers were primarily involved in light exercise during the course of the day. A single value may not be consistent with the working conditions in the facility during the early years of operation and is inconsistent with other NIOSH site profiles, such as Table 3 in the Bethlehem Steel Site Profile. In addition, NIOSH has not considered oro-nasal breathing, which produces greater deposition in the lung than nasal breathing.

The use of 1948 air-concentration data as a surrogate for 1942-1947 may underestimate the dose for early years. For uranium air concentration, the TBD used daily weighted-average exposure levels measured for workers by AEC in 1948 as surrogate for the dust exposure levels of workers in the 1942 to 1946 timeframe. SC&A considers the surrogate use of 1948 data to be claimant unfavorable due to the fact that for earlier years, ventilation was poor or non-existent, and adequate radiation protection practices had not yet been developed. In the absence of bioassay data prior to 1948, air monitoring records, and adequate source term data during the 1942-1947 timeframe, SC&A believes that Tables 21 to 24 do not capture the best estimate of internal dose to workers in the 1942 to 1947 timeframe.

Inconsistencies exist between the four site profiles currently under SC&A’s review. Whereas, dosimeter adjustment factors are applied to recorded external dose at the Savannah River Site (SRS) and Hanford to estimate Hp(10) doses, the MCW TBD does not recommend an adjustment to recorded film doses. It also appears that the TBD did not consider the laboratory, radiological, and environmental uncertainties in the personal dosimetry program. Lastly, the MCW site profile did not consider the occupational dose from environmental exposure, as was done in both the SRS and Hanford site profiles.

An assessment of uncertainties, as required by OCAS-IG-001 and OCAS-IG-002, has not been adequately developed for air sampling data used in lieu of bioassay data to assign internal dose.

OPPORTUNITIES FOR IMPROVEMENT

As a living document, the MCW site profile, Revision 00, may be improved by addressing specific issues raised in the main body of this review and briefly summarized below.

- **Statistical approach.** A method to determine best estimates and their uncertainties, as well as the 95th percentile value of time-weighted air concentrations, needs to be developed for internal dose calculations from air-concentration data.

- **Potential for exposure to Ac-227/Th-227, Th-230, and Pa-231 needs to be taken into account in raffinate dewatering, handling, and processing.** NIOSH should further evaluate the potential exposure pathways for internal exposure of raffinate and investigate the relative impact of trace radionuclide intakes to the total dose.

- **Improved use of film badge data**. Significant gaps exist for time periods when workers were not monitored for external or internal exposure. For example, between April 1942 and December 1945, workers were **not** assigned film badges, and there are no other monitoring data for external dose reconstruction. For workers who were employed during this time but terminated their employment prior to the use of film dosimeters, the TBD currently recommends the use of surrogate film dosimeter data contained in Table 36 of the TBD. While SC&A fully recognizes both the need for and value of surrogate data, the use of Table 36 data is clearly inappropriate for the following reasons: (1) Table 36 provides but a single median weekly dose for photons and electrons and their corresponding GSD; (2) this data set corresponds to a small group of only 32 workers, who were monitored for a brief 15-week period; and (3) the 32 workers all worked in the "pilot plant" and, therefore, represent a relatively homogeneous group with regard to job description and potential for exposure.

- SC&A recommends the development of a broader cohort of monitored workers as a credible surrogate for assigning external doses to unmonitored workers and the estimation of uncertainties associated with using surrogates.

- **Improved characterization of co-worker data.** The data in Table 31, particularly Period 1 from 1948 to 1951, need further review and analysis; of particular concern is Period 1, which covers the years 1948 to 1951. Criteria for defining co-workers need to be developed and the uncertainties associated with using co-worker data for claimant doses need to be estimated in light of those criteria.

- **The TBD should take oro-nasal breathing into account.** The dose conversion factors for light and heavy breathing should take account of the fact that many workers switch from nasal to oro-nasal breathing as the work becomes heavier. Nasal or oro-nasal breathing should be assumed in a manner that gives the claimant the benefit of the doubt. This would be similar to NIOSH's choice of claimant-favorable solubilities depending on the target organ.

- **Inclusion of oral ingestion pathways.** Attention needs to be given to several additional routes of ingestion exposure that would likely give intakes in excess of that assumed by the site profile. These would include ingestion of large particles directly deposited on food and by transfer from contaminated hands.

- **NIOSH interview site experts and former workers**. It is critical for NIOSH to conduct interviews with former workers and other site experts and integrate first-hand experience and/or association with the MCW, so as to provide further insight on job category information, site practices/processes/ conditions, management practices, and data integrity.

- **Additional data are needed to evaluate potential impacts of residual contamination between periods of uranium ore processing, separation, and refining operations.**

- **The TBD should identify high-risk jobs and incidents in order to alert the dose reconstructor to special exposure situations or likely maxima that may be used for select claims**.

- **NIOSH should maintain consistent assumptions among site profiles or further explain why alternate assumption(s) are appropriate for a particular facility**.

- **Based on SC&A's findings and issues of concern raised in behalf of the MCW TBD, NIOSH should evaluate/amend other site profiles, whenever applicable.**

ACRONYMS AND ABBREVIATIONS

Advisory Board	NIOSH Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AP	anterior-to-posterior (geometry for external irradiation)
AWE	Atomic Weapons Employers
BS	Bethlehem Steel
Ci/L	curies per liter
DOE	U.S. Department of Energy
DWE levels	time-weighted daily average exposure levels
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FUSRAP	Formerly Utilized Sites Remedial Action Plan
GSD	geometric standard deviation
HASL	Health and Safety Laboratory (of the Atomic Energy Commission)
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
IREP	Interactive RadioEpidemiologic Program
ISO	International Standards Organization
ISO	Isotropic (geometry for external irradiation)
MAC	Maximum Allowable Concentration
MCW	Mallinckrodt Chemical Works
MED	Manhattan Engineering District
MDL	Minimum Detectable Level
mR	milliroentgen
mrad	millirad
mrep	millirep
NIOSH	National Institute for Occupational Safety and Health
NOD	Net Optical Densiry
NYOO	New York Operations Office (of the Atomic Energy Commission)
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
OROO	Oak Ridge Operations Office
PDF	Portable Document Format
PFG	photofluorography
POC	probability of causation
PPE	personnel protective equipment
QAPP	Quality Assurance Program Plan
ROT	Rotational (geometry for external irradiation)
SC&A	S. Cohen and Associates
SEC	Special Exposure Cohort
SLAPS	St. Louis Airport Storage Site
SLDS	St. Louis Downtown Site
SRS	Savannah River Site
TBD	Technical Basis Document
UO_3	Orange Oxide

UO_2	Brown Oxide
UF_4	Green Salt
WL	Working Level (special unit for exposure to ^{222}Rn and its progeny)
WLM	Working Level Month

1.0 SCOPE AND INTRODUCTION

This report provides a review of ORAUT-TKBS-0005, *Technical Basis Document: Basis for Development of an Exposure Matrix for Mallinckrodt Chemical Company St. Louis Downtown Site, St. Louis, Missouri, Period of Operation: 1942-1958* (ORAUT 2003d). S. Cohen and Associates (SC&A, Inc.), in support to the Advisory Board on Radiation and Worker Health (Advisory Board) has critically evaluated the Mallinckrodt Chemical Works (MCW) site profile with the following objectives: (1) determine the completeness/adequacy of information gathered by NIOSH in behalf of the site profile; (2) assess the technical merit of the data/information; and (3) assess NIOSH's use of these data in dose reconstruction. This review explicitly addresses radiation exposure conditions at the St. Louis Downtown Site (SLDS), sometimes referred to as the Destrehan site. The review does not include the St. Louis Airport (Storage) Site (referred to as SLAPS or SLAPPS), the Latty Avenue facility, or the Weldon Springs facility. A review of these facilities will be addressed at a later date as determined by the Advisory Board.

It should be noted that NIOSH has informed SC&A that the MCW site profile is currently being revised. Thus, it is likely that many of the issues we raise in this report will be addressed in the Revision 01 update. During a recent NIOSH-SC&A meeting in Cincinnati, NIOSH also informed SC&A that a few MCW cases have already been denied. NIOSH has indicated that dose reconstructions were based on individual monitoring data supplemented by the approaches in the currently approved TBD.

SC&A also understands that NIOSH is currently evaluating a Special Exposure Cohort (SEC) petition in behalf of the MCW facility for the years 1942 to 1957. The potential significance of the SEC petition is the fact that this period of facility operation has the **least** amount of data needed for dose reconstruction. Correspondingly, even though a major portion of SC&A's review and comments were directed to this time period, they may be of limited value if there is a favorable decision to grant SEC status. Select comments and issues raised in this report may also be affected by a scheduled revision of the TBD. The Advisory Board, nevertheless, requested SC&A to proceed with its evaluation of Revision 00 even though there are plans to revise this version of the TBD (see Attachment 2).

2.0 ASSESSMENT CRITERIA AND METHOD

S. Cohen and Associates (SC&A, Inc.) is charged with evaluating the approach set forth in the site profiles, which is used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in SC&A *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A, 2004a). Consistency with other site profiles was limited to comparison of completed or in process site profile reviews. This review is specific to the Mallinckrodt Chemical Works (MCW) site profile and supporting technical information bulletins; however, items identified in this report may be applied to site profiles from other facilities. The review is organized into the following sections, which are designed to assess the degree to which the site profile fulfills the objectives of a site profile as delineated in SC&A's site profile review procedure.

2.1 STRENGTHS

SC&A reviewed the site profile with respect to the degree to which technically sound judgments or assumptions were employed. In addition, the review identifies NIOSH assumptions that give the benefit of the doubt to the claimant.

2.2 OBJECTIVE 1: COMPLETENESS OF DATA SOURCES

Objective 1 requires SC&A to identify principal sources of data and information that are applicable to the development of the site profile. The two elements examined under this objective include (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, and (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile. The ORAU site research PDF document database, as well as the referenced sources in the MCW technical basis document (TBD), were evaluated to determine the relevance of the data collected by NIOSH to the development of the site profile. Additionally, SC&A evaluated records publicly available on the MCW site and records provided by site experts.

2.3 OBJECTIVE 2: TECHNICAL ACCURACY

Objective 2 requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instruction, including evaluating workplace-monitoring data (e.g., air sampling and dose rate surveys), technical reports, standards and guidance documents, and literature related to uranium processing and handling. The goal of this objective is to first analyze the data according to sound scientific principles, and then to evaluate this information in the context of compensation.

SC&A utilized methodological illustrations to demonstrate the implications of different methods and/or assumptions for accomplishing objective 2. However, the methodological illustrations should not be interpreted as recommendations and are used solely for illustrative purposes. It is

SC&A's intention to identify issues and strategies for their resolution that will help NIOSH improve upon the scientific techniques employed in dose reconstruction.

2.4 OBJECTIVE 3: ADEQUACY OF DATA

Objective 3 requires SC&A to determine whether the data and guidance presented in the site profile are sufficiently detailed and complete to conduct dose reconstruction, and whether a defensible approach has been developed in the absence of data. In addition, this objective requires SC&A to assess the credibility of the data used for dose reconstruction.

2.5 OBJECTIVE 4: CONSISTENCY AMONG SITE PROFILES

Objective 4 requires SC&A to identify common elements within site profiles completed or reviewed to date. In order to accomplish this objective, the MCW TBD was compared to that outlined in the Bethlehem Steel, Savannah River Site, and Hanford TBDs. This assessment was conducted to identify areas of inconsistencies and determine the potential significance of any inconsistencies with regard to the dose reconstruction process.

2.6 OBJECTIVE 5: REGULATORY COMPLIANCE

Objective 5 requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000* (42 CFR 82), and the guidance and protocols defined in the OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (OCAS 2002a) and the OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline* (OCAS 2002b). SC&A also evaluated the degree to which the site profile is consistent with the guidelines set forth in ORAUT-PLAN-0001, *NIOSH Dose Reconstruction Project Quality Assurance Program Plan (QAPP).*

In order to achieve these five objectives, SC&A reviewed the MCW TBD with respect to the following issues:

- Uranium processing, separation and refining history
- Internal dose assumptions, parameters, and conditions
- Assignment of internal dose based on available air sampling and urinalysis data
- Assignment of external dose based on available dosimetric information
- Use of co-worker doses
- Statistical issues
- Internal and external exposure as a result of decontamination and decommissioning activities
- Medical x-ray doses
- Other considerations

SC&A did not evaluate the TBD with respect to ORAUT-TKBS-0005, Section 8.0, *Determination of Exposure Due to Residual Contamination Remaining from AEC/MED Operations*, because this guide is currently reserved. As such, Tables 38 through 40 of the TBD are not specifically addressed in this report because they deal with topics that are subject to this pending guideline.

2.7 THE SITE PROFILE REVIEW PROCESS

In accordance with SC&A's site profile review procedures, SC&A performed an initial review of the site profile and its supporting documentation. SC&A then submitted questions to NIOSH with regard to assumptions and methodologies used in the site profile. These questions are provided in Attachment 1, along with a list of additional documents SC&A requested as part of its review. A conference call was conducted between NIOSH and the SC&A team allowing NIOSH to provide clarifications and explain the approaches employed in the site profile. A summary of the conference call is provided in Attachment 2.

Site expert interviews were conducted to assist the team in obtaining a comprehensive understanding of the radioactive material processing at SLDS, the workplace exposure conditions, and the safety controls implemented. These interviews assisted in identifying the significant issues. Attachment 3 provides a summary of the site expert interviews conducted by the SC&A team in St. Charles, Missouri, on August 16-17, 2004. Site experts were allowed to review the interview summary for accuracy of interpretation of their input. This is an important safeguard against missing key issues or misinterpreting some vital piece of information.

After compiling site expert interviews, documentation, and NIOSH input, issues raised were carefully evaluated. Information provided by NIOSH in the conference call was evaluated against the preliminary findings and observations to finalize the vertical issues addressed in the audit report. There were three levels of review for this report. First, SC&A team members reviewed the report internally. Second, SC&A appointed an outside consultant, Mike Thorne, who did not participate in the preparation of this document, as an internal reviewer to go over all aspects of this report. SC&A also asked him to prepare a memorandum on oro-nasal breathing, which is provide in Attachment 5.

For the third and final level of review, a working draft of this document was submitted to NIOSH and the Board on January 6, 2005, and a meeting was held with NIOSH and the Board on January 18, 2005, to discuss the working draft. In these discussions, NIOSH provided SC&A with additional information regarding the assumptions employed in the TBD and clarified issues concerning the application of the site profile. This version of the report reflects the totality of the process and review cycle employed in the development of this report.

3.0 SITE PROFILE STRENGTHS

In developing a technical basis document (TBD), the assumptions used must be fair, consistent, and scientifically robust, and uncertainties and inadequacies in source data must be explicitly addressed. The development of the TBD must also consider efficiency in the process of analysis of individual exposure histories, such that claims can be processed in a timely manner. With this perspective in mind, there were a number of strengths identified in the Mallinckrodt Chemical Works (MCW) TBD. These strengths are described in the following sections.

3.1 COMPLETENESS OF DATA

NIOSH/ORAU made a concerted effort to obtain reports, technical documents, correspondence, and data relating to Mallinckrodt Chemical Works, including information from the Atomic Energy Commission (AEC), Mallinckrodt Chemical Works, the Department of Energy (DOE), and the Formerly Utilized Sites Remedial Action Program (FUSRAP). International and national guidance documents, symposium reports, epidemiologic study reports, and published papers were used to supplement this material and further support the TBD approaches. As a result of the information collected, the TBD provides an excellent description of the Mallinckrodt process history. Particular strengths in this area include:

- The site history (pages 10 to 14) and the description of processes (pages 15 to 24) provide a clear and insightful review of the nature of the plant. The narrative summary of the MCW processes provided on page 12 and 13 of the TBD provides an excellent overview of site operations.
- Valuable information is provided on operations in the various plants and buildings that make up MCW, a chronology of site operations, principal changes made in site processes and equipment, and a most useful listing of the processes and operations for each step of the uranium ore processing and refining, as well as the content, forms, and amounts of uranium ore processed (ORAUT-TKBS-0005, Tables 1-4)
- The U-235 decay chain is taken into account in the uranium processing portions of the analysis. The U-238 decay chain is also taken into account in uranium processing.

3.2 TECHNICAL ACCURACY

NIOSH/ORAU developed a number of assumptions that are scientifically appropriate and provide the benefit of the doubt to the claimant. Revision 00 of the TBD is appropriate for compensation when used to determine minimal dose. The site profile approach is also appropriate for application to nonradiological workers (i.e., those not entering radiological areas, including ore storage areas) for the years from 1950-1958 provided environmental dose is evaluated. The application of production-related data to these workers would likely overestimate their actual dose. Other strengths related to technical assumptions are as follows:

- The TBD differentiates the exposure potential by job category, recognizing that some tasks result in higher exposure than others. Furthermore, the dose reconstruction takes into consideration transfers of individuals to new jobs or tasks.
- The assumption that inhalation is the principal pathway for internal exposure to certain organs, such as the lung and respiratory tract, is technically sound. Furthermore, the focus on inhalation dose as the most likely route of internal exposure for most workers at MCW is appropriate.
- The selection of Type S solubility for respiratory tract tissues is appropriate.
- The use of standardized geometries by job title for external exposure was particularly insightful and well developed, and provides a most useful methodology to ensure better geometry factors for use in dose calculations. These default factors, however, should not be used if there is evidence from the claimant of specific circumstances that would lead to a higher exposure potential.
- Missed external dose is assigned to monitored workers from the inception of external monitoring through 1958. This approach is appropriate for personnel not in contact with radioactive material, including radioactive dust, if it can be positively established that contact did not occur.

3.3 COMMENTS ON AIR CONCENTRATION DATA

Attachment 2, "Alpha Counting of Uranium Filtered Air Samples from Contractor Facilities: Quality Control of Historic Samples," in *NIOSH Comments on the SC&A Review of Bethlehem Steel Site Profile* (NIOSH, 2004) documents an interview conducted with Naomi Harley, who worked at the AEC's New York Operations Office (NYOO) laboratory during a portion of the covered period for the St. Louis Downtown Site (SLDS). This interview was conducted to ascertain the extent of the quality control procedures in place at the laboratory that processed AEC air samples from MCW. Based on this interview, NIOSH/ORAU has determined that a laboratory quality control program was in place for analysis of air samples and/or smears. This interview helps validate the quality of air-sample and smear data collected by the AEC at MCW. However, no explanation to date has been provided with respect to the air-sampler collection efficiency, how air-sampler placement was determined, and how air-sampling equipment was calibrated. These issues are part of the total uncertainty in the air sample results and should be considered. In addition, fixed contamination levels are not specifically addressed by Harley's interview or available contamination survey reports.

3.4 REGULATORY COMPLIANCE

The TBDs use of personnel monitoring data and air-sample data to determine dose is consistent with the requirements outlined in 42 CFR 82.

- In cases where regular uranium urinalyses are available, this information is provided for use by dose reconstructors to calculate internal dose from uranium.

- Where routine film badge data are available, this information is provided for use by dose reconstructors to determine external exposure.
- Where personnel monitoring data are not available, air-sampling data are provided for use by dose reconstructors for estimating internal dose.
- Where radon data are available, these data are provided to be used by dose reconstructors to determine radon exposure. A suitable tabulation of data is provided and an appropriate conversion factor from Ci/L to WL is given. However, as discussed later in this report, the radon data are incomplete.

NIOSH/ORAU has acknowledged that Revision 00 of the MCW TBD needs to be revised in order to encompass a large subset of claimants, including some who are likely non-compensable (Attachment 2). NIOSH has stated that they are in the process of modifying the TBD to incorporate additional information and to further explain the technical basis for their assumptions. A date for the release of Revision 1 to the TBD has not been announced at the time of the preparation of this report.

4.0 COMPLETENESS OF DATA SOURCES

NIOSH/ORAU made a concerted effort to obtain relevant reports, technical documents, correspondence, and data relating to Mallinckrodt Chemical Works (MCW); however, there are additional key data sources that would strengthen the technical basis document (TBD). SC&A has identified a list of potential records that would supplement those collected by NIOSH and its contractor. A complete list of these records is provided in Attachment 4.

Of particular interest are the records collected by Oak Ridge Institute for Science and Education (ORISE) during the various epidemiologic studies. Included in the inventory prepared by History Associates Incorporated are dust concentration cards (1943-1952), film badge summaries, Radon Project records, medical records, and work history records. In the SC&A questions to NIOSH provided in Attachment 1, SC&A referred NIOSH to document sources previously held at the ORISE CER Vault Room as listed at the following website under the MCW section.

http://www.eh.doe.gov/ohre/new/findingaids/epidemiologic/orise

In the teleconference on October 13, 2004, NIOSH/ORAU indicated that they were currently reviewing records from the ORISE vault and those transferred to the Oak Ridge Operations Office (OROO) records storage vault. Six boxes of Mallinckrodt records have recently been retrieved and are under review. This retrieval effort was done primarily for the MCW Special Exposure Cohort (SEC) petition. The details of this document retrieval have not been provided to SC&A, and therefore no conclusions can be made regarding the completeness of this records retrieval effort.

With the data as presented and analyzed in Revision 00 of the TBD, dose reconstruction for the pre-1949 period does not appear to be feasible, except for minimum dose estimates for granting compensation. NIOSH indicated in a meeting with SC&A on January 18, 2005, that additional monitoring records from 1946 and 1947 have been located, but, to date, these records have not been provided to SC&A for review. For the latter period, 1949-1958, there are also numerous issues that need to be resolved before dose reconstruction can be made, other than for minimum estimates. Further discussion of this issue is provided in Finding 1 of Section 5.0 and in Section 6.2.

It should be noted that SC&A is not making any judgment or conclusions in this review about what additional data or analysis NIOSH may present in its Revision 01. Our conclusion regarding adequacy of data and analysis are limited to Revision 00 of the TBD, and the data available in the ORAU site research PDF document database.

The records listed in Attachment 4 require evaluation to determine the following:

- Have the data represented in the dataset been used to develop the site profile?
- Do the additional sources of data provide information that should be added to the site profile?

- Does the information affect the assumptions and/or outcome of the dose reconstruction methodology in the site profile?

Also of concern is the credibility of the data that are available, particularly where evidence suggests that records were falsified and/or destroyed. This concern further necessitates an evaluation of sample collection, analysis, and documentation practices with respect to data used for dose reconstruction. Where multiple sources of data are available, comparisons between the data can help to substantiate the validity of dose reconstructions.

5.0 TECHNICAL ACCURACY

There are five major findings that identify issues that SC&A believes should be addressed in Revision 01 of the Mallinckrodt Chemical Works (MCW) technical basis document (TBD). The findings have been substantiated using technical reports, and national and international guidance documents.

5.1 FINDING 1: EARLY PERIOD FINDINGS

The records used to compile Revision 00 of the Site Profile are not sufficient to support dose reconstructions for the early years from 1942 to early 1948. Based on our conversations with NIOSH, NIOSH is aware of additional records that they believe are sufficient to support dose reconstructions for 1946 to early 1948, especially for workers that might have experienced high-end exposures.

Though the history of radiological monitoring program at Mallinckrodt is one that evolved over time, it is convenient to divide the operations at the facility into an early period, with little to no radiological surveillance, and a later period, where the radiological surveillance program was initiated and matured. The early period extends up to, and perhaps beyond, early 1948. A review of the site profile and its supporting documentation reveals that Mallinckrodt began to issue film badges in 1946, with a small-scale effort initiated late in 1945. The radon breath analysis and a formal dust measurement program were initiated in 1946 and 1948, respectively. Urinalysis measurements appear to begin in 1948 (Westbrook 2003, page 25).

During the SC&A and NIOSH conference call (Attachment 2), NIOSH indicated that they had independently made the same observation. We believe that Revision 00 of the TBD needs to be revised before the TBD can be used to support dose reconstructions that can be used as a basis to reject claims. NIOSH has not indicated whether the few claims that have been denied since that conference call have used data sources in addition to those analyzed in Revision 00.

NIOSH has not indicated in the Revision 00 TBD that they used raw data air sampling cards to determine individual worker doses from 1942 to 1947. In addition, the Revision 00 TBD does not state that NIOSH did any back calculations for individuals based on urinalysis data that first became available for individual workers in 1948. This data needs to be further developed. Six boxes of MCW data recently collected by NIOSH/ORAU should be reviewed as a source of information that can support dose reconstruction for the early years.

