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ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

Review of the NIOSH Site Profile for the Weldon Spring Site in Weldon Spring, Missouri

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ACRONYMS AND ABBREVIATIONS

Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
CATI	Computer Assisted Telephone Interview
CER	Center for Epidemiological Research
CFR	*Code of Federal Regulations*
Ci	Curies
DOE	Department of Energy
DR	Dose Reconstruction or Dose Reconstructor
dpm	Disintegrations per Minute
DU	Depleted Uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EU	Enriched Uranium
GSD	Geometric Standard Deviation
keV	Kilo electron Volt
LAT	Lateral
LOD	Limit of Detection
MCW	Mallinckrodt Chemical Works
MCWND	Mallinckrodt Chemical Works Nuclear Division
MCWUD	Mallinckrodt Chemical Works Uranium Division
MDA	Minimum Detectable Activity
NIOSH	National Institute for Occupational Safety and Health
n/p	Neutron-to-Photon Ratio
NTA	Eastman Kodak Nuclear Track Film Type A
OCAS	Office of Compensation Analysis and Support
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAU Technical Information Bulletin
OW	Open window
PFG	Photofluorography
RU	Recycled Uranium
SC&A	S. Cohen and Associates
SEC	Special Exposure Cohort
SW	Shielded window
TBD	Technical Basis Document
TIB	NIOSH Technical Information Bulletin
U_3O_8,	Triuranium Octoxide (called yellow cake)
UF_4	Uranium Tetrafluoride (called green salt)

UO_2	Uranium Dioxide
UO_3	Uranium Trioxide
WS	Weldon Spring
WSCP	Weldon Spring Chemical Plant
WSRP	Weldon Spring Raffinate Pit(s)
WSQ	Weldon Spring Quarry

1.0 EXECUTIVE SUMMARY

This report provides the results of a review conducted by S. Cohen and Associates (SC&A) of the site profile for the Weldon Spring Plant, Weldon Spring, Missouri, developed by the National Institute for Occupational Safety and Health (NIOSH). This review was conducted during the period from January 2008–September 2008, in support of the Advisory Board on Radiation and Worker Health (Advisory Board) in the latter's statutory responsibility under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) to conduct such reviews and advise the Secretary of Health and Human Services on the "completeness and adequacy" of the EEOICPA program.

The site profile for the Weldon Spring (WS) site consists of six documents created in 2005:

- ORAUT-TKBS-0028-1 (Little and Meyer), Revision 0, June 28, 2005, and Revision 00 PC-1, June 30, 2008
- ORAUT-TKBS-0028-2 (Little and Boyer), Revision 00, June 24 2005
- ORAUT-TKBS-0028-3 (Lopez and Furman), Revision 00, June 24 2005
- ORAUT-TKBS-0028-4 (Boyer and Little), Revision 00, June 28 2005
- ORAUT-TKBS-0028-5 (Johnson and Falk), Revision 00, June 28 2005
- ORAUT-TKBS-0028-6 (Langsted and Little), Revision 00, June 24 2005

The Technical Basis Document (TBD) ORAUT-TKBS-0028-1, *Weldon Spring Plant – Introduction*, was reissued with some minor changes on June 30, 2008; however, the changes in that document did not have an impact on this review. In this review, unless specified otherwise, the term "WS site" will be used to refer to the Weldon Spring site in general, to include the WS Chemical Plant (WSCP), the WS Raffinate Pits (WSRP), the WS Quarry (WSQ), and any surrounding areas encompassing the Mallinckrodt Chemical Works (MCW)/Department of Energy (DOE) operations.

The WS site was constructed in the mid-1950s by the Mallinckrodt Chemical Works Nuclear Division (MCWND) to process uranium ore and other uranium materials for the Atomic Energy Commission (AEC). It was located on a 205-acre section of the Department of the Army's 17,232-acre Ordnance Works. According to TBD-2 (ORAUT 2005b), the WSCP was operated for AEC by the Uranium Division of MCW from 1957 to 1966. The WSCP processed materials from June 1957 to December 1966. Shutdown procedures were completed in 1967. It is estimated that there were approximately 600 employees at the site during peak production, of which about 300 would have handled uranium-containing materials. Four types of nuclear material were processed in the DOE-owned WSCP; natural uranium, depleted uranium (DU), slightly enriched uranium (EU) [some of these materials contained recycled uranium (RU)], and natural thorium.

The WSCP sampled the incoming uranium-bearing ore for uranium content (usually contained in metal drums with approximately 70% uranium content), processed some of the ore, and shipped some of the ore to other facilities for processing. The chemical processing consisted of changing the incoming material (mainly U_3O_8, called yellow cake) to UO_3, UO_2, and UF_4 (green salt). The green salt was then converted to uranium metal ingots through a process of heating magnesium and the green salt in a steel "bomb" shell in a furnace. The uranium metal was then extruded into rods of various shapes and sizes for machining, cutting, descaling, cleaning, etc., for shipment to other facilities for further processing for use in nuclear reactors. Additionally, some of the uranium processed at the WSCP contained RU during 1961–1966 and EU at <1% enrichment during 1963–1966, with some DU used as a substitute for natural uranium, mainly at the pilot plant to study process flow. The WSCP also processed natural thorium at various times throughout its period of operations.

The AEC turned over control of the WSCP to the Department of Defense (DOD) in 1967, when the U.S. Army was to convert some of the buildings for the production of Herbicide Orange. This project was cancelled in early 1969 and no production of the herbicide took place at the WSCP. Following this activity, no major work took place during the period 1969–1984.

In 1985, assessment and monitoring began in preparation for remediation of the WS site for both chemical hazards and radiological hazards from the ordnance and uranium operations under the auspices of the Weldon Spring Site Remedial Action Project. The clean-up effort was essentially completed by 2002 with the removal or disposal of all buildings, foundations, pits, quarry, and related material. Some of this material was shipped offsite, but the majority of it was entombed in an above-ground disposal cell located on the original WSCP site. The WS site is currently under a monitoring and surveillance program.

Scope and Approach

SC&A reviewed the WS site profile documents for the following attributes, in accordance with TASK 1 - *Site Profile Reviews*, Subtask 1 - *Site Profile Review Procedures* (NIOSH 2004):

- Completeness of Data Sources
- Technical Accuracy
- Adequacy of Data
- Consistency among Site Profiles
- Regulatory Compliance

In preparation for this report, SC&A reviewed the six WS site TBDs in detail, along with many WS site-related documents located at the WS site Interpretive Center, at the various DOE/federal record centers, and on the O-Drive. SC&A also conducted onsite interviews with former WS site workers. From these reviews, SC&A developed a number of issues regarding the WS site profile. These issues were identified, consolidated, and grouped into findings. Findings that have the potential to significantly impact the results of at least some dose reconstructions are listed as Primary Findings, and those that are important, but may have less impact on the results of dose reconstruction, are listed as Secondary Findings. Additionally, items that could potentially lead to incorrect dose assignments because of errors, lack of clarity, inconsistencies, omissions, etc., in the TBDs are listed as Observations.

In this section, a brief summary of the issues are presented, followed by a summary of the primary findings. (Primary Findings, along with Secondary Findings, are further detailed in Section 3 of this report). SC&A then provides a discussion of the strengths of the TBDs, followed by recommendations for improvement at the end of this section, which are listed as Observations.

Summary of Issues

SC&A found that detailed documentation of radiation hazards, surveys, and potential exposures were not readily available or do not exist for the WS site, especially for the operational period of 1957–1966 or the maintenance period of 1967–1984. Therefore, the underlying problem with the TBDs for the WS site is that they rely on recent WS site data (1985–2002), recent and some previous era environmental data, and very limited operational-period onsite data. Because of the limited WS site data and documentation, NIOSH also relied heavily on the Fernald site data and extrapolated it to the WS site TBDs. Unfortunately, the data/assumptions used for the Fernald site TBD are frequently estimates, instead of the results of measurements or documented information. Additionally, relatively recent data for the Fernald site was sometimes extrapolated to earlier time periods when sufficient data did not exist. The SC&A review of the Fernald site profile (SC&A 2006) points out the shortcoming of using these assumptions/data at the Fernald site. Understandably, SC&A has reservations concerning applying these questionable concepts/data from the Fernald site to the WS site profile.

During the operational period, the WS site had a basic uranium bioassay and beta/photon badging program in place, and a limited site-parameter environmental monitoring program. However, the lack of routine personnel/egress contamination monitoring, consistent and documented badging policy (with geometry correction factors), comprehensive bioassay program that encompassed all the major radioisotopes brought on site, and an onsite environmental monitoring program for unmonitored workers leads to gaps in some of the information and data. NIOSH attempted to fill in some of these gaps with extrapolated operating conditions and data from other DOE sites. SC&A found some of these recommended methods to be uncertain, not sufficiently supported, or in some cases, potentially not claimant favorable. Additionally, a site profile should evaluate the accuracy, adequacy, and representativeness of the workers' recorded internal and external dose data. SC&A could not find that NIOSH had performed a sufficient analysis of this type.

The majority of material handled at the WS site was natural uranium. In addition, some RU, EU, and DU were also handled at the WS site, along with natural thorium. NIOSH acknowledges this in the WS site TBDs and makes some provisions for it, but concludes in general that because uranium is the most prevalent, it will dominate dose reconstruction. However, it cannot be assumed that because the majority of the material handled was natural uranium, then the other radionuclides are of a minor issue. Some workers involved in specific processes that handled these other radionuclides (and workers in the vicinity) had the potential of receiving substantial doses from these other radionuclides.

1.1 SUMMARY OF PRIMARY FINDINGS

1.1.1 Findings Common to Several TBDs

In reviewing the six site profile documents for the WS site, SC&A found several issues that were common to more than one of the documents. The following is a brief summary of the primary findings that reflect these issues.

Lack of Personnel Contamination and Egress Monitoring

The WS site TBDs do not mention the lack of monitoring equipment and procedures to check workers for contamination in the work places and upon leaving the controlled areas. During recent worker interviews, SC&A did not find that the workers recalled any regular egress monitoring, either between the operations areas to the non-operations areas (cafeteria, administration offices, labs, maintenance facilities, sidewalks, storage yards, grounds, etc.), or when leaving the plant site (guard shack, parking lots). Workers were apparently allowed to leave the controlled areas and the WS site without confirmation that they were not contaminated. This could have spread contamination to non-controlled areas at the site, creating chronic exposure (internal and external) to unmonitored workers, as well as leaving contamination on the workers that could lead to chronic beta exposure to the skin (especially in the folds of the skin) and internal exposure through ingestion and resuspension/inhalation.

Inadequate Information Concerning Workers Status/Exposures for 1967–1984

The WS site TBDs do not explicitly state when DOE employees and/or DOE contractors were no longer at the WS site after it stopped operations in December of 1966. It has not been determined if DOE employees and/or contractors were present or involved during 1967–1969 when the U.S. Army was attempting to decontaminate and renovate buildings located at the WSCP; during the 1970–1984 monitoring and maintenance period; or during 1983–1984 when there were efforts to remediate leaks at the WSRP. If DOE contract personnel were present at the WS site soon after the shutdown in December 1966, they could have been exposed to numerous radionuclides during decommissioning, clean out, and revamping the facility for a completely different use. This could have lead to incidences of skin contamination, inhalation, and ingestion of radioactive materials (including uranium and thorium, as well as radionuclides contained in the raffinate concentrates and its scale/soil that had been resuspension) that were not monitored and/or recorded or grossly underestimated.

If DOE employees and/or contractors were present at any of DOE's WS facilities during the period 1967–1984, the TBDs need to be revised to include this period of dose evaluation for the site. Therefore, the issue of **legal ownership** of the property (and liability) as a function of time needs to be determined through federal/state/local records to determine if the TBDs should be revised to include additional time periods.

Individual Exposures versus Average Exposures

The TBDs rely heavily on the fact that mostly natural uranium (>97%) was processed at the WSCP; therefore, the contributions from other forms of uranium (DU, EU, or RU) and other radionuclides (thorium, radium, etc.) are small compared to natural uranium. Whereas the most likely exposures (internal and external) may have been from natural uranium, this does not negate the fact that individuals or certain groups of workers may have been exposed to materials that contained greater concentrations of other forms of uranium and radionuclides, especially in or near plant locations dedicated to the other forms of radioactive material processing and in areas around discharge streams, waste, and raffinate pits.

Assuming that natural uranium predominates as the source of a worker's dose could lead to an underestimate of the worker's correct dose if the worker was exposed to radioactive materials other than natural uranium.

1.1.2 Findings Specific to a TBD

SC&A reviewed the six TBDs for the WS site and has identified a number of issues that may impact the outcome of dose reconstruction for the WS site workers. The following is a brief summary of the primary findings that reflect these issues pertinent to each TBD.

1.1.2.1 Occupational Environmental Dose ORAUT-TKBS-0028-4

Lack of Atmospheric Monitoring Data for Operational Period

There is no substantial site-wide atmospheric monitoring data available for the operational period to assure an accurate and integrated onsite environmental dose assessment. The TBD recognizes this lack and relied upon the use of dose estimates for the public derived from its reviews of the Fernald plant data to estimate the onsite environmental dose for the WSCP workers. This is problematic, in that raw emissions data from Fernald is not easily converted to environmental dose for the WS site workers when several emission points of varying geographic locations have to be considered, as well as the lack of knowledge that could place workers at specific locations during exposure events. SC&A believes that the limited environmental data presented in the TBD and the lack of environmental surveys of onsite locations over time does not support the supposition and/or conclusion of negligible dose to onsite personnel.

Insufficient Data for Unmonitored Workers' Internal Environmental Dose

The TBD used one series of measurements (decontaminating 5-ton hoppers) and site parameter measurements to determine contributing intakes to non-bioassayed workers during 1957–1967. The hopper dust monitoring experiment consisted of measurements performed on one day under one particular condition, and the parameter measurements contributed very little (<1%) to the final results. This limited (in space, operations, and time) airborne/intake data is not sufficient to construct an adequate intake dose database for unmonitored workers at the WS complex, especially considering that a sizable fraction of the work force was not bioassayed on a routine basis during this period.

Lack of Validation for Maximum Environmental Dose

The TBD fails to validate the adequacy of estimating the maximum environmental dose due to source terms at differing locations at the Weldon Spring Plant. In the current TBD, NIOSH has offered that existing air monitoring data do not distinguish the source of emissions; therefore, to some measure, it only allows evaluation of cumulative emissions and dose. The estimation of dose methodology currently being applied by NIOSH does not reasonably address maximum dose to workers who are not routinely monitored across the site, which could have been 50% of the site workers.

SC&A believes that the lack of air monitoring stations in general and the overall lack of stations within a particular geographic location at the WSCP (of known higher releases of uranium and thorium) does not readily enable one to accurately estimate environmental dose using only the very limited existing air monitoring data.

1.1.2.2 Internal Dose ORAUT-TKBS-0028-5

Incomplete Assessment of Uranium Decay Products

The TBD recommendations for dose estimate from decay products of U-238 are incomplete, and not always claimant favorable. The dose from **inhaled** Th-234 is not included along with the dose from inhaled U-238 in the dose calculations. What is included is the dose from Th-234 that builds up inside the body after an intake of U-238 takes place. Additionally, the dose contribution due to Pa-234m from the decay of Th-234 in the body also needs to be included in the internal dose calculations. While it is true that the Pa-234m outside the body only contributes to the external dose, the Pa-234m originating inside the body from Th-234 decay must be included in the internal dose calculations.

Incomplete Assessment of Radon Exposure

The TBD describes the potential radionuclide exposure in the different buildings of the WSCP. Radon is listed as a source of exposure inside buildings 101, 103, 105, 403 and 407. However, the recommended approach used in the TBD to estimate radon doses is based on **environmental** radon concentrations for the areas within 100 meters of the assumed release point, which is the acid recovery plant stack. Using this approach requires that several assumptions be made, which results in large uncertainties in the dose estimates for workers located in **indoor** workplaces. For example, documentation shows that indoor radon concentrations averaged four times that of outside radon concentrations.

Therefore, the approach recommend in TBD-5 is not always claimant favorable. NIOSH should propose a more reliable and claimant-favorable approach to the assess radon exposure for WSCP workers.

Different Solubility Classes Listed for the Same Element

The TBD provides a list of solubility classes for uranium and thorium compounds in some of the buildings at the WSCP; however, the TBD lists different solubility classes for the same element. Because there were no means of separating isotopes of a given element at the WSCP, the chemical properties were the same for all uranium isotopes, as well as for all thorium isotopes. According to ICRP Publication 78 (ICRP 1997) the biokinetic behavior is the same for U-234, U-235, and U-238. The same applies for thorium Th-232 and Th-228.

In view of the operations that took place at the WSCP, the TBD should provide justification/clarification concerning the use of different classes of solubility for the same element at the WS site.

Missed Dose and Coworker Data Not Adequately Addressed

The TBD does not address potentially missed internal doses, which should be part of a TBD for internal dose. The limits of detection (LODs) were generally high in the earlier years, which could result in significant missed doses. For the dose reconstructor to assign missed dose, the TBD needs to provide some information concerning the minimum detectable activity (MDA) for given bioassay techniques for the important radionuclides of concern at the WS site as a function of time. Additionally, the TBD provides some coworker internal dose information, but does not provide sufficient instructions for its use or the details of the data, such as the percent of workers bioassayed or the representativeness of the data (especially important at the WS site, because not all workers were bioassayed and none continuously). Also, most internal dose TBDs provide a summary section in the main text or as an appendix with recommendations and procedural steps for using coworker data.

1.1.2.3 External Dose ORAUT-TKBS-0028-6

Shallow and Extremity Doses Not Sufficiently Characterized

The TBD briefly addresses dosimeter quantities, open window (OW), shielded window (SW), etc., and compares beta dose from NU, EU, and DU for shallow doses; additionally, electron dose is listed as >15 keV. But the TBD does not address geometry factors, total shallow dose, or extremity monitoring during the operational period. A geometry factor is needed for adequate dose assessment, because a film badge does not register the same dose as the worker's tissue/organ is receiving from the betas and low-energy photons when handling, machining, scooping, etc., uranium containing materials. No WS site documents have been located that sufficiently address the change in film badge response as a function of radionuclide exposure, especially to low-energy photons and changes in beta energies. Additionally, there is no indication that routine extremity monitoring was performed at WS during the operational period.

Badging Policy Not Consistent

The TBD does not provide sufficient and/or consistent information concerning the badging policies at the WS site. This raises the question of what badging criteria were actually used in practice and if workers not considered at the time to be exposed to radiation were potentially exposed but not monitored because of being in a pre-defined category. The lack of a consistent and documented badging policy may negatively impact dose reconstruction, because the dose reconstructor could assign an unbadged worker only external environmental dose when the worker should have been assigned coworker external dose. Additionally, badging policies could impact the validity of the coworker dose database.

Lack of Sufficient Coworker Data Development for External Dose

The TBD provides annual average gamma and beta exposures. However, the TBD does not provide any information concerning the details of this information, such as the number of data points for each entry, the percent of workers badged, the range of readings, if background was subtracted, if zeroes or outliers were included, if a threshold dose was used, etc. The data presented is a good start in creating a coworker database; however, in order to determine its validity and representativeness, there needs to be additional work performed on the data, as mentioned above. Plus, for internal coworker data, some guidance for use of the data in a summary form would be appropriate.

1.2 SUMMARY OF STRENGTHS

The WS site TBDs were written in six volumes, which assist the reader in accessing and analyzing the information in an orderly fashion. The TBDs addressed the different time periods (operational, shutdown, maintenance, and remediation) relevant to the WS site in a consistent manner. TBD-2 (ORAUT 2005b) provided a sufficient description of the site's history from its origin in 1941 as an ordnance plant to its final state containing the above-ground disposal cell. References were well documented and editorial errors were kept to a minimum. (See Section 1.3, entitled Observations, for some of the errors that were located during this review.)

The various authors were fairly consistent in the information they presented across the six TBDs, and made reasonable attempts to locate substitute data when it was missing for the WS site. This data was sometimes extrapolated from later WS site data, the Fernald site TBDs, or generic DOE documents, and these methods may be appropriate in some situations. However, because of the frequent lack of WS site-specific data/information, SC&A has concerns with using this approach. These concerns are expressed as findings in this report.

NIOSH analyzed some of the environmental, internal (in-vitro bioassays), and external (gamma and beta) dose data and provided summary tables of this information in the appropriate TBDs. Some of this data will be helpful for use by the dose reconstructor for cases where there are gaps in the workers' dose records, or for workers who were unmonitored. SC&A has reviewed this information and included their evaluation in the findings of this report.

With the information available at the time of the writing of the first version of the WS site profile, the TBDs were reasonably well written. However, SC&A suggest that the TBD be revised with any new information NIOSH has acquired since 2005 and address SC&A's concerns expressed in this report.

1.3 OPPORTUNITIES FOR IMPROVEMENT

SC&A has identified some areas where changes in the TBDs would be beneficial to the claimant by preventing possible mistakes during dose reconstruction or clarifying items to make them less ambiguous. These are listed as Observations in this section.

1.3.1 Observations – General

Observation – Lack of Coverage of Offsite Activities

Apparently, some work was performed by offsite contractors for the WS site, which consisted of inspection of uranium metal samples by cutting of the material and then irradiation using high-energy betatrons. This procedure could induce fission in uranium and create fission products that could emit radiation not normally encountered in a uranium facility, and expose nearby WS workers and transporters who may not have normally been badged; and it could have created inhalable radioactive material for which bioassays were not performed. This subject should be investigated and addressed in the appropriate TBDs.

1.3.2 Observations – Occupational Medical Dose

Equation 3-1, *Dom = SnDi*, is provided on page 6 of TBD-3 (ORAUT 2005c) and the individual terms in the equation are defined, except for the term "S." This may have been meant to be the Greek symbol sigma "Σ" for summing, instead of an "S."

1.3.3 Observations – Environmental Dose

Observation #1 – Application of Environmental Doses

Section 4.1.2 of TBD-4 (ORAUT 2005d, page 6) states the following:

> *The term occupational environmental dose refers to the radiation dose received in the course of work duties outside plant buildings, but on the WSCP site. This TBD considers internal and external exposures to radionuclides in the outdoor environment separately in calculating this dose. Dose reconstructors can use estimated occupational environmental dose to develop a reliable individual dose when a worker was not monitored adequately.*

However, this statement should be qualified to apply only to workers that were **not** routinely exposed and would not be considered a radiation worker by today's standards. If the worker would be considered a radiation worker by today's standard, then the dose reconstruction should be based on coworker dose data, not environmental dose data.

Observation #2 – Special Uranium Curie

The equation for the special uranium curie is correct on page 31 of TBD-5 (ORAUT 2005e), and on page 14 of TBD-4 (ORAUT 2005d), where it is stated that "The original data are reported in units of special uranium microcuries, defined as the sum of 3.7 × 10^4 dps from ^{238}U, 3.7 × 10^4 dps from ^{234}U, and 9 × 10^2 dps from ^{235}U." However, it goes on to state, "Converting to units of Bq, the special uranium µCi is multiplied by 3.7 ×10^4 Bq/µCi **and by a factor of 2.024** to report total uranium activity" (emphasis added). The factor of **3.7 × 10^4 Bq/µCi** is correct, but the factor of 2.024 should be omitted, because the special uranium **µCi** already includes the 2.024 factor [which consist of the sum of (3.7 × 10^4 dps from ^{238}U, 3.7 × 10^4 dps from ^{234}U, and 9 × 10^2 dps from ^{235}U)/(3.7 × 10^4 dps from ^{238}U) = 2.024].

