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November 10, 2006

Mr. David Staudt
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Subject: Contract No. 200-2004-03805, Task Order 1: *Review of the NIOSH Site Profile for the Fernald Environmental Management Project (Feed Materials Production Center),* SCA-TR-TASK1-0010

Dear Mr. Staudt:

SC&A is pleased to summit to NIOSH and the Advisory Board draft report SCA-TR-TASK1-0010, *Review of the NIOSH Site Profile for the Fernald Environmental Management Project (Feed Materials Production Center).* This site profile review covers the six volumes of the Fernald TBD; ORAUT-TKBS-0017-1 though ORAUT-TKBS-0017-6.

This review was carried over from FY 2006. With this report, all of the tasks assigned to SC&A in FY 2006 are now complete.

We look forward to discussing this draft report with the Working Group, NIOSH, and the full Advisory Board at any time that the Board takes up matters related to Fernald. Please let me know if you have any questions.

Sincerely,

John Mauro, PhD, CHP
Project Manager

cc: P. Ziemer, PhD, Board Chairperson
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ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute of Occupational Safety and Health

Review of the NIOSH Site Profile for the Fernald Environmental Management Project (Feed Materials Production Center)

Contract No. 200-2004-03805
Task Order No. 1
SCA-TR-TASK1-0010

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November 2006

Disclaimer

S. COHEN & ASSOCIATES: *Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program*	Document No. SCA-TR-TASK1-0010 Effective Date: Draft – November 10, 2006 Revision No. 0 – (Draft)
REVIEW OF THE NIOSH SITE PROFILE FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT (FEED MATERIALS PRODUCTION CENTER)	Page 2 of 169
Task Manager: __________________________ Date: ____________ Arjun Makhijani, PhD	Supersedes: N/A
Project Manager: __________________________ Date: ____________ John Mauro, PhD, CHP	

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ACRONYMS AND ABBREVIATIONS

Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
Al	Aluminum
Anti-Cs	Anti-contamination Clothing
AP	Anteriorposterior
AWE	Atomic Weapons Employer
BZ	Breathing Zone
CDC	Centers for Disease Control and Prevention
CFR	*Code of Federal Regulations*
Ci	Curie
DCF	Dose Conversion Factor
DF	Decontamination Factor
DL	Decision Level
DOE	Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
dpm	Disintegrations per minute
DU	Depleted Uranium
DWA	Daily Weighted Average
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
EPA	Environmental Protection Agency
ES&H	Environmental Safety and Health
EU	Enriched Uranium
FEMP	Fernald Environmental Management Project
FMPC	Feed Materials Production Center
FY	Fiscal Year
GA	General Area
GAO	Government Accountability Office
GE	General Electric
GI	Gastrointestinal
H&S	Health and Safety
HASL	Health and Safety Laboratory

HF	Hydrofluoric
HP	Health Physics or Health Physicist
HVL	Half-Value Layer
ICRP	International Commission on Radiological Protection
IH&R	Industrial Hygiene and Radiation Department
IIF	Incident Investigation Form
IMBA	Integrated Modules for Bioassay Analysis
INEL	Idaho National Engineering Laboratory
IREP	Interactive RadioEpidemiological Program
K-65	Pitchblende Uranium Ore from Congo containing high concentrations of Ra-226
LOD	Limit of Detection
MAC	Maximum Allowable Concentration
MDL	Minimum Detectable Level or Minimum Dose Limit
MIVRML	Mobile In-Vivo Radiation Monitoring Laboratory – ORNL Y-12
MCW	Mallinckrodt Chemical Works
MeV	Mega-electron Volts
MPLB	Maximum Permissible Lung Burden
mrem	millirem
mrep	millirep
mr	milliroentgen
MTU	Metric tons uranium
NAS	National Academy of Sciences
NCRP	National Council on Radiation Protection and Measurements
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
NLO	National Lead of Ohio
NTS	Nevada Test Site
NU	Natural Uranium
NuSal	Neutral Salt
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
OU3	Operable Unit 3

PAS	Personal Air Sampler
pCi	Picocurie
PCM	Personnel Contamination Monitors
ppb	Parts per billion
PFG	Photofluorography
Piketon	Portsmouth Gaseous Diffusion Plant
POC	Probability of Causation
POOS	Plutonium Out of Specifications
PPE	Personal Protective Equipment
RAC	Radiological Assessments Corporation
RCS	Radon Control System
RCT	Radiological Control Technician
rem	Roentgen equivalent man
REMS	Radiation Exposure Monitoring System
RMI	Reactive Metals, Inc.
RTR	Real Time Radiography
RTS	Radon Treatment System
RU	Recycled Uranium
RWP	Radiation Work Permit
SC&A	S. Cohen and Associates
SEC	Special Exposure Cohort
SRPD	Self Reading Pocket Dosimeters
SRS	Savannah River Site
STC	Strong tight container
TBD	Technical Basis Document
ThF_4	Thorium tetrafluoride
ThO_2	Thorium dioxide
TIB	Technical Information Bulletin
TLD	Thermoluminescent Dosimeter
TRU	Transuranics
TTA	Transfer Tank Area
U	Uranium

U_3O_8	Black Oxide
UAP	Uranyl ammonium phosphate
UF_4	Green Salt or uranium tetrafluoride
UF_6	Uranium hexafluoride
UNH	Uranyl Nitrate Hexahydrate
UO_3	Orange Oxide
WL	Working Level
WLM	Working Level Month

1.0 EXECUTIVE SUMMARY

This report presents the S. Cohen and Associates (SC&A, Inc.) evaluation of the site profile, *Technical Basis Document for the Fernald Environmental Management Project* (ORAUT-TKBS-0017), which was published in six volumes numbered ORAUT-TKBS-0017-1 through ORAUT-TKBS-0017-6, inclusive, referred to in this report as the Fernald Technical Basis Document (TBD), Volumes 1 through 6, or the Fernald Site Profile, Volumes 1 though 6. This review covers all six volumes of the Fernald TBD. It includes a review of related Fernald records and documented exchanges with the National Institute of Occupational Safety and Health (NIOSH) and Oak Ridge Associated Universities (ORAU) through questions sent by SC&A (Attachment 1), written answers from NIOSH and its contractors (Attachment 2), and a conference call with NIOSH and its contractors (Attachment 3). This review also includes interviews with site experts conducted by SC&A at Fernald (Attachment 4). This report was prepared at the request of the Advisory Board on Radiation and Worker Health (Advisory Board). SC&A is the technical support contractor of the Advisory Board.

The Fernald TBD was evaluated for its completeness, technical accuracy, adequacy of data, compliance with stated objectives, and consistency with other site profiles, as stipulated in the *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). As "living" documents, TBDs are constantly being revised as new information, experience, or issues arise. The results of reviews of other documents by SC&A, including reviews of other TBDs and of NIOSH procedures (SC&A 2005d), have been incorporated into the present report as appropriate.

This report is a review of Rev. 00 of the Fernald TBD, except for Volume 4, for which Rev. 01, published in February 2006, was reviewed. The five Rev. 00 volumes were published between February 11, 2004, and May 28, 2004. Rev. 01 of Volume 4 relating to environmental dose was published on February 7, 2006. They represent the most recent published version of the Fernald TBD on NIOSH's web site as of May 7, 2006.

Following the introduction and a description of the criteria and methods employed to perform the review, the report discusses the strengths of the TBD, followed by a description of the major issues identified during our review. The issues were carefully reviewed with respect to the following five review criteria specified in SC&A 2004:

(1) Completeness of Data Sources
(2) Technical Accuracy
(3) Adequacy of Data
(4) Consistency among Site Profiles
(5) Regulatory Compliance

1.1 SUMMARY OF STRENGTHS

(1) Volume 1 of the TBD gives a very helpful overview of operations at Fernald without going into technical detail. Volume 2 provides a useful description of Fernald on a plant-by-plant basis, and within that by processes and activities, followed by radiation sources. It is helpful and takes the reader through site operations in a coherent manner.

Furthermore, it is useful to group waste management facilities, activities, and processes, and discuss them after the presentation of operational aspects of the site. The summary of Fernald Environmental Management Project (FEMP) radioactive materials and characteristics is properly placed at the end of the document.

(2) The recommendations with respect to neutron dose reconstruction have been well documented, and make a number of claimant-favorable assumptions.