5.1.1 Film Badge Summary Data

Film badge summary data for individual workers are not available before December 1945. In the absence of personnel film badge data, the TBD recommends using average weekly doses from workers with recorded film badge doses from 1946 to 1950, or co-worker data, as the basis for reconstructing the doses to workers who were exposed from 1942 to 1945. SC&A believes that it is scientifically unsound to reconstruct doses that occurred in the early years using weekly doses that were compiled during later years, or using sparse or

non-existent co-worker data, because of the potential for underestimating the doses, particularly for employees who worked in high-exposure areas of Plants 1 and 2.

The lack of film badge data prior to December 1945 is documented in the TBD on page 42:

> *There is little information about conditions in Plants 1 and 2 during the wartime startup: no dose rate measurements from 1942-1946 appear to have survived and as noted previously, film badging did not start until late 1945, when Plants 1 and 2 were in the process of shutting down.*

The TBD instructs the dose reconstructor to use the following instructions to determine the average weekly gamma and beta dose during any unmonitored period:

> *For workers whose covered employment took place during 1942-1945 and have dose results from the early monitored period, external dose may be estimated from the total dose listed in the period in the tabulated total doses in the Mallinckrodt Radiation Summary (MCW undated). In this document, only total doses for all weeks worked are listed. For these workers, the average weekly dose is computed by dividing the listed total for gamma and beta each by the number of weeks worked. This average weekly gamma and beta dose is then applied to each week worked during the unmonitored period.*

In addition, the TBD provides the following instructions on page 59:

> *When the record indicates that the work assignment changed, co-worker data should be found that corresponds with the likely work assignment assigned for the appropriate period.*

There appears to be very little co-worker data that has survived from the 1942 to 1945 timeframe. For what little data there is, the instructions cited above may not capture that individual's potential dose when such an individual worked in high-exposure areas. It is also unlikely that there are co-worker or other data that can be used to reconstruct doses during the early period. The use of average weekly doses to reconstruct early-period external doses also seems to disregard the Atomic Energy Commission (AEC) assessment quoted in the TBD that the unmonitored early period exposures were "moderately" more severe (ACE 1950d). This would certainly be an issue if the TBD were to be used in denying claims, which apparently is not the case up to this point.

An overarching issue that bears on reconstructing doses during both the early and later time periods is the extent to which pitchblende ore was processed at the facility. Supposedly, pitchblende was only processed from 1945 forward. However, on page 22 of the TBD it is stated that in 1943 there appeared to be more radiation in the feedstock, suggesting that pitchblende ore concentrate may have been used as feed before 1945. Nevertheless, it seems likely that external dose rates at the plant would have increased markedly after 1945 when high-grade pitchblende (with its higher levels of Ra-226) was used as a feedstock. NIOSH should examine radiation survey records and records from fixed-position gamma monitors at the plant for the period 1943-1946 to determine whether there is an increase in external dose rates, suggestive of the early use of pitchblende. However, the situation is complicated, because the pitchblende feedstock ore-to-UO_2 conversion process was relocated from Plant 2 to Plant 6 when the latter opened in 1946, and the latter appears to have been designed for handling high-grade pitchblende.

For workers who were outside the uranium division operation during the monitored period, the TBD recommends the use of the weekly external dose values for the period from April 1942 to December 1945, as provided in Table 36 of the TBD. As explained on page 60 of the TBD, Table 36 values were generated from the average doses received by Mallinckrodt "pilot plant" workers during the earliest known period of film badge monitoring in late 1945 (Rochester 1950):

> *From the doses in Rochester (1950), the dose distribution of the average weekly dose for the 32 workers considered was evaluated and the values in Table 36 were prepared. Distribution of the data and values for the medial and geometric standard deviation were calculated using LOGNORM™ and CystalBall©*
>
> *The median dose is applied to each cycle for which dose is reconstructed during the unmonitored period.*

This "pilot study," which consisted of a small selected group of workers, is not likely to be representative of the MCW for all other unmonitored workers from April 1942 to December 1945 because of the many different types of worker groups during the early years. Given the uncertainty in Rochester employee work locations and job tasks, as described on page 60 of the TBD, the applicability of these data to MCW workers in various jobs has not been established. It is not apparent that pilot-study workers are representative of workers with no identified records and work assignments. NIOSH should consider assigning dose for such unmonitored workers by using surrogate co-worker data. Interview information may help to identify appropriate co-workers, keeping in mind the comments in this report regarding co-workers.

Dose reconstructors should also keep in mind the possibility that dose rates are likely to have been higher in 1946 than in earlier years, at least in some parts of the plant. NIOSH should provide comments and a summary of that data in the TBD, including a description of the information found in individual data files, as opposed to data presented in Table 36. For example, it is not clear whether the data are well fitted by a lognormal distribution or whether this distribution was merely adopted for convenience.

In Section 7.2 of the TBD on page 55, there appears to be an error of logic. Many monitored workers had film results recorded as 0-50. From this it is inferred, quite reasonably, that many individuals who did not receive significant exposure were monitored. However, this is used to argue that the converse is true, i.e., that individuals who were not monitored were unlikely to receive significant occupational exposure. This neglects the possibility that the monitoring program was only partly implemented and that there were groups of workers (including both highly exposed and little exposed) who were not included in the monitoring. There could be many reasons for this, e.g., resources only available to cover a limited number of buildings, presumption that pitchblende ores would only be handled in some locations when there were actually additional locations where they were handled, and neglect of rotation of workers into high dose-rate areas.

The late 1945 dose data provided in Table 36 may not adequately reflect the higher exposure levels that some workers received. A more claimant-favorable methodology is needed for high-risk workers, perhaps by applying a correction factor to account for likely higher doses during the 1942 to 1945 time period. NIOSH should identify the higher exposure Mallinckrodt uranium ore processing and refining operations, and apply this correction factor in such cases, if one can be determined in a scientifically sound and claimant-favorable manner.

The TBD points out on page 66 that, for external dosimetry, considerations of amounts of materials and geometry characteristics render any dose estimation with this data subject to a great deal of uncertainty. To help solve this, NIOSH developed ORAUT-OTIB-0010, *A Standard Complex-Wide Correction Factor for Overestimating External Doses Measured with Film Badge Dosimeters* (ORAUT 2004). This technical information bulletin (TIB), however, is only applicable after 1970. A similar TIB is needed to deal with these uncertainties that can be used to address Mallinckrodt Chemical Works film badge estimates.

5.1.2 Uranium Dust Daily Weighted Average Exposure Levels

The TBD does not make clear how the uranium dust daily weighed average exposures were developed by NIOSH for Tables 21 to 24. This seems to be of particular concern for the early period from 1942 to 1948. There is no explanation to document how the NIOSH daily weighted averages were derived, and no statistical analysis to document the possible upper bounds of these averages.

The use of 1948 uranium dust daily weighted average exposure data for Plant 4 and Plant 6 Mallinckrodt workers in the 1942 to 1948 timeframe are not appropriate without review of individual raw data cards, back calculating from 1948 or post 1948 urinalysis data, and better addressing the variations in exposure situations in occupations or job categories in areas of high dust concentrations. Uncertainties in measurements also need to be addressed. For instance, the uranium dust daily weighted average exposure levels in Table 21 for Plant 4 were copied in many cases from columns 7 and 8 of Table 13 of the TBD, which is representative of daily weighted average exposure concentrations for mid to late 1948, and are not necessarily representative of exposures during the early period.

In Table 13 on page 95 of the TBD, the measured daily weighted average exposure concentrations by job title at Plant 4 are provided in columns 7 and 8 for May 1948 and September 1948. It appears that NIOSH has used the data entries in those columns for selected occupation categories for earlier time periods. Specifically, it appears that these data are used in Table 21, page 107, to define the dust concentration exposure levels for the period from 1942 to 1946 for Plant 4 workers in the same occupation category. Similarly, in Table 14 of the TBD, the measured daily weighted average exposure concentrations by job title in column 9 are the same as the dust daily weighted average exposure levels for Plant 6 in Table 22 in the second column for the period (1946-1948). Air dust concentration studies performed by AEC (Tables 13-14) in mid to late 1948 and October 1949 for Plant 4 (MCW 1949b) and in 1949 and 1950 for Plant 6 (MCW 1949c) may not be the best means to adequately determine the potentially higher air dust exposure levels experienced by workers in the 1942 to 1947 timeframe, because the new AEC health physics controls starting in early to mid 1948 may have already begun to lower exposure to uranium dust. The AEC dust concentration studies performed from mid 1948 to June 1950 would have been based on air concentrations after engineering and process controls were dramatically reducing dust exposure levels (see Table 1) (MCW 1950d).

The TBD states on page 35 of 125 that:

> *Tables 19 and 20 are to be used with Table 21 through 24 to help determine the exposure to an individual worker when bioassay data for the worker is missing or is conflicting and when worker bioassay data (see Section 4) is insufficient. Tables 21 through 24 derived from Tables 13 through 17 and other sources; the data they contain is nearly all average daily weighted air concentrations. All of this data is based on natural uranium mixture as discussed below.*

Since only limited uranium dust studies documenting dust concentration data for the period prior to mid to late 1948 are available on the ORAU site research PDF document database, it is apparent that NIOSH has only the 1948 and post-1948 data to rely upon to develop comparable dose estimates for the early period for 1942 to mid-1948. This is evident in the comparisons below between Tables 21 and 22 and the Caplan, K. J. to Thayer, H.E., MCW memorandum dated February 2, 1949 (MCW 1949b).

As uranium chemistry processes were improved during the late 1940s, facilities at MCW were updated and automated to streamline the operations and provide additional protection to the workers. Until the arrival of Mont Mason at MCW, the safety focus was placed on chemical exposures and conventional industrial safety rather than radiation exposures. It was felt that chemical exposures out weighed any hazards from radiation. Changes in facility design and ventilation during the late 1940s significantly affected the concentrations of airborne material. Engineering controls were designed to reduce airborne exposure to the workers. Mont Mason (Mason 1958) recommended the following changes to the operations to reduce worker exposure to uranium dust and from direct contact with uranium:

- Install well-designed ventilation in Plant 6, which occurred in 1949
- Minimize scooping and manual handling of uranium materials by the adoption of mechanical means, which was effected in 1948 and 1949
- Construct a new metal plant (Plant 6E) with a well-designed ventilation system, which opened in late 1950
- Build a new green salt UF_4 Plant 7 with well-designed ventilation, done late in 1952

- Initiate major changes in processing methods, including new process technology and equipment designed to lower uranium dust concentrations
- Eliminate hand-scooping by installation of pneumatic unloading and conveying systems

In addition, the TBD in Table 3 (page 83) expands on the description of these improvements in ventilation and engineering controls, many of which were accomplished in 1949. Table 1, which presents a portion of Table 1 from the Mont Mason's paper on 15 years of experience with dust problems in the refining and fabrication of uranium (Mason 1958), and which is provided in its entirety in the TBD in Table 9, page 92, shows that operations at the MCW Plant 6 produced uranium dust concentrations at the following levels listed as multiples of the maximum allowable concentration (i.e., 70 dpm/m^3), also referred to as tolerance levels:

Table 1. Change in Airborne Dust Loading for Different Time Periods

Ore Grinding		UO_3 Production		UO_2 Production		
		Milling	Pot Room	Load	Unload	Pkg
1946	190	180	111	76	45	161
1947	195	180	111	76	45	161
1948	195	180	111	76	45	161
1949	5	0	60	20	10	5
1950	5		5	10	5	5

According to a MCW Plant 6 Dust Study dated August 21, 1950, which covered exposures from November 1948 to July 1950, 7.1% of employees in the 1948 study experienced airborne uranium concentrations between 51 to 200 times the average tolerance levels. By the 1950 study, only 0.7% of the workers had exposure levels in this highest group, and almost 88% were at tolerance levels of 2 and below (MCW 1950d).

Table 1 above demonstrates that once the formal health program was instituted early in 1948 as a joint effort between MCW and AEC NYOO, which included the installation of engineering and process controls, uranium dust concentrations declined dramatically.

Equating airborne concentrations prior to and after installation of engineering controls is unreasonable without some analysis of the impact on the airborne concentration. Potential exposures would be expected to be higher prior to the installation of engineering controls. NIOSH has not provided an analysis of the impact these controls had on exposure potential (internal and external), but has simply applied data available for the latter part of 1948 to the years from 1942-1947 (MCW 1949b; MCW 1949c).

An additional issue that raises some concern is our review of the time-weighted average data provided in Table 21 of the TBD. Our concerns arise as a result of our review of the data used to derive the values in Table 21. First, the method used to derive the values in Table 21 from the supporting database is not apparent. Second, our review of the supporting database reveals that the individual measurements that were used as the basis for the values in Table 21 are highly variable. The following are examples of the reasons for these concerns.

- The highest uranium dust daily weighted exposure level in Table 21 in the TBD is 13,000 dpm/m^3 for a TA-7 (green salt) UF_4 unloader (operator) when the raw data in the February 2, 1949 Dust Study at MCW Plant 4 shows an average of 27,400 dpm/m^3 and a high of 40,500 in a TA-7 packing job of removing and replacing a mixer top (page 5).
- Table 21 in the TBD shows no job listing for a worker that dumps D-7. The 1949 Plant 4 Dust Study report shows an average of 823,000 dpm/m^3 and a high of 2,870,000 dpm/m^3 for the job category "When dumping D-7 in a D-7 area" (MCW 1949b, page 6). D-7 is one of many of the numbered dust collectors or filter presses. D-7 is a term that is also used to refer to the material collected there or a type of scrap. This is as pointed out in the TBD Table 5.
- Table 21 in the TBD shows an average of 3,360 dpm/m^3 for a furnace loader (UF_4-derby) and no category for a furnace cleaner. The 1949 Plant 4 Dust Study shows an average of 53,400 dpm/m^3 and a high of 77,000 dpm/m^3 when cleaning the bottom furnace area (MCW 1949b, page 6).

The above examples demonstrate that a re-evaluation of Table 21 is needed, especially for the column for 1942-1946, in order to ensure that all higher-exposure job categories are included in Tables 21-24.

Documents on the ORAU site research PDF document database for Plant 6 (April 21, 1949) also indicate that there were some workstations with extremely high levels of dust, at levels of several hundred thousand or even above one million dpm/m^3. These levels correspond to a few hundred milligrams per m^3.[1] (MCW 1949c). This seems plausible, as similar concentrations of resuspended dust have been recorded when ploughing (NCRP 1999). These are much higher than the Plant 6 concentrations in Table 9 or Table 22 of the TBD for 1948 and earlier.

Additional examples of the variability in dust loadings include (1) the dust levels in the fumes in the pot room in Plant 6 were measured at 2,040,000 dpm/m^3 "after turning into powder" and at 18,700 dpm/m^3 "before turning into powder;" the latter value was presumably for UNH, which is Class F; (2) "checking and leveling of buckets" was 347,000 dpm/m^3; and (3) "opening of bins for inspection" was 693,000 dpm/m^3. The TBD does not address these extremely high dust levels and does not caution the ORAU dose reconstructors to take these into account (MCW 1949c).

In Attachment 2, page 6, NIOSH indicated that, after comparison of spot table dust concentrations for comparable tasks between earlier years and later years, the dust-weighted exposures (DWEs) in Tables 21 and 22 conservatively cover the air concentrations in earlier years. However, when the newly formed Health and Safety Division (HSD) of the AEC New York Operations Office (NYOO) did a comparison of their dust study results at MCW Plant 6 in May, 1948 (AEC September 1950), NYOO found that the average exposure of 170 MCW workers sampled was 53 times MAC, whereas, MCW November 1948 results showed the average to be 12 times MAC (Table 1, AEC, September 1950). In a similar manner, the NYOO Table 1 comparison shows that the high exposure of the 170 individuals was 660 MAC,

[1] A concentration of 100 mg/m^3 is equal to 140,000 dpm/m^3 for natural uranium.

compared to MCW results, which showed 196 MAC in May and November 1948. By July 1950, the high exposure was only 20 MAC. These differences between the values reported by NYOO and AEC should be verified.

Table 1 of AEC, September 1950, also shows that by July 1950, both MCW and NYOO found the average had been reduced by new ventilation system controls and other radiation safety practices to only 2 MAC. These data indicate that later years data (after 1949) do not appear to be a good basis upon which to determine uranium dust daily weighted average exposure levels in Tables 21 and 22 for the early years from 1942 to 1947. Any back extrapolation must be technically justified in detail with supporting data.

5.1.3 Early Uranium Dust Lung Burdens and Other Organ Doses Need Further Analysis

NIOSH should do further analysis to determine individual uranium dust lung burdens and other organ dose, since even in the early 1950s, AEC experts expressed a concern that more needed to be done with respect to characterizing lung burdens. The TBD has not provided that re-evaluation.

Hanson Blatz and Merrill Eisenbud issued a report on November 30, 1950 entitled *An Estimate of Cumulative Multiple Exposures to Radioactive Materials, Mallinckrodt Chemical Works, Plant 4 and 6, July 1942 to October 1949* (AEC 1959).[2]

The objective of the report is to attempt to estimate the cumulative radiation dose to the "critical" organs of all employees of MCW Plants 4 and 6, who had more than 6 months of exposure to radioactive materials. A memo issued by Merrill Eisenbud on January 31, 1951 (Eisenbud 1951 - same web location) states that the report shows that there were 17 employees at MCW who experienced lung doses in excess of 1000 rem. The report, in Appendix B, pages 15 and 16, presents a calculation of dose to lung tissue from alpha radiation using the methodology available at the time. The report presents a calculation showing a lung dose of 8,950 mrem/week from alpha. To that is added 75 mrem/week from gamma radiation, for a total of 9,025 mrem/week. The text of the report does not specifically mention the 17 individuals with a lung dose of 1000 rem. In order to derive a lung dose of 1000 rem, Dr. Eisenbud must have been working with 17 individuals who had an undocumented exposure history of about 108 weeks. The report pointed out the future investigations needed, including:

- Further study of human data – autopsy material to show the lung deposition or uranium in workers in known environments
- Study of the ratios of uranium and radium present in dust samples taken for certain operations
- Additional environmental radon data in order to know the proper method of sampling radon in breath

[2] This report can be found on the web at http://www.whistleblower.org/getcat.php?cid=20.

- A better correlation of beta radiation, as indicated by film badges, with the actual dose received by the skin
- Better uranium dust exposure data for soluble compounds, as well as various oxides

NIOSH should consider additional ways to include all these factors in trying to assess organ doses for Mallinckrodt workers.

Additional special attention should also be placed on internal doses while working in the Ore Rooms and the Pot Rooms. The TBD points out on page 33 that when handling UO_3, openings between the operating area and the drum storage alleys in the Ore Room addition resulted in winds that blew into the area and upset the ventilation balance causing the dust to be blown into the operator areas. NIOSH needs to find additional individual Ore Room worker files (1) to properly verify elevated dust levels in the drum room alleys, (2) to ensure that monitoring devices, bioassay or urinalysis detected and quantified the internal dose due to such exposures, (3) to verify the extent and uncertainty of elevated dust levels with elevated oro-nasal breathing in the drum room alleys, and (4) to better quantify the internal dose due to such exposures.

The complexity of the operations at the facility exacerbates the difficulties associated with developing a more comprehensive understanding of the nature and extent of the exposures at the facility. For example, the source of uranium dust was continuous in uranium ore processing and refining operations, though its radionuclide content varied with the type and richness of the ore, and whether the dust originated from the ore or subsequently generated uranium compounds that would have been depleted in progeny of uranium.

5.2 FINDING 2: INTERNAL EXPOSURE FINDINGS

The internal dosimetry issues summarized below and noted in each subsection of this finding should be considered by NIOSH in preparing Revision 01 of the TBD.

- Air Concentration data are not complete for the early years and there are unresolved measurement issues for 1948.
- Breathing rates and the variable component of oro-nasal breathing are not fully addressed and play a role in determining the amount of inhalation of uranium and other radionuclides, and the characteristics of inhaled aerosols, e.g., in terms of particle size distribution.
- The lack of respiratory protection, especially in the early years, may have resulted in extremely high inhalation exposures.
- Raffinate handling, dewatering and processing doses need to be evaluated.
- Incidents and high-risk operations represent a potential for significant missed dose and have not been fully addressed. In addition, there are other radionuclides that contribute to internal dose that have not been addressed or only partially addressed.

- Chemical burns and reactions with other chemicals and material pose a potential entry port for internal contamination.
- More needs to be done to quantify the inhalation and ingestion dose from contamination of skin and gloves. In addition, the effects of residual contamination on external and internal dose are not considered. This has been left open as a "reserved" Section 8.0, which is being developed by NIOSH in Revision 01.
- Ingestion dose needs to be better evaluated to take into account large particles.

5.2.1 Air Concentration Data

The TBD is limited to a partial evaluation of air concentration data. The evaluation needs to be completed, both with regard to the field conditions and to ICRP 75-related considerations. Although the various AEC air dust studies state that they were following an established AEC protocol, documentation describing the protocol is lacking (TBD, page 31). NIOSH has not demonstrated the relationship between the radionuclide concentrations in the air samples and those in the breathing zone of the worker.

ICRP 75 indicates that air samples utilized for quantitative determination of intake should be evaluated with respect to the degree to which they are representative of the air concentration in the breathing zone. In addition, air samples are only representative of the breathing zone if they are placed strategically in a work area. Utilization of air concentration data alone does not demonstrate representativeness of an air sample. Airflow patterns must be established to determine the best location for air samplers.

NUREG-1400, *Air Sampling in the Workplace*, provides guidance on how to demonstrate compliance with Regulatory Guide 8.25 (NRC 1992). NUREG-1400 provides two examples comparing personal air-sample results with fixed air-sampler results. This guide was explicitly created as "appropriate for workers whose intake is likely to exceed 10% of an ALI and **whose dose of record will be based primarily on air sampling**." (p. 3.1, emphasis added).

The first scenario described in NUREG-1400 presents an analysis of a room occupied by a single individual who spends most of his/her time at or near a hood. The second scenario presents an analysis of a room with seven fixed air-sample heads and six workers. The average correction factors were 3.58 for the first scenario and 4.75 for the second scenario. The recommendation to equate the fixed air sample to a breathing zone sample was to multiply the fixed air-sample result by the correction factor (NRC 1993). These data are from uranium fuel fabrication facilities. The multiplicative factors found ranged from about 2 to 11. Note that all samples were for a workday or longer. In the case of the MCW air-sampling data, the variability would be expected to be much greater, since samples are short term, most being well under 1 hour, and some being under 1 minute. Thus ICRP 35 and 75 analyses are confirmed by the Nuclear Regulatory Commission (NRC) and given quantitative expression in NUREG-1400.

NIOSH should examine ICRP 75 guidance to evaluate air-concentration data. Such an evaluation would consist of a detailed investigation of where the air samples were taken relative to the actual breathing zone and what correction factors might be justified.[3] NIOSH has indicated that it has data regarding the nature of the air samples. This evidence needs to be discussed in the revised TBD; it also needs to be analyzed in the context of ICRP 75, NUREG-1400, and site expert evidence.

The differences between MCW and AEC air-concentration data for 1948 need to be explained. On page 33, The TBD states the following:

> *Table 12 shows that AEC and Mallinckrodt's data were in general agreement, although there were some differences. In this technical basis document, AEC's data are used preferentially because AEC set the standard of measurement for the uranium processing sites and because AEC's figures for the most exposed workers are typically higher than Mallinckrodt's.*

However, the MCW data and the AEC data in Table 12 are not in general agreement. They are shown below in ascending order of the ratios of AEC to MCW in units of times MAC (and ratios). It is evident that the MCW data are higher than the AEC data in many cases (12), and the reverse is also true (15 cases). Moreover, the largest discrepancy is the case where the MCW measurement is greater than the AEC measurement by a factor of about 19. The average of the ratios derived from an empirical lognormal distribution is less than 1.

The AEC measurements may have set the standard for the time, but this cannot be a reason to exclude MCW data when it is higher than AEC data. The MCW data need to be taken into account explicitly in a manner that gives claimants the benefit of the doubt in the face of uncertainty – that is, MCW data should be used preferentially when they are higher – unless NIOSH finds a systematic problem that would rule out the use of MCW data entirely. In that case, the nature of the problem and NIOSH's analysis of it should be presented in detail. NIOSH should investigate whether some of these differences came from the specific locations and/or times that the samples were taken.

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[3] See also the SC&A Bethlehem Site Profile Review Report, Procedural SCA-TR-Task1-0001, Conformance Issue #1 (SC&A Task 1, Oct 2004).