Observation #3 – Corrections to Text of TBD-4

- The equation on page 5 should read, "WL Working Level = 1.3 × **10^5** MeV of alpha energy in 1 liter of air;" not "**105** MeV."

- The equation on page 5 should read, "WLM Working Level Month = Exposure from 1 WL **of** radon daughters for 170 working hours;" not "…**or** radon…"

1.3.4 Observations – Internal Dose

Observation #1 – Years of Thorium Use

Table 5-2 (ORAUT 2005e, page 10) lists the starting date for potential Th-232 exposure as 1963, 1965, and 1966 depending on the building. This should be verified, as it would seem that WS would have processed thorium fairly uniformly throughout the different buildings, at least on a yearly basis.

Observation #2 – Changes in Text of TBD-5

- The second paragraph on page 12 appears to be out of place in this location; it may be more applicable to the contents of page 9.

- The last paragraph on page 12 contains an incorrect table and document reference; it should read, "Table **2-7** in ORAU (**2005b**) gives the annual (fiscal year) mass receipts of each of these feed materials;" not "Table **2-4** in ORAU (**2005a**)…"

- The second paragraph on page 36 states that "Under these assumptions, the claimant-favorable assumption results in an annual exposure of **735 MAC-hr** (in comparison to 1,050 MAC-hr for Fernald)…" when actually it is **1,050 MAC-hr** for the WS site, based on the definition of the MAC for the WS facility. Considering that the MAC for the WS facility was set at 70 dpm/m^3 compared to 100 dpm/m^3 for the Fernald facility, it would be **equivalent** to 735 MAC-hr as defined for the Fernald facility.

1.3.5 Observations – External Dose

Observation #1 – Changes in Text of TBD-6

- Table 6-6, page 15, contains "?" where the gamma symbol should be, which causes some confusion while reading the contents of the table.

- In Table 6-6, page 15, under the **Report** column, the text in the first and second row both refer to "Figures A-1 – A-6;" however, they describe different contents. Apparently, each one of them should refer to only a few of the Figures, not all six of them.

Observation #2 – Missing Data in TBD-6

- Table 6-2 (*Summary of historical recorded dose practices*) on page 12 is not complete, in that it does not contain any information (has blank spaces) for the time periods other than 1958–1966. No *Dosimeter measured quantities* or *Compliance dose quantities* are provided for 1957, or the periods when EU and RU (*Plant operations period Special case for enriched uranium*) were processed, or 1967–1984 (*Maintenance period*), or for *Landauer*. This information is important during dose reconstruction to correctly interpret the recorded data and to determine if adequate data exist to assign accurate doses, especially for beta doses, which were prevalent at the WS site.

- For the period 1957–1969, Table 6-14 (page 25) provides data for potentially missed gamma dose during 1957–1958 and 1959–1969; however, Table 6-16 only provides beta missed dose data for 1957–1966 (does not include 1967, 1968, and 1969).

2.0 SCOPE AND INTRODUCTION

The review of the Weldon Spring (WS) site, in Weldon Spring, Missouri, was conducted during January – September 2008 by a team of SC&A health physicists and technical personnel. Almost all the records for the site have been declassified at this time. However, one member of the SC&A team held a "Q" clearance that permitted unencumbered access for this review, as needed.

Some SC&A team members also participated in the MCW downtown St. Louis, Missouri (Destrahan Street), site profile review and were involved in the Special Exposure Cohort (SEC) petition for that site. Because the downtown site was a precursor for the WS site, experience gained at the first site was useful for the WS site profile review.

SC&A understands that site profiles are living documents, which are revised, refined, and supplemented with NIOSH technical information bulletins (TIBs) as required to help dose reconstructors. Site profiles are not intended to be prescriptive or necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. However, future revisions in the WS site TBDs would serve to mitigate some of the gaps and issues raised in this report.

2.1 REVIEW SCOPE

Under the EEOICPA and federal regulations defined in Title 42, Part 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program,* of the *Code of Federal Regulations* (42 CFR Part 82), the Advisory Board is mandated to conduct an independent review of the methods and procedures used by NIOSH and its contractors for dose reconstruction. As a contractor to the Advisory Board, SC&A has been charged under Task 1 to support 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 provides a review of the six site profile documents (ORAUT-TKBS-0028-1 through ORAUT-TKBS-0028-6) for the WS site in Weldon Spring, Missouri. The TBD ORAUT-TKBS-0028-1, *Weldon Spring Plant – Introduction,* was re-issued with some minor changes on June 30, 2008; however, the changes in that document did not impact this review. To date, these documents have not been supplemented by site-specific TIBs, but there are several generic TIBs that provide additional guidance to the dose reconstructor.

Implementation guidance is also provided by so-called "workbooks," which have been developed by NIOSH for selected sites to provide more definitive direction to the dose reconstructors on how to interpret and apply TBDs, as well as other available information. To date, no WS site-specific workbooks have been developed.

SC&A, in support of the Advisory Board, has critically evaluated the WS site TBDs for the following:

- Determine the completeness of the information gathered by NIOSH in behalf of the site profile, with a view to assessing its adequacy and accuracy in supporting individual dose reconstructions
- Assess the technical merit of the data/information
- Assess NIOSH's use of the data in dose reconstructions

SC&A's review of this site profile document focuses on the quality and completeness of the data that characterized the facility and its operations, and the use of these data in dose reconstruction. The review was conducted in accordance with *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004) which was approved by the Advisory Board.

The review is directed at "sampling" the site profile analyses and data for validation purposes. The review does not provide a rigorous quality control process, whereby actual analyses and calculations are duplicated or verified. The scope and depth of the review are focused on aspects or parameters of the site profile that would be particularly influential in deriving dose reconstructions, bridging uncertainties, or correcting technical inaccuracies.

The WS site TBDs serve as site-specific guidance documents used in support of dose reconstructions. These site profiles provide the health physicist who conducts dose reconstructions on behalf of NIOSH with consistent general information and specifications to support their individual dose reconstructions. This report was prepared by SC&A to provide the Advisory Board with an evaluation of whether and how the TBDs can support dose reconstruction decisions. The criteria for evaluation include whether the TBDs provide a basis for scientifically supportable dose reconstruction in a manner that is adequate, complete, efficient, and claimant favorable. Specifically, this review was conducted using the criterion of whether dose reconstructions based on the TBDs would provide for robust compensation decisions.

The basic principle of dose reconstruction is to characterize the radiation environments to which workers were exposed and determine the level of exposure the worker received in that environment through time. The hierarchy of data used for developing dose reconstruction methodologies is dosimeter readings and bioassay data, coworker data and workplace monitoring data, and process description information or source term data.

2.2 ASSEESSMENT CRITERIA AND METHODS

SC&A is charged with evaluating the approach set forth in the site profiles that 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 2004). This review is specific to the WS site profile, and supporting TIBs; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms and exposure conditions. The review identifies a number of issues and discusses the degree to which the site profile fulfills the review objectives delineated in SC&A's site profile review procedure.

2.2.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which 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 are (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.

2.2.2 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 instructions, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred at the WS site. The goal of this objective is to analyze the data according to sound scientific principles, and then evaluate this information in the context of dose reconstruction.

2.2.3 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. The adequacy of the data identifies gaps in the facility data that may influence the outcome of the dose reconstruction process. For example, if a site did not monitor all workers exposed to neutrons who should have been monitored, this would be considered a gap, and therefore an inadequacy in the data. An important consideration in this aspect of our review of the site profile is the scientific validity and claimant favorability of the data, methods, and assumptions employed in the site profile to fill in data gaps.

2.2.4 Objective 4: Consistency among Site Profiles

Objective 4 requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the WS site TBDs were compared to other TBDs previously reviewed. This assessment was conducted to identify areas of inconsistencies and determine the potential significance of any inconsistencies with regard to the dose reconstruction process.

2.2.5 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 42 CFR Part 82. In addition, SC&A evaluated the TBDs for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions.

2.3 DOSE RECONSTRUCTION UNDER EEIOCPA

In order to place the above objectives into the proper context as they pertain to the site profile, 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 [r minimized dose(s)] corresponds to a probability of causation (POC) value in excess of 50%, assuring compensability to the claimant. In some cases, such partial/incomplete dose reconstructions with a POC greater than 50% may 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 (based on the LOD) that results in a POC greater than 50%. For this reason, dose reconstructions in 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 equal to or greater than 50%.

Category 2: A second category of dose reconstruction defined by federal guidance 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, and that the approach is scientifically supportable.

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, 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 to satisfy this type of a dose reconstruction. Thus, for external exposures, maximum dose rates must be identified in time and space that correspond to a worker's employment period, work locations, and job assignment. Similarly, in order to maximize internal exposures, highest air concentrations and surface contaminations must be identified.

Category 3: The most complex and challenging dose reconstructions consist of claims where the case cannot be dealt with in one of the two categories above. For instance, when a minimum dose estimate does not result in compensation, a next step is required to make a more complete estimate. Or when a worst-case dose estimate that has assumptions that may be physically implausible results in a POC greater than 50%, a more refined analysis is required. A more refined estimate may be required either to deny or to compensate. In such dose reconstructions, which may be represented as a "reasonable" or "best-case" estimate, NIOSH has committed to resolve uncertainties in favor of the claimant. According to 42 CFR 82, NIOSH interprets "reasonable estimates" of radiation dose to mean the following:

> *… estimates calculated using a substantial basis of fact and the application of science-based, logical assumptions to supplement or interpret the factual basis.* ***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.*** (Emphasis added.)

SC&A's draft report and preliminary findings will subsequently undergo a multi-step resolution process. Prior to and during the resolution process, the draft report is reviewed by the DOE Office of Health, Safety, and Security, to confirm that no classified documents or information have been incorporated into the report. Resolution includes a transparent review and discussion of draft findings with members of the Advisory Board Working Group, petitioners, claimants, and interested members of the public. This resolution process is intended to ensure that each finding is evaluated on its technical basis in a fair and impartial basis. A final report will then be issued to the full Advisory Board for deliberation and a final recommendation.

All review comments apply to Rev. 00 of the WS site TBDs, which are the most recently published versions. SC&A is aware of some minor revisions made to TBD-1 (ORAUT 2005a) in June 2008; however, this revised edition was not yet available on the Center for Disease Control (CDC) website at the time of the writing of this report. SC&A does not anticipate that these minor revisions will impact this review.

Site expert interviews were conducted with former WS site workers to help SC&A obtain a comprehensive understanding of the radiation protection program, site operations, and historic exposure experience.

Attachment 2 provides summaries of the interviews conducted by SC&A during the course of this review. The interviewees included a good cross-section of former WS site workers, including production, maintenance, safety, office, and radiological safety personnel that worked at the WS site at some point during the production period of 1957–1966. The interviews were conducted at the Weldon Spring Site Interpretive Center located at 7295 Highway 94 South, St. Charles, Missouri, and also with a former WS site worker in the St. Louis, Missouri, area. A telephone interview was conducted with a medical doctor closely associated with the WS site and its former workers. The interviews were conducted by Ron Buchanan (SC&A/Saliant Inc.) and Kathy Robertson-DeMers (SC&A/Saliant Inc.), from April 28–30, 2008, and on September 8, 2008.

Because of the singularity of purpose, limited operating period, and relatively small size of the WS site (as opposed to other DOE sites or national laboratories), SC&A did not submit a list of questions to NIOSH as part of its evaluation of the WS site TBDs. SC&A believed that the resources and time that would have been involved in submitting questions and obtaining responses could be more effectively spent in performing document research and other tasks for this site profile review.

2.4 REPORT ORGANIZATION

In accordance with directions provided by the Advisory Board and with site profile review procedures prepared by SC&A and approved by the Advisory Board, this report is organized into the following sections:

(1) Executive Summary
(2) Scope and Introduction
(3) Vertical Issues
(4) Overall Adequacy of the Site Profile as a Basis for Dose Reconstruction.

Based on the issues raised, SC&A prepared a summary list of findings, which are provided in the Executive Summary. Issues are designated as Primary Findings if SC&A believes that they represent deficiencies in the TBD that need to be corrected and which have the potential to have a substantial impact on at least some dose reconstructions. Issues can also be designated as Secondary Findings or Observations if they simply raise questions, which, if addressed, would further improve the TBDs and may possibly reveal deficiencies that will need to be addressed in future revisions of the TBDs. Detailed analyses of the primary and secondary findings are provided in Section 3 of this report.

3.0 VERTICAL ISSUES

SC&A developed the issues for the six WS site profile documents using the five objectives defined in SC&A's review procedures (SC&A 2004). Some issues were related to more than one TBD and are covered under Section 3.1, *Common Issues*, and some are related to a specific TBD and are covered under Section 3.2, *Specific Issues*. The issues were identified, consolidated, and grouped into findings. Findings that could substantially impact the results of dose reconstruction for some workers are listed as Primary Findings, and those that are important, but may have less impact on the results of dose reconstruction, are listed as Secondary Findings. SC&A has also identified some areas where changes in the TBDs would be beneficial to the claimant by preventing possible mistakes during dose reconstruction, or where clarification of items would make them less ambiguous. These were listed as *Observations*.

3.1 COMMON ISSUES

In reviewing the six WS site TBDs, SC&A found several issues that were common to more than one of the documents. Therefore, to eliminate repetition, SC&A has consolidated these issues. The following are five areas that SC&A has identified where the present TBDs lacks sufficient information/data that may impact NIOSH's ability to perform claimant-favorable dose reconstructions.

3.1.1 Primary Findings

Finding #1: Lack of Personnel Contamination and Egress Monitoring

The WS site TBDs do not mention the lack of monitoring equipment and procedures to check workers for contamination in the work places and upon leaving the controlled areas. SC&A could not locate any documentation to verify if such procedures and equipment were used at the WS site during the operating period of 1957–1966. At that time, uranium was considered to be mostly a chemical hazard and control measures were mainly based on chemical toxicity limits, not radiological limits (ORAUT 2005e, page 11). During recent worker interviews, SC&A did not find that the workers recalled any regular egress monitoring, either between the operations areas to the non-operations areas (cafeteria, administration offices, labs, maintenance facilities, sidewalks, storage yards, grounds, etc.) or when leaving the plant site (guard shack, parking lots). Workers did indicate, and documents support, that they were required to change clothing when entering and leaving the operations areas (some workers showered, but this policy does not appear to have been strictly enforced); however, there is no evidence that the workers were checked for contamination before leaving the controlled areas to ascertain that they were not contaminated. Documents indicate that some area monitoring (i.e., with portable survey instruments and swipes) and cleanups were performed to keep some surfaces below certain limits (MCW 1965b, page 20), but there is no indication that survey instruments or hand/foot monitoring stations were available and routinely used to monitor workers as they left the operational areas or the WS site. Contamination was apparently commonplace inside the process areas as evident by a statement in MCW Uranium Division (MCWUD) *Summary of Health Protection Practices* (MCW 1965b, page 20), which states that "Inside the process locations, surface contamination measurements have little significance." Contamination was apparently common on workers, as described in a 1960 WS site document (Burr 1960):

> *His shoes and his gloves were especially loaded with green salt. The packing was done by foot…He had a respirator around his neck but was not using it… it was suspected that the ventilation was inadequate…the operator distributed additional green salt in the bomb by hand and visible clouds of dust could be seen around the shell top and in the working area.*

It would not be difficult to create contamination in the work areas, considering that the beta exposure rates of some operations were in the 10–35 rep/hr (rep ~ rem) range, as stated in Table I of a WS site document (MCW 1959b). A little scale, cuttings, or dust from these operations would quickly contaminate the work area.

Workers also indicated that they were allowed to smoke and drink liquids in the break rooms located inside the controlled areas without washing of hands, changing of clothes, or contamination checks. This practice could lead to undetected intakes in some individuals who were not monitored on a regular basis, especially those who were present in the work areas, but not considered as at-risk workers, such as supervisors, clerks, and security personnel.

Workers were apparently allowed to leave the controlled areas and the WS site without confirmation that they were not contaminated. This could have spread contamination to non-controlled areas at the site, creating chronic exposure (internal and external) to unmonitored workers, as well as leaving contamination on the workers that could lead to chronic beta exposure to the skin (especially in the folds of the skin) and internal exposure through ingestion and resuspension/inhalation. Because workers only periodically submitted urine samples, as described in TBD-5 (ORAUT 2005e), some of these individual internal exposures could have been missed. Additionally, personnel badges worn during working hours would not have picked up this offsite external dose on the workers.

Finding #2: Inadequate Information Concerning Workers Status/Exposures for 1967–1984

It is not explicitly stated in the TBDs when DOE employees and DOE contractors were no longer working at the WS site after operations ceased in December of 1966. In Section 2.2.2.4 of TBD-2 (ORAUT 2005b, page 22), it is indicated that no AEC contractors were present until August 1975 (this is reiterated on page 30 of TBD-2); however, Section 6.13.2, page 12 of TBD-6 (ORAUT 2005f), states that:

> *"There is some anecdotal information to indicate that some former WSCP workers continued their employment during this period."* and "*We do not feel such a contractor will need film badge services." However, it is not clear if this statement refers to a continued presence by MCW staff.*

This is referring to the 1967 to 1969 time period.

The WS site TBDs do not state if DOE employees and contractors were present or involved during 1967–1969 when the U.S. Army was attempting to decontaminate and renovate buildings located at the WS Chemical Plant, during the 1970–1984 monitoring and maintenance period, or during 1983–1984 when there were efforts to remediate leaks at the WS Raffinate pit.

Sections 4.2.2.2 and 4.2.32 of TBD-4 (ORAUT 2005d); Sections 5.3.2, 5.4.2, 5.5.2, 5.5.3, and 5.6.2 of TBD-5 (ORAUT 2005e); and Sections 6.1.3.2 and 6.1.3.3 of TBD-6 (ORAUT 2005f) do not contain sufficient information for the dose reconstructor to be able to assess dose to claimants who may have worked for DOE or its contractors at the WS site during 1967–1984. If DOE contract personnel were present at the WS site soon after the shutdown in December 1966, they could have been exposed to numerous radionuclides during decommissioning, clean out, and revamping the facility for a completely different use. Because uranium was viewed as a chemical rather than a radiological hazard at that time, sufficient controls and monitoring practices may have not have been in place. This was more likely to occur during the time period immediately following plant closure, because the MCW health and safety infrastructure at the WS site was no longer in place. Plant operating protocol would not have been in enforced; buildings and equipment were considered surplus, and supplies/materials (including leftover radioactive material or contaminated material) would have been considered a nuisance and disposable. Working under these conditions could have created a mindset that radiological safety was not an issue (for both the contractor and the workers). This could have lead to incidences of skin contamination, inhalation, and ingestion of radioactive materials (including uranium and thorium, as well as radionuclides contained in the raffinate concentrates and its scale/soil that had been resuspension) that were not monitored or recorded, or grossly underestimated.

It should be determined if there were DOE or DOE contractor shutdown personnel, decontamination and decommissioning workers, or clean-up crews during the years immediately following the 1966 closure, and if there were guards and security staff during the period 1967–1984. If DOE employees and DOE contractors were present at any of DOE's WS facilities during the period 1967–1984, the TBDs need to be revised to include this period of dose evaluation for the site. Therefore, the issue of *legal ownership* of the property (and liability) as a function of time needs to be determine through federal/state/local records to determine if the TBDs should be revised to include additional periods.

Finding #3: Individual Exposures versus Average Exposures

In a number of places (ORAUT 2005d, page 11–12, and ORAUT 2005f, page 23), the TBDs rely on the fact that mostly natural uranium (>97%) was processed at the WS Chemical Plant; therefore, the contributions from other forms of uranium (DU, EU, or RU) and other radionuclides (thorium, radium, etc.) are small compared to natural uranium. Whereas the most likely exposures (internal and external) may have been from natural uranium, this does not negate the fact that individuals or certain groups of workers may have been exposed to materials that contained greater concentrations of other forms of uranium and radionuclides, especially in or near plant locations dedicated to the other forms of radioactive material processing and in discharge streams, waste, and raffinate pits.

Calculating the dose from the radioisotopes that produce 95% or 99% of the dose, as was done in TBD-4 (ORAUT 2005d, pages 11–12), to arrive at the conclusion that natural uranium over-rode all the other radionuclides is not claimant favorable to some workers monitored for only natural uranium who may have received a significant fraction of their internal and/or external doses (either chronic or acute) from other radionuclides. Additionally, non-bioassayed and unbadged workers located near, but not in, a process area may have received unrecorded environmental internal and external doses from sources other than natural uranium.

Likewise, it may not be claimant favorable to assume that all the beta doses were received from natural uranium (as in ORAUT 2005f, page 23), based solely on the fact that 97% of the material processed was natural uranium. Some workers may have received beta doses from other radioisotopes if they were involved in EU, RU, thorium, and other mission-specific projects or processes.

Assuming that natural uranium predominates as the source of a worker's dose could lead to an underestimate of the worker's correct dose if the worker was exposed to radioactive materials other than natural uranium.

3.1.2 Secondary Findings

Finding #4: Recycled Uranium Not Adequately Recognized in the TBDs

Recycled uranium (RU) and its associated radionuclides are one of the major concerns of former WS site workers. During onsite worker interviews, in Computer Assisted Telephone Interview (CATI) reports, and in potential SEC issues, the radionuclides from RU (plutonium, neptunium, U-236, and fission products, such as Tc-99) are listed as foremost concerns and among the items that the workers believe the government did not know, or was not fully disclosing the health hazards of. Therefore, RU should be clearly identified in the TBDs and included in the materials handled at the WS site, such as in the bullet points on page 6 of TBD-1 (ORAUT 2005a) and in Section 2.2.2.2 of TBD-2 (ORAUT 2005b, page 10), with equal importance compared to other materials. TBDs 1, 3, and 6 make no mention of RU; TBD-2 contains one paragraph on page 23, and TBD-5 (ORAUT 2005e) has a short section concerning RU on page 15 and mentions it on page 35, along with enriched (1%) uranium for 1963–1967. Of the six TBDs, the environmental dose TBD-4 (ORAUT 2005d) contains the most material concerning RU. On pages 10–12 of TBD-4, the assumption is made that because the amounts of RU handled at the WS site were a small fraction of the total uranium materials handled, then there is no need to consider RU and its associated contaminants to be potentially significant contributors to onsite environmental dose. This may be true on average or for chronic offsite environmental doses, but this assumption does not consider the fact that some workers or certain groups of workers may have received a substantial portion of their inhalation dose from RU and its associated contaminants for a significant amount of time near an RU-handling process. Although TBD-4 (ORAUT 2005d) did mention RU, it did not address the issue of RU for unmonitored workers environmental dose in sufficient detail.

Not only are the details of the RU at the WS site important, but also the source of the RU is important, because RU from different DOE facilities contained different concentrations of radionuclides (DOE 1985). Therefore, the associated radiation hazards (internal and external) to WS workers would depend on the source of the RU. Defaulting to the Fernald site concerning RU issues [as recommended in WS TBD-5 (ORAUT 2005e, page 15)] may not be technically sound, especially in areas where data for Fernald is uncertain. SC&A's review of the Fernald site profile (SC&A 2006) is summarized as follows:

> *The recycled uranium (RU) data are internally inconsistent and also inconsistent with some available DOE documentation. They are incomplete and do not appear to be claimant favorable for many workers and periods, though they are likely to be claimant favorable for many others. The problem in regard to adequacy of RU data is even more difficult for RU raffinate streams, in which the trace radionuclides, notably plutonium-239, thorium-230, and neptunium-237, became concentrated.*

Therefore, basing the WS site dose reconstruction recommendations on the Fernald site profile may lead to claimant-unfavorable assumptions and underestimated doses assigned to some workers.