(3) Available (sparse) data for radioactive dust concentrations (non-radon) during the loading of the K-65 Silo 1 have been used in a claimant-favorable way in the suggested dose reconstruction procedure; however, there are other aspects of K-65 raffinate dose estimation procedure that are not claimant favorable (see Findings 7 and 8).

(4) The use of the anterioposterior (AP) geometry for all working conditions and radiation fields is claimant favorable and is a positive part of the document.

1.2 SUMMARY OF FINDINGS

1.2.1 Highlights

There are some points worth highlighting broadly from the 33 findings below and the analyses pertaining to them in Section 5 and Section 7 of this report.

- The thorium data in the TBD are particularly incomplete in regard to what is available and, as they stand, inadequate for dose reconstruction. The approach to dose reconstruction for thorium in the TBD is not well founded in the available data and not claimant favorable. NIOSH has stated that it has additional data that it will incorporate into a revision of the TBD.
- 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.
- The TBD does not address the extremely high uranium dust concentrations that were associated with certain jobs, locations, incidents, and time periods. The adequacy of uranium bioassay data in terms of the frequency of bioassay needs to be assessed in this context.
- Workers who may have worked with raffinates may be missed by the protocol specified in Vol. 5 of the TBD. The guidelines for determining which workers were exposed to raffinate dusts are too restrictive and place far too great a reliance on completeness of records for job assignments, or in the alternative, place the burden of proof on the claimant. They have not been adequately justified by measurements and are not claimant favorable. There is no dose reconstruction protocol specified relative to the raffinate

streams in Plant 2/3; this may be especially important for employees exposed to raffinate streams from high-grade ore processing, including pitchblende processing.

- Shallow external doses, including dose to the fingers and hands, appear to be underestimated. Correction factors to recorded dose for the differing locations of the organ and badge relative to the source need to be developed for certain jobs and practices.
- The characterization of radon sources is not complete and occupational radon dose estimation is not claimant favorable.
- There is documentation indicating that the source term for uranium used for occupational environmental dose has significant deficiencies and that a higher source term should be used. The main source of occupational environmental dose may be from diffuse uranium and thorium emissions in production areas; this has not been evaluated.

1.2.2 List of Findings

Finding 1: The list of facilities in which thorium-232 was processed, the time periods of thorium processing, and the thorium production data shown in the TBD have significant gaps. Entire periods of processing and plants in which the work was done have been missed. These gaps may affect the feasibility of dose reconstruction for workers for certain time periods and in certain plants.

Finding 2: Air concentration data for thorium in the TBD are sparse and incomplete, though considerably more data are available on the NIOSH Site Research database. The TBD contains no thorium-232 bioassay or in-vivo data.

Finding 3: Thorium intakes due to fugitive emissions and resuspension in production areas may have been significant for some locations and periods. The TBD does not address the issue of fugitive emissions in production areas. Furthermore, the TBD does not provide a method to estimate resuspension intakes in the pre-1986 period and for those workers without lapel air sampling in the post-1986 period.

Finding 4: The guidance in the TBD regarding exposures from redrumming thorium is not well founded and is not claimant favorable.

Finding 5: The TBD has not evaluated exposures due to thorium fires. The TBD has also not evaluated other thorium incidents or failures of industrial hygiene.

Finding 6: The approach suggested for estimating thorium intakes does not reflect the history of production or the available thorium air concentration data. It is likely to result in significant underestimates of internal dose from thorium.

Finding 7: The TBD does not specify a method for estimating doses in the raffinate streams, which are uranium-poor, from ore processing in Plant 2/3. These doses may be very difficult to calculate, especially for high-grade ores, notably pitchblende ore from Congo.

Finding 8: Workers who may have worked with raffinates may be missed by the protocol specified in Vol. 5 of the TBD. The guidelines for determining which workers were exposed to raffinate dusts are too restrictive and place far too great a reliance on completeness of records for job assignments, or in the alternative, place the burden of proof on the claimant. They have not been adequately justified by measurements and are not claimant favorable.

Finding 9: The data on trace contaminants in RU in the Fernald TBD are incomplete and appear to be incorrect. Different official documents have very different values for various aspects of RU data, including production and contamination. The contradictions have not been sorted out in the TBD.

Finding 10: The radionuclide list for RU in the TBD is incomplete. Furthermore, the concentrations of trace radionuclides in the raffinates, which are much higher than those in the feed material, are not adequately discussed.

Finding 11: The suggested approach for RU dose estimation in the TBD is claimant favorable for many RU workers, but not claimant favorable for others and for some periods; it is not based on an evaluation of the available data.

Finding 12: The TBD notes that uranium batches with enrichment greater than 2% were processed at Fernald. NIOSH's assumption of 2% enriched uranium is claimant favorable most of the time, but not for periods and batches when uranium of higher enrichments was processed.

Finding 13: Female employees were not monitored for long periods at Fernald, even though at least some of them were at some risk of internal intakes of radionuclides.

Finding 14: The TBD does not address the extremely high uranium dust concentrations, which were present at Fernald under a variety of circumstances, and their effect on dose reconstruction. Particle size and solubility assumptions for workers who experienced chip fires should be examined.

Finding 15: Ingestion doses are not considered in the TBD.

Finding 16: Protocols for reconstructing shallow external dose during the operations at FEMP need to be further developed.

Finding 17: Extremity doses appear to be underestimated.

Finding 18: Beta dose to the rest of the body would also be underestimated, based on the TBD guidance.

Finding 19: The TBD does not analyze the special problems associated with geometry of the source relative to the exposed organ and dosimeter in thorium handling and production.

Finding 20: Correction factors used during an initial period of use of thermoluminescent dosimeters (TLDs) at Fernald are not scientifically appropriate.

Finding 21: The method for estimating external dose to unmonitored female employees is incomplete and its claimant favorability has not been appropriately demonstrated.

Finding 22: The source term for atmospheric uranium emissions from Fernald is significantly underestimated.

Finding 23: The TBD has not adequately considered various aspects of internal environmental dose, including the applicability of the Gaussian model, episodic releases, and particle size.

Finding 24: Diffuse emissions of uranium and thorium may have produced significant internal exposures for some personnel

Finding 25: NIOSH's modeling of radon dose is not claimant favorable and does not take actual working conditions into account.

Finding 26: NIOSH has not considered a major source of radon dose—the storage source of pitchblende ore onsite near Plant 1.

Finding 27: The TBD does not consider outdoor diffuse emissions in production areas as a source of external environmental dose.

Finding 28: External environmental dose for workers near the K-65 silos needs to be better evaluated.

Finding 29: Occupational internal exposure to radon is estimated based on just two radon data points from 1953. This is an inadequate basis to reconstruct occupational radon dose.

Finding 30: The possible use of photofluorography (PFG) at Fernald in the early years was ruled out in the TBD without adequate documentation. This is contrary to NIOSH general guidance and is not claimant favorable.

Finding 31: The assumption that there was a 15% retake rate for x-rays is not adequately documented or analyzed.

Finding 32: The assumption that there was collimation is not technically justifiable based on the evidence provided in the TBD and is not claimant favorable.

Finding 33: NIOSH has prematurely concluded that lumbar spine x-rays for laborers and construction workers were not conditions of employment. Based on the evidence provided, this assumption is not sufficiently documented and is not claimant favorable.

1.3 OPPORTUNITIES FOR IMPROVEMENT

SC&A suggests that NIOSH evaluate the following suggestions for incorporation into the revised TBD:

(1) Various internal inconsistencies and problems of a factual nature in the TBD identified in this review should be corrected.

(2) All aspects of the estimation of internal thorium-232 dose need to be reconsidered based on a more complete compilation and analysis of the data. Ingestion doses particularly need to be taken into account for thorium dose estimates that are developed only from air concentration data. A model for estimating thorium resuspension doses is also needed.

(3) Clearer criteria for who worked with raffinate waste streams should be developed to ensure that internal dose estimates are scientifically defensible and claimant favorable. The radionuclide ratios to be used for dose reconstruction for raffinate workers also need amendment, including dropping the lead-210 term.

(4) NIOSH should verify whether its use of ORAUT-OTIB-0002 results in a larger dose than intakes from the raffinate waste streams or K-65 waste handling.

(5) NIOSH should undertake a more complete review of RU data and apply them in a manner that ensures that workers who handled the process streams with higher concentrations receive claimant-favorable treatment. Particular attention to the intakes associated with raffinate streams during RU processing is needed.