Table 2. AEC and Mallinckrodt Air Concentration Data in Units for 1948 of MAC and Their Ratios
(from Table 12 of the TBD)

AEC	Mallinckrodt	Ratio
2.7	52	0.051923
0.6	4.1	0.146341
1.6	6.8	0.235294
5	18.7	0.26738
0.8	2.9	0.275862
0.4	1.4	0.285714
10.4	32.4	0.320988
2	4.6	0.434783
5	10.7	0.46729
5	9.1	0.549451
1.6	2.2	0.727273
13.3	13.8	0.963768
51	42.4	1.20283
73	59	1.237288
7.5	5.7	1.315789
9.1	6.1	1.491803
47.7	30.7	1.553746
47.7	29.7	1.606061
61	36.5	1.671233
26.3	11.5	2.286957
57	24.6	2.317073
61	23.2	2.62931
186	66.8	2.784431
15.8	5.4	2.925926
186	57.2	3.251748
63	13.1	4.80916
51	7.5	6.8

5.2.2 Breathing Rate and Type

The assumption of nasal rather than oro-nasal breathing in the TBD is not claimant favorable; neither is the breathing rate of 1.4 m^3/hr.

5.2.2.1 Breathing Rate

As reported in Finding 4 of SCA-TR-TASK1-0001, *Review of NIOSH Site Profile Review of NIOSH Site Profile for Bethlehem Steel Plant, Lackawanna, NY*, the ICRP default of 1.7 m^3/hour air breathing rate was used for the maximum dose distribution (Table 3). This breathing rate consisted of an activity distribution of seven-eighths light exercise and one-eighth heavy exercise for the upper-bound matrix, implies that the workers were involved in heavy work only 12.5% of the time. In addition, the dose conversion factors for light and heavy breathing should take into account the fact that many workers switch from nasal to oro-nasal breathing as the work becomes heavier. A further discussion of this issue is provided in Finding 4 in SCA-TR-TASK1-0001. For many MCW areas, the breathing rate of 1.7 m^3/hr appears to be appropriate. However, in areas where strenuous work was done for more than one-eighth of the time, it may need to be evaluated as to adequacy. On page 52 of Section 6.1 of the TBD, NIOSH states that the breathing rate for all workers should be 1.4 m^3/hr. This should be revised upward. Moreover, this is not consistent with the Bethlehem Steel TBD.

5.2.2.2 Oro-Nasal Breathing

Doses to portions of the respiratory tract are augmented significantly by oro-nasal breathing. The doses change because fractional deposition in the various regions of the lung varies between nasal and oro-nasal breathing at all breathing rates, though the specific fractions are different at different breathing rates, as can be seen from Table 3 prepared for SC&A by consultant Dr. Mike Thorne. Attachment 5 provides a detailed explanation of the assumptions that were used in this comparison.

Table 3. Particle Size, Breathing Rate, and Breathing Type Effects on Respiratory Tract Deposition as a Percentage of Inhaled Activity

Individual	**Standard effort level (31.2% sitting, 68.8% light, 0% heavy)**			**Strenuous effort level (0% sitting, 87.5% light, 12.5 % heavy)**		
AMAD (µm):	**1.0**	**5.0**	**10.0**	**1.0**	**5.0**	**10.0**
ET_1	16.52	33.85	34.71	15.56	30.92	31.36
ET_2	21.12	39.91	38.38	20.71	40.44	40.08
BB	1.24	1.77	1.26	2.12	2.65	2.86
bb	1.65	1.10	0.63	1.57	0.74	0.71
AI	10.66	5.32	2.37	10.30	5.11	2.23
Individual:	**Adult - Light Exercise - Nose**			**Adult - Light Exercise – Mouth**		
AMAD (µm):	**1.0**	**5.0**	**10.0**	**1.0**	**5.0**	**10.0**
ET_1	17.51	34.80	35.28	4.52	11.59	12.71
ET_2	22.51	40.94	38.86	8.40	32.66	41.51
BB	1.31	1.80	1.24	3.27	9.76	8.66
bb	1.47	0.90	0.48	2.51	3.70	2.56
AI	9.94	4.49	1.90	15.22	13.04	7.01
Individual:	**Adult - Heavy Exercise - Nose**			**Adult - Heavy Exercise – Mouth**		
AMAD (µm):	**1.0**	**5.0**	**10.0**	**1.0**	**5.0**	**10.0**
ET_1	8.75	17.38	17.63	4.16	9.50	10.04
ET_2	14.39	38.67	44.34	9.63	36.89	46.18
BB	4.99	11.04	8.50	6.18	14.69	11.47
bb	1.92	2.41	1.46	2.26	3.16	1.95
AI	11.59	7.28	3.39	13.05	9.15	4.37

ET_1 = anterior nose, ET_2 = posterior nose-larynx-pharynx, BB = bronchi, bb= bronchioles, AI = alveolar interstitium.

It is clear that for the deep lung (BB, bb, AI), oro-nasal breathing results in considerably larger deposition for all particle sizes, especially for light exercise (the second set of values for mouth breathing). Light exercise is the dominant breathing mode for the exercise model used by NIOSH. The set of values in the first set on the right side of the matrix for strenuous effort typifies the NIOSH approach at 1.7 m^3 per hour. The necessity for taking oro-nasal breathing into account is evident in these numbers. The heavier deposition in the deep lung due to oro-nasal breathing would also affect dose calculations for non-respiratory tract organs due to different patterns of mobilization of the radionuclides from the lung. Heavier depositions in the deep lung will result in greater direct uptake by the systemic circulation. In reviewing Table 3 and Attachment 5, it is useful to remember that NIOSH uses a value of 5 micron AMAD for particle size.

5.2.3 Incidents and High-Risk Work

The TBD makes no distinction between routine dose conditions and unique exposure conditions, such as high-risk work and incidents. Lists of occupation type or job category (provided in the numerous dust studies on the ORAU site research PDF document database) list dust concentrations that are sometimes an order of magnitude greater than the average dpm/m^3 values shown in Tables 21 – 24, which NIOSH has not fully taken into account.

The TBD focuses on the potential exposures from routine operations of uranium ore processing and refining. There is no differentiation between routine exposure conditions and special exposure conditions, or no demonstration that the TBD methodologies bound these incidents or high-risk jobs. The TBD does provide the dose reconstructor with guidance on when to perform event-related analyses to complement the methodologies described in the TBD. Furthermore, the collection or recording of air-monitoring data used in the computation of time-weighted averages may have explicitly excluded situations in which air concentrations were substantially increased as a result of events. It would be of interest to determine whether separate records were maintained of routine and incident monitoring. However, it is also possible that incidents could have substantially increased aerosol concentrations in the respiratory region without substantially increasing area-averaged values.

There were a number of areas and operations where higher exposures, especially to dust, occurred at the MCW. The relative exposure potential was highly dependent on the job an individual was performing. There were a number of jobs and incidents that were likely to result in exposure to higher than routine airborne concentrations, including the following:

- Furnace Blowouts
- Entry into and cleaning of the furnace
- Confined space entries into tanks
- Dust bag replacement
- Cropping, cutting, and machining of uranium metal
- Maintenance and cleanup of pots and furnaces and other equipment, including manual scraping
- Manually shoveling and scooping radioactive material

The MCW TBD should provide additional information pertaining to furnace blowouts and the potential dose impact of such off-normal incidents. Other than depending on the claimant's DOE dose record, NIOSH needs to develop a methodology to calculate doses for personnel who report being exposed to furnace blowouts. These probably occurred from time to time throughout the Mallinckrodt Chemical Works ingot producing operations from 1942 to 1958.

Also of concern were those jobs that involved maintenance work in highly contaminated areas for brief periods. For example, at the National Lead Company of Ohio facility, a December 7, 1960, memorandum from K. J. Klein documents an incident where an operator cleaning under a burnout conveyor had a breathing zone reading of 18,000 times MAC. In another event, an operator positioned himself under the inspection plate to remove it for access under the oxide conveyor. This caused much of the oxide to come down on him, and his breathing zone sample result was found to be 97,000 times MAC (Klein 1960). Similar operations were likely performed at MCW, since uranium reduction to metal was performed at both facilities. Exposure to such concentrations for even small fractions of the workday can result in doses greater than those estimates from exposure to routine air concentrations measured at workstations. The specific ways in which these data are factored into the estimates of exposure are critical to the reliability of dose reconstructions. For instance, an exposure for 5 minutes per week to 20,000xMAC would result in an annual exposure over 50 weeks of over 80,000 MAC-hours. This is equivalent to an exposure of over 40xMAC for each work hour of a full time work year of 2,000 hours.

From 1946 through 1955 the St. Louis Site processed pitchblende ore that was up to 60% uranium (70% U_3O_8). Because of the radium present in this ore, the potential exposure to external ionizing radiation was much greater than at other uranium processing plants. Workers who were employed in the early steps of refining prior to removal of the radium content of the ore were at the greatest risk (Dupree-Ellis 2000). Workers who were employed in Plant 6 and Plant 6's warehouse also had the potential to have been exposed to radium-containing dust and radon gas. Revision 00 of the TBD states the following (page 30):

> *Ra-226 (in equilibrium with its daughter products) constitutes a significant gamma source and thus produced most of the external whole-body dose received by the Mallinckrodt workers, while Th-234 and Pa-234, both beta emitters, produced most of the extremity dose. In addition, radon and radioactive dusts were released in storage and processing, resulting in internal dose due to inhalation. The concentration of radium and other daughters present in the ore, processed uranium, and processing residue at any given time mostly strongly depended on the concentration of uranium in the ore and its radium content. The maximum Ra-226 content over the 2.25 possible years of processing (i.e., the 15-year maximum) was 0.158 mCi (ignoring decay of Ra-226) and the maximum Rn-222 content was 0.158 mCi (ignoring decay of Rn-222).*

Pot denitration processes involved the handling of the "light" thorium oxide, which produced visible air concentrations in open operating areas. According to a memorandum in 1965 regarding thorium operations at Mallinckrodt:

> *The most questionable activity was the hand scooping of ThO_2 from the denitration pots. This was done largely outside the post-exhaust enclosure and, at*

the time it was observed, was subject to vigorous air currents from partially open outside doors, essentially nullifying the effect of design ventilation. (MCW, 1965)

On page 35 of the TBD, where it discusses AM-7 residue conversion to thorium nitrate solution, there is a substantial inconsistency between the text and the data in Table 17. Table 17 presents an overall weighted average concentration of 0.07 alpha dpm m^{-3}. It seems to be implied that the Table 17 data should be compared with the Mound data. However at Mound, the concentration of Th-230 in the 'high risk' area was typically $1.63\ 10^{-9}$ μCi/cm^3. This converts to $1.63\ 10^{-9} \times 3.7\ 10^4 \times 1\ 10^6 \times 60 = 3620$ dpm m^{-3}. No comment is made on why the Table 17 values are so much lower. This example also raises a question about the specific way in which the weighting was done. This should be explicit and transparent.

Some areas, including ore unloading and storage areas as well as areas associated with K-65 residues, were likely to have high radon levels. Radon data are scattered and incomplete (TBD Section 5.3.4 and Tables 25 and 26). Revision 00 of the TBD does not appear to contain sufficient data to make complete, claimant-favorable, or worst-case dose estimates for high radon areas, though it can be used to make minimum estimates for compensation purposes.

Site experts have identified a number of incidents that occurred at SLDS (see Attachment 3). Involvement in these incidents is not explicitly considered in the TBD and may affect the outcome of the dose reconstruction.

5.2.3.1 Chemical Burns and Reactions with Other Chemicals and Material Pose a Potential Entry Port for Internal Contamination

Chemical burns resulted in the potential for entry of radioactive material though wounds. Chemical burns occurred frequently in processes involving acids and other caustic material. Workers were treated for moderate to severe burns and sent back into areas with radioactive material. Uptake through wounds is not addressed in the TBD. It is thought likely to be of limited significance compared with inhalation, but this should be confirmed by explicit scoping calculations.

5.2.3.2 Dust Bag Ruptures with Release to the Work Area and Atmosphere

Although specific reference to such dust bag ruptures could not be found on the ORAU site research PDF document database, the site expert interview summary in Attachment 3 mentions this as a potential route of significant uranium dust inhalation and internal exposure.

5.2.3.3 Other Potential Incident Situations

NIOSH should attempt to find, if not available in the individual worker file, the additional dose impact from tank explosions in Building 52 and later in Plant 6, Building 105 ("Ether House"), spills, and furnace blowouts. Revision 01 of the TBD should include a list of activities and incidents that would serve as a guide in dose reconstruction.

5.2.4 Contamination on Skin and Gloves

Contamination from dust settling onto skin and clothes, as well as contamination on gloves carried into lunchrooms and smoke rooms, may result in a greater ingestion dose than acknowledged by the TBD. Metal flakes could also have been a problem at MCW. The NIOSH Technical Information Bulletin, OCAS-TIB-009, has been developed to help in such cases. NIOSH should address more fully the potential ingestion and inhalation dose contribution from such contamination sources.

Wolf (1947) stated the following with respect to Plant 4.

> *No hand counts, feet counts or clothing checks were made on employees going to the adjacent offices or lunchroom, which was also used as a smoking room where employees came intermittently to smoke or have a snack. The thorough washing of hands rule seems rather difficult to enforce in this case, particularly when the employees apparently do not consider the material unusually toxic.*

External doses from dust settling onto skin and clothes, may be important. A 1955 Oak Ridge Operations Office (OROO) document on laundering of gloves (OROO 1955) has extensive data on contamination of gloves from uranium facilities under the jurisdiction of OROO. The average measured dose rate from beta-gamma contamination was 12.88 mrep/hour, with many gloves having contamination in excess of 20 mrep/hour. The TBD does not address doing an analysis of these data to assess doses to the hands at MCW. These data seem to be useful also in determining doses from deposition of dust on clothing, as well as exposed parts of the body. For claimants with skin cancer or cancers of organs near the skin surface, NIOSH should characterize the depth dose distribution to workers who often had contamination on their skin or inside their gloves or shoes when handling and scooping the uranium slag residues out of drums or out of the containers they called “bombs.” Also, even though workers used respiratory protection in some cases, their masks could be contaminated on the inside if mask fit and handling were not appropriate. This is another potential source of internal exposure that should be considered.

5.2.5 Ingestion of Large Particles

The potential for considerable ingestion due to the presence of large flakes needs to be explicitly evaluated, in light of the information provided in the Site Profile on Aliquippa Forge published by NIOSH in December 2004 (ORAUT 2004, page 9).

> *A NYOO report of an AEC visit to Vulcan Crucible on February 15 and 16, 1949, describes time-weighted radioactive dust exposures between 2.7 and 5300 times the preferred level depending on the type of job (AEC 1949b). A review of the February 1949 report and calculations shows that February report was in error and overstated the maximum exposure by about a factor of 10. When discussing the higher concentration, the report states:*

> *It was noted during the sampling that relatively large flakes of scale were being thrown from the rods at this operation. The above concentrations may therefore represent some number of large, non-respirable particles, and not be a true indication of exposure.*

This issue was also discussed in the SC&A review of the Bethlehem Steel Site Profile. Uranium metal was produced at MCW. Cropping of the metal and other operations, such as scraping equipment, would be expected to yield large particles. Large particles may be a principal route of ingestion exposures and should be evaluated.

5.2.6 Dose From Raffinate Waste and Other Process Materials are Not Fully Addressed with Respect to Trace Radionuclides

NIOSH should address in more detail the potential for internal dose during the handling of raffinate wastes and during waste residue processing and other operations involving materials containing radionuclides in the U-235 and U-238 decay chains. Data or analysis regarding exposure potential from some of the steps of handling or processing raffinates are lacking in the TBD.

In Appendix C, Attachment 1, of a report prepared as a part of the Mound Dose Reconstruction Project, MJW Corporation summarized various special processing campaigns involving Pa-231, Ra-226, and Ac-227 (Mound 2000, pages 2 and 3). The following statement is made with respect to the Ra-226 program:

> *According to Mound documents, two different source materials were used in the program. The Mallinckrodt Chemical Works in St. Louis, Missouri produced residue containing radium in the process of recovering uranium from a Belgian Congo pitchblende ore. This residue was known as K-65 residue. ^{226}Ra occurs with uranium in pitchblende ores at 1 part in 3 million. In October of 1949, about 200 pounds of this residue was shipped to Mound.*

Mound used the residue to extract Ra-226. Mound also had a program to recover and purify Pa-231 from material. The following statement on page 3 of Appendix C, Attachment 1, demonstrates the linkage between the Mound program and Mallinckrodt Chemical Works (Mound 2000).

> *Several different source materials were researched, including materials from Mallinckrodt Chemical Works in St. Louis, Mo., the AEC Fernald Plant in Ohio, and the Cotter Corporation in Canon City, CO. It appears, however, that the majority of the protactinium produced was obtained from two materials. One was 80 drums of a rather inhomogeneous material supplied by Mallinckrodt known as Sperry press cake, which consisted of 0.1-0.2 parts per million of protactinium in a matrix of iron, aluminum, calcium, magnesium, cobalt, and copper (Salutsky, et al., 1956). This material was determined to have a significantly different composition from samples used during the research phase of the program. A*

> *second material from which protactinium was produced was the Cotter Concentrate, which was a somewhat aged and possibly more processed version of the St. Louis Airport Cake (see Section 2.3) also produced by Mallinckrodt, but still containing uranium and thorium. This material was also used in the Ionium (Th-230) Program.*

Page 17 of the TBD states that raffinates were "on occasion" dewatered using a Sperry press. Page 87 of the TBD cites a Pa-231 concentration of 0.1 to 0.3 ppm, compared to 0.1 to 0.2 ppm in the Mound TBD. A concentration of 0.3 parts per million by weight of significant amounts of Pa-231 equals $1.43*10^{-8}$ Ci/g of Pa-231 in the cake, which is about 530 becquerels per gram of Sperry cake. Approximately an equal amount of Ac-227 may be present, since both these radionuclides would be in equilibrium with U-235 in the ore, and both pass into the raffinate almost entirely during uranium extraction. Thorium-230 in the decay chain of U-238 would also be expected in this material.

The pressing of the raffinate may have the potential of causing the suspension of fine particles or liquid droplets containing both U-238 and U-235 decay chain radionuclides. Specifically, Th-230, Ac-227, and Pa-231 may be significant concerns. Routine inhalation of even milligram quantities of Sperry cake (e.g., 1 milligram per month over a few years) has the potential for significant internal radiation doses, notably to the bone surface and lungs. Thorium-227, the main decay product of Ac-227, is a potential concern for lung dose as well. Dose from these radionuclides in raffinates needs to be evaluated. There are no data in the TBD that permit further evaluation of this issue, which could be an important issue, since the times of raffinate pressing appear to be uncertain.

In addition to the potential for suspension of raffinate particles during dewatering, MCW also processed raffinate from uranium production for extraction of Th-230 (TBD, page 20). Similar concerns regarding Th-230, Ac-227, and Pa-231 would apply. Table 32 needs re-evaluation and, as it stands, does not appear to be a sound basis for dose reconstructions that account for all potentially significant sources of exposure.

Exposures to Pa-231 and Ac-227 between the years 1955 and 1957 during the processing of the material in Plant 7E for Th-230 need to be evaluated.

Exposures to these decay-chain radionuclides may also have occurred in other operations, such as scraping of filtered wastes (pages 18, 19, 42, and 43 of the TBD).

The outdoor pitchblende ore storage problem would constitute environmental exposures, and could cut across job categories. This needs to be evaluated.

In summary, a further evaluation of the trace radionuclides (notably Ac-227 and Pa-231) during all operations, but especially during handling and processing of raffinates, should be included in Revision 01 of the TBD.

5.2.7 Solubility Assumptions Should Be Carefully Considered in Regard to the Urinalysis Interpretation

The solubility assumptions that are used to estimate organ dose from urine need to be discussed. For instance, an assumption of Type S or Type M (and in the case of UNH of Type F) must be more carefully considered when deriving doses to organs based on urinalysis data, since a Type S assumption in this case may yield a higher dose for non-respiratory tract organs than a Type M assumption. Analysis of organ dose from urine data can be complex and more specific analysis is needed in the revision to the TBD.

5.2.8 NIOSH Should Further Investigate the Potential for Exposure to Uranyl Nitrate in the Production and Laboratory Facilities. Consideration of Trace Elements Should Be Given to Samples Received from Hanford.

NIOSH has done some investigation on the question of whether uranyl nitrate fumes may have been present in the air. However, a more definitive investigation is called for. Uranyl nitrate is highly toxic when inhaled, and non-respiratory organ doses are high per unit of radioactivity because it has Type F solubility. For instance, it is possible that some portion of the dust levels in the pot room were uranyl nitrate. In one instance, this level was measured at 18,700 dpm/m^3 "before turning [uranyl nitrate] into powder," while later the level was measured at 2,040,000 dpm/m^3. The process for refining uranyl nitrate involved boiling. While the boiling was done in enclosed kettles, the highly acidic atmosphere may have corroded the linings, which would create the possibility for leaks of airborne uranyl nitrate. The corrosion of linings and seals as a possibility is not investigated in the TBD. Other potential areas for suspension of uranyl nitrate should be evaluated, such as during unloading and transfer operations when it was received from offsite.

As a general matter, inhalation of uranyl nitrate should be considered in more detail, even outside of the boiling step. Uranyl nitrate is considered dangerous even in laboratory settings, and precautions are advised against it. The potential for uranyl nitrate to be suspended in the industrial settings is also an important issue in radiation protection. This is illustrated by the extensive attention given to the topic by radiation protection authorities.[4] Therefore, Revision 01 of the TBD should analyze in more detail the steps in the uranyl nitrate conversion in terms of its physical and chemical properties, laboratory experiments, and corrosion data on nitric acid processes that could provide more positive indication that the processes in use not only did not generate significant airborne uranyl nitrate, but that the maintenance and operating problems did not give rise to conditions when uranyl nitrate fumes were present. This would be particularly important for the early period. In case uranyl nitrate exposure turns out to be important for some workers, a further issue would be combined exposure of uranyl nitrate with nitric acid. It is acknowledged that this is a gray area in terms of dose calculations and even the science, but it may be an issue that requires consideration.

NIOSH should also evaluate the potential exposures attributable to impurities in uranyl nitrate solutions from Hanford. Clagett and Maness (1950) state the following:

[4] See, for instance, the publication NRPB-W22 of the British radiation protection board.

> *The Redox and tributyl phospate(TBP) separations processes discharge recovered uranium as aqueous uranyl nitrate solution. Subsequent processing by either the K-25 plant or Mallinckrodt Chemical Works involves conversion of this material to UO_3 as an intermediate step. It is planned to effect this conversion at Hanford Works to provide a preferred form of recovered uranium for handling and shipping for further processing.*

As the solution shipped from Hanford underwent the separations process, it is possible that the material provided to MCW was from processing of recycled uranium.

5.3 FINDING 3: EXTERNAL EXPOSURE FINDINGS

5.3.1 NIOSH Should Review Doses Assigned as Shallow/Beta Doses

For select cancers that involve surfical tissues (e.g., skin, testes, breast, and eyes), radiation doses may be dominated by external beta fields. Accurate assessment of surfical doses may be handicapped for a variety of reasons that include (1) the failure to **monitor** the shallow dose, (2) the failure to **record** a shallow dose, even when such measurements were taken, (3) the use of inappropriate calibration methods, and (4) the misuse of dosimeter data. The first two deficiencies are obvious and require no explanation. A discussion of the remaining two deficiencies is given below.

<u>Inappropriate Calibration</u>. Even when past film dosimeters included an "open window" for the purpose of defining the shallow dose, calibration of the film dosimeter may significantly obscure a contribution by beta radiation. This is due to the fact that silver halides (or the radiation-sensitive component of the dosimeter) have a high atomic number, which causes the dosimeter to grossly over respond to photons that interact with the dosimeter by photoelectric interaction. In recognition of this, algorithms were commonly developed to compensate for the over response. In contrast to photons, the interaction of beta particles with film is **not** governed by the energy-dependent photoelectric interaction. In brief, past calibration methods for determining shallow dose may have been inappropriate, and the contribution of the beta dose in the presence of a mixed photon field is difficult to interpret.

<u>Misuse of Dosimeter Data</u>. Sections 5.4.3.2 and 7.3.1 of the TBD describe the method by which the beta dose is derived from a film dosimeter with an open window and a 1000 mg/cm^2 filter:

> <u>Page 45 of the TBD</u>:
>
> . . . *This issue* [i.e., derivation of beta dose] *involved the subtraction of the film density value under the beta "shield"* [i.e., 1000 mg/cm^2 filter] *from the value under the* [open] *window.*

and

Page 56 of the TBD:

For Mallinckrodt, it is assumed that 'the beta readings are obtained by subtracting the density under the shield from the density under the window and assuming the difference in density is due to beta radiation' (MCW 1950g). ***For the purposes of dose reconstruction, the 'beta' readings in the Mallinckrodt dose records are assumed to be equal to the shallow dose****, Hp(0.07). A claimant-favorable dose conversion factor of one is assumed for application of shallow dose to the skin, testes, and breast.* [Emphasis added.]