The statement on page 35 of TBD-5 (ORAUT 2005e) consists of the following:

> ***If specific information is not available*** *in the worker's file, the DR should consider the following default uranium source terms:*
>
> · *Natural uranium, before 1961*
> · *Natural uranium, recycled, 1961 to 1962*
> · *Enriched (1%) uranium, recycled, 1963 to 1967.* (Emphasis added.)

This recommendation is not conducive to consistency in dose reconstruction and appears to be an over simplification resulting from the lack of sufficient information/data or investigation of the RU issue.

Although RU was a small fraction of the total uranium processed at the WS site, its contribution to external and internal doses, especially to the workers associated with processing it and exposed to it by products, could be of significance in dose reconstruction. Therefore, RU should play a more predominate role in the TBDs and in dose reconstruction.

Finding #5: Lack of Accident/Incident Documentation Not Sufficiently Addressed

The WS site TBDs do not address accidents or incidents at the WS site (or the apparent lack of their documentation being readily available), except for the brief mention of two accidents on page 27 of TBD-2 (ORAUT 2005b). Accidents and incidents that could potentially release material to the operations area and to unmonitored workers onsite are important at the WS site, because the radiological hazards may not have been fully recognized, investigated, or documented at the time of its occurrence. During onsite interviews with former WS site workers, the subject of accidents/incidents was mentioned with the concern that MCW did not identify and document radiological events sufficiently, either through lack of knowledge of the radiological hazards, or as a manner of policy at that time. SC&A's preliminary investigation of several cases indicates that the accidents described by former workers were not evident or were not recorded sufficiently in the workers DOE files. For example, a serious furnace accident occurred in 1960; however, the only mention of it in the worker's DOE records was a couple of brief sentences describing the *medical* aspect of the worker's complaints; no investigation into the radiological aspect of the accident was evident. There was no other documentation of the accident in the worker's files that SC&A could locate. Another serious accident apparently occurred in 1961; the only reference in the worker's DOE file was an entry in the "PERSONAL MONITORING SUMMARY RECORD," which stated that "*Data included in Feb. Accident File*." There was no other record of it in the worker's DOE records. Fortunately, this accident was written up in a MCW report (MCW 1961) and the dose reconstructor evaluated the dose received from the accident during the dose reconstruction process. However, this may not always be the case.

Accounting for accidents and incidents that have the potential to lead to radiation exposures are problematic at a number of DOE and DOE contractor sites. The WS site is no exception; it is especially prone to this problem, because uranium was treated mostly as a chemical rather than a radiological hazard during the plant's operational period. Therefore, occurrences may not have been documented sufficiently or be readily available to the dose reconstructor to allow dose reconstruction by today's standards. Although NIOSH's WS site profile cannot correct the lack of documentation in the workers' DOE files, it can provide information concerning where the dose reconstructor might search to locate any accident or incident files, and outline some of the major occurrences that the dose reconstructor should be aware of to match them to possible exposures for a given case. By the nature of the operations at the WS site, most doses came from chronic low-level exposures; however, unusual occurrences, accidents, and incidents could lead to acute intakes and/or contamination that greatly exceed the normal levels.

3.2 SPECIFIC ISSUES

SC&A reviewed the six TBDs for the WS site and has identified a number of issues that may impact the outcome of dose reconstruction for the WS site workers; these are listed in the following section as findings associated with each specific TBD.

3.2.1 Occupational Medical Dose ORAUT-TKBS-0028-3

Background and Introduction

The current version of the WS site TBD for occupational medical dose (ORAUT 2005c) is a relatively short TBD, and contains some general information and data gathered from DOE site profiles and technical documents. There is very little information available concerning the WS site occupational medical procedures, equipment, x-ray exam frequency, etc. Some references are made to MCW documents associated with the Destrahan Street location. The TBD does present dose conversion factors (DCFs) and organ dose estimates for a number of organs/tissues for the periods prior to 1970 and after 1985 taken from ORAUT-OTIB-0006 (ORAUT 2005g). Because of the lack of WS site documentation in the occupational medical area, this TBD is by nature mostly a genetic document. SC&A has reviewed this TBD and has the following Secondary Findings pertinent to the WS site.

Finding #6: Inconsistence in Frequency of X-ray Exams

TBD-3 (ORAUT 2005c, page 8) assumes annual x-rays for **all periods,** and in Section 3.1.2 (page 7), it recommends annually from **1955 through 1966**. However, in the same paragraph it states, "A review of pre-1970 files indicates that, approximately 30% of the time, workers received two sets of chest x-rays in a period of 9 months or less (excluding x-rays for termination of employment);the files do not provide reasons for this." (This would equate to an overall average of 1.25 x-ray exams per worker per year.) In the last paragraph of Section 3.1.2 (page 7), it suggest an x-ray exam was conducted every 2 or 5 years for post-1985 workers. And in the next to the last paragraph on page 13 of the TBD, it recommends annual chest x-rays for **1958–1964**.

While the frequency of x-ray exams are discussed in Section 3.1.2 of TBD-3 (ORAUT 2005c), no mention is made of the frequency of retake exams (because of technical or medical complications) that might add to the total number of x-ray exams performed. ORAUT-OTIB-0006 (ORAUT 2005g, page 14) states, "Retakes should serve as a signal to give special consideration to the evaluation of technique factors, and hence the resultant dose calculations." This indicates that retakes were not an uncommon event.

TBD-3 (ORAUT 2005c) should recommend a defined set of claimant-favorable x-ray exam schedules, so that dose reconstructions can be performed in a consistent manner. It should also be determined if some workers or groups of workers [such as those that wore respirators, were food handlers (tested for tuberculosis), etc.] may have had more frequent x-rays exams; perhaps this was the reason for the increase in frequency as noted in Section 3.1.2 of the TBD.

Finding #7: Photofluorography Exams Not Adequately Addressed

TBD-3 (ORAUT 2005c) mentions photofluorography (PFG) exams on page 7. However, no recommendations to the dose reconstructor are made concerning this type of exam, other than that there had not been any indications that PFG exams were conducted at the WSCP. ORAUT-OTIB-0006 (ORAUT 2005g, page 21) states, "It is reasonable to presume that at least some of the occupational medical diagnostic chest x-rays with the DOE and its predecessor organizations were accomplished by PFG and, in the absence of data to the contrary, the use of PFG should be assumed to ensure claimant-favorable dose reconstructions." Table 7-6 of ORAUT-OTIB-0006 (page 24) also indicates that DOE/AEC facilities used PFG equipment from 1953–1968, which would encompass the 1957–1966 operating period at WSCP. If PGF equipment was not located at the WSCP site, workers may have had occupational PFG exams performed at offsite locations, such as Barnes Hospital Labs, which serviced MCW workers in the earlier years. TBD-3 (ORAUT 2005c) does not show evidence of investigating this subject sufficiently (such as checking Missouri state records, etc.) to justify discounting the possibility that some WS site workers received PGF exams.

Finding #8: Lumbar Spine Exams Not Addressed

TBD-3 (ORAUT 2005c) makes no mention of lumbar spine x-rays and states on page 7 that, "Therefore, the analysis for this TBD assumed annual PA and LAT chest x-ray examinations for all employees, and considered no other view." This excludes both PFG and lumbar spine exams. Lumbar spine exams were sometimes performed for workers that performed heavy and strenuous work, such as laborers and construction workers, or those with back problems. ORAUT-OTIB-0006 (ORAUT 2005g, page 21) states, "However, the possibility of periodic lumbar spine examinations, including an exit employment physical examination should not be precluded." Therefore, TBD-3 should address the issue of lumbar spine exams for WS site workers.

Finding #9: Use of ICRP-34 Instead of ICRP-74

TBD-3 (ORAUT 2005c) utilizes ICRP 34 (ICRP 1982) instead of ICRP 74 (ICRP 1996), which was used in NIOSH's OCAS-IG-001 (NIOSH 2002) to determine absorbed dose from kerma values. Preliminary studies by SC&A indicate 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 PFG chest x-ray exams, where doses can double or triple based on the differences between ICRP 34 and ICRP 74; for PA and lateral x-rays, the underestimations are not as significant. This issue amplifies the need to ascertain whether WS site workers received PFG exams, as outlined in the previous finding.

3.2.2 Occupational Environmental Dose ORAUT-TKBS-0028-4

Background and Introduction

In TBD-4 (ORAUT 2005d), most of the environmental dose to WSCP workers is attributed to uranium and thorium. Internal dose from exposure outside the process areas is assumed to be due mainly to facility releases and resuspension from contaminated soils, or from waste storage and holding areas (WSQ and WSRP). Source terms are derived mainly from limited process knowledge and calculated or estimated maximum releases from stacks and vents. Because uranium was viewed mainly as a chemical hazard rather than a radiological hazard, little actual onsite environmental measurement data exist for the early years of operations, especially for unmonitored workers on the site premises, but outside the immediate operating areas. Most effluent data utilized in the TBD were derived from several annual environmental reports for the years 1981 to 2002, inclusive. Most releases and subsequent doses were presumed to be primarily from natural uranium (mostly U-238); lesser contributors to environmental dose were Th-232 and Th-230. Notably, the Th-232 was not monitored routinely, as it was believed to be a minor contributor to dose. The TBD concludes that estimates of environmental dose can be derived strictly from uranium air monitoring data, as it should account for resuspension of other radionuclides in soil. Because of the lack of environmental monitoring for unmonitored workers during the operational period, this TBD relies heavily on data obtained during the remedial period, environmental parameter measurements, and the air concentration measurements during a hopper cleaning event.

The current version of TBD-4 (ORAUT 2005d) was published with significant data gaps in the environmental data before 1985. Therefore, the current TBD version already warrants a future revision due to these existing data gaps, especially because of the need for historical data during the operational period (1957–1967). Any revisions should include additional information pertinent to onsite environmental monitoring and effluent data collected, and any applicable information that comes from NIOSH responses to SC&A's site profile review that have occurred since the publication of this TBD.

SC&A has reviewed the TBD, as written, and has identified the following findings.

Primary Findings

Finding #10: Lack of Atmospheric Monitoring Data for Operational Period

There is no substantial site-wide atmospheric monitoring data available for the operational period to assure an accurate and integrated environmental dose assessment. The current TBD-4 (ORAUT 2005d) recognizes this lack of site-wide atmospheric monitoring data. SC&A has previously emphasized the need for such site-wide data during crucial periods and questioned whether NIOSH could reasonably assess environmental dose, using only limited environmental data, as presented in this TBD. NIOSH has relied upon the use of dose estimates for the public, derived from its reviews of the Fernald plant data, to estimate the onsite environmental dose for the WSCP workers. This is problematic in that raw emissions data from Fernald is not easily converted to environmental dose for the WS site workers when several emission points of varying geographic locations have to be considered, as well as the lack of knowledge that could place workers at specific locations during exposure events. The TBD also evidences that effluent data before 1981 has not been identified and/or validated, and therefore, has relied solely on an incomplete air monitoring data point as its basis. NIOSH should therefore consider the need to revise the TBD or better demonstrate that use of this approach is claimant favorable.

The TBD describes the predominant operation of the WSCP (1957–1967) as basically a limited uranium conversion operation to produce metal for shipment offsite. It is further argued that newly formed metals and other products were not prone to any long-term storage and would release minimal environmental contaminants. It is also concluded that only minimal releases of uranium occurred up to 1985 as the facility was shut down from 1967 to 1985. Although thorium was monitored in more recent years, the TBD emphasizes the fact that significant quantities of Th-232 and Th-230 were not introduced at WSCP, and accordingly present a lower (less than 5%) environmental dose hazard. Based upon these conclusions, NIOSH believed an estimated atmospheric dispersion model for WSCP was not warranted to further estimate environmental dose. The TBD further concludes, based solely upon limited air monitoring data after 1981, that environmental doses to all onsite workers would be negligible (i.e., less than 100 mrem per year) during the monitoring and pre-restoration period (1967–1992). SC&A believes that the limited environmental data presented in the TBD and the lack of environmental surveys of onsite locations over time does not support the tacit conclusion of negligible dose to onsite personnel.

Finding #11: Insufficient Data for Assigning Unmonitored Workers Internal Environmental Dose

TBD-4 (ORAUT 2005d, page 14) used one serial of measurements (decontaminating 5-ton hoppers, August 1960) (Holt 1960) and site parameter measurements to determine contributing intakes (Table 4-6 of TBD-4) to non-bioassayed workers during 1957–1967. The hopper dust monitoring experiment was measurements performed on one day under one particular condition, and the parameter measurements contributed very little (<1%) to the final results. The following are some of the reasons that it may not be a technically sound approach to use this limited data to assign unmonitored workers' internal environmental dose over a period of 11 years:

- There are no indications if this operation (cleaning the hopper) would have constituted a representative source term for all operations over the entire 11-year period.
- There are no other WS site operational measurements to compare these result to in order to assess if they might be at the high, average, or low end of the air concentration range.
- The WS facility was a relatively large complex. Air concentration in one location on a given day most certainly would not be representative of all locations on all days.
- The site environmental parameter measurements had very little influence on the resulting average value (Table 4-5, max = 1.7E-2/4.4 Bq/m^3 = 0.4%; hence, the final values for 1957–1967 were essentially derived from the one hopper monitoring experiment).
- Validating the results of this measurement by comparing it to the average **estimated** value for Fernald (see ORAUT 2005d, page 16) is not supported, because conditions/ operations at the two facilities would not be sufficiently identical on a daily basis; plus the Fernald value was based on an estimated value, not a measured value.

This limited (in space, operations, and time) airborne/intake data is not sufficient to construct an adequate intake database for unmonitored workers at the WS complex; especially considering that a sizable fraction of the work force was not bioassayed on a routine basis during this period.

Finding #12: Lack of Validation for Maximum Environmental Dose

The TBD (ORAUT 2005d) fails to validate the adequacy of estimating the maximum environmental dose due to source terms at differing locations at the WS site. In the current TBD, NIOSH has offered that existing air monitoring data do not distinguish the source of emissions; therefore, to some measure, it only allows evaluation of cumulative emissions and dose. The estimation of dose methodology currently being applied by NIOSH does not reasonably address maximum dose to workers who are not routinely monitored across the site. At WSCP, as many as 50% of the site workers were not routinely monitored.

SC&A believes that the lack of air monitoring stations in general and the overall lack of stations within a particular geographic location at the WSCP (of known higher releases of uranium and thorium) do not readily enable one to accurately estimate environmental dose. It will be difficult for the dose assessor to accurately estimate environmental dose to an individual without more comprehensive air monitoring data, environmental surveys, and substantial knowledge of where workers were located during such episodic and acute releases.

The TBD also does not attribute any significant environmental dose to pre-existing contamination of the environment from plant operations. Very limited environmental analyses of soils are used to suggest that nearly all uranium contamination is attributable to natural causes. The aerial radiological survey referred to in TBD-4 (ORAUT 2005d, page 25) was performed after the WSCP ceased operation by approximately a decade. There is no supporting evidence presented to indicate that the resulting exposure rate (61–88 mrem per year) resulting from this later measurement would have been applicable during the operational period, given the plant has operated for 10 years, had a reasonably high throughput (14,000 tons per year), and experienced numerous incidents and episodes of environmental releases. For monitored workers (nearly

50%) of the population prior to 1992 when restoration commenced, it is assumed that the dosimeters that were provided would reasonably include an environmental dose component. This approach tends to discount any potential dose resulting from inhaled materials that would not be assessed by dosimetry badges that monitored only ambient gamma radiation. Also, some workers were not included in sufficient routine bioassay programs to assess internal dose. For unmonitored workers (nearly 50% of the population), environmental dose is attributed to only ambient (gamma) radiation levels. Similarly, this approach does not consider internal deposition or variations due to spatial locations on the site or episodical releases.

To this extent, NIOSH has recently agreed for other sites that using emissions data alone to estimate air concentrations may not be appropriate. There is a need for more historic environmental data to fill the gaps for sampling and air monitoring for a larger group of radionuclides, such as thorium that was disposed of in the WSQ.

Secondary Findings

Finding #13: The TBD Lacks Sufficient Effluent Data Prior to 1967

The TBD (ORAUT 2005d) has relied, to the extent possible, on data derived from known source terms, yet the validation of that data remains in question. NIOSH/ORAUT should validate this data against any remaining effluent data or reports for the period of 1992 through 2002, when restoration took place and sufficient monitoring data exists.

NIOSH has indicated that an obstacle to its evaluation is that effluent data back to the 1950s has not been found at the time this TBD was written and approved for dose assessor use. Another source of ongoing controversy involves the development of coworker data that could possibly be used in some instances to address unaccounted for doses from environmental releases. This is particularly important, due to the very large numbers of unmonitored workers at WSCP.

Another significance of the lack of environmental data is the lack of any early thorium data as there is no basis to estimate thorium releases prior to 1967, even though thorium was first stored and used at WSCP as far back as 1958. Also, significant quantities of thorium in the WSQ were not routinely sampled until after 1985. It would be important to locate any early (1950s and 1960s) air monitoring or soil analyses data to validate the presence or absence of these nuclides in the environs at WSCP.

SC&A believes that the lack of substantial environmental data before 1967 warrants closer scrutiny to effectively assess all doses from environmental sources to ensure claimant favorability.

Finding #14: Stated Uranium/Thorium/Radium/Lead Ratios should be used with Caution

TBD-4 assumes that during the operations period, Th-230 was 5% of the U-238 activity, Ra-226 was 1% of the U-238 activity, and Pb-210 was 1% of the U-238 activity (ORAUT 2005d, page 9). These values may have been applicable for some locations and time periods at the WS site; however, this may not have been true for certain locations, as acknowledged in TBD-5

(ORAUT 2005e, page 14). For example, a 1967 WS site document (WS 1983, page 2) lists the thorium/uranium (no isotopic information provided) concentrations as 63,600/27,600 = 2.3; much greater than the 0.05 assumed. Another example is a 1983 WS document (Eberline 1983, page 10), which shows that the raffinate pits contained much higher concentrations of Th-230 as compared to U-238. The ratios for sludge samples from the pits were as follows:

- Pit #1: (Th-230/U-238) = 33.8
- Pit #2: (Th-230/U-238) = 51.1
- Pit #3: (Th-230/U-238) = 26.9
- Pit #4: (Th-230/U-238) = 2.6

These samples were analyzed on August 18, 1983; therefore, there was decay product in-growth during the period from the end of operations to the sampling date (approximately 18 years compared to 11 years of plant operations). However, the Th-230/U-238 ratios were so much greater than 0.05, that even a small in-growth, or residual thorium, would exceed the 5% level. Therefore, the TBD stated value for Th-230 as 5% of the U-238 concentration should be used with caution as it may not apply to all situations of potential exposure at the WS site during the operational period.

Finding #15: Natural Thorium-232 Not Always Negligible

TBD-4 (ORAUT 2005d, page 9) assumes that because the amounts of natural thorium handled/ processed at the WS site were a small fraction of the total uranium materials handled and processed, natural thorium is probably not a significant contributor to environmental inhalation doses during the operational period. This may be true on average, but this assumption does not consider the fact that some workers or certain groups of workers may have received a substantial portion of their inhalation dose from thorium and it decay products for a significant amount of time near a thorium handling process, or from operations that concentrated thorium, such as the raffinate pits. A 1983 WS document (Eberline 1983, page 10) shows that the raffinate pits contained significant concentrations of Th-232 as compared to U-238; approximately 20% on average. A 1965 WS site document (MCW 1965a) concerned with thorium operations states the following:

> *It is observed that the pot denitration operations are of marginal adequacy. Procedures in use for handling the "light" thorium oxide produced visible air concentrations in open operating areas….* and, *…Control of this situation when thorium is involved is complicated further due to the unreliability of conventional bio-assay methods in documenting internal exposures.*

This latter statement is supported by an article concerned with the problems of thorium bioassays even today (Stradling et al. 2004).

Therefore, assuming that Th-232 was insignificant as compared to uranium should be used with caution as it may not apply to all situations of potential exposure at the WS site during the operational period.

Finding #16: Use of External Environmental Dose from Protracted Fernald Estimated Data

TBD-4 (ORAUT 2005d, page 25) outlines the method used to determine the environmental external dose values at the WS site for the time period of 1957–1967. The external dose of 383 mrem per 2000 hours (1 work-year) was derived from using the dose information from the Fernald site TBD-4 (ORAUT 2004a) and is listed in Table 4-11 of TBD-4 (ORAUT 2005d, page 27) for the WS site. The data from the Fernald site was not measured directly, but was derived from measurements post-1976 and then projected back to the pre-1976 period by scaling of production levels. This methodology is unreliable and may not result in appropriate external environment dose assignments to WS site workers for several reasons:

- It would be questionable if the external environmental doses at the Fernald site would be sufficiently similar during the post-1976 period when the dose measurements were performed to make them applicable to most of the pre-1976 years, even at Fernald.
- Although the Fernald and WS sites both processed uranium, their source terms and physical site characteristics (types/amounts of material discharged to the air/soil/water, the contour of the land, the soil/vegetations, the rainfalls/winds, etc.) would not be sufficiently compatible to allow reasonable application of the Fernald site data to the WS site, as was done in TBD-4.
- The external dose value of 1675 mrem/year represents a one-size fits all locations (at WSCP and WSQ) for 11 years (1957–1967). This is a broad generalization that is not supported.

TBD-4 (ORAUT 2005d) only lists the ore concentrate stored onsite, the raffinate pits, and the quarry as sources of external environmental exposure during the operational period (1957–1967). This omits any external radiation originating from discharges from the process buildings (through the stacks or out of the openings in the buildings); as direct radiation, as particulates in the air, or from the settling out of radioactive material on the soil/surfaces. These are source terms that should be included in external environmental dose considerations.

In view of this information, it is concluded that TBD-4 does not provide sufficient data to allow the construction of an adequate database for assigning external environmental doses to unmonitored workers at the WS complex with reasonable confidence. Additionally, because a considerable fraction of the workers at the WS site were not monitored, this could potentially impact a significant number of workers.

Finding #17: Episodic Releases

TBD-4 (ORAUT 2005d) details some of the known episodic releases, but fails to give significant estimates of environmental dose for those episodes or provide consideration for unknown incidents.

The TBD also notes that there is a paucity of information regarding episodic releases, resulting in potential environmental contamination of workers. NIOSH believes the purpose of the TBD is not to provide estimates of dose, but rather to offer estimates of source terms to be used by dose assessors to estimate the dose to the individual claimant. Effluent data used by dose assessors would often include quantities for both routine and episodic releases; however, NIOSH recognizes that significant current gaps exist in this information.

Episodic releases detailed in the TBD are limited to two events. The most significant event was a spill of uranyl nitrate. Estimated doses to the immediately impacted workers were made; however, no dose to the nearest public member and unmonitored onsite workers are estimated. Because there were no apparent environmental measurements performed during or after the event, it is not possible to validate the level of environmental exposure from the incident. The other event described is the exposure of a worker to soluble uranium in a dust enclosure. This event was also not monitored, and reportedly no environmental samples were taken. SC&A believes this, as well as statements in the TBD, do not seem to support the idea that environmental exposures were necessarily negligible and resulted mostly from incident exposure to resuspended uranium compounds. To the contrary, the lack of sufficient environmental data would suggest the need to develop a maximum exposure scenario for numerous events. Although not all events were recorded, knowledge of potential releases and events at this site could be used to better estimate maximum exposures that are claimant favorable.