(6) The use of uranium bioassay as the primary source of data for uranium internal dose reconstruction is appropriate; however, NIOSH should ensure that its assumptions about particle size during events like chip fires are claimant favorable. NIOSH should also check to see if bioassay frequency was sufficient to capture some very high episodic air concentrations, such as those arising from maintenance or repair work. More complete data are needed to determine which batches of uranium processed at Fernald had enrichments greater than 2%.

(7) Specific guidance for internal and external dose reconstruction for female employees should be developed, especially since they were not monitored at all during 1951–1960 and 1969–1978.

(8) A claimant-favorable approach to estimating beta doses to the extremities and to the rest of the body needs to be developed.

(9) An investigation into the external dose of record in employee files for the period between January 1983 and October 1985 is needed, due to inappropriate correction factors that were applied to TLD measurements.

(10) A more complete and thorough approach to environmental dose estimation is needed, including consideration of source terms, episodic releases, diffuse emissions in production areas, and use of models suitable for considering exposures near buildings.

(11) An approach to estimating radon dose that takes more complete account of working conditions and locations should be developed, including consideration of workers near Plant 1 and Plant 2/3, and near the K-65 silos.

(12) NIOSH should attempt to better characterize occupational radon exposures to workers who handled K-65 waste.

(13) If further research that NIOSH is conducting into occupational medical dose does not lead to positive evidence that PFG was not used, dose reconstruction guidance for Fernald should specify an assumption of PFG use from 1951 to 1958.

(14) The assumption that there was collimation in the medical x-ray units from inception of use should be discarded unless new evidence is developed in this regard.

(15) More detailed suggestions for improvement are mentioned or discussed as part of the various findings in Section 5 and the discussion in Section 7 of this review.

2.0 SCOPE AND INTRODUCTION

2.1 REVIEW SCOPE

Under the Energy Employees Occupational Illness Compensation Program Act of 2000 (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 on Radiation and Worker Health (Advisory Board) is mandated to conduct an independent review of the methods and procedures used by the National Institute for Occupational Safety and Health (NIOSH) and its contractors for dose reconstruction. As a contractor to the Advisory Board, S. Cohen and Associates (SC&A, Inc.) has been charged under Task 1 to support the Advisory Board in this effort by independently evaluating a select number of site profiles that correspond to specific facilities at which energy employees worked and were exposed to ionizing radiation.

This report provides a review of the following six technical basis documents (TBDs) related to historical occupational exposures at the Feed Materials Production Center (FMPC), whose name was changed during the decommissioning phase to the Fernald Environmental Management Project (FEMP), and which is commonly known as Fernald or the Fernald Plant:

- ORAUT-TKBS-0017-1, *Technical Basis Document for the Fernald Environmental Remediation Project – Introduction*, Vol. 1, Rev. 00 (Fernald TBD, 2004a)
- ORAUT-TKBS-0017-2, *Technical Basis Document for the Fernald Environmental Remediation Project – Site Description*, Vol. 2, Rev. 00 (Fernald TBD, 2004b)
- ORAUT-TKBS-0017-3, *Technical Basis Document for the Fernald Environmental Remediation Project – Occupational Medical Dose*, Vol. 3, Rev. 00 (Fernald TBD, 2004a)
- ORAUT-TKBS-0017-4, *Technical Basis Document for the Fernald Environmental Remediation Project – Occupational Environmental Dose*, Vol. 4, Rev. 01 (Fernald TBD, 2006)
- ORAUT-TKBS-0017-5, *Technical Basis Document for the Fernald Environmental Remediation Project – Occupational Internal Dose*, Vol. 5, Rev. 00 (Fernald TBD, 2004d)
- ORAUT-TKBS-0017-6, *Technical Basis Document for the Fernald Environmental Remediation Project – Occupational External Dosimetry*, Vol. 6, Rev. 00 (Fernald TBD, 2004e)

These documents are referred to in this review as Fernald TBD Vols. 1 through 6. There were no technical information bulletins (TIBs) specific to Fernald that had been published as of the end of July 2006. SC&A also reviewed a variety of literature, including that on the NIOSH Site Research database, GAO report, historical documents (including those available from the worker and offsite litigation at Fernald), and Congressional Hearings. SC&A, in support of the

Advisory Board, has critically evaluated the Fernald TBDs and supplementary and supporting documents in order to:

- Determine the completeness of the information gathered by NIOSH, 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 guidelines for the use of the data in dose reconstructions

SC&A's review of the six volumes that comprise the TBD, along with its supporting supplemental documentation, focuses on the quality and completeness of the data that characterized the facility and its operations, and the adequacy of these data in dose reconstruction. The review was conducted in accordance with *SC&A 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 dose reconstructions, bridging uncertainties, or correcting technical inaccuracies. This review does not explicitly address the issue of radiation exposures to cleanup workers and decommissioning workers, as that is not addressed in the TBDs.

The six volumes of the Fernald TBD are supposed to serve as site-specific guidance documents to be used in support of dose reconstructions. While dose reconstructors use other data, information, and guidance documents in making dose estimates, the purpose of site profiles is to provide dose reconstructors 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 the various types of dose reconstruction estimates that NIOSH performs—minimum for compensation only; maximum, with worst-case assumptions to be used for denial only, and "best-case" or "reasonable" dose estimates to be used for both compensation and denial, according to the probability of causation (POC) corresponding to the dose estimate. The criteria for evaluation include whether the TBDs provide a basis for scientifically supportable and claimant-favorable dose reconstructions that systematically resolves uncertainties in favor of the claimant as required by 42 CFR 82, which is the regulation governing the dose reconstruction process.

The basic principle of dose reconstruction is to characterize the radiation environments to which workers were exposed, and determine the levels of exposure the workers received in those environments 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.

The review of Fernald has some precedent in prior SC&A reviews of NIOSH TBDs, as well as the process of comment resolution regarding those TBDs initiated by the Advisory Board. This is especially true regarding certain aspects of Fernald dose reconstruction, such as that relating to thorium exposures (Mallinckrodt and Y-12), K-65 silo materials (Mallinckrodt), recycled uranium (RU) (various TBDs), ingestion, resuspension, and clothing contamination.

2.2 REVIEW APPROACH

SC&A's review of the TBDs and supporting documentation concentrated on determining the completeness of data collected by NIOSH, the adequacy of Fernald personnel and environmental monitoring data, and the evaluation of key dose reconstruction assumptions. Site expert interviews were conducted with current and former Fernald workers.

All review comments apply to the versions of the Fernald TBD cited above, since they are the most recent published versions.

In May 2006, SC&A sent questions to NIOSH as part of its evaluation of the TBD. These questions are reproduced in Attachment 1. ORAU sent written responses to the comments in August. They are reproduced in Attachment 2. A conference call was held with NIOSH and contractor personnel. A summary of that conference call is included here as Attachment 3.

Site expert interviews were conducted to help SC&A obtain a comprehensive understanding of the radiation protection program, site operations, and environmental contamination. The site experts included current and former staff from radiation control, operations, environmental monitoring, maintenance, security, and other support organizations. Attachment 4 provides an integrated summary of the interviews conducted by SC&A. These interviews were conducted during the course of the Fernald Site Profile Review. The summary is a paraphrase of conversations held with a number of site experts, rather than a verbatim transcript. Their statements have been grouped into categories to provide a linkage with various portions of the Fernald Site Profile. References to the names of specific site experts have been omitted for privacy reasons. These individuals were given the opportunity to review the interview summary for accuracy. This is an important safeguard against missing key issues or misinterpreting some vital piece of information.

While none of the interviews were classified, they were submitted to the DOE along with the summary in Attachment 4 for declassification review as a precautionary measure.

2.3 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) Assessment Criteria and Methods
(4) Site Profile Strengths
(5) Findings
(6) Observations
(7) Overall Adequacy of the Site Profile as a Basis for Dose Reconstruction

Based on the issues raised in each of these sections, SC&A prepared a list of findings, which are provided in the Executive Summary. Issues are designated as 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. These findings are not meant to be exhaustive, but rather issues of dosimetric significance that SC&A investigated in more detail in order to develop suggestions for improvement of any revisions to the Fernald TBD and for use in dose reconstruction, as appropriate. Issues can also be designated as observations if they simply raise questions, which, if addressed, would further improve the TBDs and might possibly reveal deficiencies that would need to be addressed in future revisions of the TBDs.