The passage from page 56 not only repeats the statement from page 45, but includes a second error, as explained below.

The dose-response of a film dosimeter is defined by the net optical density (NOD) as a function of exposure. The function of **NOD** versus **exposure**, however, is **not** linear and, therefore, invalidates simple subtraction of NOD values for determining the beta component (see Figure 1). To support this contention, SC&A will defer to the 1989 National Research Council (NRC)/National Academy of Sciences (NAS) study *Film Badge Dosimetry in Atmospheric Nuclear Tests*. (NRC 1989)[5] Statements from this study that may be relevant to Mallinckrodt include the following:

Page 39 of the NRC/NAS Study:

The filter system used in most atmospheric testing operations included a lead (atomic number 82, density 11.34 g-cm^3) filter and open areas (wrapped with paper and plastic). Only very high energy beta particles could penetrate the lead filter. As a result, contribution of beta particles to the NOD under the lead filter was small, and had little effect on the evaluation of photon exposures. ***NODs in open areas, however, were affected by high-energy photons, low-energy photons to a much greater degree, and beta particles, to an extent dependent on beta-particle energy****.*

When a film badge with only a lead filter and an open area is exposed to unknown mixtures of beta and photon energies, it is ***not*** *possible to determine contributions from each component to NOD in the film open area. At one extreme, an excess NOD in the open window may be the result of only photons. At the other extreme, it may be the result of only beta radiation.* [Emphasis added.]

Page 40 of the NRC/NAS Study:

The final attempt to evaluate and report ***beta exposure*** *with film badges during atmospheric testing was at Camp Desert Rock, outside NTS, during Operations PLUMBBOB in 1957. . .*

[5] See http://books.nap.edu/books/0309040795/html

This badge had four filter areas: lead-tin laminate, open window, copper, and aluminum. This combination was thought to be capable of providing beta exposures, but the analytical procedures used were faulty. The NOD measurements were improperly incorporated into certain equations, when converted exposure data should have been used instead. ***As stated previously, the function of NOD versus exposure is not linear, and NODs from a film must be converted to exposure with a common calibration curve because an increment of NOD can represent a different amount of exposure at different locations on a calibration curve.***

Each of the film badge types used to monitor beta dose at the three test operations discussed could have been used to adequately monitor exposure to photons. Use of these badges to monitor beta dose, however, was ***unsuccessful****.* [Emphasis added.]

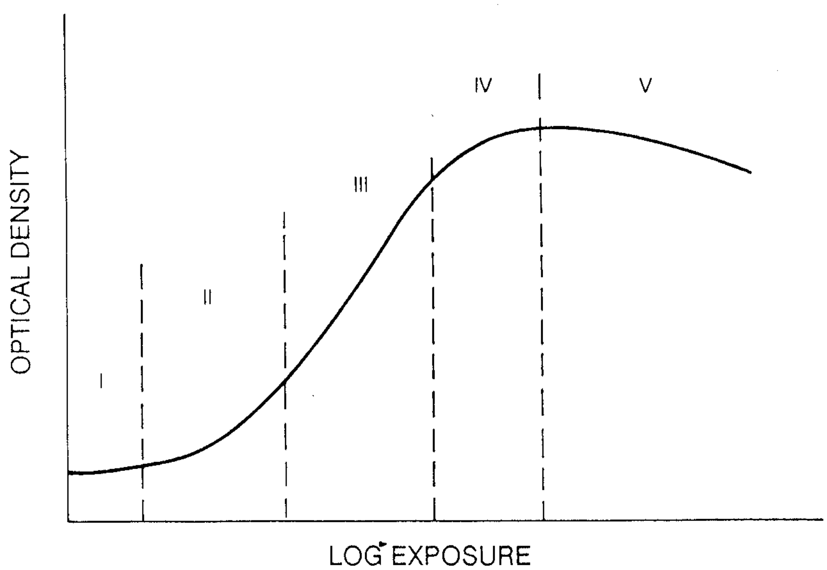

Figure 1. Characteristic Response Curve (H & D) for a Photographic Emulsion Exposed to Ionizing Radiation
(Source: NRC 1989)

These statements confirm the difficulty of defining the beta component in film dosimeters and clearly invalidate the simple method of subtracting NODs.

Also of concern is NIOSH's need to even identify the beta component. For skin dose determination, the open window (or shallow) dose may, in fact, include a combination of exposure to betas and photons. However, the combined dose of betas and photons should define the dose used in dose reconstruction.

5.4 FINDING 4: SURROGATE CO-WORKER DOSES

The specifications for defining co-workers in the TBD are not well developed. Analysis of job category equivalence and variation between individual doses within a job category are required for each period for which a co-worker approach is used for dose estimation. Table 31 of the TBD needs further analysis before it can be used to make anything other than minimum dose estimates for compensation.

Table 31 provides uranium dust surrogate inhalation rates. However, it is not clear how these inhalation rates should be applied to individuals, because individual work assignments may vary from the ones in the list. NIOSH should also check that the work assignments in the list are actually contemporaneous with the times listed. Uncertainties in regard to use of co-worker data for specific individual workers need to be addressed. This will enable a scientifically defensible way of estimating doses that gives the claimant the benefit of the doubt in the face of uncertainties occasioned by using co-worker data. NIOSH should also examine the analysis that resulted in Table 31, since most of the geometric standard deviations (GSDs) are in error. The table presents GSDs that are less than 1, which is theoretically impossible. NIOSH has stated that it is aware of this problem, and an assessment of how this error came about would be instructive and help prevent similar problems in the future.

A further problem is that air concentrations at adjacent workstations can be quite different. These differences create significant uncertainties that need to be addressed in defining co-workers and using co-worker data. For instance, see the discussion below on brushing man/chipper air concentration data. Such issues would also apply to co-worker badge data or urinalysis data.

The use of the term "co-worker" in both claimant interviews and for surrogate workers in specific jobs is problematic. Moreover, SC&A notes also that NIOSH procedures do not require co-worker interviews, even in the case of family member claimants (SC&A 2005). Nor does there appear to be any method to link the data provided by co-workers as part of the interview process with the process of producing the TBDs. Only about a dozen co-worker interviews have been done, even though more than 6,000 dose reconstructions have been completed.

At the present time and in the present state of analysis, it is questionable whether co-worker data can be used to perform worst-case dose reconstructions. There is also a need for a systematic distinction between the two types of co-workers – those identified in interviews and those used for dose reconstruction surrogates.

In the pre-1948 early period, there is concern that there is insufficient co-worker data (or in many cases no co-worker data) in Revision 00 of the TBD to properly characterize worker dose, particularly for uranium dust inhalation. Co-worker data may be of value for film badge exposures after 1945, with the provisos above regarding definitions of co-workers and uncertainties. Revision 01 to the TBD should address the degree to which co-worker data can be used for claimant-favorable dose reconstruction for dust inhalation exposures for the time period from 1948 to 1957.

5.5 FINDING 5: TIME-WEIGHTED AVERAGES

The TBD's use of time-weighted averages to quantify uranium dust inhalation dose does not take into account a number of variables. Such averages cannot be used to reliably estimate anything other than minimum doses.

The use of time-weighted averages using averages for each location is appropriate for minimum estimates that are used to compensate. However, additional raw data confirmation, determination of uncertainties, and use of the upper 95th percentile values, estimated by sampling the various locations, is needed in order to provide a more claimant-favorable dose reconstruction in the face of substantial uncertainties, such as amount of time actually spent by the specific employee at various locations and the air concentrations at those specific times.

The air concentrations experienced by individual workers may vary from the measured average due to a number of factors, including the following:

- Measurement uncertainties, due to too few measurements or measurements over periods that were too short.
- Measurements that were not representative of the breathing zone.
- Measurements that may have been taken on one or a few days, or over time periods that may not accurately represent the entire covered period.
- The variation of the routine of individual workers from the average represented by workstation data.
- Variations in ventilation conditions over time (other than those due to new equipment).
- Off-normal practices not observed during the time when measurements were being taken.
- Job categories of a specific claimant over time may not correspond to the ones specified.
- High episodic air concentrations.
- Job categories that the worker actually worked in may not be accurately known or remembered. This problem is likely to disproportionately affect family member claimants (SC&A 2005)

The use of average values for minimum doses can be justified for compensation purposes. However, in view of the uncertainties, the average value for each workstation will not provide a value that gives the claimant the benefit of the doubt, much less provide a worst-case value, should a procedure for estimating worst-case doses be needed.

In order to use a time-weighted approach to worker exposure, there must be sufficient air samples at each location. These samples must be established to be representative in space and time for that location. This enables a distribution of air concentrations to be fitted for each location. The various distributions can then be sampled and weighed according to the estimates of worker-time spent there. Ideally, the variation in worker-time estimates would also be sampled. Careful account must be taken of changes in process, working conditions, ventilation, and other factors. A 95th percentile value can then be estimated for the job category.

If workstations have only one measurement, distributions cannot be constructed. Alternative procedures, such as constructing a facility air profile for the process, might be joined to workstation data in that case. It is conceivable that one could pool similar stations to create distributions from similar populations of data, provided that the pooling is technically carefully justified and uncertainties are taken into account in a claimant-favorable manner.

NIOSH has indicated that it has not used raw data in its time-weighted average estimation, but has accepted the data calculated by AEC. It is also not clear whether the high values of air concentration that were measured have been integrated into the average. These values cannot be a priori excluded. As noted above, extremely high concentrations in the many hundreds of thousands of dpm/m^3 have been recorded even after the end of the 1950s at Fernald (Klein 1960)**.** Such values can disproportionately affect exposure and need to be considered.

The absence of any account in the MCW TBD of how raw data was analyzed, e.g., for air concentrations, is considered a weakness of the TBD. NIOSH should display the underlying raw data (or, if extensive, provide it electronically with the report), state the statistical procedures used, and display the results obtained. This is important, as the dose reconstructor for an individual may wish to select from the raw data on the basis of specific information about the individual, but then perform standard statistical procedures on the selected data to obtain modified results, e.g., time-weighted air concentrations with uncertainties, that are deemed more appropriate to the individual than the standard values.

To take a simple example from Table 15 of the TBD, it seems that concentrations experienced by a brushing man/chipper decreased markedly from 1955 to 1956. This may be only a consequence of uncertainties due to small numbers of samples (compare the air concentration for the brushing man in 1955). However, if the reduction is real, it might imply a change of work practice sometime in 1955. If this were the case, it would potentially make a great deal of difference if an individual worked as a brushing man/chipper early in 1955 and then moved to some other occupation, or whether they became a brushing man/chipper late in 1955. This issue can only be addressed by examining the raw data underlying the weighted averages. However, we do not believe that the analyses presented are adequate. For example, the year-by-year weighted averages of air concentrations differ from each other, but we do not know whether these differences are statistically significant, whether there are trends with time or sharp discontinuities at particular times, and whether there are spatiotemporal correlations between the measurements and occupancies of different types of workers. With respect to the last of these issues, consider again the brushing man/chipper and the brushing man in 1955. One has a weighted average concentration of 2110 dpm/m^3 and the other 47 dpm/m^3. However, we would expect them to work in close proximity to each other.

SC&A's review of the database turned up several instances of very high air dust concentrations. The raw data in the February 2, 1949 dust study at MCW Plant 4 shows an average of 27,400 dpm/m^3 and a high of 40,500 in a TA-7 packing job of removing and replacing a mixer top (page 5). TA-7 packer is a job category in Table 21 (7,210 dpm/m^3). The report shows an average of 823,000 dpm/m^3 and a high of 2,870,000 dpm/m^3 when dumping D-7 in a D-7 area (page 6). By contrast, the highest uranium dust daily weighted exposure level in Table 21 is 13,000 dpm/m^3 for a TA-7 (green salt) UF_4 unloader (operator)(MCW 1949b).

An average of 53,300 dpm/m^3 and a high of 77,000 dpm/m^3 when cleaning the bottom furnace area were recorded (page 6), whereas Table 21 shows an average of 3,360 dpm/m^3 for a furnace loader (UF-4-derby) and no category for a furnace cleaner. Tables 21-24 appear to be in need of re-evaluation for inclusion of additional data. It would also be helpful to have an indication of temporal variations in concentrations, as well as time-weighted averages, recognizing that presence at a workstation; hence exposure may be either positively or negatively correlated with dust loads in air.

Documents on the ORAU site research PDF document database for Plant 6 also indicate that there are some workstations with extremely high levels of dust; levels of several hundred thousand or even above one million dpm/m^3. These are much higher than the Plant 6 concentrations in Table 9 or Table 22 of the TBD for 1948 and earlier. For instance, (1) the dust levels in the fumes in the pot room were measured at 2,040,000 dpm/m^3 "after turning into powder" and at 18,700 dpm/m^3 "before turning into powder;" (2) the dust levels associated with "checking and leveling of buckets" was reported to be 347,000 dpm/m^3 (MCW 1949c); and (3) "opening of bins for inspection" was cited as having dust loadings of 693,000 dpm/m^3.

The TBD does not address these extremely high dust levels and does not caution the ORAU dose reconstructors to take these into account (MCW 1949c). It is noted that some of these high levels were associated with operator actions; hence these high concentrations were sometimes correlated with the presence of particular workers or types of workers.

In Table 22, for instance, it is noted that jobs like "Furnace operator," "LF-9/brown/UO_2 package/unloader," and "Ore Room operator" have uranium dust daily weighted-average exposure levels of 24,780, 38,990, and 13,720 alpha dpm/m^3, respectively, and that these values are orders of magnitude greater than other job exposure levels. Since these are averages, it is likely that workers in these job categories had maximum levels even higher than those listed. An uncertainty analysis is necessary to be able to estimate the 95th percentile values that would provide a more reasonable basis for translating area-monitoring data into individual claimant dose estimates that give the claimant the benefit of the doubt in a statistically defensible way.

6.0 ADEQUACY OF DATA

The health and safety program with respect to radiological control was not established until early 1948 (Mason 1958). Therefore, the data prior to this period are extremely limited.

6.1 DATA ADEQUACY FOR DOSE RECONSTRUCTION

Mallinckrodt Chemical Works (MCW) did not begin monitoring personnel with dosimeter badges until 1945. Prior to this time, there was no personnel monitoring for external radiation.

The TBD on page 42 supports this when it stated:

> *There is little information about conditions in Plants 1 and 2 during the wartime startup: no dose rate measurements from 1942-1946 appear to have survived and as noted previously, film badging did not start until late 1945, when Plants 1 and 2 were in the process of shutting down.*

There is evidence to indicate that MCW did undertake eight measurements reported as dust concentrations of "X" dust ("X" in the early days meant uranium) in micrograms/m^{3}and time tolerance dose at MCW as early as March 1944. In a memo from John Ferry to J.A. Kyger dated March 31, 1944, Captain Ferry reported on results collected at MCW (assumed to be the Plant 51 complex, although it is not so identified), which includes some air sample sheets (Ferry 1944a).

In another memo from John Ferry to H.E. Thayer dated June 9, 1944, Captain Ferry noted the following (Ferry 1944b):

> *Measurements of radioactive dust collected at Mallinckrodt Chemical Company, 9 May and 19 May 1944 are presented on the enclosed tabulation [8 sample results].*
>
> *These results indicate that dust concentrations are in general too high in the neighborhood of bomb and biscuit operations. It is recommended that steps be taken to provide a more thorough cleaning of the floor and a more efficient localization of high dust concentrations at dusty operations. Biscuit chippers, personnel working in the vicinity of burning crucibles and in the orange oxide milling room should continue the wearing of respirators.*

These early air monitoring data were not related to any individual worker's dose, but were a means to get some idea of the dust concentrations levels at that time.

By 1957, MCW had processed more than 45,000 metric tons (50,000 tons) of natural uranium products at its facilities (DOE 1996). Tyco Healthcare/Mallinckrodt currently owns the site.

Mont Mason (Mason 1958) reported the following:

No regular dust sampling program was in effect during 1943 through 1947, but sufficient samples were collected to show that air-borne uranium concentrations were high by present standards; concentrations of 50 to 100 times the present MAC were not uncommon, and some operations produced concentrations up to 1000 MAC for a few minutes. Note that these are air concentrations, not intakes to the lungs.

It is apparent that there was no routine air sampling data for uranium dust to adequately assess individual worker dose. This is particularly important for employees who worked in high dust areas. The TBD on page 35 of 126 reported that:

Mason (1958a) stated that MED and Mallinckrodt agreed in the early years of work that production would proceed on a priority basis with the understanding that in high dust areas extensive use of respirators would need to be made. Thus during 1946-1948, respirators were used for "practically all" plant operations. Thus it is clear that respirators were used from at least the late years on. Mason (1958a) commented that the exposures received depended partly on the effectiveness of the respiratory program (at that time).

Site expert interview information in Attachment 3 provides testimonial evidence that it was left up to the worker as to how committed he or she was to wearing respiratory protection. The TBD, on page 35, confirms that respirators were not consistently used. Without a formalized health protection program, it was reported that many workers did not use respiratory protection.

By 1945, MCW was beginning to get a handle on gamma and beta dose, and film badge summary information begins to show up around April 1946.

The TBD states the following on page 50:

For analysis of urine samples, only uranium was counted, and in the air sampling, only gross alpha was counted. Thus, it is not possible to know, e.g., how much radium was in the urine sample.

Also most workers will have some gaps in monitoring because routine bioassay did not begin until 1948 and because there were undoubtedly some missed bioassays. The intakes over the gap periods will have to be determined either by comparable (surrogate) worker data or failing that, by the use of time-weighted daily average dust exposure data.

6.2 GAPS IN DATA AND ANALYSES

There are many gaps and issues in the data and analysis in Revision 00 of the TBD. NIOSH has indicated that it is correcting or has internally corrected some of these problems, such as the erroneous GSDs in Table 31. The following comments pertain to data adequacy and associated analyses provided in Revision 00 of the TBD.

Revision 00 is insufficient for estimating doses that give the claimant the benefit of the doubt in the face of uncertainties, or worst-case dose estimates (with the latter being used for denial only). For adequacy in calculating either of these types of doses, the data and analysis should include the following:

- An analysis of co-workers that would be technically and statistically sufficient to estimate uncertainties in individual worker dose estimates
- Development of a method that would enable a 95th percentile value to be estimated by the time-weighting approach
- An analysis of the raffinate handling and processing (including raffinate dewatering and raffinate processing) that provides estimates of airborne materials that would contain uranium-238 and uranium-235 decay products, specifically including thorium-230, protactinium-231, and actinium-227
- An analysis of how the high concentrations that were present at MCW would affect doses and uncertainties in doses
- An analysis of incidents and high-risk job categories in relation to the way air concentration data are used to estimate individual doses and uncertainties in those doses
- An investigation into the integrity of film badge and urinalysis data recording practices
- Development of an approach that appropriately combines solubility, particle size, and breathing type assumptions (or inferences) when using urine data to infer organ doses that give the claimant the benefit of the doubt in the face of uncertainty
- An investigation into the reasons that some workers were not monitored in order to verify or change the assumption that unmonitored workers were not likely to have had significant exposures
- Analysis of internal and external monitoring criteria with respect to the workers

Finally, the problem of determining what parameters to apply when the job description is unknown is difficult in the case of MCW, due to the complexity of operations, the complicated statistical and data-related issues connected to the proposed use of co-worker data, sporadically very high radionuclide air concentrations, and paucity of data and analysis in some areas.

7.0 CONSISTENCY AMONG SITE PROFILES

The processes and assumptions contained in the Mallinckrodt Chemical Works (MCW) technical basis document (TBD) were compared with those of the Bethlehem Steel (BS), Savannah River Site (SRS), and Hanford TBDs. Mallinckrodt Chemical Works had some attributes of an Atomic Weapons Employer and some attributes of a larger DOE facility, which made comparisons with DOE and AWE facilities appropriate.

There were a number of key elements in the Revision 00 TBD that are typically similar to elements commonly used by NIOSH in other site profiles. These include a site description, occupational medical dose, internal dose, and external dose. Occupational medical dose represents dose from x-rays required as a condition of employment and is usually tracked via site medical records. Internal dose represents dose from radioactive material taken into the body, including that resulting from residual contamination. External dose represents exposure to sources of radiation external to the body from beta particles, photons, neutrons, and other heavy particles. Environmental dose results from exposure to radioactive material that has been released to the air, water, or soil, or from exposure to disposed waste, such as at a burial ground. Table 4 contains a summary of the elements addressed in the MCW, BS, SRS, and Hanford TBDs.

Table 4: Site Profile Comparison

	MCW	Bethlehem Steel	SRS	Hanford
Site Description	Included	Included	Included	Included
Occupational Medical Dose	Included	Included	Included	Included
Internal Dose	Included	Included	Included	Included
External Dose	Included	Included	Included	Included
Environmental Dose	Not Included	Not Included	Included	Included

Although Hanford and SRS have sections on the development and assignment of environmental dose, this is absent from the MCW and BS site profile. In the case of MCW, post-operation monitoring data as a result of remediation programs has indicated the presence of soil and water contamination. DOE/EM-0319, *Linking Legacies*, documented that 170,000 m^3 of contaminated solid media resulted from weapons production operations at MCW. A survey conducted by Oak Ridge National Laboratory in 1981 summarized the environmental conditions at St. Louis Downtown Site (SLDS) as follows (Goldsmith et al. 1981):

> *The survey included measurements of the following: residual alpha and beta-gamma contamination levels in the existing buildings that were used in the uranium projects; external gamma radiation levels at 1 m above the surface in these buildings and outdoors around these buildings; radon and radon daughter concentrations in the air in these buildings; uranium, radium, actinium, and thorium concentrations in surface and subsurface soil on the site; concentrations of radionuclides in water and sediment found in drains both inside and outside the buildings; and concentrations of radionuclides in ground and surface water*

on the site and in river water taken near the site. Alpha and beta-gamma contamination levels inside and outside some of the buildings were above limits set by current federal guidelines concerning the release of property for unrestricted use. Elevated external gamma radiation levels were measured at some outdoor locations and in some of the buildings. Licensable concentrations of uranium were found in soil at some places, and the concentration of uranium in a water sample taken from a core hole between Buildings 100 and 101 was in excess of limits set by current federal standards. Radon and radon daughter concentrations in three buildings were in excess of current federal guidelines for nonoccupational radiation exposure.

Based on post-operational concentrations of radioactive material in the soil and water, it is feasible to expect similar or greater levels of environmental release during the production years. This is further collaborated with site expert testimony that fumes were released from production buildings. The likelihood of exposure from environmental release is significant and requires further consideration in the site profile. Also, for consistency and completeness of the site profile, environmental exposure should be addressed, whether or not the dose consequences are judged to be significant.

The assignment of dose for occupational medical exposure is discussed in ORAUT-TIB-0006, which is applicable to AWE and DOE facilities. In the case of Hanford and SRS, there was considerable data on the particular x-rays units and medical monitoring procedures. Due to the lack of medical records at MCW and BS, an annual standard chest x-ray was assumed for each covered year of the facility. The SRS and Hanford TBDs assumed early x-rays included photofluorography, while the MCW TBD did not include photofluorography. Photofluorography was a common technique prior to 1960 (OCAS 2002) and should be considered. Additionally, the MCW TBD utilizes different analogue organs for input into IREP than the SRS TBD. In the case of default assumptions, such as kVp, mAs, source-to-image distance, and uncertainty, the approach is consistent among the site profiles examined.

The methodology for assignment of internal dose is somewhat specific to the site. In the case of MCW, SRS, and Hanford, urinalysis data was available for a portion of the covered period. This information was used as the primary source for internal dose calculation. MCW supplemented urinalysis data with air concentration data, which is similar to the approach taken at BS. Alternate internal dose assumptions were utilized for MCW as compared with other site profiles. The explanation for the alternate assumption was not provided in the TBD. Some issues of concern in internal dose assumptions between MCW and the other site profiles include the following:

- BS and MCW site profiles both had statistical procedures and or data tables that result in dose estimates that do not give claimants the benefit of the doubt in the face of uncertainties in at least some cases.
- The BS TBD assumed 10-hour workdays, while the MCW TBD assumed 2,000 hours per year (effectively an 8-hour workday.)

- An analysis of ingestion dose was included in the BS TBD (Revision 01), whereas ingestion dose was deemed to be negligible in the MCW TBD. Large particle ingestion was not taken into account in either case.