3.2.3 Internal Dose ORAUT-TKBS-0028-5

Background and Introduction

TBD-5 (ORAUT 2005e) was written to provide the dose reconstructor with recommendations concerning internal dose reconstruction at the WS site during the operational period of 1957–1966, the monitoring period 1975–1984, and the remediation period 1985–2001 (it does not include the period 1967–1974). The TBD covers the major areas of concern, such as radioactive material source terms, air concentrations, the assessments of intakes, and the in-vitro and in-vivo measurements. During the operational period, 1957–1966, the workers at WS were periodically monitored by urinalysis for uranium, but were not bioassayed for other radionuclides. Some one-time qualitative in-vivo bioassays for thorium were conducted in July 1966. Because there was limited onsite uranium and no thorium or radon air sampling up until 1985, the authors of this TBD relied heavily on the Fernald site internal dose TBD-5 (ORAU 2004b) and WS site environmental and remediation monitoring data, and then applied this data to the WS site during the operating period. Natural, enriched, depleted, and recycled uranium and natural thorium were included as potential internal dose contributors. SC&A reviewed the TBD according to *Site Profile Reviews Procedures* (NIOSH 2004) and has the following findings.

Primary Findings

Finding #18: Incomplete Assessment of Uranium Decay Products

TBD-5 (ORAUT 2005e) recommendations for dose estimates from decay products of U-238 are incomplete, and not always claimant favorable. For example, the following is stated on page 13 of the TBD:

The materials handled at WSCP were uranium concentrates and, to some extent, natural thorium. The short-lived decay products of ^{238}U, which are ^{234}Th (24-d half-life) and ^{234m}Pa (1.175-min half-life), would have built into equilibrium before the material was handled. Thorium-234 and ^{234m}Pa emit beta particles. The dose from inhaled ^{234}Th is included in the dose from ^{238}U as it builds into equilibrium in the body in a relatively short period of time (less than eight months). The ^{234m}Pa beta is a high-energy beta and contributes to the external dose but, due to its short half-life, does not in itself contribute to internal dose.

SC&A does not agree with this analysis for the following reasons.

Inhaled Th-234

The dose from **inhaled** Th-234 is not included when the dose from inhaled U-238 is calculated. What is included is the dose from Th-234 that builds up inside the body after an intake of U-238 takes place. Th-234, with its 24-day half-life, and Pa-234, with its 6.7 hour half-life, would be present along with, and in about equal concentrations as, U-238 in the yellowcake, and hence in the workplace air. The same analysis applies to Ra-228 and Ac-228 from natural thorium. The radionuclides from the uranium and thorium decay series present in the workplace needs to be considered as an additional source of exposure, independent of the U-238, U-235, or Th-232 inside the body. ICRP Publication 78 (ICRP 1997) points out that if there is a mixture of radionuclides in the workplace, those radiologically significant ones need to be taken into consideration in the dose estimate (ICRP 1997, page 33):

Workers may be exposed to a mixture of radionuclides and this must be taken into account in calculating pre-determined derived investigation levels. It will often be the case that only a few radionuclides in the mixture make a significant contribution to the committed effective dose. In principle, the radiologically significant radionuclides should be identified and monitoring programmes should be designed to assess intake and committed effective dose for these radionuclides. However, there may circumstances where it is easier to measure one of the other, less radiologically significant, radionuclides and to use this as a "tracer" for the mixture. This is feasible when the composition of the mixture is well-known and constant. A common example is the use of ^{241}Am as a tracer for plutonium isotopes.

Table 1. Dose Coefficients for the GI Organs due to Inhalation of U-238 and Th-234

Organs	Dose coefficients for inhalation (AMAD= 5um) (Sv/Bq)			
	Type M		Type S	
	U-238	Th-234	U-238	Th-234
Stomach Wall	5.15E-09	4.56E-10	6.55E-10	4.42E-10
Small Intestine Wall	5.77E-09	1.07E-09	1.34E-09	1.10E-09
Upper Large Intestine Wall	1.12E-08	6.17E-09	7.36E-09	6.49E-09
Lower Large Intestine Wall	2.41E-08	1.75E-08	2.18E-08	1.85E-08
Colon	1.67E-08	1.10E-08	1.36E-08	1.16E-08

This is the case for Th-234, which delivers significant dose in the gastrointestinal tract. Table 1 illustrates the dose coefficients for gastrointestinal organs due to *inhalation* of U-238 and Th-234. The dose coefficients due to inhalation of Th-234 are very similar to the ones due to inhalation of U-238. Therefore, Th-234 inhalation needs to be considered in addition to the inhaled U-238 and sequent build up of Th-234 inside the body from the inhaled U-238.

Dose from internal Pa-234m

The dose contribution due to Pa-234m from the decay of Th-234 in the body also needs to be included in the internal dose calculations. While it is true that the Pa-234m outside the body only contributes to the external dose, the Pa-234m originating inside the body from Th-234 decay must be included in the internal dose calculations.

Finding #19: Incomplete Assessment of Radon Exposure

Table 5-2 of TBD-5 (ORAUT 2005e) describes the potential radionuclide exposure in the different buildings of the WSCP. Radon is listed as a source of exposure inside Buildings 101, 103, 105, 403 and 407. However, the recommended approach in TBD-5 (page 37) to estimate radon doses is based on *environmental* radon concentrations (calculated from source terms) for the areas within 100 meters of the assumed release point, the acid recovery plant stack. Using this approach requires that several assumptions be made, which results in large uncertainties in the dose estimates for workers located in *indoor* workplaces.

The data from MCW St. Louis Downtown Site and the St Louis Airport Site in ORAUT-TKBS-0005 (ORAUT 2005h) has shown that there is no correlation between outdoor and indoor radon concentration. In Table 24 of ORAUT-TKBS-0005, page 209, radon measurements for indoor and outdoor are listed. Indoor radon measurements in the Scalehouse and outdoor radon measurements in Scalehouse exhaust are reproduced in Table 2 for 1948. The average values for indoor measurements are approximately 4 times greater than the average values for outdoor measurements. The same pattern is observed in the indoor and outdoor measurements presented in other tables in ORAUT-TKBS-0005.

Table 2. Comparison of Indoor and Outdoor Radon Measurements for the Scalehouse
(Data from Table 24 of ORAUT-TKBS-0005)

Workplaces	Measured radon concentrations for 1948 in units of 1 × 10^{-10} Ci/L				
	No. of samples	**Min**	**Med/Mean**	**Max**	**GSD**
Indoor areas					
Scalehouse	21	0.00	4.05	33	
Scalehouse	193	0.03	2.02	32.8	
Scalehouse Sample room	6	0.22	4.10	19	
Scalehouse Sample room	68	0.03	2.84	25	
		Average =	***3.25***		
Yards and other outdoor areas					
Scalehouse intake/exhaust	3		0.12		2.06
Scalehouse exhaust	18		0.13		3.08
Scalehouse exhaust	1		0.93		
Scalehouse exhaust	24	0	2.2	49	
		Average =	***0.85***		

Ratio of Indoor/Outdoor = 3.25/0.85 ~ 4.

This shows that the approach recommended in TBD-5 is not always claimant favorable. NIOSH should propose a more reliable and claimant-favorable approach to assess the radon exposure for WSCP.

Finding #20: Different Solubility Classes Listed for Same Element

Table 5-6 of TBD-5 (ORAUT 2005e, page 15) provides a list of solubility classes for uranium and thorium compounds in some of the buildings at the WSCP. Some of this information is summarized below:

Table 3. Solubility Classes for Uranium and Thorium at WSCP

Building 103:
U-234: D=0.20; W=0.50; Y=0.30;
U-235: D=0.20; W=0.44; Y=0.36;
U-238: D=0.75; W=0.25.
Building 108:
U-234: D=0.19; W=0.20; Y=0.61;
U-235: D=0.14; W=0.47; Y=0.39;
U-238: D=0.19; W=0.20; Y=0.61.
Buildings 406, 408, 410, 417:
Th-232: W=0.35; Y=0.65;
Th-228: W=0.65; Y=0.35.

Because there were no means of separating isotopes of a given element at the WSCP, the chemical properties were the same for all uranium isotopes and the chemical properties were the same for all thorium isotopes. According to ICRP Publication 78 (ICRP 1997), the biokinetic behavior is the same for U-234, U-235 and U-238 (see Tables A.10.6, A.10.7 and A.10.8, page 127). The same applies for thorium Th-232 and Th-228 (see Tables A.9.8, A.9.9, and A.9.10, page 107).

Although Table 5-6 of TBD-5 (ORAUT 2005e) was taken directly from the reference DOE/OR/21548-241 (DOE 2001), it does not appear to be applicable here. In view of the operations that took place at the WSCP, TBD-5 (ORAUT 2005e) should provide justification/clarification concerning the use of Table 5-6 and the classes of solubility that should be assumed in the different workplaces at the WS site.

Finding #21: Missed Dose and Coworker Data Not Adequately Addressed

Missed Dose

TBD-5 (ORAUT 2005e) does not address potential internal missed dose, which should be part of the TBD for internal dose, especially considering the complexity of the workplace conditions and the urinalysis techniques applied at the WS site. The urinalysis was based on a photofluorimetric method and reported in units of mg U/liter urine; the isotopic composition of uranium in urine samples was unknown. Additionally, the LOD was generally high in the earlier years, which could result in significant missed doses. For the dose reconstructor to assign missed dose, the TBD needs to provide some information concerning the MDA for given bioassay techniques for the important radionuclides of concern at the WS site as a function of time, and specific radionuclides to assume, or a claimant-favorable default radionuclide. If the MDA values are unknown, the worst-case scenario for a combination of MDA/radionuclide should be provided.

Coworker Dose

If the dose reconstructor needs to apply internal coworker dose, TBD-5 (ORAUT 2005e) does not provide sufficient instructions for the use of Tables 5-8 through Table 5-17, especially in view of the problem with cost-center code listings, as described in a previous finding. Most internal dose TBDs provide a summary section in the main text or as an appendix with recommendations and procedural steps for using coworker data.

An item of importance that applies to both missed and coworker dose data is the fact that in the everyday operations at the WS site, urine samples were not necessarily collected, as stated in some of the documents. For example, TBD-5 (ORAUT 2005e, page 17) quotes the following from MCW 1965b:

> *The routine sampling program seeks to have one or more persons from each operational group in the plant sample(d) each week. When a person represents his group in the sample, he is asked to give samples on (1) Monday a.m., (2) Friday p.m., and (3) Monday a.m. The Monday sample tends to show the amount semi-fixed in the body, the Friday sample reflects the daily uptake. The sample from each person is analyzed separately and entered in his summary.*

Each exposed person is scheduled three or more times per year, more frequently if there is reason to suspect increased exposure. The rotation of group representation tends to show the average level and variation within each plant area. Unexposed persons are scheduled less frequently to provide a control base.

Additionally, a document entitled, *Urinary Uranium Program*, issued by MCWUD in 1960 (MCW 1960) provides instructions for waged and salaried personnel:

1. *Wage – Wage employees working with uranium are to be sampled in a series of five samples twice a year. As much coverage as possible is desired for different types or degrees of exposure; therefore, each series of samples or group weeks should contain personnel from as many work areas or crafts as possible. Example: All the pipefitters or the Pot Room operators should not be scheduled in the same series.*

   For the selection of these groups, the place and type of work needs to be known. The names and cost centers of the employees may be obtained from the IBM wage report. For Maintenance personnel, the information as to crafts may be obtained from the Maintenance Office. The shift schedules of the Production operators in the Sampling Plant and Refinery may be obtained from the Job History Sheets received by the Health Department.

2. *Wage personnel not in contact with uranium are sampled once quarterly, as close scheduling is not necessary; therefore, the IBM wage report will suffice for selection.*

3. *Salary – Salaried personnel are sampled one, two or three times a year; therefore, all the salaried personnel are treated as one representative group.*

However, SC&A's preliminary review of some of the WS site claimant files indicates that, while the urine samples were sometimes started on a Friday, they did not necessarily follow a M-F-M schedule, and were not generally on a rotating or routine basis. Therefore, when urinalysis data is used, either for individual claimants or as a basis for deriving coworker doses, it should be used with the caution that it is does not necessarily represent the prescribed sampling schedules in the MCW documents. From an initial analysis of WS site claimant files, SC&A did find that, while the urinalysis sampling routine was not always as prescribed, most of the claimants' DOE files contained individual urinalysis results by date, as opposed to an average of a number of analysis results by week or quarter.

Secondary Findings

Finding #22: Cost-Center Codes may not be Reliable for Dose Reconstruction

The use of the cost-centers codes listed on pages 19 and 22–27 of TBD-5 (ORAUT 2005e) are not practical, because workers' DOE files generally do not contain cost-center information; some may contain job titles, or work locations. Additionally, TBD-2 states the following (ORAUT 2005b, page 20):

> *"Beginning in 1954 the (cost center) codes changed about once every 6 months. Documentation of changes was made only to the extent that was necessary to obtain the money for the UD (Uranium Division) operations from the government* [Dupree 1983]*." Assuming that the practice continued into the WSCP operations of 1956 and beyond, using cost center codes to help assess worker dose may not be reliable.*

Examples of more useful tables are those in TBD-6 (ORAUT 2005f, pages 17–18).

It is difficult to analyze or compare the excretion rates for the years 1959–1966 [Tables 5-10 through 5-17 of TBD-5 (ORAUT 2005e)], because cost-center codes changed. Using cost-center codes as this TBD has appears to be an ineffective way of organizing the data. Additionally, using cost-center codes to group the data in these tables does not allow the dose reconstructor to directly use the solubility information provided in Table 5-6, which is listed by area/building numbers.

The internal dose assessment for WSCP is very complex, because the workers were exposed to different uranium compounds (or different classes of solubility), as well as natural, recycled, depleted, and EU, and thorium. Additionally, the measurement technique for urinalysis used at the WSCP was mainly photofluorimetric, which did not provide sufficient information to have a reliable dose assessment when there was a mixture of uranium compounds and uranium isotopes. Based on these facts, it would be more appropriate to have the data grouped according to work location or job title, such as in TBD-6 (ORAUT 2005f, pages 17–18), to avoid confusion and possible incorrect assignment of dose.

Finding #23: Negative In-vivo Results Do Not Necessarily Indicate Lack of Thorium Uptake

TBD-5 (ORAUT 2005e, page 28) indicates that a portable whole-body counter was set up for in-vivo thorium measurements in 1966. On page 29, it is states the following:

> *The overall results showed workers involved in areas 101, 103, 301, 403, Maintenance, and Health and Safety, which were principal exposure positions, had a more frequent occurrence of 'trace' detections. No workers monitored showed a 'positive' designation. (Ingle 1991)*

Because the LODs for this bioassay technique were generally very high during that period, the results of these measurements should not be considered as indicative of a lack of internal exposure. Hence, measurements recorded as "negative result" should not be interpreted as the workers not being exposed to thorium. These in-vivo measurements were only performed once in July 1966; the TBD does not address the issue of workers potentially exposed to thorium in early periods and if the thorium and/or decay products would be sufficiently present in the workers' lungs to be detected by this method. Additionally, the TBD did not provide information concerning the MDA for these in-vivo measurements for use in dose reconstruction to address missed thorium doses, as well as recommendations for dose reconstruction for workers who may have been exposed to thorium, but did not have in-vivo measurements performed. Further analysis of these bioassay results may provide upper bounds for thorium intake, but most likely they would not provide definite quantitative values.

A 1965 DOE Annual Health Protection Review of the MCWND, WS site (DOE 1965, pages 8 and 10 of Weldon Springs Health Protection memorandum) states the following:

> *2. Internal Exposure: Bio-assay procedures and action criteria have been given detailed consideration previously and no significant change has since resulted. Note is made, however, that conventional bio-assay techniques are not adequate for monitoring potential thorium exposures as result from current MCW production operations.*
>
> *E. Thorium pot denitration operations were observed to be poorly contained and visibly dusty. Particularly was this noted during a hand scooping transfer procedure which was being done outside the hood. Air movement in the vicinity was vigorously adverse to contamination control due to a partially open outside door. Air line respirators are required for this operation which, due to a specification requirement of the "light" oxide material, will not permit the use of a more desirable pneumatic transfer procedure. Air sampling by the Health and Safety Department indicated average time weighted concentrations to be slightly less than the thorium MPC; however, the visible dusting observed would suggest that undue confidence may have been placed in these data and the procedures requiring respirator use.*

This indicates that thorium operations were of concern, and perhaps not as well controlled/monitored as would be desired.

Finding #24: Enriched Uranium Not Sufficiently Addressed

TBD-5 (ORAUT 2005e) discusses EU on page 12, where it is stated, "*WSCP also processed depleted uranium and slightly enriched (up to 1%) uranium as well as natural thorium.*" And on page 13, where it states, "For slightly enriched uranium, it is reasonable to assume that the composition of 1% enriched uranium in the Technical Basis Document for the Fernald Environment Management Project – Occupational Internal Dosimetry (ORAU 2004a, Table 5-3) is applicable to slightly enriched uranium at WSCP." In addition, it states, "Although uranium with enrichments of less than 1% might have been processed at WSCP, it is claimant-favorable to assume 1% enrichment for all slightly enriched uranium at WSCP." These statements imply that if the dose reconstructor uses 1% EU with the composition as listed in the Fernald TBD [and reproduced in Table 5-5 of WS site TBD-5 (ORAUT 2005e)], then this is likely an overestimate and, therefore, claimant favorable. There are several problems with this assumption:

- There is no documentation presented that shows that the WS site only received EU from Fernald.

- There is no supporting evidence that the EU received at the WS site was never >1%. A WS document (MCW 1966, page 4) states up to 1.5% enrichment.
- If the EU was received from Fernald, there is no guarantee that it was always <1% enrichment. Fernald's TBD-5 (ORAUT 2004b, page 9) states the following:

  Late in 1964 the Fernald site provided the first production of 1.95% ^{235}U billets for the Hanford Site. During the following production years uranium was processed in a variety of enrichments ranging from depleted to as high as 20%. The quantities of enriched material above 2% was not documented, but was qualitatively reported to be small and/or insignificant in total mass. The reported highest enrichment level processed in quantity was 2%.

- SC&A questioned the validity of the assumption that the Fernald site handled <2% enrichment in their review of the Fernald site profile (SC&A 2006).

TBD-5 (ORAUT 2005e, page 35) recommends that the dose constructor use 1% EU for the period 1963–1967. However, as outlined above, assuming a maximum enrichment of 1% is not supported by the documentation presented.

3.2.4 External Dose ORAUT-TKBS-0028-6

Background and Introduction

The current version of TBD-6 (ORAUT 2005f) covers the operational period 1957–1966, and the remediation period 1985–2000. The TBD provides some information concerning dosimetry records, badge exchanges, missing entries, calibration, and workplace radiation fields as a function of building. Basic coworker gamma and beta dose values as a function of job description are provided, along with LOD/exchange tables for calculation of missed dose. As with the other TBDs for the WS site, this TBD draws on information/data from other DOE sites, such as Fernald, because of the lack of WS site documentation, especially in the area of neutron exposure, dosimeter response, and radiation field characterization. Overall, the TBD addresses external doses from gamma, neutron, and electron radiation, but SC&A has areas of concern as detailed in the findings listed below.

Primary Findings

Finding #25: Shallow and Extremity Doses Not Sufficiently Characterized

Shallow (mainly beta) dose was briefly addressed in TBD-6 (ORAUT 2005f) on pages 12 (dosimeter quantities, OW, SW, etc.) and on pages 20–23 (compared beta dose from NU, EU, and DU). Electron dose is listed as >15 keV in Table 6-10 concerning energy distribution by building or area. Extremity monitoring is addressed briefly for the period 1992–1994 on page 12.

As described in a previous finding, there appears that there was no personal contamination or egress monitoring at WS during the operations period 1957–1966 to detect contamination on the workers after they changed clothes and left the operation areas. Additionally, there is no indication that routine extremity monitoring was performed at WS during this period, or that geometry factors were used to correct for the position of the badge versus the radiation source. No WS site documents have been located that address the change in film badge response as a function of radionuclide exposure, especially to low-energy photons and changes in beta energies. Therefore, SC&A has the following areas of concern:

- **No egress monitoring –** Unmonitored external and internal doses from lack of personal contamination and egress monitoring was previously described. The result of this lack of egress monitoring applies to both unmonitored and monitored workers and is especially important for shallow dose exposures.

- **Badge vs. exposure geometry factors –** The problems associated with handling uranium material [contact work as stated on page 20 of TBD-6 (ORAUT 2005f)] close to the body/hands and having the dosimeter badge located on the chest area was not addressed in TBD-6 or other WS site documents. A film badge does not register the same dose as the worker's tissue/organs are receiving from the beta and low-energy photons when handling, machining, scooping, etc., uranium containing materials. For example, a 1958 office memo (MCW 1959) illustrates the fact that the shielding on a lathe greatly affects the beta dose measured; i.e., decreases it from an average of 122 mrep/hr to 0 and Table I of that document lists non-trivial beta doses as high as 10,000 to 35,000 mrep/hr (mrep ~ mrem). Therefore, any material/distance between the beta source and the badge on the worker's chest that is not between the beta source and the worker's trunk area will cause an under-response in the recorded dose. A TIB needs to be developed for the WS site to correct for this underestimate of dose, such as OCAS-TIB-0013 (NIOSH 2005) was for the MCW Destrahan Street site. This is especially important for beta exposures.

- **Total shallow dose –** According to page 16 of TBD-6 (ORAUT 2005f), the dosimeters at the WS site were calibrated using radium photon and uranium beta sources. This is standard practice for uranium processing facilities. However, the WS site also handled other radionuclides, as described in TBD-6 and other WS site documents; these included Th-232 and RU with their associated decay products. Some of these radionuclides have different beta energies than uranium. Additionally, TBD-6 does not address shallow dose from low-energy photons, which may have been more predominate from these radionuclides as compared to uranium. TBD-6 briefly discusses mixed beta-gamma exposures on page 11 and states that they were determined by subtraction; it is assumed that this means that the reading from the portion of the film behind the cadmium shield (called SW) was subtracted from the reading of the film without cadmium shielding (called OW), as indicated in Table 6-2 on page 12. This is not a valid procedure, unless the beta-to-gamma ratio is known and remains constant, because beta and gamma radiation have different darkening effects per unit dose. The response of film to gamma radiation is very energy-dependent because of the photoelectric effect, whereas beta interactions are not subject to this dependence. Shallow doses from both beta and low-energy photons concerning calibration versus workplace radiation fields as a function of location and time needs further investigation and more adequately addressed in this TBD.

Finding #26: Badging Policy not Consistent

TBD-6 (ORAUT 2005f) provides a reasonable amount of detail concerning the badge **exchange cycles**, such as on page 11 and elsewhere in the TBD. However, insufficient information is provided concerning the **badging policies** at the WS site. TBD-6 does not provide a consistent outline of what workers were badged and when. Table 6-4, page 14, states "**All** MCW Uranium Division wage (hourly) personnel are assigned permanent film badges." (Emphasis added.) However, on page 14 of Section 6.2.2.4, it states, "'Office females' were not routinely assigned film badges," and on page 13, it states that female workers were not routinely monitored, especially in the early days. Table 6-5 of TBD-6 lists several facilities that were considered "non-badged areas." However, Section 2.5.1.1 of TBD-2 (ORAUT 2005b, page 29) states that "According to Mason (1955) health protection program document, **each** employee except office females wears (a) combination film badge-security badge" (emphasis added). This raises the question of what badging criteria were actually used in practice, and if workers who were not considered at the time to be exposed to radiation were potentially exposed, but not monitored because of being in a pre-defined category. The lack of a consistent and documented badging policy may negatively impact dose reconstruction, because the dose reconstructor could assign an unbadged worker only external environmental dose, when the worker should have been assigned coworker external dose. Additionally, the validity of a coworker database depends on how well it represents a cross-section of the workers; to determine this, a knowledge of why, when, and where workers were badged at the WS site is necessary.