3.0 ASSESSMENT 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 Fernald Site Profile; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms and exposure conditions. Similarly, we have drawn on prior SC&A reviews and scientific discussions with the Working Group of the Advisory Board and NIOSH and its contractors relating to similar issues at other sites.

3.1 OBJECTIVES

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

3.1.1 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 include (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, and (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile. For example, if data are available in site technical reports or other available site documents for particular processes, and if the TBDs have not taken into consideration these data where they should have, this would constitute a completeness of data issue. The ORAU site profile document database, including the referenced sources in the TBDs, was evaluated to determine the relevance of the data collected by NIOSH to the development of the site profile. Additionally, SC&A evaluated records publicly available relating to the Fernald site and some of the records that were part of the Fernald Special Exposure Cohort (SEC) Petition. SC&A also reviewed some Fernald claimant files in order to examine how the data and the TBD were being applied in practice and coordinated parts of this review with Task 4 of this project, under which SC&A is auditing individual dose reconstructions.

3.1.2 Objective 2: Technical Accuracy

SC&A reviewed the site profile with respect to Objective 2, which 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 Fernald. The goal of this objective is to first analyze the data according to sound scientific principles, and then to evaluate this information in the context of dose reconstruction. If, for example, SC&A found that the technical approach used by NIOSH was not scientifically sound or claimant favorable, this would constitute a technical accuracy issue.

3.1.3 Objective 3: Adequacy of Data

SC&A reviewed the site profile with respect to Objective 3, which 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 thus 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.

3.1.4 Objective 4: Consistency among Site Profiles

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

3.1.5 Objective 5: Regulatory Compliance

SC&A reviewed the site profile with respect to Objective 5, which 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 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 (or minimized dose(s)) corresponds to a POC value in excess of 50%, and assures compensability to the claimant. Such partial/incomplete dose reconstructions with a POC greater than 50% may, in some cases, involve only a limited amount of external or internal data. In extreme cases, even a total absence of a positive measurement may suffice for an assigned organ dose (based on limits of detection (LOD)) that results in a POC greater than 50%. For this reason, dose reconstructions in behalf of this category may only be marginally affected by incomplete/missing data or uncertainty of the measurements. In fact, regulatory guidelines recommend the use of a partial/incomplete dose reconstruction, the minimization of dose, and the exclusion of uncertainty for reasons of process efficiency, as long as this limited effort produces a POC of greater than or equal to 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, to satisfy this type of a dose reconstruction, the TBD must, at a minimum, provide information and data that clearly identify (1) all potential radionuclides, (2) all potential modes of exposure, and (3) upper limits for each contaminant and mode of exposure. Thus, for external exposures, maximum dose rates must be identified in time and space that correspond to a worker's employment period, 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 under 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 Part 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.]

Fernald TBD Vol. 1, ORAUT-TKBS-0017-1, *Technical Basis Document for the Fernald Environmental Management Project – Introduction*, explains the purpose and the scope of the site profile. It also explains the role of each TBD in support of the dose reconstruction process. During the course of its review, SC&A was cognizant of the fact that the site profile is not required by the EEOICPA or by 42 CFR Part 82, which implements the statute. Site profiles were developed by NIOSH as a resource for identifying site-specific practices, parameter values, and factors that are relevant to dose reconstruction. Based on information provided by NIOSH personnel, SC&A understands that site profiles are "living" documents, which are revised, refined, and supplemented with TIBs, as required, to help dose reconstructors. Site profiles are not intended to be prescriptive nor necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. Hence, the introduction helps in framing the scope of the site profile.

Fernald TBD Vol. 2, ORAUT-TKBS-0017-2, *Technical Basis Document for the Fernald Environmental Management Project – Site Description*, is a very important document, because it provides a description of the facilities and processes, including historical information that serves as the underpinning for the specific dose estimation volumes of the Fernald TBD. It also provides air concentration and other data relating to the Fernald site.

Fernald TBD Vol. 3, ORAUT-TKBS-0017-3, *Technical Basis Document for the Fernald Environmental Management Project – Occupational Medical Dose*, provides a set of procedures for reconstructing the radiation exposures of workers from medical radiographic procedures that were required of employees at the Fernald site.

Fernald TBD Vol. 4, ORAUT-TKBS-0017-4, *Technical Basis Document for the Fernald Environmental Management Project – Occupational Environmental Dose*, provides background information and guidance to dose reconstructors for reconstructing the doses to workers who may have been exposed to routine and episodic airborne emissions from the facilities when they were outdoors at the site. It also includes an evaluation of dose from radon, emitted from the K-65 silos, and its radioactive decay products. SC&A reviewed this section from the perspective of the source terms and the atmospheric transport, deposition, and resuspension models used to derive the external and internal doses to these workers.

Fernald TBD Vol. 5, ORAUT-TKBS-0017-5, *Technical Basis Document for the Fernald Environmental Management Project – Occupational Internal Dose*, presents background information and guidance to dose reconstructors for deriving occupational internal doses to workers. This section was reviewed with respect to background information and guidance regarding the types, mixes, and chemical forms of the radionuclides that may have been inhaled or ingested by the workers; the recommended assumptions for use in reconstructing internal doses based on whole-body counts and bioassay data; the methods recommended for use in the reconstruction of missed internal dose; and the methods recommended for characterizing uncertainty in the reconstructed internal doses. Some attention is also paid to intakes via wounds.

Fernald TBD Vol. 6, ORAUT-TKBS-0017-6, *Technical Basis Document for the Fernald Environmental Management Project – Occupational External Dose*, presents background information and guidance to dose reconstructors for deriving occupational external doses to workers. This section was reviewed with respect to background information and guidance regarding the different types of external radiation (i.e., gamma, beta, and neutron) and the energy distribution of this radiation to which the workers may have been exposed. SC&A also reviewed the recommendations for converting external dosimetry data to organ-specific doses, the methods recommended for use in the reconstruction of missed external doses, and the methods used for applying correction factors to the measured dose.

It is important to note that SC&A's review of the Fernald TBD is not exhaustive. The findings are oriented to in-depth consideration of selected issues that SC&A has concluded have a potentially significant impact on either the scientific soundness of the dose reconstruction process or the claimant favorability of the result of the estimation procedure. In all its reviews, SC&A uses the same general criteria in evaluating adequacy of data or completeness of the data search by NIOSH. These are large, complex documents, and SC&A used its judgment in selecting those issues that we believe are important with respect to dose reconstruction.

There are three levels of review for this report. First, SC&A team members reviewed the report internally. Second, SC&A consultants who had not participated in the preparation of this report were asked to review all or portions of the report, according to their specializations. The third level, referred to as the expanded review cycle, will consist of a review of this draft by the Advisory Board and NIOSH. The first two of these have been completed prior to submittal of this report to the Advisory Board.

The usual procedure, after the Advisory Board and NIOSH have had an opportunity to review the draft report, is a comment resolution process, for which a public record is maintained. The Advisory Board usually initiates this, in order to resolve as many of the issues as possible and for any outstanding differences to be transparent.

4.0 SITE PROFILE STRENGTHS

In developing a TBD, the assumptions used must be fair, consistent, and scientifically robust, and uncertainties and inadequacies in source data must be explicitly addressed. The development of the TBD must also consider efficiency in the process of analyzing individual exposure histories, so claims can be processed in a timely manner. With this perspective in mind, we identified a number of strengths in the Fernald TBD. These strengths are listed below.

4.1 INTRODUCTION TO THE TBD

Volume 1 of the TBD gives a very helpful overview of operations at Fernald without going into technical detail.

4.2 SITE DESCRIPTION

As a general point, the organization of the description on a plant-by-plant basis, and within that, by processes and activities, followed by radiation sources, is very helpful and takes the reader through site operations in a coherent manner. Furthermore, it is useful to group waste management facilities, activities, and processes, and discuss them after the presentation of operational aspects of the site. The summary of FEMP radioactive materials and characteristics is properly placed at the end of the document.

4.3 AIR CONCENTRATIONS RELATING TO K-65 MATERIAL

While the data for radioactive dust concentrations (non-radon) during the loading of the K-65 Silo 1 are sparse, they have been used in a claimant-favorable manner in the suggested dose reconstruction procedure. However, there are other aspects of K-65 raffinate dose estimation procedures that are not claimant favorable (see Findings 7 and 8).