In the case of MCW, SRS, and Hanford, film badge data was used as a primary source of external exposure, where available. Some inconsistencies in external dose assumptions between MCW and the other site profiles include the following:

- Adjustment factors are applied to recorded external dose at Savannah River Site and Hanford to estimate Hp(1.0) doses. The MCW TBD does not recommend an adjustment to recorded dose. The TBD therefore did not take into consideration the laboratory, radiological, and environmental uncertainty in the personal dosimetry program.
- The BS TBD assumed 10-hour workdays, while the MCW TBD assumed 2,000 hours per year (effectively an 8-hour workday.)

SC&A recognizes that operations, exposure conditions, and facility designs vary, even in facilities with the same production mission. We have presented some consistencies with the MCW TBD in relation to other TBDs. Based on the source term and the workplace conditions at MCW, variations in assumptions may be justified. Further explanation in the TBD is required to account for the alternate assumptions with MCW verses other site profiles in light of the similarities in source term at BS, portions of Hanford, and portions of the SRS.

8.0 REGULATORY COMPLIANCE

The dose reconstruction process must comply with the requirements of 42 CFR 82, *Methods for Conduction Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000*. As a method of effectively implementing these requirements, NIOSH has written technical guidance documents on external and internal dosimetry. ORAU has committed to the use of these guidance documents in its quality assurance program plan. The issues identified below are cited circumstances where the Mallinckrodt Chemical Works (MCW) technical basis document (TBD) is not consistent with the guidance outlined in 42 CFR 82, NIOSH guidance documents, the ORAU quality assurance program plan, and other relevant technical documents. SC&A recognizes that the MCW Revision 00 TBD is undergoing revision, and that a Revision 01 may rectify some of these issues. These items are listed as a reminder to NIOSH/ORAU that they should be addressed.

8.1 COMPLIANCE WITH POLICY AND DIRECTIVES IN 42 CFR 82

42 CFR 82 requires the use of worst-case assumptions when efficiency methods are employed as a basis for denying a claim. The guidance provided in the MCW TBD for nonradiological workers (i.e., those not entering or working in process areas) likely overestimates the actual radiation dose experienced by these workers, with the caveat that environmental exposures still need to be evaluated. In the case of radiological workers, Revision 00 of the TBD is not a suitable basis for estimating either worst-case estimates for purposes of denial or for dose estimates that give the claimant the benefit of the doubt in the presence of substantial uncertainties. While NIOSH is revising the TBD in view of the deficiencies that NIOSH recognizes, SC&A makes the comments below because the limitations of Revision 00 are not explicit in the TBD as it stands now. Specifically, Revision 00 does not explicitly limit its scope to minimum dose calculations to be used for calculations. SC&A recognizes that NIOSH uses some claimant-favorable assumptions, such as Type S solubility for respiratory tract doses, even in minimum dose calculations. However, as discussed in this section, 42 CFR 82 commits NIOSH to resolving uncertainties systemically in favor of the claimant whenever these are determined to be present. The conclusions below should be seen in light of the comments in this paragraph.

Given the above conclusion, Revision 00 of the MCW TBD does not adequately follow 42 CFR 82.10(k)(2&3), which states:

> *(2) Dose is determined using worst-case assumptions related to radiation exposure and intake, to substitute for further research and analyses; or*
>
> *(3) Worst-case assumptions will be employed under condition 2 to limit further research and analysis only for claims for which it is evident that further research and analysis will not produce a compensable level of radiation dose (a dose producing a probability of causation of 50% or greater), because by using worst-case assumptions it can be determined that the employee could not have incurred a compensable level of radiation dose.*

Our concern is that the estimate of internal dose is based on average values, rather than values that give the claimant the benefit of the doubt. Since there are substantial uncertainties in these averages, their use does not meet the commitment that 42 CFR 82 makes to claimants that:

> *Claimants will in no case be harmed by any level of uncertainty involved in their claims, since assumptions applied by NIOSH will consistently give the benefit of the doubt to claimants.*

Since this statement is made as part of the explanation for a "reasonable" dose estimate (page 22324, 42 CFR 82), the lack of 95th percentile values for estimating time-weighted doses means that Revision 00 does not meet the test that uncertainties be resolved in favor of the claimant.

The analysis of early data did not account for lack of radiological controls prior to 1948. The application of co-worker data has been developed by job title grouping, and does not include the evaluation of dose from co-workers identified in the CATI process.

Although NIOSH/ORAU have indicated that they are currently retrieving and evaluating data previously available to ORAU for use in epidemiologic studies, these data are not addressed in Revision 00 of the MCW TBD. Retrievable personnel and workplace monitoring data were not adequately evaluated for Revision 00, and therefore the TBD is in conflict with 42 CFR 82.14(b) and (e) which states:

> *NIOSH will obtain the types of information described in this section for dose reconstruction, as necessary and available:*
>
> *(b) Worker monitoring data, including:*
> *(1) External dosimetry data, including external dosimeter readings (film badge, TLD, neutron dosimeters); and*
> *(2) Pocket ionization chamber data.*
>
> *(e) Workplace monitoring data including:*
> *(1) Surface contamination surveys;*
> *(2) General area air sampling results;*
> *(3) Breathing zone air sampling results;*
> *(4) Radon and/or thoron monitoring results;*
> *(5) Area radiation survey measurements (beta, gamma and neutron); and*
> *(6) Fixed location dosimeter results (beta, gamma, and neutron); and*
> *(7) Other workplace monitoring results.*

Since the internal monitoring program did not begin until 1948 with the inception of a urinalysis program, and since routine individual or worker group air-sampling data was limited prior to 1948, NIOSH did not fully utilize other validating dose reconstruction techniques, such as the use raw data cards, available as a part of the DOE epidemiology program, as a potential method for determining internal dose during the early years from 1942 to 1948. Information such as payroll records were also not used to validate worker claims of extended workdays (Attachment 4).

Three components (laboratory, radiological, and environmental) of uncertainty are associated with personnel dosimeter, such as the film badges used at MCW. 42 CFR 82.15(5)(b) states:

> *NIOSH will evaluate the instruments and procedures used to collect individual monitoring data to determine whether they adequately characterized the radiation environments in which the covered employee worked, (adequately for the purpose of dose reconstruction), based on present-day scientific understanding. For external dosimeter measurements, this includes an evaluation of dosimeter response to radiation types (gamma, x-ray, neutron, beta, or other charged particle) and the associated energy spectrum….An analysis of the monitoring programs will also be conducted to determine the potential for undetected dose.*

The MCW TBD briefly describes the external monitoring program in Section 7.0, *Determination of External Doses*. The MCW TBD states that the badge is similar to that used in the past by the Idaho National Engineering and Environmental Laboratory (INEEL). Table 6-3 of ORAUT-TKBS-0007-6, *Technical Basis Document for Idaho National Engineering and Environmental Laboratory (INEEL) – Occupational External Dosimetry*, summarizes the uncertainties related to INEEL dosimeters, including film badges (Rohring 2004). MED/AEC/DOE beta/photon dosimeters, presumably including MCW film badges, are expected to be a reasonable measure of the $H_p(10)$ dose under most workplaces with low-energy photons. The TBD, therefore, does not apply adjustment factors to recorded film badge results to equate it to the present-day scientific understanding of dosimetry.

A qualitative examination of the radiological exposure conditions in relation to the film badge has been included in the TBD. Other uncertainties related to laboratory and environmental effects on film badges were not considered. In addition, there was no correction factor applied for changes in calibrations, such as use of a phantom. Further evaluation of the MCW film badge program is necessary in order to verify the equivalence of this particular dosimeter to an $H_p(10)$ dose.

Uncertainty is inherent in all types of measurement data, including the air-dust concentrations, urinalysis, and dosimeter data. 42 CFR 82.19 states the following:

> *The estimate of each annual dose will be characterized with a probability distribution that accounts for the uncertainty of the estimate.*

Evaluation of the uncertainty in internal dose, as evaluated by air-concentration data, is not provided in Tables 21-24 and Table 32, which provide the basis for calculation of intake quantities.

8.2 COMPLIANCE WITH OCAS-1 AND OCAS-2

Similar compliance issues to those listed in Section 8.1 were observed with respect to OCAS-1 and OCAS-2. A detailed analysis of these issues is not provided here; however, NIOSH/ORAU has referred to these guidance documents for further details on how to resolve the issues described above.

8.3 COMPLIANCE WITH QUALITY ASSURANCE

ORAUT-PLAN-0001, *NIOSH Dose Reconstruction Project Quality Assurance Program Plan (QAPP),* outlines the quality assurance elements to be implemented in all aspects of the dose reconstruction process. The QAPP states the following:

> *Dose reconstructions will be performed in accordance with the requirements of 42 CFR 82 and with NIOSH technical guides, as described in approved written procedures (pg. 5 of 18).*

Well-developed procedures and/or technical documents are necessary to insure that methods are effective and consistent. Applying procedures can provide continuity of assessment over time and across multiple facilities. An important portion of any procedure is the scope, which defines the circumstances under which the procedure is applicable.

Section 1.0 of the MCW TBD, *Purpose and Scope*, outlines the period of coverage as well as the facilities at that are covered. Post-operation exposure is also within the scope of the TBD. NIOSH has indicated that the TBD is not applicable to the dose reconstruction of all MCW workers, specifically those who are likely noncompensable. The general process for dose reconstruction involves review of available data, identification of inadequacies in data, application of personal monitoring data where available, and use of the TBD where inadequacies in data exist. The site profile is not intended to encompass each specific exposure situation at a particular facility. For unusual exposure conditions, the dose reconstructor has the option to deviate from this standardized procedure and complete an individualized dose reconstruction. Section 1.0 of the TBD provides no guidance on when the TBD methodology should be applied and who is not covered under the methodology outlined in the TBD. ORAUT-PROC-0003, *Internal Dose Reconstruction,* provides general information on when to conduct individualized dose reconstructions; however, site-specific recommendations are not available in either this procedure or the TBD. In addition, the TBD does not include references to when technical information bulletins (TIBs) should be applied. This absence of guidance provides confusion on when to apply which particular method.

In the absence of personal monitoring data, each individual's exposure conditions must be compared against the TBD to determine whether this standard methodology applies to that particular claimant. This includes consideration for high-risk jobs, such as cleaning furnaces, coming in direct contact with radioactive material, receiving partial-body exposure due to task assignments, etc. These high-risk jobs, which may result in higher exposures than the standard approach, should be identified in the TBD. In addition, dose reconstructors should be made aware of significant incidents, releases, and spills, which has been done to a limited extent in Section 5.4.5, *Skin Contaminations and Other Radiological Incidents*, of the TBD. This would include the contamination of personnel and personal affects, which could significantly influence the dose to the skin and near-surface organs. Knowledge of these situations is of particular importance when worker dose is evaluated based on job categories or facility averages. Although the MCW TBD addressed skin contamination and incidents in Section 5.4.5, there is no guidance in the TBD whether the standard approach bounds these events or how these incidents might affect the individual dose reconstructions. Site expert and claimant interviews often provide valuable input into high-risk exposure conditions and incidents.

Although efficiency is an important element of the compensation program, special exposure conditions should be identified and evaluated against the TBD methodology, in order to ensure that the claimant has been given the benefit of the doubt. This information should be communicated to other dose reconstructors to provide consistency and fairness in the dose evaluation process.

9.0 REFERENCES

42 CFR 82, 2002. *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000*, Code of Federal Regulations, May 2, 2002.

Anderson, J.L., 2003. *Technical Information Bulletin: Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities, ORAUT-OTIB-0004,* Oak Ridge Associated Universities, Oak Ridge, Tennessee.

Atomic Energy Commission. *Urinalysis Procedure for Plant 6*. Memorandum from B. S. Wolfe of AECNY to J. J. Koenig of AEC-St. Louis; 13 January 1948.

Atomic Energy Commission (AEC). Urinary Uranium Analyses for Mallinckrodt Chemical Works. Memorandum to M. Eisenbud from J. Harley. 7 February 1950a.

Atomic Energy Commission (AEC). Conference on Radiation Exposure at Mallinckrodt Chemical Works. Memorandum to M. Eisenbud from W. B. Harris; 11 July 1950b.

Atomic Energy Commission (AEC), New York Operations Office. Monthly Report of Industrial Hygiene Branch Field Activities, August 1950 report issued by W. B. Harris, 8 September 1950c.

Atomic Energy Commission (AEC). Visit to Mallinckrodt Chemical Works, St. Louis, Missouri, September 27 and 28, 1950. *Memorandum to M. Eisenbud from H. Blatz*; 3 October 1950d.

Atomic Energy Commission (AEC), *An Estimate of Cumulative Multiple Exposures to Radioactive Materials, Mallinckrodt Chemical Works, Plants 4 and 6.* Report covering July 1942 to October 1949. Mallinckrodt-5, 20 November 1950e.

Atomic Energy Commission, New York Operations Office, *Mallinckrodt Chemical Works Dust Study 1952 to 1953* on ORAU site research PDF document database. 30 November 1953.

Atomic Energy Commission (AEC), Health and Safety Laboratories. *Mallinckrodt Chemical Works Plant 7 Occupational Exposure to Airborne Contamination*. HASL-MCW-23; 27 May, 1955a.

Atomic Energy Commission (AEC), Health and Safety Laboratories. *Mallinckrodt Chemical Works Plant 7E Occupational Exposure to Airborne Contamination*. HASL-MCW-24; 22 June, 1955b.

Atomic Energy Commission (AEC), Health and Safety Laboratories. *Mallinckrodt Chemical Works Plant 6E Occupational Exposure to Airborne Contamination*. HASL-MCW-25; 21 September, 1956a.

Atomic Energy Commission (AEC), Health and Safety Laboratories. *Mallinckrodt Chemical Works Plant 7 and Slag Separation Plant Occupational Exposure to Airborne Contamination*. HASL MCW-28; 25 October 1956b.

Atomic Energy Commission (AEC). *Environmental Hazards Associated with the Milling of Uranium Ore.* HASL-40; Revised, 14 November 1958.

Blatz, H, Eisenbud, M., November 20, 1950. An Estimate of Cumulative Multiple Exposures to Radioactive Materials, Mallinckrodt Chemical Works, Plants 4 and 6, July 1942 to October 1949, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division. (Also cross referenced as AEC, 20 November 1950.)

Clagett, F. and Maness, R.F., 1950. *Conversion of UNH to UO_3 – Progress Report*, HW-19496, Hanford Works, Richland, Washington.

Caplan, K. J. to Thayer, H.E., February 2, 1949*, Dust Study at MCW Plant 4*, September and October 1948 on OUAU database.

Caplan K. J. to Thayer, H. E., April 21, 1949 Memorandum, *Dust Study of Plant 6*, October-November 1948, on ORAU site research PDF-document database.

Caplan, K. J. to Thayer, H.E., July 1, 1949, *Dust and HF Study in Plant 4 Furnace Room*, July 1949 in ORAU site research PDF document database.

Department of Energy (DOE), Office of Environmental Management. *Linking Legacies: Connecting the Cold War Nuclear Weapons Production Processes to Their Environmental Consequences*.

Department of Energy (DOE) Baseline Environmental Management Report (BEMR) for the Mallinckrodt Chemical Company St. Louis Downtown Site (Missouri FUSRAP Sites) available at http://web.em.doe/gov/bemr96/slds.html

Department of Energy (DOE), 2000. Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities, U.S. Department of Energy, Washington DC.

Dupree-Ellis E, Watkins JP, Ingle JN, Phillips JA. *External Radiation Exposure and Mortality in a Cohort of Uranium Processing Workers*. U.S. Department of Health and Human Services. 1998.

Dupree-Ellis E, Watkins J, Ingle JN, Phillips J. *External Radiation Exposure and Mortality in a Cohort of Uranium Processing Workers*. Am J Epidem, 152(1): 91-95; 2000.

Eisenbud, M., Memo to Kelly, W. E., *Report on Mallinckrodt Employees*, U.S. Atomic Energy Commission, New York Operations Office, Health and Safety Division. January 31, 1951.

Eisenbud M. *Discussion of Apparent Anomalies in Lung Retention of Uranium.* In: Symposium on Occupational Health Experience and Practices in the Uranium Industry. Proceedings of a United States Atomic Energy Commission conference. New York City: United States Atomic Energy Commission; HASL-58; 1958: 212-213.

Eisenbud M. *Early Occupational Exposure Experience with Uranium Processing*. In: Occupational Health Experience with Uranium, Proceedings of a U.S. Atomic Energy Commission conference. Arlington, Virginia: ERDA-93; 1975: 9-24.

Ferry, J. L. Memorandum to J. A. Kyger, *Measurements of Radioactive Dust Concentrations at Mallinckrodt Chemical Company* on March 10, 1944; dated March 31, 1944a.

Ferry, J. L. Memorandum to H.E. Thayer. *Measurements of Radioactive Dust Concentrations at Mallinckrodt Chemical Company*, May 9 and 19, 1944; dated June 9, 1944b.

Formerly Utilized Sites Remedial Action Program (FUSRAP), Army Corps of Engineers. St. Louis Downtown Site (SLDS). Fact Sheet. Available at: http://www.mvs.usace.army.mil/engr/fusrap/SLDS.htm. Accessed 2 January 2003.

Formerly Utilized Sites Remedial Action Program (FUSRAP), US Department of Energy. Mallinckrodt, Inc. Site description of St. Louis Downtown Site; undated. Effective Date: 10/24/2003.

Glauberman H, Harris WB. Air Sampling Procedures in Evaluating Exposures. In: Symposium on Occupational Health Experience and Practices in the Uranium Industry. Proceedings of a United States Atomic Energy Commission conference. New York City: United States Atomic Energy Commission; HASL-58; 1958: 208-211.

Goldsmith, W.A., Leggett, R.W., and Haywood, F.F. (1981). *Radiological Survey of the Mallinckrodt Chemical Works, St. Louis, Missouri.* DOE/EV-0005/27, ORNL-5715, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Harris WB, Mason MG. Operating Economics of Air-Cleaning Equipment Utilizing the Reverse Jet Principle. In: Proceedings of the Third AEC Air-Cleaning Conference. Proceedings of a United States Atomic Energy Commission conference. Los Alamos: United States Atomic Energy Commission; WASH-170; 1953: 68-78.

Hickey, E.E., Stoetzel, G.A., Strom, D.J., Cicotte, G.R., Wiblin, C.M., and McGuire, S.A. *Air Sampling in the Workplace*, NUREG-1400, U.S. Nuclear Regulatory Commission, Washington DC. 1993

Klein, P., Memorandum to R. J. Starkey. *Cleaning Under Burnout Oxide Conveyors – Plant 5*, National Lead Company of Ohio, 7 December 1960.

ICRP, 1982. *Protection of the Patient in Diagnostic Radiology*. ICRP Publication 34, Annals of the ICRP, Vol. 9/2. ICRP, Pergamon Press, Oxford, England.

ICRP, 1982. *General Principles of Monitoring for Radiation Protection of Workers: A Report of Committee 4 of the ICRP*, Annals of the ICRP, Volume 9, Number 4, Pergamon Press, Oxford, England.

ICRP, 1994. Human Respiratory Tract Model for Radiological Protection, ICRP Publication 66, Annals of the ICRP, Vol. 24/1-3, Pergamon Press, Oxford, England.

ICRP, 1995. *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients*. ICRP Publication 71; Pergamon Press, Oxford, England.

ICRP, 1995. *Dose Coefficients for Intakes of Radionuclides by Workers. A report of a task group of Committee 2 of the International Commission on Radiological Protection*. ICRP Publication 68; Pergamon Press, Oxford England.

ICRP, 1996. *Conversion Coefficients for Use in Radiological Protection Against External Radiation.* ICRP Publication 74, Pergamon Press, Oxford, England.

ICRP, 1997. *General Principles for Radiation Protection of Workers*, ICRP Publication 75, Pergamon Press, Oxford, England.

ICRP, 2002. *Supporting Guidance 3, Guide for the Practical Application of the ICRP Human Respiratory Tract Model*, Vol. 32, No. 1-2, Pergamon Press, Oxford, England.

Johnson, N.L., Kotz, S., and Balakrishnan, N., 1994. Continuous Univariate Distributions, Volume II, Section Edition, John Wiley and Sons.

Kathren, R.L., Shockley, R. E., Thomas, E. M. and Taulbee, T. D., 2003. *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures,* ORAUT-OTIB-0006, Oak Ridge Associated Universities, Oak Ridge, Tennessee.

Makhijani, A., 1988. *Release Estimates of Radioactive and Non-Radioactive Toxic Materials to the Environment by the Feed Materials Production Center* 1951-85, Institute for Energy and Environmental Research, Takoma Park, Maryland, 7 July 1988.

Mallinckrodt Chemical Works (MCW). *Mallinckrodt Chemical Works – Plant 4*. Memo to F. M. Belmore, January 24, 1949a.

Mallinckrodt Chemical Works (MCW). *Dust Study at MCW Plant 4 Conducted during September and October, 1948*, Memo and report to H.E. Thayer from K. J. Caplin, 2 February 1949b.

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

Mallinckrodt Chemical Works (MCW). *Evaluation of Past Dust Exposures at Plant 4 and Plant 6*. Letter to M. Eisenbud of AEC from K. J. Caplan of Mallinckrodt. 16 January 1950a.

Mallinckrodt Chemical Works (MCW). *Mallinckrodt Chemical Works Plant Four Dust Study*, Memo to K. J. Caplan, 1 March 1950b.

Mallinckrodt Chemical Works (MCW). *Mallinckrodt Chemical Works Plant Four Dust Study,* Memo to K. J. Caplan and M. G. Mason, 1 June 1950c.

Mallinckrodt Chemical Works (MCW), *Mallinckrodt Chemical Works Plant Six Dust Study* August, 1950, 21 August 1950d.

Mallinckrodt Chemical Works (MCW), *Plant 6 Surveys at Mallinckrodt Chemical Works*, Memo and report to W. B. Harris from A. R. Piccot, 22 September 1950e.

Mallinckrodt Chemical Works (MCW), *Recheck of Dust Study in Ore Room and Ore Room Addition*, Memo to M. G. Mason, 29 September 1950f.

Mallinckrodt Chemical Works (MCW). *Results of Dust Study at Plant Six-E*, Memo to H. E. Thayer from K. J. Caplan, 26 February 1951.

Mallinckrodt Chemical Works (MCW), *Mallinckrodt Chemical Works Plant 6 – Ore Room Addition*, Occupational Exposure to Radioactive Dust, R. E. Morgan, 22 May 1953.

Mallinckrodt Chemical Works (MCW). *Activity Levels, Final Radioactivity Survey, Destrehan Street Facilities*. Report by the Health and Safety Department; 30 November 1961.

Mallinckrodt Chemical Works (MCW). *Thorium Operations at MCW*. Memo to J. W. Ruch and H. W. Roth from R. B. Martin, 2 Nov 1965.

Maroncelli, J.M. and Karpin, T.L., 2002, *The Traveler's Guide to Nuclear Weapons: A Journey Through American's Cold War Battlefield.* Historical Odysseys Publishers, Silverdate, Washington.

Mason, MG, 1955, *Mallinckrodt Chemical Works Health Program Policies, Status, and Summary*. February 21, 1955.

Mason MG. *A Summary of Fifteen Years of Experience with Dust Problems in the Refining and Fabrication of Uranium*. In: Symposium on Occupational Health Experience and Practices in the Uranium Industry. Proceedings of a United States Atomic Energy Commission conference. New York City: United States Atomic Energy Commission; HASL-58; 1958: 3-9.

Mound Pre-1989 Dose Assessment Project, Phase II Final Report, Appendix C, MJW Corporation, Williamsville, NY, June 2000.

NCRP, 1989. *Medical X-Ray, Electron Beam, and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment, Design, Performance, and Use*. National Council on Radiation Protection and Measurements 102: 1989.

NCRP, 1999. *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*, National Council on Radiation Protection and Measurements, Publication 129, ISBN 0-929600-61-4.

National Institutes of Occupational Safety and Health (NIOSH). *External Dose Reconstruction Implementation Guideline*. OCAS-IG-001. Rev. 1; August 2002a.

National Institutes of Occupational Safety and Health (NIOSH). *Internal Dose Reconstruction Implementation Guideline*. OCAS-IG-002. Rev. 0; August 2002b.

National Institutes of Occupational Safety and Health (NIOSH). *NIOSH-InteractiveRadioEpidemiological Program (NIOSH-IREP) Technical Documentation, Final Report*.

National Institute for Occupational Safety and Health (NIOSH), Office of Compensation Analysis and Support; Cincinnati, Ohio; June 2002.

National Institutes of Occupational Safety and Health (NIOSH) Office of Compensation Analysis and Support, *Technical Information Bulletin: Estimation of Ingestion Intakes*. OCAS-TIB-009, Rev. 01, 13 April 2004.