Finding #27: Lack of Sufficient Coworker Data Development for External Dose

Section 6.2.3 of TBD-6 (ORAUT 2005f, page 16) mentions that annual average gamma and beta exposures were calculated. The information for 10 categories of worker is listed in Table 6-8 and graphically displayed in Figures 6-4 and 6-5 on pages 18 and 19. However, the TBD does not provide any information concerning the details/application of this information, such as the following:

- The ***number*** of data points for each of the dose entries; i.e., how many readings were used to calculate the dose value of 110 mrem for Engineers in 1957
- The ***percent*** of workers who were monitored
- The ***range*** of readings within a given data point; i.e., what were the minimum and maximum values for Engineers for 1957
- The 50^{th} and 95^{th} ***percentile*** values for each entry.
- It should be stated whether the reading from an occupationally unexposed (background) film was ***subtracted*** from the doses before the average values were calculated, or if it was not
- It should be stated whether ***zeros*** were include in the dose readings used to calculate the listed values
- It should be stated whether these values were derived from dose values greater than some ***threshold*** (i.e., LOD, ½ LOD, 50 mrem, etc.)

- It should be stated if any unusual ***outliers*** were excluded/included in the data

The data presented is a good start in creating a coworker database, but in order to determine its validity and Representativeness, there needs to be additional work performed on the data as outlined above. Additionally, to be useful to the dose reconstructor, there needs to be recommendations for use of the data, such as a summary appendix with specific dose assignment recommendations, numerical values, and tables, as contained in many other site profiles.

Secondary Finding

Finding #28: Lack of Documentation and Details for Neutron Doses

Table 6-3 of TBD-6 (ORAUT 2005f, page 13) states, "Estimate neutron dose as 10% of the reported gamma dose in facilities containing UF_4 and UF_6." Table 6-4 on page 14 states that "All MCW Uranium Division personnel who work directly with enriched uranium materials are assigned special neutron dosimeter badges, which are worn in conjunction with the regular film badges." However, the results of this badging (presumable NTA film) were not discussed and no data is presented, except to mention in Section 6.2.4.2 (page 19) that no neutrons were anticipated or measured with the WSCP film badge. TBD-6 then switches to the use of Fernald's TBD-6 (ORAU 2004c) neutron-to-photon ratio (n/p) value of 0.1, with the statement that the use of the Fernald analysis is appropriate and will be used in this TBD. The Fernald TBD-6 (ORAU 2004c, pages 18–20) describes the process of deriving the n/p value of 0.10; this consisted of measuring the neutron doses from UF_4 (green salt) canisters in 1995 and then measuring the photon dose from 56 drums of UF_4 in 2001. The n/p geometric mean value was 0.10, with an upper 95th percentile of 0.23, and with a geometric standard deviation of 1.71. There are a number of problems with assuming that the n/p value of 0.1 from the Fernald site can be used at the WS site:

- There are no indications that the "containers" used in 1995 and the "drums" used in 2001 are the same geometry.
- There are no indications that the UF_4 in the containers used in the 1995 measurements and the UF_4 in the drums used in the 2001 measurements are of the same radioisotope composition and concentrations to create similar radiation fields for measurements taken 6 years apart.
- There is no indication that the matrix material, which would affect the self-shielding of the emitted radiation, is the same in both the 1995 and the 2001 measurements.
- There is no analysis to demonstrate that the radiation fields created by the materials in the containers or drums used at the Fernald site reasonably duplicate the radiation fields at the WS site, to include such variables as radioisotope composition, concentrations, matrix materials, and geometry.

The methodology to derive the n/p value of 0.1 at Fernald is questionable, and the application of this n/p value to the WS site is not technically supported in the TBD.

Additionally, the TBD needs to provide information to assist the dose reconstructor in determining when to assign neutron dose to workers. Information such as job titles, where and when UF_4 and UF_6 materials were present to create potential neutron exposures, etc., would assist the dose reconstructor in determining when to assign neutron dose.

SC&A has not found any neutron doses recorded or columns labeled for entry of neutron doses in the Center for Epidemiological Research (CER) or DOE databases for neutron doses in the claimant files analyzed to date. From the information contained in the TBD, it cannot be determined if the neutron film badges were issued or read, what the results were, and if they were recorded in the workers' files.

4.0 OVERALL ADEQUACY OF THE SITE PROFILE AS A BASIS FOR DOSE RECONSTRUCTION

The SC&A procedures call for both a "vertical" assessment of a site profile for purposes of evaluating specific issues of adequacy and completeness, as well as a "horizontal" assessment pertaining to how the profile satisfies its intended purpose and scope. This section addresses the latter objective in a summary manner by evaluation of (1) how, and to what extent, the site profile satisfies the five objectives defined by the Advisory Board for ascertaining adequacy; (2) the usability of the site profile for its intended purpose (i.e., to provide a generalized technical resource for the dose reconstructor when individual dose records are unavailable); and (3) generic technical or policy issues that transcend any single site profile that need to be addressed by the Advisory Board and NIOSH.

4.1 SATISFYING THE FIVE OBJECTIVES

The completeness, accuracy, and adequacy of data (to include data to be used for monitored workers' individual dose reconstructions and data to be used in deriving coworker database for unmonitored workers) should be validated to demonstrate its usefulness. SC&A has performed extensive document searches and found over 300 MCW/WS site documents available on the O-Drive plus many other documents located at the various DOE document storage/retrieval centers, as well as information available at the Weldon Spring Interpretive Center, located on the original WSCP site. SC&A also reviewed approximately 30 of the WS site claims to assess the information available in the individual energy employee's dose records and their applicability to dose reconstruction and coworker databases. SC&A also conducted several days of onsite interviews with former WS site workers to obtain information concerning working conditions and exposure potentials that may impact the completeness and usefulness of dose records. The following is a summary of SC&A's evaluation of the present resources available (TBDs, dose records, site documents, etc.) to the dose reconstructor for reconstruction of dose to WS site workers with reasonable completeness and accuracy.

4.1.1 Objective 1: Completeness of Data Sources

During its review of the WS site TBDs, SC&A's found that NIOSH did not sufficiently address the completeness of the dose records for the workers at the WS site for both internal and external doses. For example, the WS site TBDs do not explicitly state when DOE employees and/or DOE contractors were no longer at the WS site after it stopped operations in December of 1966. It has not been determined if DOE employees and/or contractors were present or involved during 1967–1969 when the U.S. Army was attempting to decontaminate and renovate buildings located at the WSCP, during the 1970–1984 monitoring and maintenance period, or during 1983–1984 when there were efforts to remediate leaks at the WSRP. If DOE contract personnel were present at the WS site soon after the shutdown in December 1966, they could have been exposed to numerous radionuclides during decommissioning, clean-out, and revamping the facility for a completely different use. This could have lead to incidences of skin contamination, inhalation, and ingestion of radioactive materials (including uranium and thorium, as well as radionuclides contained in the raffinate concentrates and its scale/soil that had been resuspension) that were not monitored and/or recorded, or grossly underestimated. Therefore, the present dose records may not be complete if workers were exposed after the operational period and not properly monitored. The issue of *legal ownership* of the property (and liability) as a function of time needs to be determine through federal/state/local records to determine if there should be dose records available and dose reconstruction performed for any workers during the time period 1967–1984.

The WS TBDs do not sufficiently address accidents or incidents at the WS site, or the apparent lack of their documentation being readily available. Accidents and incidents that could potentially release material to the operational areas and to unmonitored workers onsite are important at WS, because the radiological hazards may not have been fully recognized, investigated, or documented at the time of occurrence. This could have lead to exposures that were not monitored and do not appear in the energy employee's records.

The WS TBDs do not address the issue of whether the dose records for the WS workers contain the complete dose records for the workers to allow for reasonable dose reconstructions without excessive extrapolation or use of other data. SC&A could not find that an analysis of the completeness of the dose records and their representativeness of the worker population has been performed.

4.1.2 Objective 2: Technical Accuracy

SC&A finds that the existing TBDs do not sufficiently address the accuracy of the dose records for the WS site workers. For example, the accuracy of shallow dose measurements are very much affected by geometry factors (any material/distance between the beta source and the badge on the worker's chest that is not between the beta source and the worker's trunk area will cause an under-response in the recorded dose). The external dose TBD (ORAUT 2005f) did not address these geometry factors for the WS site, nor did it include extremity monitoring or the lack of it during the operational period. Total shallow dose consists of low-energy photons plus beta radiation; the film badge response changes (and therefore, its accuracy) when the energies or ratios of the photons to betas changes. The ability of the film badges used at the WS site to accurately record the total shallow dose was not addressed in the TBDs. The accuracy of neutron dose assignment (TBD-6 recommended using an n/p value of 0.1, derived from the Fernald site, to assign neutron dose to workers who may have been exposed to EU) was not verified or sufficiently substantiated in the TBD.

The internal dose TBD (ORAUT 2005e) does not fully address the problem of radioisotopes other than uranium that may have been present in the workers' intake, but not analyzed for in the urinalysis. According to the workers' dose records reviewed to date, there were no analyses performed for any element beside uranium, except some workers had an inconclusive one-time thorium chest count in July 1966. These other radioisotopes were addressed in the WS site profile by extrapolation from other DOE sites; the accuracy of this method has not been verified.

The WS TBDs do not address the issue of whether the dose records for the WS workers are sufficiently accurate to perform dose reconstructions. SC&A's preliminary review of the WS site worker claim files indicate that the summary sheets and later data sheets generally agree with the dose values listed on the copies of the original data card, worksheets, etc. (some of the originals were handwritten and some were typed). Additionally, the CER supplemental dose database, which accompanies *some* of the workers' files, appears to contain a fairly accurate representation of the original data, and is listed in a consistent format. However, this was a very limited qualitative review of a few cases by SC&A.

4.1.3 Objective 3: Adequacy of Data

The lack of WS site-specific data is evident in the WS site profile TBDs because in many situations (environmental, internal, and external), the authors of the TBDs had to revert to use of genetic dose reconstruction documents (i.e., for occupational medical), other DOE site data/TBDs (such as Fernald), or less-than-complete WS site data (such as parameter instead of work area data) for the operational (1956–1966) and maintenance (1967–1984) periods at the WS site. As previously pointed out by SC&A, the lack of adequate and accurate radiological health documentation and data is the main issue concerning claimant-favorable dose reconstruction for former WS site workers. The three main areas where the adequacy of data is of concern are environmental, internal, and external doses, as outlined below.

The TBD used one serial of measurements (decontaminating 5-ton hoppers) and site parameter measurements to determine contributing intakes to non-bioassayed workers during 1957–1967. The hopper dust monitoring experiment was measurements performed on one day under one particular condition, and the parameter measurements contributed very little (<1%) to the final results. This limited (in space, operations, and time) airborne/intake data is not sufficient to construct an adequate environmental intake dose database for unmonitored workers at the WS complex, especially considering that a sizable fraction of the work force was not bioassayed on a routine basis during this period.

The TBD does not address potentially missed internal doses, which should be part of a TBD for internal dose. The LODs were generally high in the earlier years, which could result in significant missed doses. For the dose reconstructor to assign missed dose, the TBD needs to provide some information concerning the MDA for given bioassay techniques for the important radionuclides of concern at the WS site as a function of time. Additionally, the TBD provides some coworker internal dose information, but does not provide sufficient instructions for its use. Most internal dose TBDs provide a summary section in the main text, or as an appendix, with recommendations and procedural steps for using coworker data. To have adequate data for internal dose reconstruction, missed dose and coworker dose data must be considered along with recorded dose.

The external TBD (ORAUT 2005f) does not provide sufficient and/or consistent information concerning the badging policies at the WS site in order to evaluate the adequacy of the workers' dose records. Therefore, it has not been determined what badging criteria were actually used in practice, and if workers who were not considered at the time to be exposed to radiation were potentially exposed, but not monitored because of being in a pre-defined category. The lack of a consistent and documented badging policy may have impacted the adequacy of the dose records necessary for dose reconstruction.

TBD-6 (ORAUT 2005f) provides annual average gamma and beta exposures. However, the TBD does not provide any information concerning the details/application of this information, such as the number of data points for each entry, percent of workers badged, the range of readings, if background was subtracted, if zeroes or outliers were included, if a threshold dose was used, etc. The data presented is a good start in creating a coworker database, but in order to determine its validity and Representativeness, there needs to be additional work performed on the data, as mentioned above. Plus, as for internal coworker data, some guidance/limitations concerning the data in a summary form would be appropriate.

The WS TBDs do not specifically address the issue of whether there are adequate dose records available for WS site workers to perform reasonable dose reconstruction for individual workers, or to create a technically sound coworker database for both external and internal dose for unmonitored, or under-monitored, workers. One of the first areas that should be evaluated when a site profile is being performed is to assess the adequacy, accuracy, and representativeness of the recorded dose database for internal and external dose reconstruction. This is especially true for a location such as the WS site because, by the nature of its operations, a significant portion of the worker population were possibly not monitored. If there were large portions of the work force that were not monitored, and/or there are excessive gaps or inconsistency in the recorded data of individual workers, then this indicates a problem for individual dose reconstruction, as well as difficulties in creating a reliable coworker database for unmonitored/under-monitored workers. If a solid recorded dose database is found, then this is an indication that there is a basis for technically sound dose reconstructions, subject to the verification of the accuracy of the monitoring methods (external badging, internal bioassay techniques, etc.).

SC&A's preliminary review of several of the WS site workers' dose records indicate that for the workers that were monitored during a given time period, there is a reasonable amount of recorded **external** dose data during that time period. However, this was a very limited qualitative review of a few cases, and does not reflect if there were other periods of time when a given worker should have been monitored and was not, or if there were other workers that should have been monitored but were not. **Internal** dose records are more difficult to evaluate, because it was not a policy at the WS site to continuously bioassay any worker; only periodically perform a Monday-Friday-Monday (M-F-M) urinalyses for uranium by means of a grab sample (as opposed to a complete 24-hour voiding) of a few workers. This sampling program was meant to provide representative samples for each major group of workers. SC&A did find that for the claims reviewed, generally individual samples and analysis dates were posted, not just weekly, quarterly, or annual average values. However, there did not appear to be a constant M-F-M urine sample collection sequence, or repeatable pattern in a given worker's bioassay data in the claimant records that SC&A reviewed. Additionally, there were no bioassay data for any radioisotope other than the element uranium (and some inconclusive thorium in-vivo counts). It should be emphasized that, because this was a site profile review and not an SEC evaluation review, SC&A only performed a very limited qualitative review of the claimants' DOE records to obtain an indication of the contents of the files.

In summary, there has been insufficient analysis of the recorded internal and external dose data to determine the percent of workers who were monitored annually and the representativeness of that data for the worker population at the WS site through the years, and therefore, the adequacy of the recorded and/or coworker dose data.

4.1.4 Objective 4: Consistency among Site Profiles

When compared to other site profiles, SC&A's review of the WS site profile TBDs (ORAUT 2005a–f) did not find major inconsistencies that would significantly impact dose reconstruction or create claimant-unfavorable situations. In reviewing the WS site TBDs, SC&A did note that surrogate information/data was used more frequently than normally used in other site profiles. The WS site TBDs went beyond comparing the general operations and mission of the WS site with other sites, to actually using some of the recorded/derived data from the Fernald site. Additionally, the WS site TBDs did not provide summary sections concerning the application/limitations/instructions for use of the coworker dose data presented in the TBDs as most site profiles do.

4.1.5 Objective 5: Regulatory Compliance

No regulatory compliance issues were identified by SC&A in the WS site TBDs.

4.2 USABILITY OF SITE PROFILE FOR INTENDED PURPOSES

Because the purpose of a site profile is to support the dose reconstruction process, it is critical that the site profile assumptions, analytic approaches, and procedural directions be clear, accurate, complete, and auditable (i.e., sufficiently documented). The WS site TBDs generally provided some method of assessing worker's internal, external, occupational medical dose, and environmental dose; however, SC&A has some concerns in the use of these TBDs for dose reconstruction.

4.2.1 Fernald Site Data Applied to Weldon Spring Workers

While NIOSH attempted to use WS site information and data to the extent it was available, NIOSH also made extensive use of Fernald site data and extrapolated it to WS site workers. The assumptions necessary to equate Fernald site information/data to WS site workers was not always sufficiently supported. Therefore, SC&A questions whether some of the data and recommendations in the present WS site TBDs are usable for WS site workers.

4.2.2 Incomplete/Incorrect Information

In several places in the WS site TBDs, complete information/data is not provided for the dose reconstructor. For example, the method used at the WS site to determine shallow dose is not sufficiently addressed, and Table 6-2 on page 12 of TBD-6 (ORAUT 2005f) is not complete. Additionally, cost-center codes are not reliable categories to use to assess uranium urine data as used in TBD-5 (ORAUT 2005e). Different solubility classes are listed for different isotopes of the same element in Table 5-6 of TBD-5 (ORAUT 2005e), but the WS site could have had only one type of solubility for all isotopes of a given element in a given process or building. SC&A found that TBD-5 (ORAUT 2005e) failed to include some decay components of the uranium decay chain, and that the assessment of radon exposure was incomplete.

4.2.3 Incomplete Dose Reconstruction Recommendations

TBD-5 (ORAUT 2005e) provides some coworker internal dose information, but does not provide sufficient instructions for its use. Most internal dose TBDs provide a summary section in the main text or as an appendix with recommendations and procedural steps for using coworker data. TBD-6 (ORAUR 2005f) provides annual average gamma and beta exposures. However, the TBD does not provide any information concerning the details/application of this information, such as the number of data points for each entry, percent of workers monitored, the range of readings, if background was subtracted, if zeroes or outliers were included, if a threshold dose was used, etc. The data presented is a good start in creating a coworker database, but in order to determine its validity, there needs to be additional work performed on the data (as mentioned above), as well as determining the representativeness of the data for the entire worker population. In addition, some guidance/limitations concerning the use of the data in a summary form would be appropriate for both internal and external coworker data.

4.2.4 Lack of Defined Monitoring and X-ray Exam Criteria

The WS site TBDs does not inform the dose reconstructor of a documented badging/bioassay policy and potential x-ray exam exposures in a consistence manner. The dose reconstructor cannot be reasonably certain whether an unmonitored worker should have been badged and/or bioassayed, and therefore, assigned a coworker dose, or if an environmental dose assignment is more appropriate. Likewise, the frequency and types of x-ray exams are not sufficiently defined to allow the dose reconstructors to assign consistence occupational medical doses.

4.3 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

A number of issues identified in the WS site TBD review represent potential generic policy issues that transcend other individual site profiles. Issues raised in this review that are common to other DOE/contractor site investigations include a lack of recorded data analysis for adequacy/representativeness, inadequate documentation of badging policy, lack of sufficient environmental data for onsite unmonitored workers, insufficient knowledge/documentation of source terms and radiation fields, lack of geometry factors for beta and low-energy photon doses, and lack of adequately developed (or insufficient data for) coworker internal and external dose development. As with many other DOE sites, the WS site also lacks documentation concerning accidents, incidence, and episodic releases that would have potential radiological consequences, especially in the operational years. Additionally, the lack of information concerning occupational medical procedures, equipment, types of exams (PA/LAT, PFG, lumbar), frequency of exams for different job titles, etc., are prevalent for the WS site and obvious in TBD-3 (ORAUT 2005c), as it is for many of the earlier DOE sites. A common problem that the WS site has with other uranium processing facilities in the early days is that uranium was mostly controlled using chemical toxicity levels, rather than being viewed as a radiological hazard. This lead to some working conditions and lack of monitoring that would not be acceptable by present standards. These issues are discussed in detail as findings in Section 3 of this report.

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ATTACHMENT 1: NIOSH TECHNICAL DOCUMENTS CONSIDERED DURING THE REVIEW PROCESS

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ATTACHMENT 2: SITE EXPERT INTERVIEW SUMMARY

INTRODUCTION

In accordance with its mandate under the Energy Employee Occupational Illness Compensation Program Act (EEOICPA), the Advisory Board on Radiation and Worker Health (Advisory Board) requested that SC&A review the Weldon Spring site profile (ORAUT 2005a, ORAUT 2005b, ORAUT 2005c, ORAUT 2005d, ORAUT 2005e, and ORAUT 2005f). SC&A was requested by the Advisory Board to assist in these investigations. A large number of interviews were concerned with obtaining first-hand information regarding the nature of the day-to-day working environment of the various categories of personnel at the site. This report summarizes the results of the interviews performed to date by SC&A.

A total of 20 interviews were conducted with former Weldon Spring workers and other site experts. Workers covered the time period from construction to remediation. Dr. Ron Buchanan and Ms. Kathryn Robertson-DeMers conducted interviews from April 28–30, 2009, in the St. Louis, Missouri, area. One subsequent interview was conducted in Oak Ridge, Tennessee, and one interview was conducted by telephone. The purpose of these interviews was to hear first-hand accounts of past radiological control and personnel monitoring practices, and to better understand how operations and safety programs were implemented at the site over time. Interviewees were identified through available site reports, public meeting transcripts, local advocates, other interviewees, and previous interviews conducted for the Mallinckrodt Destrehan Street Plant.

Collectively, those interviewed worked at the Weldon Spring (WS) Plant from 1956–1966. Employees interviewed worked at the Administrative Building, the Digestion and Denitrification Building, the Extraction Building, the Metals Building, the Green Salt Building, the Pilot Plant, the Maintenance and Stores Building, the Laboratory, and the Raffinate Pits. Some individuals worked throughout WS and also transported materials to other Mallinckrodt Chemical Works (MCW) facilities, such as the Destrehan plant and the Latty Avenue facility. A number of interviewees transferred from the MCW Destrehan plant when WS was built. The worker categories represented by the interviewees include the following:

- Administrative
- Computer Operations
- Construction
- Document Control
- Environmental Advocate
- Environmental Restoration
- Health and Safety (H&S)
- Operations
- Machine Operations
- Maintenance and Crafts
- Manufacturing
- Transportation

SC&A explained that the interviews were being conducted on behalf of the Advisory Board as part of their investigations of NIOSH's site profile. Participants were told that the interviews were unclassified, and that they should not disclose any classified information. Summaries from each interview set were prepared and provided to the interviewees for review. Not all participants responded to the request for review of their interview summary. As a result, the information in these interviews was not included in this summary.

The information provided by the workers and site experts has been invaluable in helping SC&A to better understand the Weldon Spring site operations. ***This report is not a verbatim presentation of the material contained in the interview notes, nor is it a statement of SC&A findings or opinions. It is a consolidated summary of statements, opinions, observations, and comments that the interviewees communicated to SC&A.*** A few interviewees had extensive knowledge on not only Weldon Spring, but Mallinckrodt Chemical Workers. They also actively participated in the MCW SEC petition process and had extensive personal knowledge and comments to share related to previous reviews and how these reviews impact the Weldon Spring site. ***The sole intent of this summary is to communicate information acquired by SC&A during interviews to the Work Group, the Advisory Board, and other interested parties.***

Information provided by the interviewees was based entirely on their personal experience at WS. It is recognized that site experts' and former WS workers' recollections and statements may need to be further substantiated; however, they stand as critical operational feedback and reality reference checks. These interview summaries are provided in that context. Key issues raised by site experts are similarly reflected in our discussion, either directly or indirectly. Interviews from all workers who reviewed and approved their individual interview summaries were consolidated into a single summary document. The information was categorized into topical areas related to operations at the sites, radiological monitoring, shipping and receiving, environmental monitoring and waste management, radiological records, incidents and unusual occurrences, occupational medical, technical basis document (TBD)-related comments, and miscellaneous comments. This interview summary represents what was communicated to SC&A interviewers by the interviewees. Comments or clarifications made by SC&A are provided in brackets. Where conflicting observations and statements have been received, both perspectives have been retained in this summary report.