4.4 NEUTRON DOSE ESTIMATION

The TBD recommendations with respect to neutron dose reconstruction have been well documented, and make a number of claimant-favorable assumptions. The neutron-to-photon dose ratio and the neutron-spectrum assumptions are claimant favorable, and the summary of reasonable but claimant-favorable assumptions for missed neutron dose is also a positive part of the document.

4.5 AP GEOMETRY

The use of the AP geometry for all working conditions and radiation fields is claimant favorable and is a positive part of the document.

5.0 FINDINGS

SC&A has developed a list of key issues regarding the Fernald Site Profile. These issues relate to each of the five objectives defined in SC&A 2004. Some issues are related to a particular objective, whereas others cover several objectives. Many of the issues raised below may be applicable to other Department of Energy (DOE) and Atomic Weapons Employer (AWE) sites, and should be considered in the preparation and revision of other site profiles. This would more likely be the case for sites where (1) uranium was processed into metal, (2) uranium ores were refined into U_3O_8 (black oxide), (3) residues from uranium ore processing were handled and stored, (4) thorium was processed in various chemical forms or as metal, and (5) scrap materials processing.

NIOSH/ORAU are making or planning various revisions to the Fernald TBD in response to the questions that SC&A sent NIOSH (Attachment 1). (NIOSH/ORAU's responses to those questions are in Attachment 2.) The revisions that NIOSH is planning to the TBDs were discussed during a conference call between NIOSH, ORAU, and SC&A on August 18, 2006 (Attachment 3). The list below summarizes the action items that NIOSH/ORAU are pursuing. SC&A has nonetheless presented its review of these items, so that NIOSH may have the details of their review that SC&A has already completed. The list below and the review in this chapter may make the process of revising the TBD and addressing outstanding issues more efficient in terms of time and resources.

NIOSH/ORAU are pursuing the following items as part of their revision of the Fernald TBD:

(1) NIOSH/ORAU will create a flowsheet for the processing of high-grade ores at Fernald (residues were stored in Silo 2) and try to benchmark that with Mallinckrodt Chemical Works (MCW).

(2) Volume 2 of the TBD will be made consistent with Vols. 4 and 5 in regard to in-plant thorium-232 concentrations. The suggestion in Vol. 2 that in-plant concentrations are quantitatively related to emissions will be removed. It will also make Vol. 2 and Vol. 5 consistent by removing the implication in Vol. 2 that a decontamination factor for the use of respirators is to be used in dose reconstruction. No use of respirators will be assumed in dose reconstruction, as explained in Vol. 5 of the TBD.

(3) NIOSH/ORAU will send staff to the Fernald records center, look at some of the archived records, including medical x-ray films, and try to resolve some outstanding questions, including whether PFG was used, whether the black line at the bottom of the films was due to collimation, and whether work-related lumbar spine x-rays were done.

(4) NIOSH will clarify where it got its assumption about a 15% retake rate for x-rays.

(5) NIOSH will review its use of the Boback et al. (1987) and Dolan and Hill (1988) source terms for releases of uranium to the atmosphere. NIOSH will also reassess thorium-232 releases. As part of this, NIOSH/ORAU will also consider the reports of the Radiological Assessments Corporation (RAC) prepared for the Centers for Disease Control and Prevention (CDC) during the 1990s.

(6) NIOSH/ORAU are re-evaluating their approach to thorium-232 dose reconstruction and will post additional documents that they have found on thorium on the NIOSH Site Research database.

(7) NIOSH/ORAU will review the issue of correction factors to film badge and TLD readings, including those discussed in Volume 4 of the Westinghouse 1986 transition report, to ensure that inappropriate correction factors were not used for doses that are in worker records.

(8) NIOSH/ORAU will assess the issue of geometry of source relative to organ and film badges/TLDs and estimate correction factors as needed. In particular, a correction factor will be developed for workers who sat astride ingots to stamp identification numbers on them.

A general comment should be made regarding the internal and external dose monitoring at Fernald, which will provide some perspective on the findings. Routine bioassay monitoring for uranium was done throughout the program for production workers. These data are available for individual dose reconstruction. Workers were issued film badges from the onset of production operations and these data should also be useful in dose reconstruction. Some issues relating to the adequacy or completeness of these data are explored in these findings, along with other issues.

5.1 ISSUE 1: THORIUM-232 EXPOSURE

5.1.1 Thorium Processing Facilities and Periods

Finding 1: The list of facilities in which thorium-232 was processed, the time periods of thorium processing, and the thorium production data shown in the TBD have significant gaps. Entire periods of processing and plants in which the work was done have been missed. These gaps may affect the feasibility of dose reconstruction for workers during certain periods and in certain plants.

The TBD considers thorium-232 work to have been done mainly in the Pilot Plant and Plant 9. It also acknowledges work in Plant 8 and, for a short period, of production in Plant 4. The TBD does not mention Plant 6 in connection with thorium production; however, the documentation clearly shows that thorium was processed in Plant 6 at least from 1960 to 1962.

Table 1 shows Plant 6 thorium air dust data from documents that are on the NIOSH Site Research database Furthermore, it is clear that production continued into 1963. The dust survey report from which the data in Table 1 are derived was written in March 1963. Despite the extremely dusty conditions in some operations (notably raking cold residue into the furnace at 1,260 Maximum Allowable Concentration (MAC)), production was continuing at the time the report was written. The report recommended that "this furnace should be shut down immediately after processing the thorium now on site. J. Carvitti estimates that this should be completed by approximately July 1, 1963" (Starkey 1963).

Table 1: Plant 6 Air Dust Data, 1960 to 1962

Location	Sample Year	Type of Sample	Air conc, xMAC	Comments
Raking excessive cold residue into furnace	1962	BZ	**1,260**	Recommended for shut down July 1, 1963 for clean up
Unplugging furnace discharge line	1962	BZ	**417**	
Unplugging furnace discharge line	1961	BZ	**4.0**	Same location as 1962
Unplugging furnace discharge line	1960	BZ	**4.0**	Same location as 1962
Loading Th metal into 5-gal can from 55-gal drums	1962	BZ	**69**	
Raking drum residue into Rotex sifter	1962	BZ	**27**	
Raking drum residue into Rotex sifter	1961	BZ	**31**	Same location as 1962
Raking drum residue into Rotex sifter	1960	BZ	**33**	Same location as 1962
Changing drum at product canning station	1962	BZ	**19**	
Changing drum at product canning station	1961	BZ	**4.0**	Same location as 1962
Changing drum at product canning station	1960	BZ	**4.0**	Same location as 1962
Charging furnace with pieces of metal	1962	BZ	**7**	
Charging furnace with pieces of metal	1961	BZ	**3.0**	Same location as 1962
Charging furnace with pieces of metal	1960	BZ	**3.0**	Same location as 1962

Source: Starkey 1963
Note: 1 MAC = 70 dpm/m^3

A Fernald history of thorium residue processing indicates that burning of residues began in Plant 6 in 1959, when a furnace there was modified to burn residues accumulated from metal production during 1955 and 1956 in Plant 9. There were 80 tons of residues (Mead 1972, p. 86). Hence, there is documentary evidence for thorium residue burning from sometime in 1959 until at least mid-1963. (It is unclear whether thorium operations took place in Plant 6 after that date.) A 1954 evaluation of dust levels at various plants involved in chemical and metallurgical work with thorium provided recommendations for the steps to be taken at Fernald in order to make Plant 6 "suitable for thorium rolling" (Klevin 1954, p. 19).