National Institutes of Occupational Safety and Health (NIOSH). NIOSH Typical letter to Claimant, Introduction Section, 2003.

National Institutes of Occupational Safety and Health (NIOSH) Office of Compensation Analysis and Support. NIOSH Comments on the SC&A Review of Bethlehem Steel Site Profile, December 2004.

National Research Council, National Academy of Sciences, 1989. *Film Badge Dosimetry in Atmospheric Nuclear Tests*, National Academy Press, Washington, DC.

Nuclear Regulatory Commission (NRC), 1992. *Air Sampling in the Workplace*, Regulatory Guide 8.25, U.S. Nuclear Regulatory Commission, Washington, DC.

Oak Ridge Associated Universities (ORAU). *Mallinckrodt Chemical Works: Four Plant Study Classifications of Radium, Radon and Thorium Exposure*, Memo from J. N. Nicolas, 16 September 1991.

Oak Ridge Associate Universities (ORAU). *NIOSH Dose Reconstruction Project Quality Assurance Program Plan*, ORAUT-PLAN-0001, Rev. 0, January 30, 2003a.

Oak Ridge Associated Universities Team (ORAUT), *Dose Reconstruction Project for NIOSH. Internal Dose Reconstruction*. ORAUT-PROC-0003. Rev. 0; 1 May 2003b.

Oak Ridge Associated Universities Team (ORAUT), *Dose Reconstruction Project for NIOSH. External Dose Reconstruction.* ORAUT-PROC-0006. Rev. 0; 27 June 2003c.

Oak Ridge Associated Universities Team (ORAUT), Technical Basis Document for the *Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site, St. Louis, Missouri, Period of Operation 1942 to 1958*. ORAUT-TKBS-0005, J. L. Westbrook, Rev. 00, 24 October 2003d.

Oak Ridge Associated Universities Team (ORAUT) *Technical Information Bulletin: Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities*, ORAUT-OTIB-0004, J. L. Anderson Rev. 02, 4 December 2003e.

Oak Ridge Associated Universities Team (ORUT), Technical Basis Document: *Basis for Development of an Exposure Matrix for Aliquippa Forge, Pennsylvania, Period of Operation July 28, 1948 to February 28, 1950*, ORAUT-TKBS-0021, Rev. 00, Shelby L. Gubin, 21 December 2004.

Oak Ridge Operations Office (OROO). *Decontamination of Gloves*, Memo from S. R. Sepiris to C. L. Carl, 26 July 1955.

Rochester, University of (Rochester), School of Medicine and Dentistry, Atomic Energy Project Memorandum from Russell Hayes to Mr. Jesse Cherry, Health and Safety Division, US AEC, New York Operations Office. 12 January 1950.

Rohring, N., 2004. *Technical Basis Document for Idaho National Engineering and Environmental Laboratory (INEEL) – Occupational External Dosimetry.* ORAUT-TKBS-0007-6, Oak Ridge Associated Universities, Oak Ridge, Tennessee.

SC&A, 2004a. SC&A *Standard Operating Procedure for Performing Site Profile Reviews,* Revision 0, March 18, 2004.

SC&A, 2004b. Task 1, Document No. SCA-TR-Task1-0001-*Review of NIOSH Site Profile Review of NIOSH Site Profile for Bethlehem Steel Plant, Lackawanna, NY*, October 14, 2004.

SC&A, 2004c. Response to NIOSH *Rebuttal Regarding the SC&A Bethlehem Steel Site Profile Review,* December 14, 2004.

SC&A, 2005. *The Review of NIOSH/ORAUT Procedures and Methods Used for Dose Reconstruction*, Report, SCA-TR-Task3-0001, S.Cohen and Associates, McLean, Virginia.

Sepiris, S. R. to Karl, C. L., Oak Ridge Operations Office Memorandum, July 26, 1955, *Decontamination of gloves*.

Utnage WL. Laundry Operations in a Uranium Feed Materials Plant. In: Symposium on Occupational Health Experience and Practices in the Uranium Industry. Proceedings of a United States Atomic Energy Commission conference. New York City: United States Atomic Energy Commission; HASL-58; 1958: 168-171.

Weinstein MS. Environmental Contamination. In: Symposium on Occupational Health Experience and Practices in the Uranium Industry. Proceedings of a United States Atomic Energy Commission Conference. New York City: United States Atomic Energy Commission; HASL-58; 1958: 180-184.

Westbrook, J, L., Oak Ridge Associated Universities Team (ORAUT), Technical Basis Document for the *Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site, St. Louis, Missouri, Period of Operation 1942 to 1958*. ORAUT-TKBS-0005, Rev.. 00, 24 October 2003.

Wolf, B.S., 1947. Letter from B.S. Wolf to R.E. Hayden, “Health Hazards at Mallinckrodt Chemical Company’s St. Louis Plant,” August 9, 1947.

ATTACHMENT 1

MALLINCKRODT CHEMICAL COMPANY QUESTIONS SUBMITTED TO NIOSH

The evaluation of the Mallinckrodt Chemical Company (Mallinckrodt) Site Profile so far has included review of some source records, interviews with Mallinckrodt workers and site experts, and a partial review of some considerations relating to potential exposure from dust inhalation during the early years from 1942-1945. We are sending you this memorandum setting forth the questions that we consider important at this time regarding the completeness and adequacy of the Site Profile as part of our preparation for drafting our Site Profile Review. For that reason we would appreciate an early response.

The documents identified to date included primarily information gained from the FUSRAP site and declassified documents regarding early exposures at Mallinckrodt workers. This constitutes only a fraction of the source information listed in *Technical Basis Document: Basis for Development of an Exposure Matrix for Mallinckrodt Chemical Company St Louis Downtown Site, St. Louis Missouri,, Period of Operation: 1942-1958, ORAUT-TKBS-0005, Version 00 dated October 24, 2003*. We have not yet had the time to go through the documents in the NIOSH and ORAU Site Research Database, but we have sampled a few of them.

In addition to document review, Tom Bell and Kathy Robertson-Demers conducted site expert interviews with 27 Mallinckrodt site experts who provided their input in St. Charles Missouri on August 16 and 17, 2004. The workers discussed the functions and operations they individually performed at the various plants that made up the St. Louis Downtown Mallinckrodt Chemical Works complex starting with initial uranium processing that started at the Main Plant (Building 1) and the Plant 2 complex (Buildings 2, 50, 51, 51A , 52, 52A and 55) and Plant 4 from 1943 to 1945, with continuing use of Plant 4 in 1946 and expanding to new refinery facilities built at the Destrehan Street Plant complex in Buildings 5, 6, 6E, 7 and 7E. As a result of the document reviews and interviews with the workers, a number of issues with respect to the Mallinckrodt Chemical Works technical basis document (TBD) have surfaced. The questions have been organized within sections (i.e., general, early period, external, medical x-ray, internal, and other) so that related questions can be addressed together during their discussion at our next conference call.

I. General questions

1. Are NIOSH and ORAU planning to include Plant 5 in their dose reconstructions? Plant 5 did commercial processing of euxenite (ore) in the 1950s and was mentioned by workers in the interviews conducted by SC&A?
2. Some workers allege that parts of the dose records may be unreliable or fabricated. For instance, we understand that workers would sometimes throw their badges into orange oxide containers to see if anyone would notice and the workers claim that no one noticed. They also claim that zeros were being improperly entered into dose records. Note that

the GAO reported in 1994 that zeros were entered into dosimetry records when workers did not turn in badges. Have NIOSH and ORAU investigated such claims? Are NIOSH and ORAU dose reconstructors adjusting doses to reflect the potential for fabrication of data, and if so, how?

3. Have NIOSH and ORAU tried to construct a list of incidents or determine the frequency of problems in the denitration pots or UF_4 reduction furnaces? Has NIOSH tried to determine the typical dosimetric situation that prevailed with respect to such incidents and the workers who were present or participated in cleanup activities? How do such incidents affect the use of worker surrogates when records for individual claimants do not exist?
4. Have NIOSH and ORAU developed a list of especially hazardous jobs such as replacement of filter bags in baghouses, furnace operation, and pot operation?
5. NIOSH and ORAU mention Ac-227 on p. 51 of the TBD, but did not include it in the table of values on that page used for dose reconstruction. Did NIOSH and ORAU decide not to include Ac-227? Did NIOSH do any screening calculations to determine whether Ac-227 was important in the parts of MCW? If NIOSH took Pa-231 into account, why does it seem to have dropped Ac-227, given that each of them have a mortality coefficient that is two orders of magnitude larger than those of U-234 for Type F material (EPA Reg. Guide 13). The difference is much smaller for Type S material. Further, the table on p. 51 assumes that the radionuclides in the decay chains of U-238 and U-235 are present in equilibrium in urine. What is the basis of this assumption, given that the mobilization of Th, Ra and Pa in the body would be different than U?
6. Could NIOSH provide the specific references for Tables 21 to 24 and especially for the 1942-46 dust levels?
7. Did NIOSH and ORAU do any statistical analysis on the air concentrations data, cohort bioassay data, or cohort external dose data to determine whether the choices of parameters for dose reconstruction are claimant favorable?
8. In Table 31, most GSD values are listed as less than 1. However, GSD is always ≥ 1. Could NIOSH and ORAU explain these values? Could NIOSH and ORAU also provide SC&A with the details of the statistical analysis that was done to derive these values? How have these GSD values been used in dose calculations?

II. Early Period

1. The method for dose reconstruction for the 1942-1945 period on page 59 of the TBD is to use 1946 external dose data and assign the values to the earlier period. This appears to disregard the AEC assessment (quoted in the TBD) that the unmonitored early period exposures were "moderately" more severe. Other parts of the TBD use the same process for assigning missed doses (e.g., para 1 in Section 7.4.2, p. 60). How does NIOSH justify this as claimant favorable?
2. How did NIOSH and ORAU establish that all workers who did radiological work were badged after 1946 (p. 60 first sentence)?

3. Has NIOSH recalculated the internal doses in the Hanson Blatz and Merrill Eisenbud issued a report on November 30, 1950 entitled *"An Estimate of Cumulative Multiple Exposures to Radioactive Materials, Mallinckrodt Chemical Works, Plant 4 and 6, July 1942 to October 1949."* using ICRP 66 techniques? If so what was the result? We request NIOSH to provide us with the details of any calculations that were done.
4. How have NIOSH and ORAU taken into account the observation of Caplan (letter to Eisenbud, Jan. 16, 1950, online database) that the "dust exposure calculated from dust study data may be seriously in error if the individual job is highly variable (viz. maintenance work)"?
5. In a 1995 interview with the Advisory Committee on Human Radiation Experiments, Eisenbud recalled that MCW workers were excreting a milligram of uranium per day in urine and that air dust levels were routinely several milligrams per cubic meter. Has NIOSH done an upper bound analysis of organ doses assuming that such levels were typical in the early days?
6. How are NIOSH and ORAU taking into account the observations of Caplan (Jan. 19, 1950, *op. cit.*) that dust data prior to the fall of 1948 are not reliable?
7. Have NIOSH and ORAU considered workstations with extremely high levels of dust, at levels of several hundred thousand or even above one million dpm/m3 (*Dust Study of Plant 6, Oct.-Nov. 1948*, Caplan to Thayer, on database)? These are much higher than the Plant 6 concentrations in Table 9 or Table 22 of the TBD for 1948 and earlier. For instance the dust levels in the fumes in the pot room were measured at 2,040,000 dpm/m3 "after turning into powder" and at 18,700 dpm/m3 "before turning into powder." The latter value was presumably for UNH, which is Class F. "Checking and leveling of buckets" was 347,000 dpm/m3; "opening of bins for inspection" was 693,000 dpm/m3. How do the numbers in the TBD tables relate to these values?
8. Urinalyses for uranium until 1950 were suspect (see page 40). Mallinckrodt was asked if they could salvage these urinalysis samples, and it thought that it could not. NIOSH has stated that because of the lack or recorded film badge data, urinalysis data and bioassay data in the early days, that the only logical way to calculate dose to unmonitored workers is to use surrogate (comparable) worker inhalation intake values in pCi/year (see Table 31). Also see page 50 and 52. Since internal doses are very important, how has NIOSH compensated for the suspect data in the period for 1950s and before? Does NIOSH feel confident that such surrogate doses can adequately fill in missed dose to overcome this lack of film badge data, urinalysis data and bioassay data? For instance, has NIOSH taken into account the frequent incidents that occurred in various parts of the plant, such as denitration pots and UF_4 reduction furnaces? Did NIOSH determine the variability to be expected among workers? If so, how was this used to ensure a claimant favorable approach when using surrogate data?

III. Questions relating to external doses

1. External doses from dust settling onto skin and clothes were likely to have been high. A 1955 document on laundering of gloves in the NIOSH and ORAU Site Research

Database ("Decontamination of gloves" July 28, 1955) has extensive data on contamination of gloves from uranium facilities under the jurisdiction of the Oak Ridge Operations Office. The average measured beta-gamma contamination was 12.88 mrep/hour, with many gloves being over 20 mrep/hour. Have NIOSH and ORAU done an analysis of this data to assess doses to the hands at MCW? Do NIOSH and ORAU believe that this set of data may be useful in determining doses from deposition of dust on clothing as well as exposed parts of the body? Can this set of data provide some indication of external doses in the 1940s, using claimant favorable assumptions for uranium concentrations in air? For claimants with skin cancer or cancers with organs near the skin surface, have NIOSH and ORAU characterized the skin dose to workers who often had contamination on their skin or inside their gloves or shoes when handling and scooping the uranium slag residues out of drums or out of the containers they called "bombs"? Did the NIOSH and ORAU review find that erythema-level external doses were a problem needing special attention, especially during the early years?

2. It appears to us that the external dose potential for workers who handled, packaged, or processed ores (especially pitchblende), raffinate, and filter cake residues should be explicitly considered. Do NIOSH and ORAU agree? In this context, how would NIOSH and ORAU handle exposures from dust deposition on clothes and exposed parts of the body? What would be a claimant favorable shielding factor. How would claimant favorable external exposure scenarios be constructed?

3. NIOSH and ORAU do not seem to have taken radium-226 external doses into account in its assessment of thorium-230 production and associated handling of raffinates (p. 35 of the TBD). Is this correct? If so, what is the technical rationale behind this decision?

4. How is NOSH correcting for film badge underestimate of low energy photon exposure at MCW? Is NIOSH considering producing a TIB similar to ORAUT-OTIB-0010, 1/12/2004 Rev.. 00 entitled: *A Standard Complex-Wide Correction Factor for Overestimating External Doses Measured with Film Badge Dosimeters to use for facilities and AWEs for the period prior to 1970*?

5. When dealing with Mallinckrodt plant workers who worked in areas adjacent to the production plants, the TBD reports that surface alpha was 2500 dpm/100 cm^2 with an average beta exposure of 2 mrem/hr and with hot spots as high as 35,000 dpm/100 cm^2 and 15 mrep/hr beta (see page 37). NIOSH and ORAU have developed in its ORAUT-OTIP-0004, 12/04/2003 Rev. 02 a procedure to develop annual organ dose due to external exposure to ground surfaces contaminates from natural uranium dust. NIOSH/ORAU has made the assumption that in estimating the airborne contamination from residual contamination during uranium operations that these factors reached an equilibrium that caused the airborne and surface contamination to remain at a constant level. Is this claimant-favorable for resuspension in hot spots and for workers who worked at or near the hot spots for extended periods? Has NIOSH developed a similar method for organ dose that also provides a reasonable estimate of dose to the skin for claimants with skin cancer who worked in areas adjacent to the production plants and were exposed to ground contamination at Mallinckrodt? NIOSH (see Table 4, page 6 of 13). http://www.cdc.gov/niosh/ocas/pdfs/tbd/awemaxd2.pdf

6. How are NIOSH and ORAU taking into account dust deposition on clothing and exposed parts of the body from jobs with high dust levels such as those in the 1948 Caplan to Thayer document cited above?

7. **Amounts of materials and geometry characteristics.** The TBD points out on page 66 that for external dosimetry, considerations of amounts of materials and geometry characteristics render any dose estimation with this data subject to a great deal of uncertainty. To help solve this, NIOSH has developed *ORAUT-OTIB-0010, 1/12/2004 Rev. 00 entitled: A Standard Complex-Wide Correction Factor for Overestimating External Doses Measured with Film Badge Dosimeters*. See http://www.cdc.gov/niosh/ocas/pdfs/tbd/doebadge.pdf

This TIB, however is only applicable after 1970. How are these uncertainties being estimated in the MCW case where production happened prior to 1970?

IV. Medical X-ray Exposures

1. In the Mallinckrodt TBD (Page 119), ICRP 34 was utilized instead of ICRP 74 used in NIOSH's OCAS1 to determine absorbed dose from kerma values. Preliminary indications by SC&A indicates that the use of ICRP 34 may tend to underestimate the absorbed dose. ICRP 34 does not have 10 organs that are now in ICRP 74. The use of ICRP 74 is particularly important when the medical examinations included photofluorography chest x-ray where doses can double or triple based on the differences between ICRP 34 and ICRP 74. In PA and lateral x-rays the underestimations are not as significant. Has NIOSH validated that photofluorography was not used at Barnes Hospital? If it is found that photofluorography was used, has NIOSH considered recalculating the estimated annual medical occupational x-ray organ dose using ICRP 74 which is required by 42 CFR Part 82 rather than NIOSH's use of ICRP 34?

2. The TBD assumes annual x-rays, but some workers remember semi-annual X-rays. Have NIOSH and ORAU investigated the possibility that some workers had more frequent X-rays or that they were taken more frequently in earlier periods?

V. Internal Doses

1. What is the basis for using 1970s data to assume that the UF_4 to metal process has had a low respirable fraction even in the early period?

2. What is the basis for the statement on p. 40 that errors in urinalysis "are in a conservative direction and thus are claimant favorable"?

3. The TBD points out on page 33 that when handling UO_3, openings between the operating area and the drum storage alleys in the Ore Room addition resulted in winds that blew into the area and upset the ventilation balance causing the dust to be blown into the operator areas. Such records may be included in the records held at the ORISE CER Vault Room as listed at the following website under the Mallinckrodt Chemical Works section:

http://www.eh.doe.gov/ohre/new/findingaids/epidemiologic/orise

Has NIOSH found any documentation of these individual Ore Room worker exposures verifying these elevated dust levels in the drum room alleys; verifying which monitoring devices were used; and verifying which urinalysis bioassay was used to detect and quantify the internal dose due to such exposures?

4. The choice of Type M solubility does not appear claimant favorable in view of the presence of both UF_4 and more importantly uranyl nitrate. Why did NIOSH and ORAU choose Type M over Type F, since UNH is clearly type F and was present at the plant?
5. Have NIOSH and ORAU done a consistency check to see if their estimates for lung burdens of radium are consistent with the radon in breath measurements reported by Eisenbud in a letter to Caplan on August 31, 1949?
6. We are presuming that NIOSH and ORAU used nasal breathing assumption. Is this correct?
7. Why did NIOSH and ORAU choose 1.4 m^3/hour for MCW instead of the heavy work 1.7 m^3/hour it used at Mallinckrodt Chemical Company?
8. The TBD states that ingestion would most likely take place during eating and smoking breaks. Has ORISE/ORAU taken into account additional likely ingestion routes from sore throats from dust, oro-nasal breathing and when dust got into their mouths? This was especially a problem in the early days when no masks or only painter's dust masks were routinely used. Have NIOSH and ORAU considered ingestion doses from large particles, such as metal flakes, being deposited on food in addition to dust setting out?

Other issues

1. Have NIOSH and ORAU completed Section 8.0, Determination of Exposures Due to Residual Contamination Remaining from MED/AEC Operations?
2. NIOSH and ORAU have assumed that the ^{238}U: ^{230}Th: ^{226}Ra ratio is 1:1:0.3 (p. 31). The ratio assumes wet grinding of ore. Have NIOSH and ORAU checked that only wet grinding was done at MCW to validate the assumptions on p. 31? Also have NIOSH and ORAU calculated doses from ore storage outdoors and indoors, especially from pitchblende storage?
3. Individual interviews with Mallinckrodt site experts also indicated that career workers often transferred to Weldon Springs when the St Louis downtown site was closed. Does the ORISE/ORAU dose reconstruction take into account additional dose that workers later received after their work ceased at the St. Louis downtown site TBD? Likewise, if the worker later worked on cleaning up post-production residual contamination past the time of this Mallinckrodt TBD, has NIOSH and ORAU added that dose to his Mallinckrodt TBD dose when determining total dose?
4. In doing the site profile for Mallinckrodt Chemical Works, what plants were included? Did the review include the Main Plant (Building 1) and the Plant 2 complex (Buildings , 2, 50, 51, 51A , 52, and 55) and Plant 4 from 1943 to 1945, with continuing use of Plant 4

in 1946 and expanding to new refinery facilities built at the Destrehan Street Plant complex in Buildings 5, 6, 6E, 7 and 7E? Was the Latty Plant included?

5. Please provide all parameters used to run RESRAD BUILD for both 1959 to 1961 and 1962 onward for each building. Also was RESRAD done for outdoor areas? Were hot spots taken into account?

6. In your site profile review of Mallinckrodt, did NIOSH and ORAU make use of a record block cited under the Mallinckrodt Chemical Works section which is located at the ORISE CER Vault Room? These records include, but are not limited, to dust concentration cards from 1943 to 1952; radioactive dust study monitoring records, 1944 to 1966 and film badge summary records, 1944 to 1966?

   See: http://www.eh.doe.gov/ohre/new/findingaids/epidemiologic/orise/

Document Request

1. The Mallinckrodt TBD in the reference section on page 74 lists a reference that does not seem to be on the NIOSH and ORAU Site Research Database. Is it possible to get a copy of Mason, MG *A Summary of Fifteen Years of Experience with Dust Problems and Fabrication of Uranium? In: Symposium of Occupational Health Experience and Practices in the Uranium Industry*. Proceedings of a United States Atomic Energy Commission conference. New York City; United States Atomic Energy Commission; HASL-58; 1958 3-9? Table 8 and 9 footnotes reference this document. A query of the NIOSH and ORAU Site Research Database using either Mason alone as the author (16 hits) and a combination of Mason and Mallinckrodt together (9 hits) fails to bring it up.

ATTACHMENT 2

CONFERENCE CALL WITH NIOSH AND SC&A

Individuals who participated included:

SC&A: Kathy Behling, Tom Bell, John Mauro, Kathy Robertson-DeMers

NIOSH/ORAU: Dave Allen, Cindy Bloom (ORAU team), Judsen Kenoyer (ORAU team), Jim Neton, Janet Westbrook (ORAU team), Mark Rolfes (ORAU team), Tom Tomes

Date: October 13, 2004
Time: 10:00 am – 11:30 am EDT

General Discussion

NIOSH Introductory Remarks

We would like to start with a preamble statement with respect to your questions and the status of the MCW site profile document. The points SC&A has raised are valued. We have already considered many of these issues and are working on addressing them in Revision 1 to the Mallinckrodt TBD. NIOSH does not find that SC&A questions point to any major factual inaccuracies but do raise some issues that NIOSH needs to address. For your knowledge, 42 out of the 126 MCW claims completed have been compensable.

SC&A: Were those awarded mostly for lung cancer?

NIOSH/ORAU: Yes most all awarded claims were probably for lung cancer, but I don't have that data at hand. I believe that some claims were awarded for skin cancer as well.

When we put out the MCW TBD, we attempted to cover what the dose reconstructors needed to know based on the information we had available at the time. We felt it was important to provide a TBD so that the dose reconstructors could move forward. When we tried to apply the site profile to noncompensable cases, we ran into a number of road blocks. As a result, no noncompensable cases have been completed using this profile. Those cases are awaiting the issuance of Revision 1, which is currently in the works. Many of the questions you provided to NIOSH will be addressed in Revision 1 of the site profile.

SC&A: As a point of clarification, are you saying that by and large, you are finding that our questions do not bring up issues that you feel will impact any of the cases and therefore will not have an impact on compensation?

NIOSH/ORAU: Yes, we fell the TBD has been adequate to address the cases we have processed so far and the issues raised would not have resulted in a change to our analysis. Perhaps the best way to clarify this is for NIOSH to advise SC&A of the questions which

NIOSH does not agree on or has already started to address in the up coming revision to the MCW TBD.

SC&A: What are the changes being integrated into Revision 1 of the document?

NIOSH/ORAU: The MCW TBD revision is wide sweeping. Since the revised TBD is in internal review, it would not be appropriate for us to enumerate on these in detail but collectively perhaps ORAU can point out some of the major changes.