With the preceding qualifications in mind, this summary has contributed to our understanding of issues raised in the site profile.

OPERATIONS

The Fruin-Colnon Construction Company of Utah was responsible for building the WS. Construction started in 1955, and operations began in 1957. The plant was hopping in 1957, 1958, and 1959. By 1961, things were a lot quieter, with fewer people out at the plant. Many employees from the Destrehan plant were offered work at WS when Destrehan closed. Many felt that they had no option but to move or lose their jobs. WS continued operation until December 1966, when it shut down. The remediation process began in 1986.

Mallinckrodt was a producer of chemicals, one of which was diethyl ether. The uranium separation process involved diethyl ether, so MCW became involved with the Atomic Energy Commission (AEC), because they made ether.

The MCW Uranium Division began at Destrehan and continued through WS operations. The plant design and practices at WS incorporated many lessons learned from experience at Destrehan. At one meeting, NIOSH representatives showed a diagram of the radiation history at Destrehan. On a graph, the average radiation level was highest at the beginning; by the time it was closed, the radiation level had come down a little bit, but it was still over the danger threshold. The WS Plant started at that level and stayed at that level, because all of the safety improvements carried over from Destrehan. WS did not use ether in the purification process like Destrehan, so WS didn't have the danger of ether house explosions. At Destrehan, one plant was built right next to and/or on top of another plant. At WS, the different plants (e.g., metals plant, salt plant, etc.) were at least one or two blocks apart. The exposure levels at WS would be lower than those at Destrehan.

By 1953, the division produced multiple metal products, including "**Betatron slices**" (see page 46 of the original Mallinckrodt Exposure matrix)[ORAUT 2005], **slabs**, **billets**, **ingots** made from **derbies**, and **dingots** (direct ingots) made by an MCW patented process. Because of dimensional instability discovered during reactor irradiations at Hanford, MCW had to add zirconium, iron, and other elements as an alloyed product. The Department of Energy (DOE) Legacy Management outgrowth brochure indicates that the uranium ingots contained small amounts of thorium, as well as magnesium, manganese, etc. The dimensions, weight, and exact chemical composition of each of these metallic forms needs to be described in detail in order to assign a correct radiation dose to those handling the forms with widely varying geometries.

The material coming into the plant generally originated from Colorado Plateau, although there may have been some material from other areas (i.e., Canada, Belgium Congo). The material was primarily uranium carbonates (grayish or brownish) that had been filtered out from the ores. That came into the Warehouse facility in 55-gallon drums. The drums were not labeled in terms of concentration. All they would say is that they came from this facility (i.e., the name of the mine). There was some processing at the mine to get rid of the rock, and they ended up with 70%–80% uranium carbonate. This is what was drummed up and sent to WS. WS's mission was to further concentrate the material. Primarily, the incoming product was ore, but every once in a while, they would get drums of some other concoction. WS also received metal cylinders from Hanford or some place like that. This material was dissolved and processed like any other material.

The uranium ore and other material were sampled at the sampling plant to test for uranium content. Uranium ore concentrates were shipped by train car to WS. The ore was loaded into a hopper, sealed, and weighed. There would be up to 3 tons of material in the hopper. The weight was recorded on a form, including information about the percentage [of uranium].

WS had three separate processes in the production of uranium trioxide; digestion, purification by solvent extraction, and denitrification. At the first processing plant, the ore was fed into a digester, where it was treated in big vats of nitric acid. The material had to be fed into the digester at the correct rate; otherwise it would react with the acid and blow off the top. Operators had to monitor how fast material could be fed into the digester; the appropriate rate varied with different materials. The resulting aqueous solution was passed through an organic solution of diethyl ether; the two liquids were running counter-currently. In that mixing, the uranyl nitrate entered the diethyl ether, and the raffinate dropped out. This produced a UNH [uranyl nitrate hexahydrate] aqueous solution. The resulting slurry contained UNH aqueous solution, nitric acid, and various impurities. The slurry was mixed with tri-butyl phosphate (TBP) in hexane. Raffinate was produced as a byproduct and carried most of the impurities. At the end of this process, you end up with yellow salt (i.e., uranium nitrate). The UNH was extracted and piped to denitrification pots, where uranium trioxide was made. They cooked the uranium slurry in pots over a flame until it was powder. The pots were unloaded with a suction system. This would not preclude some of the material becoming caked and individuals having to chip it out. This operation generated a lot of dust.

In the hydrofluorination process, uranium powder [uranium trioxide] was run through screws and pipes. The yellow powder was run counter-currently through a bank of screws with anhydrous hydrofluoric acid. Screws were used to push the uranium powder through, converting it to uranium tetrafluoride [UF_4, green salt]. The screws were about 20–25 feet long; they were made at WS by curving the metal around and welding it to another piece of metal. A pipe was used to move the material from one end to the other. This process was heated and pressurized to keep the material moving through the process. The screws were unloaded in dust-protected systems. This process posed significant chemical exposure hazards, especially when the tanks were unloaded. People wore protective suits for this work.

In the Metal Plant, UF_4 was reduced to uranium metal, and the resulting metal was finished. The goal was to get pure metallic uranium. Workers would take the refined green salt (UF_4) and mix it with elemental magnesium. The mixture was put into a big steel container, about 10 feet in circumference at the top, about 4–5 feet in circumference at the bottom, and about 15 feet tall. The container was lined with magnesium fluoride and some lime for further insulation. When the mixture was heated up to a high enough temperature (~1,300 F) in a furnace, it underwent a thermite reaction. The uranium dropped out of its fluoride salt form down to pure metal dingot down to the bottom of the container. Remaining slag had to be chipped off the ingot. This work was done with a Plexiglas shield. Weldon Spring produced cylinders of highly pure uranium metal that were about 17 inches in length by 17–18 inches in diameter. The product weighed 2,000 to 3,000 lbs.

The uranium metal was taken to a lathe, where the isotopic impurities would be machined off from the very top surface. The surface of the cylinder was clean except for the top layer, where it had a pitted appearance that did not look like the rest of the cylinder. They would put it on a metal turn table and machine the top down to shiny metal. WS had Bullard Lathes, vertical lathes they used to take a 1-inch cut off of the ingot. They would take a deep cut off of it, and the chip would just curl off of the ingot. The six-spindle and eight-spindle lathes were enclosed, with coolant flowing over the uranium. Even with the coolant, it would turn red. The chip would curl off and it was real hot looking. Right out on the end, it would start turning red. There was a big well, and the chip would fall down into it and coolant would cover it up and put it out. The end result was a very pure ingot, which would be shipped offsite.

Once the ingot was cleaned up to a certain level, it was put in a salt bath at a certain temperature, and it got red hot. They would then go into an extrusion press and were cut to a particular length to make rods. In later years, induction furnaces were used in lieu of a salt bath to heat the metal for extrusion. This produced 7-inch diameter rods. This product would head to Hanford, Savannah River, or Oak Ridge.

The end product was sent offsite for quality control analysis.

All of the pure magnesium used in the metal process was burned up. Magnesium fluoride was a byproduct of the magnesium and green salt reaction. It was recovered by putting it through a sieve to remove the metal elements or other elements, so the magnesium could be captured for reuse. It was put into a grinder to break it up into a powder; then it was put into the shells and packed with mandrels.

The Bullard Lathes required periodic repair of the pumps and adjustments by the operators. The guys that ran the Bullard Lathes wore rubber gloves. All of the coolant was contaminated. There would be shaving particles in the air. The layer with impurities that was cut from the ingot would be turned into black oxide inside the rotary kiln.

There were ongoing experiments and testing done by manufacturing at the Pilot Plant. These were done on a small scale. For example, they were trying to grow seeds. General Electric would take this material, drop it down into a hopper and vibrate it down, and it would come into an electric welder and tried to make seed. There were a lot of test projects going on that only the people working on them knew about. These projects had special handling and were sent out for evaluation. Some samples were sent down to the storeroom, put into a pickup, and taken to be x-rayed somewhere. The storekeepers were in charge of this.

The raffinate generated by WS was kept onsite. Initially (i.e., ~1957–1958), the raffinate was pumped into drums. There were several quarries out by the WS. For a few years, those drums were dumped in quarries. Later, they started to collect raffinate in a stainless steel tank, adding lime and pumping it out into a pit for evaporation. The operators were responsible for sampling the raffinate and neutralizing it before pumping it out to the tank holding area for disposal. When a raffinate tank was full, operators would take a sample with a stainless steel cup on a chain. They dropped it down into the tank, collected a sample, pulled it back up, and put it into a sample container. The sample was taken to the laboratory and checked for pH. The lab would tell the operators how to neutralize it. A neutralizer was added, the material was agitated for maybe 20 minutes, and another sample was taken to the lab. When the laboratory determined the acid was neutralized, the raffinate was pumped out to a pit, and the sun was supposed to dry it out. At one point, they talked about recovering minerals from the dried material, but it never did materialize, because the raffinate didn't dry out enough. The rain water kept it from drying out. Later on, they put cast iron pipes in the system. If the raffinate wasn't neutralized enough, it would eat the pipes.

Enriched uranium [~3%, according to H&S site experts] came in as a hexafluoride gas in about early 1958. This was a small run campaign that didn't go on very long. When WS received enriched uranium, staff was required to go down to Oak Ridge for 4 months and work with a criticality expert. The appropriate process for handling this material at WS was determined in order to prevent any potential criticality problems. The only change in the Radiation Protection program during handling of enriched uranium was to make sure that the volumes and masses were kept in check to prevent a criticality. Other than that, it was treated like normal uranium. Individuals were not monitored any differently.

Recycled Uranium (RU)

Interviewees observed that, officially, the remediation crews deny that they received recycled uranium (RU, material that was previously irradiated in a reactor) at WS. Interviewees expressed concern that the source term characterization is incomplete in this regard. They think MCW and WS, and even upper levels at DOE, are incorrectly denying or underestimating the presence of RU on site.

DOE tracked fissionable materials, including RU, around the complex. There are several tables tracking the shipment of material. Documents retrieved from Oak Ridge (Recycled Uranium Mass Transfer Ohio field report mentioned in the site profile) and a handwritten memo from an unidentified participant at a symposium indicated that 74,800 metric tons of uranium containing small amounts of plutonium, neptunium, and americium were shipped to and from "Mallinckrodt" and/or "Weldon Spring" from 1962–1967. In addition, MCW records alluding to urine sampling for plutonium were retrieved from the Oak Ridge Associated Universities Center for Epidemiologic Research vaults.

Interviewees further noted that documents from lower levels are in conflict with the higher-up DOE reports. Officials of the DOE Weldon Spring Site Remedial Action Project team denied that the site ever received RU shipments, although DOE field office reports indicate that it did. A statement in the WS site profile ("most of the uranium was natural") seems to deny that RU was present, but the interviewees claim that 70,000–74,000 metric tons of RU can't be so lightly dismissed in the site profile, like it didn't happen.

The interviewees made a number of points (as follows): The instruction provided in the site profile was based on an inaccurate definition of the amount (mass) of RU-transuranic source terms. There is a disconnect between saying RU is not there and coming up with assumptions for dose reconstruction on RU. The dose reconstruction is supposed to be claimant favorable and also plausible. Plausibility is required to prevent assumptions that were made, where the amounts of RU-transuranics were wildly under-reported (based on the RU mass transfer field report cited in the WS site profile). Making things up out of thin air violates the intention of the SEC law.

The interviewees who raised this concern believe that every effort should be made to discover the relevant records at DOE. It is difficult to track exactly what went to MCW. As a practical matter for dose reconstruction, interviewees stated that the amount of RU source material is not known. Without this knowledge, the interviewees believe that they can't apportion the dose reconstruction to RU.

Maintenance

There was a Maintenance Foreman assigned to each building, who was responsible for keeping that plant up and running. A small crew, perhaps a couple of mechanics, an electrician, and/or a pipefitter, would be assigned to a building. The assigned crew took care of routine maintenance and emergencies. If a big job came up, they called the central maintenance pool for support. Workers from the central pool were assigned out to different buildings, making it possible for such individuals to work anywhere on site. There were no restrictions on where individuals could go at the plant. Electricians were responsible for conducting inspections of lines, insulators, and breakers when the plant was taken down (i.e., during the holidays). Access was controlled by a single guard station at the gate.

The plant furnished general maintenance tools, which were carried around to the plant areas. Special tools required for the job were available at the job location.

WS had one large maintenance building that contained a machine shop, weld shop, an electric shop, and an instrument machine shop. The building had a big aisle down the front end of it from one end to the other. On one side of the aisle was a storage area. The machining area had lathes and a big radial drill press; machinists could do everything on that drill press. It was separated from the other areas by chicken wire.

Transportation

Couriers intermittently went to all the buildings where people worked, delivering the mail to the plant population. Couriers were also responsible for transporting Oak Ridge visitors to the plant. There were three mail runs through the plant each day (morning, afternoon, and evening). Couriers also picked stuff up at the shipping dock and transported it downtown twice a day.

Couriers also carried a lot of product out of WS, including samples or cores. The material was transported in a wooden crate that was marked with a yellow crayon. The crates were transported one at a time in an AEC pickup truck to the Destrehan. Couriers would go to the receiving dock, take the crate off the dock, put it in the vehicle, take it down to Destrehan, and unload the vehicle at the Shipping and Receiving building. The contents of the crates appeared to be three or four pieces of metal with hack marks on them. A couple of times, cores were transported for analysis.

Offsite Contract Work

MCW at Destrehan and WS had some offsite contract work. Two sites they contracted with were General Steel Industries (GSI) in Granite City, Illinois, and Dow Chemical in Madison, Illinois.

GSI had two particle accelerators (Allis-Chalmers 24–25 MeV Betatrons serviced by Picker X-ray) to inspect large scale items. WS wanted to identify cracks in the uranium dingots. Subsequent research has shown that another key purpose of GSI Betatron Non-Destructive Testing (NDT) x-ray work was to define the thickness of the outer non-uranium crust on the top, bottom, and sides of the MCW direct ingots (dingots). This was part of the quality assurance of the production runs at WS.

MCW–Destrehan made "Betatron slices" of uranium [ORAUT 2005, pg. 45]. They would stack these up and send them over to GSI. Weldon Spring also held a contract with GSI from 1953–1966 for evaluation of uranium. Slices were shipped to GSI after 1953. The materials were sent by truck or rail. When they were sent by truck, MCW drivers were to accompany the slices. GSI would take an x-ray film and check to see if the product was of adequate quality. This information was sent back to WS.

In the case of Dow Madison, WS-MCW Uranium Division/AEC had a contract from 1957 to 1960 to perform experimental research and development on uranium "R&D gamma extrusions" and rod straightening. Some of the work done at Dow Madison in Illinois is not mentioned at all in the site profile, and it should be. Any AEC technical reports on the results of the experimental gamma phase extrusion on uranium at Dow Madison should also be referenced in the WS site profile; they are not currently cited. It is unbelievable that only a few work orders *and no technical reports* survived. They were doing experimental extrusion work with uranium to obtain more details on the techniques. At that time, they didn't know how to work very well with thorium.

RADIOLOGICAL CONTROL

The H&S department at WS initially encompassed all aspects of H&S, including Medical, the analytical laboratory, field monitoring, personnel monitoring, environmental sampling, and industrial hygiene. There was no other department or unit in this area. In the Weldon Spring Plant H&S group there was a manager, three individuals in analytical support (i.e., bioassay, film badge processing, sample analysis, instrumentation), and about four men in the field group responsible for sampling. Most of the staff remained consistent throughout operation, but a few were replaced. The H&S department worked closely with plant management and the AEC. They were in contact with the New York Operations Office H&S laboratory, Rochester University, and Oak Ridge. Their dealings with New York had to do with bioassay sampling rather than processes. At WS, H&S had enough time to start things up, get the lab going, find all of the procedures they were going to use, and staff the department.

There were procedures and requirements for some of the operations. There was a safety procedure and notification system for the arrival of anhydrous HF [hydrofluoric acid] tankers; this procedure included routine checks to verify that the workers wore their rubber suits and air masks. There was probably a procedure for unloading the ore concentrate.

MCW seemed to be more open about the operations at WS and there was a lot more emphasis on safety, compared to the downtown Destrehan Plant. The unions held meetings in the shop. In the plant, every month they would go from one facility to another to learn about what was going on. However, workers noted that they did not receive training on how to work with uranium. Workers generally lacked understanding of the radiological hazards associated with uranium; they did not know there was a reason to be concerned. Only personnel who had transferred from the St. Louis Plant had acquired some low-level experience working in uranium processing; the new hires at WS depended on information obtained through safety meetings covering both industrial (i.e., electrical) safety and chemical operations within the plant.

Even though new processes implemented at WS showed improvement, many later created new problems. Then too, production output at WS far exceeded that which was produced at the St. Louis Plant. The workers had little knowledge that the additional output exposed them to a much higher radiation dosage; some interviewees concluded that most job assignments were at risk due to a lack of knowledge and training.

Plant Conditions & Contamination Control

From the start, WS primarily dealt with natural uranium. At one point in time, slightly enriched uranium (~3%) was handled on site. Uranium is basically an alpha emitter; there was very little gamma and very little beta. Without any significant gamma, uranium didn't pose an external radiation hazard; the skin would stop alpha and beta from getting through. There was some external dose from the raffinate, which would carry other radioactive impurities from the incoming ore concentrates, but the primary concern for H&S was to control exposure to breathable particulates. This rationale was supported by the AEC National Health and Safety Offices.

They were also saying at the time that in terms of radiation, there was a certain level of radiation the human body could tolerate. For example, the natural radiation exposure in the St. Louis area is different from the exposure received by people living in Denver. That difference in radiation has been with us throughout time. In those days, there was not a significant worry about the accumulation of radiation over a person's lifetime.

Depending on what plant a worker was in, they may be exposed to uranyl nitrate (UNO_3), ore concentrates, uranium tetrafluoride, or uranium metal. There was potential contact with green salt (UF_4) in the metal reduction process. In the machining process, there was some potential for exposure to uranium metal and oxide. In addition, exposure to oxides was possible from the clean-out of the magnesium fluoride to make new refracting material. Minute particles would come, some of which contained the radioactive contaminants they were trying to remove. Workers were also exposed to the byproducts of the uranium processing.

There was mention of thorium being handled at WS. There could have been some decay products in the material machined from the uranium metal, and thorium was found in the raffinate.

There were three major health hazards that H&S really looked for in the yellow cake operation: how to handle the sludge and raffinate; how to control the potential fire hazard; and how to control the powdery uranium nitrate salt during evaporation and drying. Significant dust control and protection was needed.

In comparison to Destrehan, WS was a fairly clean plant. The amount of dust encountered in the work area depended on the area in which you worked. In the processes, everything in the green salt and yellow salt plants was closed, except for the cooking pots in the yellow salt plants. They had dust collection around them. There was very little chance to get escapes other than some kind of failure (hood system, filters, etc.). Some interviewees mentioned issues with heavy dust in the pot room. Workers noticed dust visible in the air in the refinery. In the refinery, dust would build up on the high voltage transmission lines to a point where the cross arm would get burned. Electricians had to clean insulators at least once per year. While weighing hoppers, some dust and spillage from the hoppers would fall on the scale floor. In the extrusion area, hot gases came off the uranium into the air; they are visible in pictures. When they machined the uranium, there were shaving particles shooting through the air.

[The green salt plant contained] three banks of furnaces. There was leakage around the drive end of screws (i.e., agars) used to turn the uranium to green salt. Green salt is a bluish-green color, and it was heavy like the regular uranium metal. Some packing leaked around the fluid bed. Workers would take orange oxide, run it down to the fluid bed, and convert it to brown oxide. It went to the other end of the screw. The hydrofluoric acid would start to turn it into green salt. A lot of times, when the hydraulic pressure in one screw would get too great, the screw would lock up. They would notice this at the panel board. If they sped it up too much with the hydraulic pressure to turn that screw, a lot of times it would break. If the screw broke, they would have to shut that bank of furnaces down. They would have to call the maintenance crew over, pull the screw out, bring it out over the whole plant area with a hoist, drop it onto the floor, and crack the wet green salt off of the screw. They salvaged what they could of the green salt. They broke it up and got rid of the scrap material; at one time, they dumped the contaminated scrap in the quarry.

Acid fumes were a major problem in the refinery; they painted all of the metal girders with acid-resistant paint. There was no buildup of material in the breaker boxes, because they were explosion-proof and solidly sealed, so that no spark could set off an explosion, but acid residue was visible when the breakers were opened.

There were chemical vapors (i.e., hydrofluoric acid fumes) coming out of the fluorination process all the time. The fumes could be overwhelming. Maintenance workers had to go over there and take up on the packing. To pack them right, the worker cut the packing at an angle. They would put one opening where it would wrap around, and push that in with a flange. Additional packing would be on the other side on the bottom. Usually, it took about five or six packing strips. If they were not cut just right, the gases would come back through them. As it was packed, the packing would wear out on the inside. Workers would have to add packing to take up that space where the gases were leaking through. Once the gases got in there and start eating through too much, they start grinding away on the journal of the screw. As the metal of the screw became corroded and worn down, more leakage would occur. The leaks would get so bad that the maintenance man would have to go out and fix it if he could. A mask was required, but it didn't seem to stop anything; sometimes the mask wouldn't operate properly. The maintenance worker would take a deep breath, go in and take up on that screw as much as possible, and go back out again for air.

There was a lot of residue around the process area. Up on the top floor, workers used to hoist up 20,000 lbs of orange oxide. They had a well area that went clear to the top of the building. The trucks would bring the big containers in, and the plant worker would let the hook down, hook up the tank, and bring it up by hoist. Then they would bring it up to the different banks of furnaces. The orange oxide from the tank funneled down and dropped into a screw and went down to the fluid bed. When they opened the valve where that orange oxide came through, a lot of dust would be piled up from the vibration. That stuff would leak out and run out on the area where they set the tank. Orange oxide was all over the place. Workers used vacuums to try to keep the area clean.

There were big jolters that used to take the shells and bounce them down to pack the liner down. It had four bolts with 2 to 3 inch hexagon nuts that would hold them down. The studs would come up out of there. This thing would work itself loose. A worker would have to go down and tighten up on the screws to keep it from shaking. Sometimes, an attempt to tighten the bolt caused it to break off; the constant jolting just deteriorates the metal.

Some jobs caused more radiation exposure than other jobs. One example was picking up a die out of the extrusion area. There was a large bank of hydraulic engines that pushed the uranium through a die. It would extrude a 2-inch rod, squeezing it out like toothpaste. The rods were about 15–20 feet long. As the stuff would go through the die, it would tear and scrape and form black oxide. The black oxide would form around the dies and stay there.

There is some disagreement among workers regarding the extent of contamination spread and the potential for incidental exposure. For example, interviewees from H&S did not recall any visible contamination on cars in the parking lot, but some other workers reported this type of contamination. Some workers reported that contamination was sometimes tracked in to the administrative office areas, other non-radiological areas, or outside, but others disagreed.

Some workers expressed concern that cars parked in the plant area were becoming contaminated, and non-production workers were exposed when they rode in these cars. Cars were parked between the Administrative Building and the Foundry. The whole area was dusty and gritty. The dust and grit came from the stacks and would settle on the cars. It was like gray sand. Some guys had to have their cars repainted. One individual who parked his car in the parking lot got into an automobile accident; when the body shop pulled the panel off his car to fix it, it was loaded with yellow material. The plant sometimes sold its transport cars or traded them in; some cars had to be buried, because they were radioactive.