Neither Table 5-13 nor Table 5-14 in Vol. 5 of the TBD, which show production data by plant, chemical form, and time period, have any thorium production listed for 1960, 1961, 1962, or 1963. The Site Description (Vol. 2 of the TBD) also does not mention Plant 6 as a thorium production location. Finally, one of the main references that NOISH used in compiling the thorium production data (Dolan and Hill 1988) also does not list Plant 6 as a production location for thorium:

> *Thorium was processed at the FMPC throughout much of the thirty-five year history of the site. The demand for various thorium materials fluctuated greatly and the FMPC developed or modified processes to meet these varying requirements. During different periods, thorium was processed through Plants 2/3, 4, 8, 9, and the Pilot Plant.* [Dolan and Hill 1988, p. 57]

Thorium tetrafluoride was produced in a "short" campaign in Plant 4, but production data are not available:

> *In 1954, Plant 4 was used for a short campaign to produce dry ThF_4 from the ThO_2 dried and calcined in Plant 9 in hydrofluorination Bank 7. The ThF_4 was returned to Plant 9 and used to produce thorium metal. This was a short-duration process due to mechanical difficulties in Bank 7. Production quantities are not available for ThF_4 production in Plant 4.* [TBD, Vol. 2 p. 24]

While the TBD does not provide a reference for these statements, it appears that they are based on Dolan and Hill (1988, p. 61). However, Dolan and Hill are not as definite that production did not occur at other times:

> *Production quantities are not available for ThF_4 in Plant 4. Because of the problems encountered, it is* ***believed*** *that this process was only operated for a short period and hence the potential for emissions was very slight.* [Dolan and Hill 1988, p. 61] [Emphasis added.]

Since thorium residues, including metal residues, were processed in a furnace in Plant 6 between 1960 and 1963 (inclusive), the question arises as to where the thorium processing was done to produce the metal in this period. Neither the TBD nor Dolan and Hill provide any production data for these years. It is plausible that chemical processing of thorium, including production of thorium tetrafluoride and reduction of the tetrafluoride to metal, occurred at Fernald during 1960 to 1963 (possibly only the first half of 1963). It may also have occurred in the late 1950s and in other periods.

Dolan and Hill (1988) concluded that thorium production in the Pilot Plant started in 1964. Vol. 2 of the TBD indicates that thorium tetrafluoride was produced in the Pilot Plant and then reduced to metal in the 1969–1971 period. Reduction of ThF_4 to metal occurred in Plant 9. Dolan and Hill (p. 59) also state that "[t]horium metal was produced in Plant 9 from 1954 through 1955." Machining was also done in Plant 9 during this period (p. 59).

It is possible that these facilities were used in the 1960–1963 period for ThF_4 production and reduction; however, this needs to be more carefully investigated. In that case, it is also possible that Plant 2/3 may have been used to produce the thorium nitrate feedstock that was the starting point of the ThF_4 production process.

SC&A has not located any positive documentation that Plant 5, where the UF_4 reduction to metal was done, was also used for ThF_4 reduction. However, a 1954 evaluation (Klevin 1954) of thorium health hazards recommends that consideration should be given to the use of the "'F' machine in charging thorium bombs since these have proved to be effective in controlling airborne contamination and are operationally satisfactory at both MCW and FMPC Plant 5" (p. 11). It appears that at least at the time of the evaluation (March 1954), such a machine was not available in Plant 9, where the ThF_4 reduction was being carried out. Hence, it is possible that the charging of the bombs may have been done at Plant 5 for some time until a suitable machine was procured for Plant 9. It may also have been used in the later 1960–1963 period.

SC&A stresses that it is making the above statements about possible work in Plant 4 and Plant 5 (or additional undocumented work in Plant 9 and/or the Pilot Plant) as pointers for research into thorium production history, rather than as conclusions. Thorium data are likely to be one of the most critical parts of dose reconstruction for Fernald claimants who worked there from 1954 onwards. As NIOSH and ORAU acknowledged in the August 18, 2006, conference call, the TBD does not reflect a considerable amount of documentation that is available or becoming available (see Section 8.1.1).

The TBD lists Plant 2/3 as a location for thorium processing:

> *In 1968, Plant 2/3 was used to process thorium as a thorium production test for a short duration. Few details are available regarding this process. Thorium nitrate crystals were produced in a denitration pot in Plant 2/3. Interviews with long-time employees indicated that this was a short-term operation; probably one pot of crystals was produced. Other records discuss the production of thorium oxide in Plant 2/3 by a process of denitration, redigestion, and drying.* [TBD, Vol. 2, p. 20]

No plant-specific data enabling dose reconstruction are provided. Production data shown in Table 6 of Dolan and Hill do not contain any data for Plant 2/3 thorium production amounts or time periods (Dolan and Hill 1988, p. 20). Since Plant 2/3 was the refinery where uranium ores were processed, it may be presumed that thorium ores were also processed there. This has considerable significance for worker exposure. The TBD does mention the processing of thorium ores at Fernald, but lists them as being processed in the Pilot Plant as part of the thorium processing there between 1964 and 1980 (TBD, Vol. 2, p. 11); however, records show that thorium production at Fernald went back to 1954. This raises the question whether thorium processing took place in Plant 2/3 in connection with early thorium-related processes in Plant 9 and Plant 4. The information in Dolan and Hill on thorium was partly based on interviews, but NIOSH was unable to provide any interview records to SC&A.

According to the TBD, much of the thorium data was destroyed in the 1970s:

> *Much of the thorium production data has been lost, and the plant and bioassay monitoring data recovered to date has been sparse. A comprehensive effort to reconstruct the effluent of uranium and thorium from the Fernald plants in 1988 discovered that a large number of records and files were destroyed in the early 1970s during declassification efforts (Dolan and Hill 1988). Reviews of AEC records in Oak Ridge and Atlanta failed to uncover additional details.* [TBD, Vol. 5, p. 18]

There are other problems with the production data as well. For instance, Vol. 2 of the TBD states that thoria gel production for 1964 and 1965 was estimated based on a linear extrapolation of the quantity produced in 1966 through 1970:

> *Production records also indicate that 492 metric tons of thorium as thoria gel were produced from 1966 to 1970. Production for 1964 and 1965 was estimated*

> *based on a linear extrapolation of the quantity produced in 1966 through 1970. The estimated total production from this process is 686 metric tons assuming linear production from 1964 to 1970.* (TBD Vol. 2, p. 11).

No justification for this assumption is provided in the TBD. Furthermore, the data shown in Table 5-13 of the TBD (Vol. 5, p. 20) show that NIOSH assumed that only thoria gel was produced in 1964 and 1965, even though there was other processing and at least one other chemical form (thorium oxalate) produced in the Pilot Plant in the 1966 to 1970 period. If the average of the total production in the Pilot Plant were extrapolated backwards, the estimated production of thorium in the Pilot Plant in 1964 and 1965 would be 238 metric tons in each year, or about 2.4 times the amount estimated by NIOSH (98 metric tons in each year). No explanation is provided for the more limited extrapolation.

Furthermore, if thoria gel was produced in 1964 and 1965, one would expect purified thorium nitrate solution also to have been produced. However, the text only discusses production from 1966 onward. Was there any such production in 1964 and 1965? In fact, though Table 5-14 shows that thorium nitrate was produced in the Pilot Plant, it is not explicitly mentioned in Table 5-13 where production estimates are provided. In this same context, it is confusing that some items of production have quantitative estimates (but without references) in Vol. 2 of the TBD, but there is no counterpart tabulation in Volume 5 on internal dose reconstruction. For instance, thorium nitrate production is not shown in Table 5-13 of Volume 5; however, Volume 2 gives a rather precise value of 790.4 metric tons for the 1966–1973 period for the Pilot Plant (p. 11).

Finally, a 1988 thorium records search document (Bonfer 1988) also indicates that the TBD compilation of production at Fernald is incomplete. The starting date for thorium production of 1954 appears to be correct according to Bonfer 1988, which provides a date of January 26, 1954, with metal production operations starting on February 15, 1954—all in Plant 9. Bonfer 1988 also mentions "extraction studies" being started in the laboratory in April 1954. These studies continued well into 1955. Furthermore, while Tables 5-13 and 5-14 show Plant 9 production only in 1954 and 1955, there is clear evidence that Plant 9 production covered a longer time span. For instance, Bonfer states the following:

> *The final Plant 9 process of manufacturing massive thorium metal continues into 1956.* [Bonfer 1988, p. 2]

Similarly, while Tables 5-13 and 5-14 show Pilot Plant production only beginning in 1964, Bonfer 1988 states the following:

> *A project was initiated during July 1956 in the Pilot Plant to demonstrate the sylvania reduction process for calcium reduction of thorium oxide to thorium metal powder.* [Bonfer 1988, p. 2]

Attachment III in Bonfer 1988 is a catalog of orders for a variety of forms of thorium. It includes orders that were filled in 1957, 1958, and 1959—years that are not discussed for thorium production in the TBD. In this context, it is noteworthy that while the TBD does not mention thorium metal production in Plant 9 in 1956, the history of residue recovery does. The quantity of production must have been significant, because the residues from 1955 and 1956 amounted to 80 tons (Mead 1972, p. 86). Finally, Attachment II in Bonfer (1988) also shows three orders in 1985, but it is not clear whether these orders were filled with material that had already been produced prior to that time or whether there was post-1979 production at Fernald. The TBD does not discuss these orders or cite Bonfer (1988).