- The Section 8 reserved section on determination of exposures due to residual contamination remaining from Manhattan Engineering District (MED) and AEC operations has been developed and addresses many of the residual contamination issues not covered in Rev. 00 of the MCW TBD.
- A more comprehensive handling of ingestion doses has been developed and we have incorporated the use of ORAUT-OTIB-009 for potential ingestion dose.
- Some alpha-neutron calculations as a result of uranium interactions with metals have been completed.
- Thorium and radium ratios are explained further.
- They only major part yet address is the external dose surrogate worker matrices.

SC&A We are most interested since we are currently looking at individual cases. The cases we are evaluating are not MCW claims. There seems to be unevenness as to how you approach the issue of residual contamination. We are interested in learning more on how NIOSH is handling radiation exposure from residual radioactivity.

NIOSH/ORAU: We want to emphasize that the dose reconstructor has to use professional judgment when evaluating doses. There are holes in the current version of the site profile. Since the original writing, we have discovered several new sources of data. NIOSH has also recently, as a result of the SEC petition, discovered new information on ORAU site research PDF document database and it is being reviewed.

SC&A: When we have attempted to access the bibliographic database there are documents that don't seemed to be loaded that we need. Those documents cited as source documents are not on the relational database. As a point of clarification, it has been found that simplifying the partial title to one or two key words produces better find results. For instance, using "Occupational Health Experiences" as a partial title enabled the finding of the Mont Mason 1958 Fifteen Year Summary at MCW. Using "urine' rather than "urinalysis" in the title field was successful in finding the bulk of MCW urine sample data.

NIOSH/ORAU: If SC&A is having problems accessing documents, please let NIOSH know and they will try to rectify the problem. Getting the TBDs out has been one of our most important objectives. We have also, of course, placed the major emphasis on handling claims and are working to catch up on our document database.

SC&A: Eva has been working with Kathy Behling and other team members to solve our document access problem and has been a big help. She also has confirmed that the simple search is more effective. Kathy Behling mentioned sometimes entry of document number is effective in retrieving documents.

We are lagging behind in entry of documents into the database. Getting the site profile out is the most important priority.

NIOSH/ORAU: It seems the best way to proceed is for NIOSH to address the questions that seemed to need the greatest clarification first. Here is our general take of some of the more significant SC&A questions.

General Question #1 Commercial Processing: Commercial processing of euxenite ore in the 1950s at Plant 5 is a bigger issue that just MCW. This is an issue that has arisen as to which types of exposures are AWEs. Should the NIOSH TBDs cover AEC related and commercial processing or should it be limited to just AEC related ore handling? A new congressional amendment to the National Defense Authorization Bill has redefined the definition of covered ionizing radiation at AWE sites. Residual contamination created as a result of DOE activities is now included. The lawyers are looking at this question of ionizing radiation or residual radiation during commercial processing of euxenite (ore). They are considering whether exposure should be limited to only that dose received in conduct of AEC/DOE activities. This issue of whether or not it should cover ionizing radiation exposure from commercial processing at AWEs is under legal evaluation.

SC&A: Are you saying that AEC activities done for 10 years at an AEC facility are covered but later commercial processing done at AEC facilities (even though they are residuals from earlier periods) may not be included?

NIOSH/ORAU: If the activities are AEC/DOE derived, they would be covered. For example, at Combustible Fuel who commercially made nuclear fuel for the Navy, this may not apply. If you cannot differentiate between radioactive material from AEC and commercial operations, this could be a problem. NIOSH is evaluating their position on this. The issue is bigger than Mallinckrodt.

General Question #3 Incidents: We apply a hierarchy of data which is bracketed to include exposures from incidents. The hierarchy is urinalysis data, co-worker data, and air sampling data in that order. To date, this process seems to be working.

General Question #5 Ac-227: NIOSH is not ignoring dose contribution from ^{227}Ac. We assume 100% equilibrium on intake (not with urinalysis). This analysis includes contributions from daughters. The intakes from actinium daughters as well are being considered.

SC&A: How do you address processes that concentrate radionuclides like ^{227}Acand ^{231}Pa?

NIOSH/ORAU: We haven't found evidence yet to verify this is a problem, but if SC&A has evidence, please provide us with the documentation.

General Question #8 GSD <1: We are aware that the GSD cannot be less than one. We are correcting this in Revision 1. The dose reconstructors have been provided with updated information with respect to GSD.

External Dose Question #1 External Dose From Dust: NIOSH realized this is an issue that needs further development. External dose from dust is an issue that is being looked at. We performed an evaluation using VARSKIN to determine a dose per unit activity. We have looked at dose per unit activity in this analysis. The dose per nCi hour deposition on skin is not considered to be a huge contribution. If one really had a pile of dust on the skin and this could approach a dose of up to 1 or 2 rem per year. This does not seem to be significant for claims purposes. It is unrealistic to assume there is enough deposition on the skin to get a large dose. We haven't seen evidence that supports such doses. I don't know if you have evaluated this using VARSKIN.

SC&A: We have not run any VARSKIN calculations.

NIOSH/ORAU:

Medical X-ray Exposures, Question #1 ICRP-34 vs. ICRP 74: Comments with respect to medical x-ray exposures are being evaluated. The approach employed in the site profiles is correct. There may have to be a revision to the guidance document however. This is still under consideration.

Internal Dose, Question #4 Type M vs. Type F Solubility: NIOSH feels Type F would only be needed if the uranyl nitrate (UNH) was airborne. The use of Type M verses Type F with respect in the presence of uranyl nitrate is justifiable. Uranyl nitrate is in liquid form and is not likely to be resuspended. Most of the material is also in process piping. The potential exposure for exposure from liquid is less than that for uranium dust. Type M is felt to be a better solubility to use exposure to liquid forms of UNH.

Other Issues, Question #2 U-238: Th-230: Ra-226 Ratio: NIOSH is re-evaluating the ^{238}U:^{230}Th:^{226}Ra ratio of 1:1:03 to evaluate the relative ratios for operations other than wet grinding. This ratio will be further dealt with in Rev. 1 of the MCW TBD.

Other Issues, Question #3 Evaluation of Weldon Springs Exposures: NIOSH is aware that approximately 50% of the individuals at MCW also worked at the Weldon Springs plant. Both are considered.

SC&A: So for claims that are compensable with MCW data alone you process the claim. With those that are not, you consider the Weldon Springs dose contribution.
NIOSH: Yes. Those who require Weldon Springs dose contribution are not being processed yet as the site profile is not completed. If the claim was not compensable at MCW at the 50% level

and an additional dose at Weldon Springs resulted in a PC of greater than 50%, NIOSH would recommend award of that case.

Also, you should be aware that and SEC petition for Weldon Springs and MCW is currently under evaluation at NIOSH. Issues raised are also being investigated by the SEC team. We hope to deliver the initial evaluation to the Board by the February meeting.

SC&A: Does this mean we can expect to start reviewing SEC claims in the Spring?

NIOSH/ORAU: That is up to the board.

SC&A: How does the SEC process work? Who does the final approval of the petition?

NIOSH/ORAU: NIOSH completes an initial evaluation of the petition. Once a NIOSH evaluation plan is developed in response to the petition, a notice must be placed in the Commerce Business Daily (CBD).

SC&A: Does ruling come out by NIOSH?

NIOSH/ORAU A report is presented to the Board for review. If the Board agrees with the SEC petition, they forward it to the Secretary of HHS. After this approval, it goes to Congress. There will be several petition reviews forwarded in the Spring to the Board.

NOTE: After the review of NIOSH positions on the questions covered above, it was decided that SC&A should bring up the additional questions that they considered important. These questions and responses are provided below.

SC&A: What sources of data were used for determining the uranium dust daily weighted average exposures in Tables 21-24? Was there a lot of guesswork around these tables? How were the values in Tables 21 to 24 calculated? The doses in the earlier period were likely higher than those in subsequent years.

NIOSH/ORAU: In order to develop the uranium daily weighted average exposures in Tables 21 to 24, ORAU started with NYOO and AEC dust sampling report and reviewed memos by those who collected air sampling data and did motion studies. This included memos and reports, as could be found, on AWE dust occupational exposures for the early period. These were often just data on hot spot maximums or on one or two spot observations. Dust weighted exposures (DWEs) were identified subdivided by tasks and were used to create the daily time-weighted average exposures. This review was done on the Dust Study Reports which stated in 1948. There were handwritten data on forms; however, this data was not used in the tabulation. The DWE was calculated base on job title. NIOSH has not spent the time to tabulate the raw data. The data was just scanned in and archived.

SC&A: There is a concern that the TBD does not adequately capture the actions taken in the analysis of data. Also, how do you account for the differences in working conditions between the early years and the later years?

NIOSH/ORAU: We did compare spot table dust concentrations for comparable tasks. These were measured in dpm/cubic meter. NIOSH then compared these with later years. One early year hot spot was somewhat higher, but it was often found that the time weighted exposure levels were higher in later years. We noted that their was more episodic air sampling during the pilot plant era due to intermittent work compared to the continuous production of the later years. The DWEs conservatively cover the air concentrations in the earlier years.

SC&A: Starting in 1949 and 1950, major upgrades were made in the ventilation in the newly build plants like Plant 6 and 6E. Manual scooping operations were replaced with automatic agitators in 1949. Doesn't it seem that doses to workers might be appreciably higher in the early days without much attention to radiation controls (i.e., ventilation, manual scooping) that doses to workers might be appreciably higher than from 1948 on?

NIOSH/ORAU: In the case of Plant 6, the original design was one of a standard industrial plant. The designers accepted what they felt was adequate initially. The plan was to backfill the safety devices into the plant at a later date. MCW reminded AEC of this promise in correspondence. Also, manual scooping was not completely eliminated.

SC&A: Why is the MCW air monitoring data less than the AEC air monitoring data?

NIOSH/ORAU: The MCW air samples were more representative because the sampling times were greater.

SC&A: Did you use DWE or raw data for development of Tables 21-24?

NIOSH/ORAU: The data used were the weighted averages taken from dust reports which included how long workers worked at tasks.

SC&A: Have you used the dust concentration cards available through ORISE from 1943-1952?

NIOSH/ORAU: We used the data available in the database. This data was not included in that data set. In their epidemiology study, they used data computerized by Mancuso and verified by ORAU staff. The film badge data required recomputerization due to errors made by Mancuso's group. Also, the DuPree study only included white male workers. Data on such dust concentration cards might be useful if you are going for accuracy. NIOSH often takes the route of not fully developing the accuracy if it is not necessary to decide the compensability of the case.

An effort is underway to review records from the ORISE vault and those transferred to the ORO records storage vault. These dust concentration cards have not been recovered to date. There is also the problem that some of these dose records are commingled with classified data. The effort to pull out MCW data to evaluate SEC petition has expedited release of some of these but declassification often takes awhile.

SC&A: It is strongly recommended that you perform an evaluation of records available through ORISE to ascertain their usefulness in development of the site profile. What is the basis on which NIOSH regarded the numbers in tables 21 to 24 to be claimant favorable?

NIOSH/ORAU: The answers above were provided to try to address this question.

SC&A: Did NIOSH do uncertainty calculations for these same tables (21 to 24)?

NIOSH/ORAU: The data set was looked at as a whole. We realize that some of this data is spotty but we think the time weighted averages reviewed are representative enough to be statistically valid. The high air concentrations were included in the weighted average. The DRs are also using specific information in the files to guide them.

SC&A: Is the information in the claim file complete?

NIOSH/ORAU: We have found that the individual AEC worker files are generally not very specific. If we think what they tell us could lead to higher dose, the dose reconstructors try to take that information into account. Most of this was done on monitored workers only and are not much help for unmonitored workers. We are working on additional co-worker dose matrices that should provide additional data in the Rev. 1 of the MCW TBD.

SC&A: In development of your tables, how did you determine the job titles?

NIOSH/ORAU: A master list of job titles from dust studies and other sources was compiled. There is also a section in the TBD which provides cross references between official job titles and those typically identified by the workers. From experience the job title information came be matched with the job described by the individual.

SC&A: Was there a statistical analysis of surrogate co-worker data?

NIOSH/ORAU: This is an issue for future consideration.

SC&A: In Table 31, most GSD values are listed as less than 1; however, GSD is always ≥ 1.

NIOSH/ORAU: As explained earlier, we acknowledge the GSD less than one is incorrect and this will be corrected in Rev. 01 of the MCW TBD.

SC&A: Could you provide SC&A with the details of the statistical analysis that was done to derive the GSD values?

NIOSH/ORAU: NIOSH is working on this and this should be addressed in the future.

SC&A: How was the large stripped urinalysis file (ORAU 2003) mentioned at the bottom of TBD Page 40 used to create Table 31?

NIOSH/ORAU: ORISE provided urinalysis data compiled by the Center of Epidemiologic Research used for the epidemiology study of 4 uranium facilities. The file was sanitized by removing the names; however, the job information was maintained. This file was more complete than the hardcopy records available in the NIOSH database.

SC&A: How did you come up with the average urine concentration?

NIOSH/ORAU: The file contained approximately 21,000 urinalysis data points. Some workers had multiple urinalysis data points and other had one. The top 25 urine concentrations were evaluated. Of this data the top two values in the table were 10 mg/l and 7.8 mg/l. The 10th highest value was down to 6 mg/l. By the 25th value on the list, concentration was down 0.35 mg/l. Beyond the five highest points, urine concentration was found to be less than 1 mg per liter. 1 mg per liter was not usual. Analysis of the urinalysis data was complicated by the possible contamination of urinalysis samples by Harshaw. The highest ones were likely contaminated; however, they are used as is in the analysis. For MCW, it was found that very few even exceeded even 0.1 mg/l.

SC&A: A search of the ORAU site research PDF document database for Mallinckrodt and partial title "urine" comes up with a series of urinalysis summary reports. A quick review indicates approximately 34,000 individual urine samples were taken from 1949 to 1958. Has NIOSH done any analysis to determine the range of concentrations in this data set? Have you evaluated the potential range of internal dose that would result and compared these with uranium dust concentration data to see if they are consistent?

NIOSH/ORAU: NIOSH had not yet had time to do such an analysis.

SC&A: Since there appear to be no Dust Study Reports on the OUAU database prior to late 1948 (title pages dated 1949) for Plants 4 and 6, is their any other air sampling data that NIOSH used. If so, how good is that data?

NIOSH/ORAU: NIOSH feels that data in the 1948 to 1950 period is representative of the possible exposure levels in the early years. Tables 21 to 24 have been useful to the dose reconstructors in evaluation of what an individual's dose would be.

SC&A: Is NIOSH concerned about the level of variability in DWEs for specific higher risk jobs? In some cases the high concentration estimates can exceed 1M or even 2M. This would indicate that sample variability is high and that levels of exposure for high exposure levels may be well in excess of values in Tables 21 and 22 and thus not claimant favorable.

NIOSH/ORAU: Where did SC&A see these kinds of levels?

SC&A: In the process of reviewing the site profile, I compiled data into a spreadsheet for the April 1949 Plant 6 Dust Study. The data is available on the NIOSH database on page 7 of the Plant 6 April 21, 1949 Dust Study Report from the ORAU site research PDF document database. Some examples are:

Task	# of Samples	Ave Conc. dpm/m^3	High Conc. dpm/m^3	Low Conc. dpm/m^3
LF-9 packing sample barrel	6	72,000	260,000	20,200
LF-9 Barrel on Roller	2	189,000	314,000	64,800
Dumping LF-9 into hopper	2	109,000	123,000	95,000
Dumping LF-9 at vibrator	2	117,000	152,000	82,500
LF-9 Filing Fiber Packs at tube	1	2,225,000		
LF-9 Fiber Packs Oper. Position	4	63,000	113,000	25,000

To my recollection, there were also high samples in the orange room. Is there adequate statistical handling of the data and have these high exposure jobs been adequately addressed?

NIOSH/ORAU: The workers were not continuously exposed to these levels over time. You cannot assume these levels for 8-hours a day, 250 days per year. A quick back of the envelope calculation at such levels, if used, would mean the dust concentration would have to be on the order of 1 g/m^3. Levels of uranium on the order of grams per cubic meter would result in deterministic affects and kidney failure.

SC&A: That is true. You couldn't breathe in this atmosphere and visibility would be limited. It is obvious that worker inhalation of uranium concentrations around operations like the above are more likely to be lower than 100 mg/m^3. But there is still a concern that the uranium dust daily weighted average exposure levels in Tables 21 to 24 may not be representative for workers working in high exposure areas. Also, in our conversations with former workers, they indicated that they worked 6-days per week up to 12 hours per day.

Particle Size and Solubility Assumptions: Eisenbud and others (1975) as well as the TBD on page 30 question that these assumptions may not be acceptable and that particle behavior formulation at the time may have been incorrect. Has NIOSH done a critical review of the validity of the early uranium particle size and solubility assumptions?

NIOSH/ORAU: First, we use the most claimant favorable solubility type. We used a 5 micron AMAD unit density particle size verses a 5 micron AMAD uranium particle size which behaves differently. 5 micron uranium particles behave like larger particles. Henry Spitz and Jim Neton wrote a paper discussing behavior of uranium in the body. You need to look at the total picture.

There are some Cascade Impactor studies performed at other similar facilities that indicate particle size also.

Closing Remarks

SC&A: When is the new revision is going to come out?

NIOSH/ORAU: We do not know but it won't be soon.

SC&A: In light of the fact that Rev. 1 of the MCW TBD will not be out in time for our current schedule, perhaps we should adjust our schedule so that our report takes into account Rev. 1 of the MCW TBD. Currently, SC&A is working to have an initial draft MCW report to NIOSH in November 2005. This is, obviously, well before, Rev. 01 of the MCW TBD is out.

NIOSH/ORAU: This question is best answered by the Board.

SC&A: The schedule currently was to have the report out to NIOSH by November. Given the pending revision, this may not be feasible. We will check with Paul Ziemer to see what he wishes to do.

NIOSH/ORAU: Receiving SC&A product in the middle of the revision would complicate things.

SC&A: You would like us to wait?

NIOSH/ORAU: We are not necessarily saying that. You have every right to review the current revision of the document.

SC&A: When is the next Advisory Board meeting?

NIOSH/ORAU: It is scheduled for December in San Francisco.

SC&A: We will have a lot of products to deliver at that time. Thank you all for your most helpful discussion of the questions and issues. Your willingness to spend this time on a teleconference with us is appreciated.

ATTACHMENT 3

SUMMARY OF SITE EXPERT INTERVIEWS

Over the course of the audit on Mallinckrodt Chemical Works (MCW), Tom Bell and Kathryn Robertson-DeMers have had an opportunity to interview a number of site experts. Site experts included a wide variety of personnel including maintenance personnel (e.g., electrician, welder, pipefitter), engineers, administrative support, production operators, chemical operators, laboratory technicians, a decontamination and decommissioning worker, and others.

The information the site experts provided has been invaluable in providing us with a working knowledge of the MCW Uranium Division. Site experts provided a baseline understanding of working conditions and the extent of the safety program through time. This information was utilized to further identify critical vertical issues. The information provided in these interviews help SC&A obtain a comprehensive understanding of the radiological risk at the facility.

Below is a summary of various site expert interviews as they related to the vertical issues outlined in the MCW review. These interviews were primarily conducted during a visit to St. Louis, Missouri on August 16-17, 2004. The information provided is not a verbatim discussion, but is a summary of information collected by all experts interviewed. Individuals have provided this information based on their personal experience. It is recognized that these recollections and statements need to be further substantiated before adoption in the TBD. However, they stand as critical operational feedback where records and other documentation are lacking. This interview summary is provided in that context; site expert input is similarly reflected in our discussion and with the preceding qualifications in mind, has contributed to our findings and observations.

General Information

Arthur Compton asked Ed Mallinckrodt, Jr. if Mallinckrodt Chemicals Works (MCW) would participate in the Manhattan Project by purifying uranium. MCW was chosen because that had the Ether Extraction process running at the time. One worker reported that Ed Mallinckrodt had concerns and did not really want to become involved with Uranium. As a part of this operation, workers were required to obtain security clearances. FBI agents would occasionally come to the home of workers to talk to them. There were safety personnel at the MCW plant. The safety focus seemed to be on the chemical and industrial hazards in the plant. There was little concern about the radiological hazards from dust or internal exposure. When Mont Mason became director of the Health and Safety Department at MCW, there was an emphasis put on radiation safety. He insisted on the use of film badges. Not all of his recommendations were implemented. The workers did not remember names of other individuals involved in the safety program in the 1940's and 1950's.

In describing the work environment at the MCW facility one worker wrote in a written response to SC&A:

> *There was also a fear that physical problems could be caused by sabotage, such as the sabotage and damage to the iron cast gear for the ore mill grinder. Along with these fears of physical danger, there was constant fear of the FBI who had a clandestine presence, and was suspicious of anyone who asked too many questions about the secret Manhattan project. Under secretive conditions nobody dared question or refuse to do a job based on unknown radiation exposure criteria.*

Some workers reported that the Explosion of the Ether House could have been the result of sabotage. They were unaware of documented proof with respect to the Ether House; however, following the incident with the iron cast gear, many remember being interviewed by security. Workers also indicated that the control over uranium was lax and workers would take pieces of uranium home.

The workers referred to three distinct areas of operation: (1) Main Plant (Broadway and Second), the Destrehan Plant, and Weldon Springs. Waste sites are located on Latty Avenue and at SLAPS near the St. Louis Airport. Mallinckrodt was eventually sold to Tyco who currently owns the facilities still remaining.

Radiation Safety Training

The workers did not receive radiation safety training. Initially they did not know they were working with radioactive material. There was no training on the concept of time, distance and shielding, or contamination control. The focus was put on the physical hazards rather than the radiological hazards (i.e., chemical and industrial safety hazards.)

They also did not receive training on off normal or incident response; however, they were cognizant of the physical hazards in the working area. They were aware of off normal conditions and when they needed to make an immediate exit from the facilities.

Work Force Characteristics

The mobility of the workforce was dependent on the job assignment. The operations folks typically worked in one or more of the production facilities during their time at the Main Plant and at the Destrehan site. The maintenance workers worked in all buildings. Security guards also moved around the plant. Many of the maintenance workers were also required to repair or clean systems in containment areas, tanks, and pipes.

In the first session workers were asked to list the buildings/facilities they worked in during their employment at MCW. This demonstrates the mobility of this portion of the workforce. The workers interviewed included primarily operations and maintenance departments.

Jobtitle	Locations Worked
Electrician	Main Plant (Plant 1), Plant 4, Plant 5, Plant 6, Plant 7 ,Weldon Springs
Secretary	Main Plant (few weeks), Weldon Springs
Production Operator	Main Plant, Plant 4 and Weldon Springs
Secretary	Weldon Springs
Warehouse Man	Plant 4, Plant 6, Main Plant, Serviced all buildings that need servicing
Chemical Operator	Radium processing, Building 50, Building 51, Plant 5, Z Building, Remediation areas
Secretary	Main Plant, Administrative Offices (Upstairs at Plant 6), Weldon Springs
Metals Plant Supervisor	Plant 6, Weldon Springs
Sheetmetal Worker	Main Plant primarily, Plant 4 and Plant 6 intermittently

When the Destrehan facility moved its operations to Weldon Springs, many individuals transferred to this plant. One worker estimates several hundred were transferred. The choice to stay at Destrehan or move to Weldon Springs was based on seniority. Those with low seniority were given the choice to move or have no job.

General Process Flow at the Destrehan Site/Main Plant

There are a number of facilities that were involved in the processing of uranium and the administration of the program. The Main Plant/Destrehan Plant covered a number of city blocks. The primary goal at the MCW facility was to extract purified uranium from uranium ore for subsequent use and or processing by other facilities. Plant 4 was the original processing facility at the MCW Destrehan site. Plant 6/6E later replaced it. Plants 6 and 6E were a part of what the workers refer to as the Destrehan Site. These plants were built after Plant 4 and had better ventilation and safety measures. These plants used electric furnaces rather than the gas furnaces that were used in Plant 4.

Plant 4 was responsible for producing brown oxide. Ore was received in drums at the facility. This ore came from domestic and international sources and had uranium concentrations from 0.1% to 65% (Belgium Congo). The drums were put behind glass. The lid was cut off by welders and the contents were dumped onto a conveyor. This was performed in an area without ventilation. Operations in the ore room were primarily done remotely. The crushed ore was dissolved in nitric acid. The material was them processed in a sieve. The uranyl nitrate was sent to the next process. Sludge and raffinate (also known as K-65 or airport cake) was disposed of at the SLAPS facility.