Depending on the wind, the office people at times would get a good blast of that dust and dirt. The ventilation system in the Administrative building brought contaminants into the building. Some workers noticed when they went to the cafeteria that there was yellow dust from the plant on some tables that were not regularly used. In addition, the plant workers were supposed to take a shower before they left work, but not all of them did. Any contamination on these workers potentially exposed other workers.

Contamination incidents occurred routinely. When there was a skin contamination incident, individuals just washed the material off. If a worker was contaminated with hot powder or acid, they would get a burn and have to go over to the dispensary to get it taken care of. The onus was put on the employee. Workers were not always successful at getting material in the cracks and crevices off. They were not required to call a radiation monitor to take measurements. If they did, they would never get any production done.

WS had a decontamination crew. A bunch of guys would run around all day long with rags, buckets, and sponges, decontaminating.

Monitoring/Surveys

Part of "monitoring" would involve looking at each step and evaluating the needs and actual performance of safety systems. When the plant was starting up, H&S analyzed each phase of operation. They looked at chemical exposures, where the dust could come out, how to contain the hazards, etc. During an evaluation, H&S tried to answer the following questions: What were the incoming materials? What were the outgoing materials? What kinds of hazards were present? These analyses were documented in reports, with the department listed as the author. H&S also conducted analyses when there was any kind of process change (i.e., new chemical, new station, new piece of equipment, etc.). The analysis included air sampling and survey measurements, as well as evaluating engineering controls. For instance, is the dust collection adequate where the cook vats of uranium nitrate are dumped? Is it containing everything or not?

The hazards identified through this process, both chemical and radiological, were monitored on a regular basis. H&S would monitor all phases of the plant regularly (a minimum of annually, but probably more like every other month). Every piece of H&S hardware associated with the operation would be monitored on a regular basis.

Geiger Counters were used to take readings in the plants. Staff would go out to the metal plant and check the readings over there. They might check the radiation level on the drums coming in with the ore, or the sludge. There were no routine contamination surveys of benches, floors, and other surfaces with smears.

WS workers were not required to monitor themselves for radiation upon exit from a radiological area. When workers left the work area, to go to the break rooms or to lunch, to go home at night, or when they got contaminated, there was no station where they could monitor themselves. Their monitor was their film badge. Some workers used neutralizer to clean their hands when they exited the operations areas.

Air Sampling

When H&S monitored a unit, they would use air pumps strategically located around the facility. During hazard evaluation studies, air samplers with filters were taken to the plants and run for a certain amount of time. There was no routine monitoring station in the plant that ran 24/7.

Occasionally, H&S would monitor an operator with a breathing zone air sampler. This was not done very often, only in response to a concern. For example, if puffs of dust were observed at a particular unit, or if the air flow over the dust collector bags was too low, they would put a filter collection device around the operator's neck. A pump was used to keep the air moving, so that any dust coming out during the monitoring time would be captured by the Millipore filter. The Tygon tube hung over the shoulder of the monitored person.

There were no formal particle size studies; however, WS did studies with Millipore filters and other filters with different size holes. Filters were analyzed for uranium concentration.

Personnel Protective Equipment and Work Practice Controls

Everybody entered the plant through the Administrative building. Many workers changed from their street clothes to coveralls when they came into the plant. The workers followed procedures for dressing out. They were constantly cautioned about not taking any of their work clothes home. Upon entering the plant, workers took off their street clothes and put them in their lockers. They went through the change room and got a whole new issue of clothes (i.e., socks, shoes, underwear, coveralls, hat, gloves (if needed), etc.).

Protective clothing requirements varied, and not all workers were required to wear coveralls. Those that worked in the area may have coveralls, but those who went in and out of the areas did not. In the Refinery, they all wore supplied clothing (i.e., underwear, socks, coveralls, and masks). By the end of the day, coveralls were dirty. Workers didn't always use common sense. For example, some workers would go to the shop with green salt on their clothes.

The radiological clothing was laundered onsite. The laundry wasn't located in any of the three operating units. The interviewees did not recall routine monitoring of the laundry, but believe that the waste water was probably collected. It probably went to the same place as the sludge.

The general policy at WS was that employees were not supposed to eat or drink in the process areas. Workers were supposed to leave their lunch bucket in the Administrative building. The facility had a cafeteria where individuals ate lunch or dinner. There were also break rooms available where the workers would eat, drink, and/or smoke. To get to the break rooms, they would exit the production area. Workers were supposed to wash their hands when they went into a break room, but many workers did not do this. Some individuals drank coffee in their work area; there was no concern at the time that it might be contaminated. At the Weldon Spring Interpretive Center, there is a picture of individuals cutting a birthday cake on top of an ingot, indicating that some eating was taking place around radioactive material. There were drinking fountains in the break rooms and other areas of the process plants. There was a potential for radioactive material to be tracked into the break rooms by workers.

Some interviewees reported showering and changing into street clothes prior to going to lunch or leaving for home, while others said they did not. If they were working in a dirty area and had contaminants on them, they would shower. When they went back to work after lunch, they would get a whole new set of clothes. The shower was a poor design, and if a guy didn't want to shower, he could walk through the middle and not get a drop of water on him. Workers from a "regular job" would just put on their own clothes and boots and go to the cafeteria. Some workers entering and passing through areas were not required to shower when they left for the day or went to lunch. There were times when some workers wore their shoe covers and coveralls to the cafeteria.

Gloves were used to protect the hands from chemicals and physical conditions (e.g., heat and cold), but they were not routinely used for radiological protection. The electricians were supposed to wear gloves, but some couldn't work with gloves on.

Depending on the atmosphere in an area, workers usually had to wear a dust mask to enter. There were a few different types of masks used for respiratory protection at WS. One type of mask would come down over the worker's nose, even with the chin. The actual filter fit up inside of this thing. It was aluminum and plastic. The plastic held these dust filters inside of there. A rubber fitting around the aluminum was used to push the aluminum in tight around the face. These masks did not seal well; no matter how hard a worker tried, they leaked. Later on, WS had half-face respirators with two chemical filters, similar to an Army mask. The cartridges were selected based on the hazard anticipated for the particular operation. These were much better, but some leakage still occurred. A lot of times, if they were really concerned, they used a full airline mask with air hooked up. These were often used for dealing with leaks in the green salt area because of the hydrofluoric acid; workers also wore rubber suits and cover boots in this environment. When they used air-line respirators, another operator or technician had to stand by to make sure that the air was regulated for the duration. This was especially true if the worker was going inside a closed area with an air-line mask.

Respiratory protection was worn by some workers, but not all. Individuals who walked through production areas to get to offices observed that some workers had respirators on while others did not. When masks or respirators were used, they were worn more than once; workers just changed the filter out. They were not sent to the laundry between uses; workers simply took a rag and wiped them out. Those workers with respirators stored them in their lockers between uses. Some of the filters were like a paper filter. The workers would just throw the paper filters away when they were too dirty. There were never any problems getting a new filter. They would just throw these away. Workers kept their masks hanging around their necks as they worked, in case they needed it. Masks were primarily used to protect against breathing in the uranium dust.

When the vacuum system went down, workers would have to get in there and scoop the uranium out; otherwise it would burn up in the pots. Dust would get on the outside and inside of the mask. When a worker got finished and pulled off the mask, he would have orange all around his mouth.

Time limits may have been used to limit the time the individuals sat at the lathes, but not in the yellow or green salt plants.

There were situations where employees would sit on the uranium metal. There wasn't a place to sit in the plant, so the uranium offered a place to sit down for a minute or two.

The mail was brought up to the messengers' work area and sorted by the mail clerks. At times, foam containers with radioactive labels were sitting there; these usually held material from WS that had to be taken to the downtown site. These containers would sometimes sit on or by a desk where someone was working. Some of the workers looking back on this situation now think that MCW wasn't taking care of them.

Engineering Controls

The material potentially released to the environment depended on the building. Each building had major dust collectors. These dust collectors were like big huge bags, and a big motor would suck the air through the bags. There was big vacuum system with two big metal rings and large bags in them. Workers would have to connect them at the top and the bottom. The exhaust system on that would cause the vacuum to pick up the stuff in the plant (e.g., spilled green salt, black oxide, etc.) It would go up into the bags, and the rings would move up and down. This would shake the stuff off at the bottom. There was a hopper underneath; as the dust collected on the sides, it became heavy and dropped into the hopper. A building might have a couple of main vacuum systems. There were several bags in each system; they were several feet long and about 18 inches in diameter. They were big enough to fit in a 55-gallon drum. They would recover the dust and send it back to the refinery. When the bags got clogged and the pressure would get high, a ring collector would start up, with air blowing from the outside of the bag to the inside, to knock the material down. Sometimes a bag split, and dust got all over the place; the operators, millwrights, and electricians would have to go clean up the mess. Major breakdowns may have caused releases to the environment.

WS used hoods during sampling of drums (material coming in). There was also a hood where they took samples from the process system. Any place where there was a potential for contact would have a dust collection system. H&S was responsible for checking out the ventilation systems.

Local 1 International Brotherhood of Electrical Workers quorum has attended many meetings regarding the safety requirements issue at Weldon Springs. They maintain that flaws in the equipment and full production process contributed to more radiation dosage and resulting health problems among the union's workers. Design Engineering could have done a much better job, since MCW had previously processed uranium in the very early 1940s.

Many of the operations at WS were hands-on versus remote operations. The guys would have their hands all over the 500 pounders. They were chipping it off after it came out, and they would take them and machine them.

Receiving the ore concentrates and the boiling down of the uranyl nitrate were probably the most hazardous processes from a uranium standpoint. Unloading of the anhydrous HF tanks also produced very challenging field conditions.

WS was under the jurisdiction of the Oak Ridge Operations Office. The AEC came down to do regular audits on some time basis. H&S staff members were not aware of any state inspectors reviewing the facility during operation. The state deferred this responsibility to the AEC.

PERSONNEL MONITORING

When Weldon Spring opened up, they needed to have a laboratory established in the H&S department to perform bioassays, air sample analysis, and all analyses associated with H&S. Film badges were processed and calibrated at this laboratory facility. The only dosimeters employees worked with were film badges.

External

The general rule for external monitoring of individuals at WS was that individuals working in the plant were assigned a film badge. No one was supposed to go in the plant without a film badge. For example, if an individual routinely went out to the plant area, even though they were assigned to the Administrative area, they were supposed to wear a radiation badge. Management, security, and warehouse support personnel would have been assigned a radiation badge if they were out in the plant area. At least some supervisors/foremen told their employees to wear their film badge when they were out in the plant area. Some individuals reported that they did not wear their film badge consistently when they were out in the plant area. Some Administrative personnel at WS indicated that they did not wear a film badge. There are reports that individuals placed their badges on or in uranium to see if they would receive an elevated dose result.

The frequency of routine badge exchange was monthly or quarterly. The badge was worn over the pocket area on the chest. Some individuals indicated that they wore the badge inside the pocket, while others wore it on the outside. Individuals were not allowed to take their radiation badges home, but were told to store then in a rack by the guard shack. Workers wearing film badges picked up their badge when they came to work and returned it at the end of the work day. Personnel involved in transportation of material offsite indicated they left their badge at the guard shack (where they were stored) when leaving the facility with material.

Initially, some pencil dosimeters may have been assigned, but a decision was made, with AEC concurrence, that these were not needed. There was no neutron monitoring at WS, even during the work with enriched uranium. Extremity dosimetry was not used at WS. There was not a routine area dosimetry program, but dosimeters were put in the area during special plant evaluations.

There were times when film badges were lost, damaged, or contaminated. If the film was damaged or black, an investigation was done to find out what happened to the film. (For example: Did the worker leave it on top of a metal cylinder? Did the worker have it on during an x-ray?)

WS maintained manual calibration curves for the film badges. Radium needles from the National Bureau of Standards were used to calibrate the film badges. The radium needles were kept in lead shields. The film was exposed for a specific amount of time to a known amount of radiation, and this information was used to calibrate the densitometer. All film badges were read, unless they were lost or misplaced. The film was read for gamma (rad) and beta (rep) dose. Beta wasn't as much of a concern, since it can't get through the epidermal layers of the skin. There was no background subtraction from film badges.

Internal Monitoring

The personnel in the analytical laboratory determined bioassay requirements. They primarily analyzed for uranium in urine, but fecal sampling may have been done on occasion under unusual circumstances.

Routine bioassay sampling intervals ranged from weekly to annually. The nitrate plant, green salt plant, and metal plant had a regular weekly collection schedule. These were typically collected as spot samples. Each plant had a separate collection day; it was divided up, so the laboratory workload would be even. If a filter bag broke and a guy got covered with dust, they might run a 24-hour sample on that person after he was decontaminated. Occasionally, a worker on a special job might have to submit additional samples. Even workers who had transferred from radiological to non-radiological areas indicated that bioassay sampling was continued for the duration of their employment.

Urine samples were generally collected at work; however, there were special occasions when urine was collected over a weekend. Workers were provided with urine sample containers in the locker rooms, where the collection was done. The lab would collect the samples from there. A sign was posted at the container station with the bioassay collection instructions, including the instruction to wash hands before providing a sample. This instruction apparently was not consistently followed; several workers indicated that they did not recall having to shower or wash their hands prior to collection.

Workers who had an incident were sent to the dispensary. For example, if a worker opened the dust bags and they were split, they would get material on them. If this happened, the worker would shower off at the plant and go to the dispensary to leave a urine sample. At the dispensary, the worker was checked over to see if anything had gotten into the mouth, eyes, etc. This would be something similar to a medical exam. These kinds of things happened occasionally. When there was a high reading on the radiation badge, workers recall being sent to the dispensary to collect urine bioassay. The only thing WS did for exposure was to take a urine sample. In some cases, workers were allowed to "cool off" for a period of time. For any 24-hour samples, H&S arranged to have it taken at the dispensary.

There were formal procedures for bioassay analysis. When samples (air filters, urine, etc.) were analyzed, WS used a fluorometer to determine the micrograms per volume in the sample. WS used some of the equipment designs from the University of Rochester laboratory. One of the things they designed was a multi-arm spoke wheel with platinum arms that had a little loop at the end. Uranium fluoresces if it gets into the right type of crystal (such as a glass substance). This substance would be set in the loop, it would rotate through the fluorometer, and a fluorescence measurement would be taken from the sample. The fluorescence unit was calibrated using standards; the uranium flouorescence of the sample was compared back to that of the calibration standard to determine the amount of uranium present. With the fluorometer, the laboratory was able to determine very low concentrations of uranium in urine. The method was also capable of determining very high concentrations in terms of personal dust samples collected from the nitrate cooking pot area. Natural uranium concentrations in urine were not subtracted from bioassay results.

Results from bioassays were recorded in laboratory logbooks. These should be used as the source of bioassay results. The internal dose or permissible body burden was not routinely calculated.

The analytical lab did not receive blind bioassay samples from the AEC, although the AEC may have come in to observe and evaluate the bioassay program. Positive bioassay results did occur among workers at WS. One worker indicated that even after transferring to an office job, the worker's urine samples still remained positive. The AEC waited to hear from WS to report any problems. For example, at one time, a particular department was getting higher concentrations of uranium in urine than normal. A report was sent to top management stating that the department was having a problem, since many of the operators were showing up with higher uranium in the urinalyses. In cases like this, the AEC might come down and help H&S try to fix the problem.

There was a situation where a staff member disagreed with the concentration levels derived for safety by the AEC for uranium. An experiment was conducted where a teaspoon of uranium was mixed up and ingested. Follow-up evaluation of the individual's urine was conducted over the next 24 hours.

Interviewees do not recall receiving whole-body or lung counts on the portable Y-12 counter. Interviewees also did not recall doing Radon Breath Analysis. There were no identified problems with radon.

ENVIRONMENTAL MONITORING/REMEDIATION

There was contamination outside the immediate process facilities. H&S did monitoring of the environment (creeks, wells around the quarries, etc.) during operation. WS measured external dose in the environment with Geiger counters. For example, if H&S walked down to the creek and saw yellow stuff in the creek bed, they would take measurements. Uranium carbonate is yellow, and it had the greatest potential for release. Interviewees did not recall any significant spills of uranyl nitrate or green salt offsite. Environmental samples were collected and analyzed for uranium.

Some monitoring of environmental air emissions was done, but they did not have any built-in air sampling equipment that operated regularly.

There were occasional releases of hydrogen fluoride that would turn the trees brown. Neighbors would have complained about the odor and fumes from the plant offsite. When it was foggy, the stuff would hang into the air.

There was a big vacuum system on the green salt plant where the off gases would come out the roof and exhaust. Some major breakdowns of dust collectors may have released puffs to the environment. There were occasional releases of nitric oxide gases. There was at least one occasion in which HF got loose. There was a situation at WS where the plant started losing water from a tank inside the area and it leaked out into the lakes in the area.

An individual was responsible for going out in a boat on the pond and collecting samples. Some unusual animals were collected from the ponds out in the plant. For example, some frogs with three eyes and too many legs were collected.

There was an approximately 150-foot tower at WS. They recovered all the nitric acid from different operations and pulled it into a nitric acid recovery system. They had water going down on to this to control the pH. If the operator wasn't paying attention, the acid would get much stronger, because there wasn't enough water. Sometimes the tower would look like red fire was coming out. Sometimes a trail of damage was visible as a path across the trees.

The residues from the main plant (Destrehan) were dumped at Weldon Spring, resulting in potential exposure to K-65 material, residues of barium, aluminum, calcium, magnesium, cobalt, copper, beryllium, iron, manganese, arsenic, asbestos, cadmium, chromium, nickel, antimony, zinc, selenium, ionium, uranium oxide, and uranium dioxide.

The quarries were down the road from the plant. Sampling was performed at the quarries, including checking the wells and collecting air samples. AEC at some time probably came down to audit WS and indicated a need for improvement. Sludge samples were probably collected and analyzed, but the location of these records is unknown. A good part of the solid radioactive waste also went into the raffinate pits.

The interviewees did not know exactly where the drinking water supply for the plant came from. There were wells at the site; there was also a water plant down the road about 1.5 miles. There were folks that worked for MCW down at the water plant.

The Weldon Spring Quarry site is close to and within direct sight of the St. Charles drinking water “well field” source. Concerns were raised by the public over contaminated drinking water around the site. Of particular interest was a study done by the Missouri Department of Health on an infant death cluster identified in the area of Weldon Spring. The investigation included surveillance-based cluster analysis and a case-control study for offsite personnel.

OCCUPATIONAL MEDICAL

The Medical Facility was located in the Administrative Building. Workers received medical exams either annually or every 6 months; these included a physical exam, urinalysis, and other medical tests. They were very thorough. Interviewees reported receiving chest x-rays as frequently as annually. Physicians from Barnes Hospital came to the plant once a week to conduct these physicals.

INCIDENTS AND UNUSUAL OCCURRENCES

Incidents and accidents, such as a bag failure, would be documented by the department in which the failure occurred. Incident reports were not generated specifically by H&S. This information may have been discussed in monthly or weekly reports. Historical incidents that have been reported publicly by former workers have varied in significance from minimal to severe.

From the H&S perspective, staff primarily wanted to know bioassay results—how much uranium was in the body? H&S reported occurrences and trends to the plant management and to AEC when a particular group had more uranium over time than other groups. The action levels (in mg/liter) and guidelines were based on whatever was published by the AEC, and were not specific to WS.

The big bomb ovens (electric ovens) in the Metals Plant at WS were of the same construction as at Destrehan. From time to time, a blowout would occur during the thermite reaction in the big shells. A blowout occurred when something went wrong with the shell or liner (the liner wasn’t thick enough, the liner had a flaw in it, or there was a misfiring of the elements). The metal, rather than settling at the bottom of the shell, would burn through the liner and the metal container, spewing everything into the furnace. Some spilled outside the furnace, too. A blowout in the furnace would destroy the furnace elements, the liner, and everything else.

Blowouts occurred often enough that they had procedures in place to prevent physical injuries when they did occur. At one point in time, the metal furnaces blew up so often (as frequently as two times per week) that the site ran out of pre-cast insulator tiles. An employee made a suggestion at the time to use regular fire brick rather than wait for the manufacturer to send in pre-formed tiles. This statement was confirmed when the Advisory Board located a record stating that the employee had received a $75 award for this suggestion to use fire bricks. After a while, they figured out that the shells were being used too often, and that is what was causing a weak spot in the liner and causing the metal to go through it and spill all over in the containers. Some interviewees indicated that blowouts were not quite as frequent at WS as at Destrehan.

After a blowout had occurred and things cooled down, the operators had to go in with their regular work shoes and clean up the mess, which was a combination of uranium and all kinds of slag and garbage. Even after the operators cleaned the furnace up, there was still a lot of material in the furnace. After this initial cleanup, the electricians would go into the furnace and rewire it. The brick liners also had to be replaced. These explosions and the subsequent clean-up were a source of potential uptake of radioactive material.

H&S would be notified when there was a blowout, and they would go out to the area. As soon as H&S was notified, personnel would go to the site of the accident. If it happened in the middle of the night, they may not get to it until the next morning. H&S staff would check out the situation, monitor the area, search for dust, maybe request special bioassay of the workers involved, and find out why it occurred. For example, was the shell recycled too many times? Was there a flaw in the magnesium fluoride liner? Every one of these things would have been investigated thoroughly. H&S would check for exposures after the incident while workers were in the process of or completed with cleaning it up.

As an additional precaution, burn-outs in element-type furnaces were replaced with Vacuum Induction Heating, only to result in a disastrous explosion, which occurred in the Recast Furnace on July 15, 1960. [Following is the story of this incident as written down by the worker before his death.]

> *The material being processed was uranium.*
>
> *The operator informed me the furnace was losing pressure. I purged the furnace down according to procedure. When this process was completed I evacuated the building in preparation for entering the furnace enclosure. [Another worker] re-entered the building and I told him again that he had to leave. [The other worker] said that I should not be left there alone.*
>
> *I understood that if the furnace lid could be raised three inches, we should be ok. [The other worker] knelt on the platform to operate the lid control buttons while I stood next to him giving him the necessary hand signals to safely raise the lid. After we achieved a height of at least three inches, I turned to [him] and said it*

looks like we're ok, I took one step back to enter the furnace enclosure, and that is when the furnace blew.

The lid lifted a short distance, fire shot out around the lid and then the lid dropped back down. The concussion hatch in the top of the furnace enclosure was blown over to the rotary kiln. I was blown back across the platform where I caught [the other worker] and laid him on the platform deck. I began administering first aid to [him] who appeared to have major arteries severed. There was so much blood that I had trouble tying the tourniquets because everything was so slick. I called for help and [one of my operators] approached the base of the platform ladder. I asked him to bring me screwdrivers or sticks to tighten the tourniquets. [He] returned with some screwdrivers. I was then able to apply sufficient pressure to control the bleeding.

I then dialed station 500, which simultaneously contacted the guard office, dispensary and boiler house. I told the guard I had a man down and to send an ambulance to take him to St. Joseph Hospital in St. Charles due to the severity of his injuries.

At this time I sent my crew to Barnes Hospital.

After I secured the area, approximately two hours after the explosion, I agreed to go to Barnes Hospital and was refused admittance due to a fear of contamination. The treatment I received was being stuck with pins and asked whether I could feel it, and being asked if I was contaminated.

After returning to the plant I was informed my work clothes had been burned and that [name](the head of safety) wanted to speak to me. The subsequent discussion was recorded. Then [name] wanted to speak to me and I told him to listen to [the head of safety's] recording because I was going home.

Upon my arrival at home I learned my family heard about the explosion through the media. No one at Mallinckrodt bothered to call.