In conclusion, it is very likely that production estimates in the TBD are significant underestimates. It is clear that Tables 5-13 and 5-14 (TBD, Vol. 5, p. 20) do not capture a large amount of the processing that was done, even from readily available documentation. The locations and time periods of processing are also significantly incomplete. A thorough revision of the TBD is necessary to establish when the workers were at risk of exposure due to production, and in which plants they were at risk.

During the conference call of August 18, 2006, NOISH stated that it was in the process of recovering considerable additional thorium data (see Attachment 3); however, that data was not available in time for this review. SC&A did not come across information on the extent and nature of the additional data and documents, and therefore cannot comment on whether they would be adequate to plug the large gaps in the data and the uncertainties that have arisen as a result of the destruction of records. The evidence discussed above indicates that a large number of workers were exposed to thorium at various times during the 1954 to 1980 period as a direct result of production work. This includes Plant 2/3, Plant 4, Plant 6, Plant 8, Plant 9, the Pilot Plant, and the laboratory.

In addition, the residue recovery history notes that the 80 tons of residues discussed above ("turnings, grinder sludge, sawdust, and miscellaneous solids") were stored on pads at Plant 9 and Plant 1 (Mead 1972, p. 86). Fires occurred on these pads during the periods the residues were stored there (see Finding 4). The TBD notes that Canadian ores containing thorium were received at Fernald beginning in 1956 and then in large amounts by June 1957 in the context of discussing Plant 1 (TBD, Vol. 2, p. 15), yet Plant 1 is not discussed in terms of thorium exposure. Finally, as noted above, it is possible that some ThF_4 reduction occurred in Plant 5, but SC&A has not found any direct evidence of this.

5.1.2 Thorium Air Concentration Data

Finding 2: Air concentration data for thorium in the TBD are sparse and incomplete, though considerably more data are available on the NIOSH Site Research database. The TBD contains no thorium-232 bioassay or in-vivo data.

According to the TBD, there were some in-vivo thorium data and one file with thorium urine data (beta count):

> *The only discovered record of thorium exposure has been in vivo lung count data sheets in a few claimant records and a single claimant record which indicates thorium urine results, counted for beta and at essentially no detectable results, from before 1986.* [TBD Vol. 5, p. 22]

Furthermore, on the same page, it is stated that there is some evidence of urinalyses for thorium in claimant files as early as 1955. This suggests more than a single claimant record, but these data are not presented in the TBD. The reason cited is as follows:

> *The thorium results are questionable because of the lack of information for readily interpreting them (e.g., there is no information regarding the in vitro separation method or counting procedure/equipment, nor is there information regarding the assumptions made to derive the in vivo results).* [TBD, Vol. 5, p. 22]

However, the analytical techniques from the period of measurements are surely known. It may therefore be possible to interpret these data. Setting them aside without further analysis in favor of the intake estimation procedure chosen (see below) appears to be questionable.[1]

SC&A acknowledges the difficulty in interpreting in-vitro and in-vivo bioassay data in terms of thorium intake and dose. To correctly interpret in-vivo monitoring data, we need to make assumptions on the equilibrium between thorium and thorium daughters, and on the absorption rates from lung to blood of the daughters in relation to Th-232. If monitoring were done measuring Pb-212 or Tl-204, which probably was the case in the 1960s and 1970s, the interpretation of results will require assumptions about Rn-220. Thus, it is not simple. Urinalysis results are not simple to interpret, either. The limits of detection until recently were so high that only very high exposures would be detected. Even today, thorium bioassay is very difficult to interpret, because of influence from the diet and very low excretion rate in urine. Given that the use of air sampling data can also be problematic,[2] all available data should be analyzed together to have a better estimate of the worker's exposure.

The TBD states that thorium workers were monitored by lapel sampling of the breathing zone after 1986; however, it does not provide any of this post-1986 thorium sampling data. There is no analysis in the TBD of the completeness in regard to coverage of (1) workers who worked in maintenance, surveillance, repackaging and other post-production operations involving thorium-232 or during decommissioning of the thorium storage areas, and (2) workers that may have been affected by resuspension of thorium dust.

The TBD contains some thorium air concentration data, but these are sparse and do not reflect the extent of data available regarding the plants for which data exist on the NIOSH Site Research database or the time periods for which data exist. For instance, the air concentration data for Plant 6 for the 1960–1962 period are not mentioned in the TBD. Table 2-1a (TBD Vol. 2, p. 12) shows very limited air concentrations for a single year (1968) for the Pilot Plant for just a few operations. The air concentrations range from about 0.3 MAC to about 5.7 MAC. Similar data are presented for uranium for the same year in the same table.

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[1] As noted above, NIOSH/ORAU have found a large amount of thorium-232-related data. SC&A's comments here apply to the TBD in its state at the end of August 2006 and the documents available until that time.

[2] According to ICRP 2002, "the use of static [air] samplers does not ensure a representative measurement of exposure of the worker, especially in workplaces where the aerosol release points are discrete and distributed." ICRP 2002, Annex B, Section B.5, p. 150. Even personal air samplers may also give misleading and inconsistent results in case of high specific activity radionuclides due to the low volume of air that is sampled (ICRP 2002, Annex B, Section B.6).

These data in Table 2-1a are used to estimate uranium intakes for 1968 and for other years by assuming that intakes were proportional to production (Table 2-1b). The uranium intakes in turn are used to estimate thorium intakes by multiplying the uranium intakes by the ratio of estimated air emissions of thorium to uranium (Table 2-1c, TBD Vol. 2, p. 14).

This thorium intake estimation procedure contradicts the procedure in the internal dose volume of the TBD (discussed below). Moreover, it contains several layers of scientifically dubious or incorrect assumptions. For instance, intakes inside a plant are not necessarily related to air emissions. In fact, if ventilation is poor, low stack emissions may correspond to high intakes, making for an anti-correlation of intakes with air emissions. Furthermore, the air uranium and thorium emission estimates themselves are suspect (see below). Finally, individual worker intakes cannot be assumed to be proportional to production. They cannot be assumed to be proportional to capacity utilization, unless it can be shown that the machines were idle for part of the day (or other time period). Dust levels depend on working conditions. Small amounts of production can still lead to very high individual exposures. Overall production or capacity utilization is arguably related to population exposure, but other conditions, including ventilation and industrial hygiene measures, must be assumed to be the same even in that case. The intake estimation procedures in Tables 2-1b and Table 2-1c should be deleted from the TBD.

Available evidence indicates that Fernald had significant levels of thorium air contamination from the start of thorium operations in 1954 to the end in 1979. Plant 6 air concentrations were especially high, up to and including 1962. Since changes were not made until July 1963 at the earliest (Starkey 1963), the high air dust problems likely continued at least until then in Plant 6.

All available data from Fernald indicates that the air concentrations of thorium were very high in the early period, defined here as 1954 through at least 1962.

Table 2 shows early air concentration data in reverse chronological order.

Data that appear to relate to Plant 9 for 1955 indicate that several workers experienced ***average*** air concentrations of about 100 MAC, with the most exposed workers experiencing an average of several times that. Data for the following year for the same plant indicate a decline to between 1 MAC and 71 MAC.

Data from Plant 6 from the early 1960s show very high air concentrations from a few times MAC to 1,260 MAC, with a possibly rising trend of air contamination in 1962 compared with the previous years. Just 1 hour of exposure in a year to the operation with the highest air concentration would exceed the annual exposure of 1,050 MAC-hours recommended in the TBD (Vol. 5).