In the pot room, a yellow liquid material was added to the "pots" and resulted in production of orange oxide. There were approximately 20 pots in the room. Ammonia and other gases were used to produce green salt. A "coffin" was used to convert orange oxide to green salt. These coffins were heated in the furnace. There were vapors and dust coming off the pots. The vapors had an acid smell. They added nitric acid to these pots which was what resulted in the fumes. An agitator was used to mix the pot material. The raffinate from this process was taken to the Latty Avenue site. The product from this operation (green salt) advanced to the Bomb Area. The area was dusty and orange oxide got down into their shoes. Respiratory use was not consistent.

Green salt was covered to a biscuit in a "bomb". The bomb had a cone type shape. The bomb was composed of a lime liner, green salt, aluminum, and a lime topping. A lid was put on top of the bomb. The bomb was sent through a furnace were it was heated. This formed what was called a biscuit (uranium metal). The bomb was put into a quench tank for cooling. The lid was removed and the biscuit was dumped out. Sometimes tongs had to be used to remove the biscuit. Equipment (e.g., drill press or jackhammer) was used to take a sample for analysis. The slag was removed and sent to the crusher. The lime went one way and the uranium went in another direction to the recast area. Materials from the crusher were put in a barrel.

Workers recollect that the green salt would get on their face and sometimes in their nose if the masks were not used or were inadequate. Workers also reported that the bombs would sometimes explode in the furnace. This would create holes contaminating the furnace and damage equipment. The maintenance and operations crew would have to enter the furnace to clean up and do repairs on damaged equipment.

Once the derby is formed it would go down to the rollers. The slag had to be removed from the uranium by chipping it off. This resulted in metal chips flying through the air. Carbon crucibles were used in the recast area. Robots were used to manipulate the carbon crucibles. Electricians had to work on the robots when they were not working. The material was sent through the recast furnace. These crucibles had scopes in them. In the recast area, the workers used marble saws to remove samples from the uranium product. These samples were analyzed for purity.

Raffinate was sent to the SLAPS facility. The material was shipped in 55 gallon drums which were dumped in the disposal facility. Individuals were stationed at the airport to handle the incoming waste. At one point during remediation, a core sample was taken of this area.

Uranium was sent to Oak Ridge for inspection. If the uranium was not within the required tolerance, it was sent back to MCW for further processing. This material was escorted by guards who rode in the same car as the uranium.

Plant 7E was described as an experimental building. There was a laboratory in this building. Workers suspected that they may have done some work with plutonium or some other material for the hydrogen bomb. The facility was unusual compared to the others as there was a hand counter in this facility. Workers could not leave the facility unless the activity on their hands was less than a certain value. They also mentioned that they were not allowed to remove tools from this building.

Building 238 involved some work with radioactive material post-1958. The workers described the building as very radioactive. It is believed that there was a tantalum manufacturing process in this building. The workers in this building were badged. The workers suspected this might have been Nuclear Regulatory Commission work but they were not sure.

The original processing at MCW took place in Buildings 51 and 52. Building 51 was retrofitted with process equipment from the companies Jersey Plant. Plant 4 did the original **production** run of processes developed in Building 51A. There may have been some NRC work performed in this building around 1965-1972. Work involved tantalum. Many individuals were not assigned a film badge. The building was later found contaminated. Buildings 50, 51, 51A, and 52 were considered part of Plant 2.

Plant 1 is also referred to as the Main Plant by the workers. The project administrative staffs including key punch operators, IBM machine operators, accounting, secretaries, etc. were housed in this building. These individuals received paperwork from operations and engineering on a regular basis. Original documents were returned to the different departments when they were finished with it. Office workers were allowed in the production area. One worker indicated that he went on a tour of the production area once and an engineer asked him to pick up a piece of uranium. He remembers thinking the uranium was really heavy. The ladies didn't like this because the stockings often disintegrated off their legs. The company used to have to replace them. This group of individuals did not typically wear a film badges; although, temporary badges may have been issued at times.

Plant 4 was closed during 1955 and 1956 and was knocked down with a bulldozer in 1957 and replaced with a parking lot. Plant 6 has been dismantled and the soil under it was dug out.

External Exposure Monitoring

Film badges were used at MCW. Some individuals were assigned permanent badges while others were assigned temporary badges (e.g., sheet metal workers) on an as needed basis. The dosimeter exchange period was weekly. The workers were not sure whether the frequency of dosimeter exchange was changed during the period 1942-1958. Mont Mason was responsible for pushing workers to wear badges; however, workers indicate this was not long lived. They also remember surveys being performed at this time. The workers did not know the criteria for assignment of a permanent film badge verses a temporary film badge.

The film badges were stored in a badge rack at the guard house. This area was separate from the production area. Workers were required to present their photo badge upon entry to the plant. Film badge exchanges apparently happened after normal operating hours. Workers in the administrative area did not recollect the use of area film badges.

The workers did not recollect the usage of finger rings, other types of extremity dosimetry, or pocket ionization chambers. There was some indication that time limits were used for certain tasks. Workers indicated that certain tasks required direct contact with uranium. In some circumstances gloves were worn and in other they were not. ^{235}U and ^{238}U cores were handled to exam them for slag. Workers also indicated that dust settled on the exposed skin and on their clothing. In the early 1960's, a computer program was written to track and record film badge results.

Workers were not typically informed of their radiation exposure. There were no periodic exposure reports provided to them. Some supervisors were told when their workers received over exposures. Workers recollected that a few workers would drop their badges in the orange oxide, shake them off, and put the badges back on. Even these individuals were not told what their exposures were.

The plant had a set limit per badge cycle for exposure to workers. A total of 34 workers in Plant 6E were permanently transferred to a new job in the downtown plant after they were apparently overexposed. An additional 18 individuals were said to have been terminated from the company as a result of this overexposure. Some workers recollected being moved to less hazardous parts of the plant temporarily to reduce exposure. The temporary job assignment would last a few days to a week. It is uncertain whether the workers high results were related to bioassay or dosimeter results as the involved workers were not provided with specific information.

MCW used portable x-ray units to check welds. Personnel were not allowed in the direct beam during these operations.

Workers were told it was okay to sit on the uranium as long as they put a piece of paper on top of it. This was supposed to prevent exposure.

Workers indicated that there was a three minute time limit for entry and loading of the furnace. The other operators would do the timing.

Internal Exposure Monitoring

The plant operated 7 days per week, 24-hours per day when producing uranium. Workers at MCW worked 12 hour shifts under routine circumstances. They worked from 5-7 days per week. When one worker moved to the uranium division, he had to agree to work six days per week. He wanted to be transferred because there was more overtime available. During accident conditions, individuals were asked to work until operations were up and running again.

The level of work activity depended on the type of work being performed. There were jobs that involved heavy work at the plant. Workers occasionally got winded on the job. The furnace area was very hot which added to physical stress.

Workers reported visible dust in the air. There were especially high dust levels in the Pot Room where UNH underwent denitration to yield UO_3. The facilities in which this pot denitration was commonly called the Orange Oxide Building. Workers would sometimes have to scoop material manually from the pots. Dust masks were used for this operation. In Plant 6E, there was a sensor on some of the equipment which required detection of a beam to operate. The dust in the air would break this beam rendering the equipment inoperable. The machine often had to be operated manually to override this problem. At times the dust irritated the lungs of workers.

There were a subset of workers (4-5 individuals) who had the job of going around the plant and dusting the pipes and equipment throughout the day. These individuals used sponges for cleaning. Workers reported blowing dust out of their nose after work. Water was used to control dust in some areas of the plant.

Workers reported that they often breathed fumes. They identified the fumes as orange, yellow and brown depending on the area of the plant. At times the fumes were only identifiable by smell such as an ammonia or acid smell. When the workers returned home after a day's work, their family could smell chemicals on their clothing and on their breath. They were told to drink beer to clear material out of their system.

In Building 7E, the MCW plant had a hand counter. The workers were not allowed to leave the building until their hands read below a certain contamination level. There were experimental operations going on in this building. Other buildings did not have a hand counter.

There was not a set policy for personal protective equipment (PPE) at the MCW plant. MCW had a general policy which required that workers change from their own clothes to the plant provided coveralls upon entry into the plant. Workers were provided with coveralls, canvas gloves, hats, and chemical protective equipment. Some workers indicated there was a use of shoe covers and some indicated they were not used. Gloves were not secured with tape to the coveralls and dust got inside at times. Some of the material could penetrate the gloves. Although they were issued gloves, the nature of some of the work required the direct contact of uranium with bare hands. Rubber suits/gloves were issued for work with acids.

Workers remember that subcontractors were not provided coveralls but wore their own clothes in the plant. Guards used their uniforms when they went through the facilities.

Prior to going to lunch, smoking rooms or leaving the plant the employees were supposed to change clothes and take a shower. The implementation of this policy seemed to be inconsistent. Some workers indicated that they religiously followed this policy while others indicated that people went offsite for lunch or home in their work clothes. The plant did have a laundry service and workers were provided with new clothes the next day. The laundry was found to have radioactive material on it. Workers report that dust would get into their hair.

Use of respiratory protection was intermittent. The primary respiratory protection used included dust masks or half-face masks with removable filters. The type used depended on the area. In pictures from the MCW magazine there appear to be similar to painters masks. Some workers in the green salt processing area remember getting green salt on their face around their mask. Respiratory protection used seemed to be variable for the different operations. The policy was to use respirators for the day and discard them for washing. The lab was responsible for cleaning the respirators and replacing filters. If a worker knew he/she might need it, he/she would carry it with them on their person. One worker indicated he used his until it was worn out. In between, uses he stored it in his locker.

In the 1960's during an OSHA visit, one worker indicated that OSHA directed the plant to dispose of all current respirators as they were not appropriate for the hazard.

Workers report that the uranium compounds at MCW included brown oxide, orange oxide and green salt. Urine samples were collected every six to twelve months starting in the late 1940's. Denise indicated that they recorded a lot of zeros recorded.

Documentation from the production areas was provided to administrative workers for processing. In some cases, the paperwork was returned to the initial organization. In other cases the paperwork was put into a library. The administrative offices were dusted once or twice a day. Some workers recollect that documents were burned.

There were lots of pipes and tanks at the facility. At times maintenance personnel (e.g., pipefitters, welders) had to enter tanks or pipes to work.

Some Radon Breath Analysis was performed for individuals working around Radium. Most of the results were recorded as zero.

Dust control measures at MCW included exhaust systems, used of vacuum, dust collectors, and water. Dust collectors contained dust bags which were monitored by a sensor. When the dust bag became plugged, the dust collector had to be turned off (originally manually) and a ring blower used to loosen the dust. The ring blower was then turned off and the dust collector returned to service. Although the dust collectors reduced dust levels, the dust bags would periodically rupture creating a mess. The plant had some gloveboxes. The level of dust control measures was less in Plant 4, the original production plant. There were wooden floors in Plant 4 and concrete floors in other areas. Plant 5 had a floating foundation. There was also outside storage.

There was a cafeteria at the facility. Although most workers ate in the cafeteria, some ate lunch in the production area. An analysis of the drinking water indicated that the water was okay.

Medical Exams

Medical examinations were given to workers on an annual basis. (Some workers indicated it was semiannually.) Chest x-rays were a part of these exams. The x-rays were done at Barnes Hospital. Urinalysis and blood samples were also performed at the physical. The doctors taking the medical x-rays for physicals did ask workers to remove their film badge during x-rays. The workers did not know the x-ray type. Office workers did not have the same frequencies of exam as other workers.

The workers indicated that medical staff personnel often inquired as to the welfare of there children. They wanted to know if they had children with defects. They also wanted to know if the wives of men who worked at the plant had still births and/or miscarriages. Several individuals indicated that they themselves or their co-workers had high occurrences of still births, miscarriages, and/or children with deformities or illnesses.

In general, when it came to common illnesses, many of the workers felt that MCW took care of them while they worked there.

Incidents

There were a number of incidents that were reported by workers.

- Acid burns
- Nailing a hand to a box with uranium rods.
- Stepping on a piece of steel which went up through the workers foot.
- Steel falling on a worker
- Dust bag ruptures with releases to the atmosphere
- Dust bags falling on workers
- Tank explosion
- Residue of lime catching on fire
- Damage of equipment and tools from acid
- Bubbling of nitric acid as it was pored on ore
- Spills and blowouts.

There was such a potential for acid burns that the company put a color indicator in the badge. The Barnes Hospital was aware of this and knew how to treat these burns. Special cream was used on the burn. Blisters often formed as a result of the burn.

The most memorable incident was the Ether House Explosion. This explosion occurred in Plant 6. An outside contractor was painting the beams for protection against acid fumes. They left the building for a while. There were three operators on the ground floor of the facility. They heard the tank rumbling. There was a reaction between chemicals and an explosion occurred. It blew a hole in the north wall and blew glass out. The aluminum scaffolding used by the painters was also damaged. There was a spread of contamination as a result. The outside painter left the MCW plant and never returned to get their tools.

Crews worked around the clock to bring the building back up quickly so production could continue. They used tarps and steam heaters temporarily. Workers were touchy with respect to noises after this incident.

There were no chelations or other therapies given as a result of intake at the MCW site.

High Risk Jobs

The operations and maintenance personnel at the Destrehan/Main Plant were involved in a number of high risk jobs as a result of routine operations. Some of these high risk jobs included:

- Entry into and cleaning of the furnace
- Confined space entries into tanks
- Dust Bags replacement
- U-235 process
- Chemical operators shoveling radioactive material.

The plant also had a number of physical and chemical hazards including:

- Hydrofluoric Acid
- Nitric Acid
- Ether
- Ammonia
- Explosive hazards
- Release of gases into the environment
- Material falling on workers including ore and steel
- Chemical reactions due to mixing of chemicals (e.g., HF and ammonia)

Maintenance personnel had the most hazardous jobs which also included response to incidents.

Environmental

Workers indicate that there were occurrences of releases of fumes from facilities. In some cases it would damage cars in the parking lot. The workers recollect that as they walked to their cars, they felt a burning sensation on their skin at times.

Originally the Building 238 did not have stacks with scrubbers. OSHA came in and told the company they needed to install them. Other sources of environmental releases included leaking drums and residual contamination in the vicinity of Plant 4.

Waste from MCW was taken to the SLAPS facility. Other waste was taken to Latty Avenue. When Boeing needed the airport property the waste site was moved. The main plant sent liquid waste to the Mississippi River. This continued until the 1960's. Sewer monitors were eventually installed. Some waste was sent to tanks and treated.

International Technology Corporation under contract with the Army Corp of Engineers was responsible for remediation at the Destrehan site. As there were so many pipes in the remediation, laborers were sent down into holes to dig out from under the pipes where backhoes could not reach. During one job, a laborer was digging in the ground under a former process facility. The beta/gamma counts were so high they pegged the Radiological Technicians meter. The laborer later heard the count was 1.2 million counts per minute. After this discovery the hole was off limits. The laborer did not have a film badge and was not on a bioassay program.

Miscellaneous Items

- High concentration of radium came from the pitchblende.
- There was a requirement to produce so much material in an 8-hour shift.
- Some individuals in their 40's – 50's had prostate cancer.
- There are pictures of the process of Weldon Springs in the April 12, 1959 St. Louis Post Dispatch.
- Workers were not aware of any radiation induced cataracts. They were not aware there was a difference.
- There were deformed frogs in the ponds near the Raffinate pits at Weldon Springs.
- No fruit trees or fish were on site at Destrehan.
- Office workers had occasion to enter the production areas.
- The floors at Weldon Springs were made of finished concrete.
- There were plant operations involving ionium (thorium) at the Destrehan Facility.
- At one point Ladue Lab in New York analyzed process of raffinate samples. They were evaluating the metals still in the raffinate.
- One worker indicated that Condor Films created a motion picture of the Plant 6E process. Condor Films is located in California.

- Mr. Mendez died at the MCW plant. Strings were placed around drums in the dryer area. Periodically these strings would have to be replaced. He would use his mouth to start the strings.
- Workers were not aware of the presence of recycled uranium at the Destrehan facility.
- Outside companies were sometimes responsible for rebuilding or repairing equipment.

ATTACHMENT 4

ADDITIONAL REFERENCES USEFUL TO SITE PROFILE DEVELOPMENT

Atomic Energy Commission (AEC), New York Operations Office. Monthly Report of Industrial Hygiene Branch Field Activities, August 1950 report issued by W. B. Harris, 8 September 1950.

Department of Energy (DOE) Baseline Environmental Management Report (BEMR) for the Mallinckrodt Chemical Company St. Louis Downtown Site (Missouri FUSRAP Sites) available at http://web.em.doe/gov/bemr96/slds.html

Document sources held at the ORISE CER Vault Room as listed at the following website under the Mallinckrodt Chemical Works section:
http://www.eh.doe.gov/ohre/new/findingaids/epidemiologic/orise

Ferry, J. L., Memorandum to J. A. Kyger on Measurements of radioactive dust concentrations at Mallinckrodt Chemical Company Plant 6E on March 10, 1944 dated March 31, 1944).

Ferry, J. L., Memorandum to H.E. Thayer on Measurements of radioactive dust concentrations at Mallinckrodt Chemical Company, May 9 and 19, 1944 dated June 9, 1944).

Harrington, C. D. and Ruelle, A. E. (1959) *Uranium Production Technology,* D. Van Nostrand Company, Inc., Princeton, New Jersey.

Makhijani, A., 1988. "Release Estimates of Radioactive and Non-Radioactive Toxic Materials to the Environment by the Feed Materials Production Center 1951-85," Institute for Energy and Environmental Research, Takoma Park, Maryland, 7 July 1988.

Mallinckrodt Chemical Works (MCW). Mallinckrodt Chemical Works – Plant 4. Memo to F. M. Belmore, January 24, 1949.

Mallinckrodt Chemical Works (MCW), Recheck of Dust Study in Ore Room and Ore Room Addition, Memo to M. G. Mason, 29 September 1950

Mallinckrodt Chemical Works (MCW). Mallinckrodt Chemical Works Plant Four Dust Study, Memo to K. J. Caplan, 1 March 1950.

Mallinckrodt Chemical Works (MCW). Mallinckrodt Chemical Works Plant Four Dust Study, Memo to K. J. Caplan and M. G. Mason, 1 June 1950.

Mallinckrodt Chemical Works (MCW), Plant 6 Surveys at Mallinckrodt Chemical Works, Memo and report to W. B. Harris from A. R. Piccot, 22 September 1950.

Mallinckrodt Chemical Works (MCW). Results of Dust Study at Plant Six-E, Memo to H. E. Thayer from K. J. Caplan, 26 February 1951.

Mallinckrodt Chemical Works (MCW), Mallinckrodt Chemical Works Plant 6 – Ore Room Addition, Occupational Exposure to Radioactive Dust, R. E. Morgan, 22 May 1953.

Mallinckrodt Chemical Works (MCW). *The Uranium Story,* Mallinckrodt Chemical Works Division News, Volume 7, June 1960, St. Louis, Missouri.

A Guide to Records Series Supporting Epidemiologic Studies Conducted for the Department of Energy, http://www.eh.doe.gov/ohre/new/findingaids/epidemiologic/orise.

Mallinckrodt Chemical Works

- Daily Schedules, 1948-1957
- Data Analysis Records, 1982-1983
- Dispensary Records, 1949-1966
- Dust Concentration Cards, 1943-1952
- Employee Cards, ca. 1947-1956
- Employee Lists, 1944-1946, 1957-1968
- Employee Rosters, ca. 1940s-1960s
- Film Badge Summary Reports, 1945-1966
- General and Hazards Information Study Records, 1948-1956
- Guard Identification Study Lists, 1975
- Hazards Assessment Records, 1962-1966
- Health and Mortality Study Research Files, 1949-1971
- Health and Safety Procedures Handbooks, 1963-1965
- Job History Sheets, 1957-1966
- Medical Examination Cards, 1957-1958
- Medical Files, ca. 1949-1966
- Payroll Cards, ca. 1942-1966
- Personnel and Environmental Monitoring Records, 1950-1966
- Personnel Records, ca. 1943-1966
- Radiation Summary Data, 1945-1946, 1950
- Radioactive Dust Study Monitoring Records, 1944-1966
- Radiographic Examination Records, ca. 1948-1966
- Radon Project Records, 1944-1957
- Security Reports, 1943-1966
- Terminated Clearances Card Index, ca. 1948-1967
- Urinary Uranium (UU) Program Records, 1958-1964
- Work History Abstract Forms, 1986

ATTACHMENT 5

DR. MIKE THORNE MEMORANDUM ON ORO-NASAL BREATHING

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External Memorandum on Oro-nasal Breathing, Prepared for SC&A

Date: 20 January 2005

I have looked at this issue using the LUDEP 2.0 model, which implements the ICRP Publication 66 respiratory tract model. The full reference for the software is:

Jarvis, N S, Birchall, A, James, A C, Bailey, M R and Dorrian, M-D, LUDEP 2.0 Personal Computer Program for Calculating Internal Doses Using the ICRP Publication 66 Respiratory Tract Model, NRPB-SR287, National Radiological Protection Board, UK, 1996.

I have run calculations using two standard breathing modes. These are for occupational exposure under standard and strenuous conditions. They correspond to predominantly, but not fully, nose breathing. To make the distinctions in deposition between nose and mouth breathing clear, I have run four cases:

- Adult, light exercise, nose breathing;
- Adult, light exercise, mouth breathing;
- Adult, heavy exercise, nose breathing;
- Adult, heavy exercise, mouth breathing.

In order to get a comprehensive set of data, I have run these cases for AMADs of a polydisperse aerosol of 1, 5 and 10 microns. Results are summarized in the following table, where I give deposition separately, as a percentage of the activity inhaled, in the five standard regions of the respiratory tract. These are the anterior nasal passages (ET_1), the naso-oropharynx/larynx (ET_2), the bronchi (BB), the bronchioles (bb) and the alveolar interstitium (AI).

Individual:	**Worker – Standard**			**Worker – Strenuous**		
AMAD (μm):	**1.0**	**5.0**	**10.0**	**1.0**	**5.0**	**10.0**
ET_1	16.52	33.85	34.71	15.56	30.92	31.36
ET_2	21.12	39.91	38.38	20.71	40.44	40.08
BB	1.24	1.77	1.26	2.12	2.65	2.86
bb	1.65	1.10	0.63	1.57	0.74	0.71
AI	10.66	5.32	2.37	10.30	5.11	2.23
Individual:	**Adult - Light Exercise - Nose**			**Adult - Light Exercise - Mouth**		
AMAD (μm):	**1.0**	**5.0**	**10.0**	**1.0**	**5.0**	**10.0**
ET_1	17.51	34.80	35.28	4.52	11.59	12.71
ET_2	22.51	40.94	38.86	8.40	32.66	41.51
BB	1.31	1.80	1.24	3.27	9.76	8.66
bb	1.47	0.90	0.48	2.51	3.70	2.56
AI	9.94	4.49	1.90	15.22	13.04	7.01
Individual:	**Adult - Heavy Exercise - Nose**			**Adult - Heavy Exercise – Mouth**		
AMAD (μm):	**1.0**	**5.0**	**10.0**	**1.0**	**5.0**	**10.0**
ET_1	8.75	17.38	17.63	4.16	9.50	10.04
ET_2	14.39	38.67	44.34	9.63	36.89	46.18
BB	4.99	11.04	8.50	6.18	14.69	11.47
bb	1.92	2.41	1.46	2.26	3.16	1.95
AI	11.59	7.28	3.39	13.05	9.15	4.37

If we concentrate on the deep lung, as this is of most relevance in respect of respiratory tract dose and transfers to the systemic circulation for substances, such as uranium, that are poorly absorbed from the gastrointestinal tract, we can make the following observations.

1. Deposition in workers under standard and strenuous conditions is very similar. This is because the regimes are less different than might be envisaged. The standard regime is 31.83% sitting and 68.8% light exercise. The strenuous regime is 87.5% light exercise and 12.5% heavy exercise.
2. Where we compare deposition under light exercise conditions, deposition in the deep lung is substantially higher for a mouth breather than a nose breather at all the AMAD values studied. This is a consequence of much reduced deposition in ET_1 (as expected) and somewhat reduced deposition in ET_2 at the smaller AMADs.
3. Similar remarks apply under conditions of heavy exercise, but the distinction between nose and mouth breathing is reduced.
4. For nose breathing, deposition in the deep lung is increased in heavy exercise relative to light exercise.
5. For mouth breathing, deposition in the bronchi is increased in heavy exercise relative to light exercise, but the situation is reversed for the bronchioles and alveolar interstitium.
6. For both nose and mouth breathing, deposition in the alveolar interstitium is higher at 1.0 micron AMAD than 5.0 micron AMAD.