Later that day my crew and I were called and asked to attend a meeting at the plant at 8:00 am the following morning, which was a Saturday. The meeting began with tape recorders being turned on and the following statement. "We want you to tell us what happened up until the time of the explosion, and what you did after the explosion." At this time, one of my operators, [name] stated the following: "Now that we've had an explosion you want to know what we did. But when [name] kept telling you that the furnace was going to blow you wouldn't pay any attention to him." The recorders were then turned off and the meeting adjourned.

The family heard about the explosion on the radio. The St. Louis Globe Democrat reported the incident as a minor gas explosion. A witness heard the explosion and went over to the induction furnace where there were several individuals on the floor. The power was shut down. Nobody got killed, but a lot of people got injured. The nurse that was there was using screw drivers as tourniquets. This process was never restored nor put back into production.

During the machining process of the ingots, there were times when the chips would catch on fire. The material cut off the ingots was drummed. Occasionally, one of the drums on the truck would catch on fire. The ingots would catch on fire, and they were moved outside and allowed to burn out. When it burned itself out, they would pick up the black oxide, and that was it. The ingots were burning right out there in the atmosphere. This didn't occur very often, but it did happen.

At one time, they had a concrete lid on the bomb (steel container) and a batch of recorders monitoring the temperatures. When they came to 1,300 degrees, they would get a glitch, and they would drop that concrete lid down to contain an explosion in case one occurred.

RECORDS AND DOCUMENTATION

WS did not routinely provide workers with the results of their bioassay or film badge monitoring.

Prior to the Advisory Board meetings concerning the Destrehan Plant, some individuals had difficulties getting hold of their exposure records. Workers were told that the records were lost. However, at one of the Advisory Board meetings, at the last minute, NIOSH came and said everything was solved and that they could reconstruct individual doses. They had located a collection of records that suddenly solved the problem. With these records was a letter from Mont Mason, the head of the Mallinckrodt Chemical Workers medical and records group. The letter said the information was very valuable, provided that it is reconstructed and correlated where it makes sense. The Advisory Board directed NIOSH to provide a copy of the cover letter to the Destrehan Plant petitioners, because they had been not aware of these documents.

In Mont Mason's letter, where he indicated the information was valuable and shouldn't be lost, he also said it should be worked on immediately to coordinate it. Interviewees with records experience described the process for tracking and compiling the kinds of data that were recovered (e.g., punch card records). These interviewees agree that the average radiation doses for departments are valid, but they have concerns about using this data for reconstructing individual doses. Their objections are related to concerns about the ability to correlate dose data with specific individual workers. This concern about individuals' records is applicable to both Destrehan and Weldon Spring.

The computer group worked with punch card records, creating average radiation records for the different departments and keeping records on the individual workers. These punch cards were a part of the records that NIOSH found. Radiation and medical records were kept by various forms of identification. Some records were identified just by name (last name and first initial); in some cases, different individuals had the same last name and first initial. Some of the records were identified by social security number, and other records were identified by five-digit worker IDs. These five-digit ID numbers cannot conclusively identify an individual worker, because the numbers ran out over time. After the five-digit ID numbers were used up, ID numbers for people who left the plant were subsequently reassigned to different workers.

Some interviewees have had a very difficult time getting their dose records assessed. Even when a worker had extensive records, they encountered road blocks in terms of obtaining and completing appropriate forms, or ran into issues with the exchange of dose-related information between DOE and NIOSH.

Some workers suspect there were issues with contaminated records, because the ventilation system blew the material into the Administrative Building. There were problems with contamination at the site. There were some unclassified documents destroyed towards the end of WS. They were taken out and burned onsite. There are witnesses to this activity.

Some workers were able to obtain radiation monitoring records by requesting them from Oak Ridge, Tennessee. However, not all workers or survivors have received the records requested. In other cases, there are indications that information is left out of the files received by workers.

At an Advisory Board meeting, the Ph.D. in charge of dose reconstruction indicated that they could do dose reconstruction even though there were so many records missing by using coworker data or other data. Workers at WS question this approach, because science should rely on accurate data.

Every operation had a logbook that would contain detailed information about the process. Workers recorded times for various steps of the process; receipt of acid, addition of acid, etc. Unusual occurrences would also be recorded in the logbook. Anything the workers thought should be in it would be written in it. In the case of maintenance, the foreman in the area would write a work order. They would bring it over to the Shop Foreman, who would assign the daily tasks.

When safety studies were conducted on the green salt plant, a report documenting this study would have been produced. It would describe when the study was done and who performed it. Routine monthly H&S reports would document all of the activities conducted. There were classified documents related to operations, and in some cases, some material in the H&S reports.

There was a Document Control group that maintained document inventories and kept track of the books and technical reports in the library. Any documents forwarded to this group were tracked.

Data completeness is a key issue that needs to be dealt with in the site profile. There is some information on the number of workers at the site (MCW/WS), but interviewees are not convinced that NIOSH has complete information on the total worker population. Without definitive knowledge of the population, how can they determine how well the available monitoring data actually represent the whole population?

When they first started discussing MCW, NIOSH was asked to identify what percentage of workers had complete records of all internal and external monitoring. After about 2 years, NIOSH indicated they had complete records for about 20% of MCW workers (2,542 white males). This data was from the Comprehensive Epidemiological Data Resource dataset for the MCW Cohort Mortality Study (Dupree-Ellis et al. 2000), which included workers from both WS and MCW-Destrehan. The site profile needs to include the sex and race statistics for the MCW and WS work forces. It also needs to identify the percentage of the individuals *in each race and* *gender* for each facility. The MCW Cohort Mortality Study (Dupree-Ellis et al. 2000) abstract reads as follows:

> *In a study of 2,514 White male workers employed between 1942 and 1966 at a US uranium processing plant, mortality was compared with overall US mortality, and the relation between external ionizing radiation and cancer was evaluated. Through 1993, 1,013 deaths occurred. The mean cumulative dose was 47.8 mSv. The standardized mortality ratio (SMR) was 0.90 for all causes of death and 1.05 for all cancers. Many cancer sites had elevated SMRs. Among nonmalignant outcomes, the SMR for chronic nephritis was 1.88 (six deaths observed). An excess relative risk estimate of 10.5 per Sv (10 cases) was observed for kidney cancer; this may have resulted from chance, internal radiation, or chemical exposures not considered.*
>
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POST-PRODUCTION ERA

It is too simplistic to think of the site as a whole when doing dose reconstruction. NIOSH needs to consider dose reconstruction in terms of periods of time.

The uranium production period ended in 1966, with the possibility of some work in 1967. In 1967, the DOE turned the site over to the Army for making Agent Orange. Did the legal ownership transfer from the DOE to the Army? The key word here is ownership. The site profile refers to “transfer” that is not equivalent to “transferred ownership” or “transferred the deed…” Did the DOE cease to own the facility in 1967? On the federal facility database, the coverage excludes the years 1967–1974 (Department of Health and Human Services (HHS) energy.gov facilities data), resuming in 1975 and continuing for the remediation period at the site. However, the site profile mentions that the Army controlled the site during 1967–1984. These two statements need to be reconciled. The AEC/ERDA [Energy Research and Development Administration] owned the site. The contamination and equipment were in place throughout this period of time. The site profile should investigate the rationale for not covering 1967–1974. Further re-reading of the site profile reveals an additional lack of clarity regarding when the site was transferred back from the Army to DOE; did this happen in 1969, in 1984, or at some other time? It is understood that these are DOE questions, but they deserve some attention.

The definition of the covered period in the site profile is confusing. This is because the necessary investigative work has not been done on site deed transfers to document land and property transfers between AEC/ERDA/DOE, Missouri Conservation Department, Missouri Department of Natural Resources (Katy Trail, supervisor), and the Department of Defense (DOD). There should be records filed with the county, state, etc., to document the transfer of site control and/or ownership to various parties. There are probably piles of documents, including letters. What source documents track these property transfers, and where are they located? The St. Charles County Recorder of Deeds would probably be the best place to start looking. Yvonne Deyo (current Weldon Spring site manager), the Long-Term Surveillance and Maintenance

(LTSM) plan section on Institutional Controls, and the DOE Office of Legacy Management should all be consulted on this important matter of ownership. [Name], who was formerly associated with Weldon Spring Ordnance Work for 16 years, is another highly knowledgeable person who could be interviewed about these matters. Dan Brown, head of the St. Charles Historical Society, wrote a book titled, *Small Glories*. During his research, he went through newspaper articles related to Weldon Spring and dug out all the legal documents. This book describes the land transactions.

Post-Production Exposure Concerns

The period between 1967 and 1969 should especially be considered for dose reconstruction. One WS site expert has been in contact with a construction worker who was on site from 1967–1969. At the time, Thompson-Stearns-Rogers (TSR, Inc.), based in Denver, Colorado, was the prime contractor at the site. This company was a merger of Stearns-Rogers (Denver) and Thompson (St. Louis). There were about 300 construction workers, hired out of the local labor market, working at the WS site during that period. The Weldon Spring site timeline posted at the Interpretive Center (document is online) mentions T-S-R.

The worker who provided information to the WS site expert worked in several former uranium production buildings. His job was to dig up the brick floor and replace it with a concrete floor. Part of the job involved washing down the area. The worker indicated that yellow cake would trickle down between the bricks and stay there. They had to beat the bricks up to get them out. In the process, they found chunks of yellow cake, which they handled with bare hands. The T-S-R workers put in a concrete floor with an extra layer of concrete.

The workers digging up the bricks were dressed in regular clothes with boots. Initially, boots were left on site, but later, they could be taken home. In the same area, some people were dressed in protective gear with masks (i.e., moon suits). The worker thought these people were monitors; sometimes they would take him out of the building and tell him to stay out. The individuals in the "moon suits" and the employees working on the bricks were in the same area (breathing space). There was little communication between the workers and the monitors. The worker's descriptions seemed to reflect that the operations were monitored, but the WS site expert did not know what company would have employed the monitors.

The worker in question now has a burning sensation in his feet and a number of other symptoms. These symptoms are similar to those seen following high skin doses of external radiation; the condition is well described in the textbook, *Radiation Pathology* [Fajardo et al. 2001]. It appears likely (in a physician's judgment) that this worker's symptoms were due to yellow cake-induced radiation injury rather than to any pre-existing peripheral vascular disease. The construction worker told his story to the state in Jefferson City, Missouri. X-rays were taken, and an examination was completed. The worker requested records from this exam, but was told they were lost.

The worker had worn a film badge on his chest, although the exposure source he encountered was on or under the floor. The worker did not recall any bioassay having been done for him, and he did not receive a dose report based on his film badge reading. This worker had not requested his records from the DOD as of the time when the site expert was interviewed. The site expert stated that there should be some high level requesting by Department of Labor (DOL) for records collected by DOD. There is a provision in the EEOICPA (section 7384w) to subpoena records.

The WS site expert suggested that SC&A should interview the worker, who has expressed willingness to talk about his Weldon Spring experience. If TSR, Inc. is still in business in Denver, they might be a good source of additional information. In addition, the worker interacted extensively over 2 years with a reporter and was featured in a series of seven articles on MCW-WS published by the St. Louis Post-Dispatch in February, 1989. The reporter and her two co-reporters might also be good candidates for interviews in regard to the WS site profile.

The WS site expert is not aware of anyone who worked at Weldon Spring from 1967–1969 who has developed cancer and filed a claim. DOL could easily answer this question, but the Privacy Act is used to shield such information from individuals who have a real need to know. For example, citizens are not allowed to have a list of employees from the site. Getting this information from DOL should be an integral part of investigating Weldon Spring Site (WSS) ownership during the "Herbicide/Agent Orange DOD period" and thereafter during the entire period that AEC/ERDA/DOE owned WSS.

The extent of the work that was done from 1975–1986 deserves more elaboration. There was a lot going on, and the monitoring program was very active during this period. Some projects conducted during that time presented a potential for much larger exposures. Ground water is a proxy for what was going on. There were levels of uranium at 12,000 pCi/liter in one well (Burgermeister Spring well 6303) used for offsite monitoring.

In 1983–1984, Bechtel was the general contractor responsible for the WS quarry and raffinate pits. The site profile referred to this as the site monitoring period. In order to do an adequate job, they had to do a finer grain analysis. Raffinate Pit 4 developed a leak, and the contaminated sludge spilled over into the Department of Conservation land. Bechtel hired Banghart [may be spelled Bangart] Brothers Company (a trucking Company); their workers went down in the raffinate sludge. Although they had a contract with Bechtel, the trucking company (subcontractor to Bechtel) would not admit employment during this time. A platform with a shower head was built, which was very unusual. On this particular job, a crew of three to four guys stayed in the same area the entire time, which was unusual. They wore workman's clothes, boots, and light gloves. They did not wear respirators, and they were not monitored during this time period.

SITE PROFILE/DOSE RECONSTRUCTION COMMENTS

There are a number of deficiencies in the Weldon Spring site profile:

(1) MULTIPLE URANIUM METAL AND URANIUM METAL ALLOYS WERE PRODUCED AT WELDON SPRING. It has become clear that the uranium metal source terms at Weldon Spring and the processing done to the billets and dingots have not been accurately and fully characterized. Interviewees intend to transmit this information in more detail to the TBD-6000 work group. The dimensions, weight, and exact chemical composition of each of these metallic forms needs to be described in detail, in order to

assign a correct radiation dose to those handling the forms with widely varying geometries.

(2) THE URANIUM METALLURGY EQUIPMENT TO PRODUCE THE VARIOUS PURE URANIUM AND URANIUM ALLOY FORMS WAS NOT ADEQUATELY DESCRIBED. The WS site profile mentions that alpha and gamma phase extrusion of uranium metal billets took place. It is not clear whether all or some of the gamma phase extrusion took place at the St. Charles facility. It is known that the AEC contract between MCW and Dow Chemical during 1957–1960 was, in part, for gamma phase R&D extrusion of uranium metal at Dow Chemical in Madison, Illinois. It is apparent from the WS profile that uranium extrusion was a cost center, implying that WS possessed extrusion presses. The physical characteristics (tonnage, manufacturer, year installed, etc.) do not appear to be described in the WS site profile. Whether or not the extrusion press(es) had vacuum accessories to collect the uranium dust during operation is very important to calculating operator radiation doses. Some such extrusion equipment had vacuum attachments, whereas some (e.g., Dow Madison plant) did not. Operators of extrusion presses that lacked vacuum accessories would receive high dust inhalation doses compared to operators of presses that were equipped with vacuums.

(3) NON-DESTRUCTIVE TESTING (NDT) AND NDT TESTING EQUIPMENT USED AT WELDON SPRING WAS INCOMPLETELY DESCRIBED. The statement can be supported that any and all facilities that produced heavy metal castings, extrusions, welded forms, and rolled products needed to be inspected by NDT methods. Ultrasonic testing is only briefly described in the WS site profile. Due to the high density of uranium metal, gamma photon (Co-60, Ir-192) or x-ray (Betatron, flash x-ray) radiography would be necessary to penetrate and image it. The same would be true for thorium metal products. The site profile should contain a complete description of all equipment used to cast, roll, extrude, or machine uranium and thorium metal, because operators of such equipment would be exposed to residual radioactivity of the equipment they operated. Job descriptions and Cost Center allocations of such jobs should also be recorded in the appropriate site profile tables.

(4) CONTRACT WORK WITH GSI AND DOW-MADISON ARE POORLY DESCRIBED AND DOCUMENTED IN THE SITE PROFILE. It is known that MCW had an AEC contract with General Steel Industries (GSI) to provide high energy (24–25 Mev) x-ray services as part of the MCW Uranium Division quality control program. However, the site profile section on WS NDT subcontractor work at GSI between 1957 and 1966 is very weak. No contract records have survived or been recovered at DOE except some relevant purchase orders from 1958 to 1966 (Considered Sites Database). Vital records, such as NDT technical reports, shipping manifests to GSI and Dow in Illinois, GSI Betatron shot records, and inspection reports in the form of Betatron x-ray interpretations have all been lost. Such information should be included in the WS site profile.

In particular, more detail is needed regarding subsequent handling of uranium that came back to the site after Betatron irradiation. When heavy metals (including U-238 and Th-232) are exposed to a 24–25 MeV beam, there is activation and some production of fission products. Some of the fission products and radioactive daughters have longer half-lives than 15 minutes. Worker exposures would depend on how quickly the Betatron-irradiated uranium was turned around and returned to WS. Weldon Spring was aiming for 100% purity when they cast uranium metal, but they actually achieved 97%–99% purity. There was also experimental work going on related to alloying of uranium [see Leaders et al. 1953 and Weakley 1963].

Workers are disenchanted with the dose reconstruction and compensation program for several reasons:

- Many former workers take exception to the dose reconstruction process, because they feel there isn't enough data. NIOSH needs to be using factual data rather than estimates. They create a process based on presumptions rather than facts. In some cases, NIOSH used surrogate data to determine a claimant's exposure. Some individuals continue to have difficulty finding records of their employment at facilities.

- It has taken a very long time to reach the point of denial. There are people who are alive and probably could use the money for medical expenses, but they are not getting it, because it is taking so long.

- NIOSH has given the benefit of the doubt to the company rather than the claimant. These individuals are low on the totem pole in terms of response to their needs. It is incomprehensible how you can spend $900 million to clean up a site, just in case it might be dangerous, and then tell the workers they have to prove they were exposed to something dangerous.

- Even when a claimant gets paid, many doctors will not accept the medical card. Doctors say there is too much red tape in the program.

NIOSH has not improved the dose reconstruction process through input provided by workers. There has been no formal response provided to some attendees at the WS worker outreach meeting. NIOSH could do a lot better in responding to former worker concerns. They seem to take the information and not do anything with it, especially not in a timely manner.

There were four to five meetings about MCW. A major fraction of the individuals who talked worked at both locations [Destrehan and WS]. There were two outreach meetings held by NIOSH representatives. The write-up of these meetings that was released as the public record is very poor and incomplete. These meetings were video taped. NIOSH needs to be producing verbatim transcripts.

MISCELLANEOUS COMMENTS

- Workers were exposed to chemicals, such as nitric acid, sulfuric acid, beryllium, magnesium, arsenic, asbestos, chromium, ionium, and uranium. There were problems with workers getting burns by walking by the nitric acid because of the fallout coming out of the gas stacks. Workers also complained about their eyes watering in certain areas.

- Workers wore rubber gloves in the green salt plant, where there was danger of hydrofluoric acid exposure. Strong acid would produce a noticeable burning sensation, but weak acid could remain on the skin for up to 8 or 9 hours without the worker knowing it was there. One worker exposed his finger to a strong acid and when he got home, his finger started to tingle. He called the plant and they sent him down to the hospital. He suspected he had cross-contaminated his finger when he picked up the glove to dispose of it. There was an area about 3/8 inch were it was eaten down. Another worker had his fingers eaten off from acid.

- Dust collected on the insulators and wood cross-arms of the high lines, causing the high voltage power lines to short out.

- In one accident, hydrochloric acid dust hit the transformers of the metal building and blew up the transformer substation.

- Solvents from the plant were recycled.

- Interviewees reported overtime ranging from none to as much as 8 hours per day in some cases. The amount of overtime depended on the worker's position and whether or not operations were proceeding smoothly. If there was an event, there was a higher chance of overtime.

- While employees waited for their security clearances to come through, they were sometimes located at the Destrehan Plant.

- At one point, an automatic attendance system was installed at WS. Badges with holes in them were put into a reader to record the badge number, and a key punch punched the badge number into IBM cards. This allowed the plant to compute the attendance for plant personnel.

- Fernald and Weldon Spring were the same kind of plant. The H&S operations at WS and Fernald were influenced by those at the Destrehan Facility.

- Costs and cash flow influenced the extent of monitoring and the enforcement of safety practices. If the plant was losing too much production, the onus was put on the employee to follow through with appropriate safety measures. This was why the same lax procedures were brought from Destrehan out to WS.

- MCW had a private plant in Hematite, Missouri, where they processed enriched uranium. They had a series of pipes that processed the material. That process was prone to explosions and other problems. There was no collaboration between Hematite and WS.

- Diseases observed in WS workers have included Leiomyosarcoma, colon cancer, breast cancer, adenocarcinoma of the bile duct, and other rare cancers. There are also individuals who suffer from decreased oxygen supply.

- Members of the WS staff visited various DOE sites (i.e., Oak Ridge National Laboratory, Y-12, K-25, Savannah River, and Hanford) throughout the country. One former worker was present at Nevada Test Site on two occasions, in the trenches (8-foot high) half a mile away from the atomic blasts. Individuals in this location wore a steel helmet and sat down on the ground. After they saw the blinding white light, they stood up on a platform and looked down to see the earth popping as the blast came towards them. Then they heard a noise. This worker was also sent to military storage sites.

OTHER MCW FACILITIES (DESTREHAN STREET AND LATTY AVENUE)

In the metals area at Destrehan Plant, a worker could be walking along and hit a piece of uranium with his shoe. The uranium would just skip on concrete and make fire. When cleaning ingots in the break-out area, workers wore rubber gloves; they would reach in with a covered shield and break it with sledge hammers. When the ingot dropped out, a lot of times a spark would get on top of the ingot down below on the conveyor where they hauled it away. That stuff would lay on that conveyor for a couple of hours or so. There was a black oxide and it would ignite and turn red. It would just burn away.

At Destrehan Plant, there were a lot of times when the furnaces would blow out and fill half of the building.

At the time when Destrehan was operating, the uranium metal dropped into a vessel about 8–9 inches high and about 10 inches in diameter. It was called a derby. The derbies were sent elsewhere to be forged into rods. WS was set up to be a more efficient process.

As far as the workers knew they were working on something pretty safe. They would have a safety meeting and they would come in at Destrehan and tell workers they had to find something wrong. This was more or less a joke.

At Destrehan, they had a building called 7E. They were manufacturing plutonium, and people were saying it was for the H bomb. In this particular building, the contamination control was tighter. Tools taken into the building could not be removed. When a worker exited the area, they had to check their hands. If the worker got a certain reading, they had to go over and scrub their hands and then recheck them.

At the Destrehan plant, they referred to "the place across the street." If you had to go into that area to work on a pump, you had to dip your tools in neutralizer and put them in a barrel. They were hauled out to the airport to the raffinate pit.

Bioassay monitoring and air sampling were not routine at Destrehan.

At Destrehan, when they had raffinate, they trucked it out to Latty Avenue by the airport, and they dumped that stuff right there. On several occasions, the waste came out of a particular building where it had been dumped into something like a big swimming pool. Stuff started coming out of there. Coldwater Creek went right through there; when we had a big rain, that stuff would go down into Coldwater Creek. The material was transported from Destrehan to Latty Avenue in regular dump trucks. If they put any type of liner in there, it was like paper, and stuff was visibly dripping out as the truck went down the road to the Latty Avenue site. They kept this up for a number of years. Sometimes they would go out to Latty Avenue, pick the material up, and bring it back to Destrehan to rerun it again.

Latty Avenue runs into Airport Road and Banshee Road that run right across Boeing. One time, over on the airport side, they built Building 66 for Boeing. They transported the excavated dirt over to Latty Avenue and dropped it in there. Apparently, some kids made a baseball field out of the area, and a couple of kids were not feeling right. The stuff had dried out and the wind carried it off.

There was a burial site at the St. Louis airport. They transported barrels in trucks down to the airport for burial. There was a dirt pile by the airport containing this waste. They have moved the pile to Berkley, Missouri. Prior to moving the pile, they sent crews of laborers down to dig up the radioactive material. Security personnel who were there on a rotational basis were monitored, but the laborers doing the digging were not monitored. The radiation level was very high.

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