Table 2: Thorium Air Concentration Data: Fernald, 1950s and Early 1960s

Operation	Plant	Year	Type of air sample	Air conc. xMAC
Raking excessive cold residue into furnace	6	1962	BZ	**1260**
Unplugging furnace discharge line	6	1962	BZ	**417**
Unplugging furnace discharge line	6	1961	BZ	**4.0**
Unplugging furnace discharge line	6	1960	BZ	**4.0**
Loading Th metal into 5-gal can from 55-gal drums	6	1962	BZ	**69**
Raking drum residue into Rotex sifter	6	1962	BZ	**27**
Raking drum residue into Rotex sifter	6	1961	BZ	**31**
Raking drum residue into Rotex sifter	6	1960	BZ	**33**
Changing drum at product canning station	6	1962	BZ	**19**
Changing drum at product canning station	6	1961	BZ	**4.0**
Changing drum at product canning station	6	1960	BZ	**4.0**
Charging furnace with pieces of metal	6	1962	BZ	**7**
Charging furnace with pieces of metal	6	1961	BZ	**3.0**
Charging furnace with pieces of metal	6	1960	BZ	**3.0**
Thorium production various steps (Note 2)	9?	1955	?	**106**
Thorium production various steps (Note 2)	9?	1955	?	**353**
Thorium production various steps (Note 2)	9?	1955	?	**3,531**
Thorium production various steps	9?	1956?	?	**1**
Thorium production various steps	9?	1956?	?	**4**
Thorium production various steps	9?	1956?	?	**71**
Thorium production (various steps?)	9?	1955	?	**500**
Thorium production (various steps?)	9?	1955	?	**600**
Cutting thorium derbies by hacksaw	9	1954	?	**36**

Sources: Starkey 1963; Harris 1956; and Karl [Illegible] 1955.
Note 1: BZ = breathing zone; GA = general air
Note 2: 106 MAC was the average for several workers; 353 MAC was the highest average; 3,531 MAC was the highest measurement.

These data indicate the following:

- Thorium dust levels were high and often very high during the 1950s and early 1960s.
- Dust levels did not diminish with time in this period. In fact, there are instances where dust levels increased.

The documents from which these data are drawn also show that production continued despite measurements of dust levels far in excess of the maximum allowable air concentration. We have already cited the example of production in Plant 6, which was allowed to continue during the first half of the year (at least), despite measurements in December 1962 of dust levels between 4 and 1,260 MAC in various operations. In regard to the latter, the March 1963 memorandum states the following:

> *Although the Thorium Furnace and Rotex sifter have ventilation, it is completely inadequate….The rabbeling arms in the top hearths of the furnace have been*

removed, thus the excessive cold residue on the edge of the hearths is raked into the furnace by hand (this operation is 1260 x MAC).

As was discussed in a meeting in your office this morning, this furnace should be shut down immediately after processing the thorium now on site. J. Carvitti estimates this should be completed by approximately July 1, 1963. [Starkey 1963]

As another example, a telegram in December 1955 noted dust levels of 500 to 600 MAC, but suggested that thorium oxide production should "continue at three four zero zero [3,400] pounds per day" during that month. Then a shutdown of six weeks for improvement of conditions was proposed, after which production was to increase to 4,000 pounds per day (Karl [Illegible] 1955).

Table 3 shows some later air concentration data for thorium.

Table 3: Thorium Dust Concentrations: 1966 and 1977

Work Location	Plant	Date	Type of sample	Air Conc. x MAC
Pilot Plant data sheets (Note 1)	Pilot Plant	1977		0.7
Pilot Plant data sheets (Note 1)	Pilot Plant	1977		5.0
Dumping ThF4 into reverter dumping station	8	1966	BZ	29
Scooping recycle ThO2 into reverter dumping station	8	1966	BZ	48
Changing drums at reverter drumming station	8	1966	BZ	21
Th reverter drum dumping station area	8	1966	GA	2.7
Th reverter drumming station areas	8	1966	GA	1.9
Th reverter level	8	1966	GA	1.8

Source: Fernald Thorium datasheets from the NIOSH Site Research Database for 1977 data and Ross 1966.
Note 1: 0.7 MAC is the empirical lognormal mean calculated from datasheets and 5.0 MAC is the 95th percentile value for the same data set.

While the highest levels of dust in the set of samples shown in Table 3 are much lower than that in the earlier period (Table 2), the later levels are often above the allowable limit in 1966. A more extensive set of samples for the Pilot Plant indicate a mean dust level of about 0.7 MAC for 1977 and a 95th percentile value of about 5 MAC (based on an empirical lognormal distribution). This is still rather high. We note here that the samples for 1968 for the Pilot Plant cited by NIOSH in Table 2-1a (discussed above) are between 0.3 MAC and 5.7 MAC. While these data indicate that the Pilot Plant thorium air dust levels may have been about the same for an extended period, such a conclusion cannot be reliably made because the data available are far too sparse and, in any case, are only for one of the plants where thorium was processed. Specifically, data from Plant 8 for 1966 show much higher concentrations than those cited by NIOSH for the Pilot Plant in 1968. Breathing zone concentrations were 21 to 48 MAC; even the general air in the area was 1.8 MAC. This indicates that uranium workers who were present in the Plant may have been exposed to significant amounts of thorium.

SC&A has not located any air concentration data for Plant 4 that are labeled as such, even for 1954, when some ThF_4 production was done there. However, there are 1954 data for metal working—production of ingots at Fernald. The dust conditions in thorium metal working at

Fernald in that year were compared unfavorably in a general way to those at Ames. It is unclear if the Fernald dust data represent Plant 4 or Plant 9. Table 4 shows the Fernald and Ames data.

Table 4: Thorium Dust Levels for Certain Operations: Fernald and Ames

FMPC	Year	MAC
Charging crucible, top furnace	1954	7.6
Disassembly Th ingot	1954	4.9
Placing top and bottom crucibles in mold section	1954	7.6
General air at face of furnace while operator works	1954	0.7
Operator inside furnace cleaning	1954	3.8
Maintenance man loosens material in broken crucible (outside)	1954	156
Same operation as above except with vent hood	1954	5.0
Ames		
Insertion of dezinced billets into crucible	1952	6.6
Removing graphite pots containing dezinced billets	1952	3.1
Cleaning furnace parts brick insulation	1952	3.6

Source: Klevin 1954, p. 13
1 MAC = 70 dpm/m^3

While the operations shown were not the same, the evaluation made an unfavorable comparison of Fernald thorium dust with that at Ames:

> *It should be understood that at Ames, ventilation was effectively employed to control these operations which at FMPC showed high dust dispersion.*
> [Klevin 1954, p. 13]

External dose data for the same operations at Fernald were also considerably higher, with job-related gamma dose rates being about 2 to 20 times higher [1 to 10.5 mr/hour at Ames and, 20 to 24 mr/hour at Fernald]. The data are shown in Table 5.

The higher external dose levels at Fernald were explained as follows:

> *Note: FMPC did not use derbies but old Th metal scrap, therefore higher intensities encountered.* [Klevin 1954, p. 14, underlining in the original.]

Dust numbers from a 1952 Ames survey, as well as the external dose numbers, indicate that the Ames data are from March 1952 (Klevin 1952). That survey showed job-related daily weighted averages (DWAs) to range from very low (near zero) to over 44 MAC. The average DWA was about 7.6 MAC (530 dpm/m^3) for all thorium workers.

Table 5: External Dose Rates and Surface Contamination, Thorium Metal Casting: Ames vs. Fernald

Ames	Alpha d/min/100 cm^2	Beta, mrep/hr.	Gamma, mr/hr.
Average dezinced billet			
Top	No data	Off scale	10.5
Bottom	No data	3.5	9.5
Middle	No data	2.5	5.0
Average cast billet			
Top	No data	6.0	7.0
Bottom	No data	1.0	5
Middle	No data	1.0	4
Average cast billet (20 hours old)			
Top	No data	1.0	3.5
Bottom	No data	4.0	4.0
Middle	No data	3.0	1.0
FMPC [Fernald]			
New billet freshly assembled from mold			
Top	1,000,000	12	24
Bottom	106	10	20
Middle	106	13	24

Source: Klevin 1954, p. 14.

As SC&A has pointed out before (Mallinckrodt reviews), the use of DWAs is not a claimant-favorable approach, especially as each operation has very few measurements associated with it (typically 1 to 3). They may be used for minimum dose estimation purposes, however. The higher thorium dust levels at Fernald compared to Ames, at least for some operations indicated by the above data, need to be taken into account in evaluating the adequacy of the data, given that both Ames and Fernald data are limited, and in selecting the values for thorium intake estimation.

Klevin (1954) also provides data from other sites, including Lindsay, where thorium ore was processed, and for Simonds Saw and Steel, where thorium metal was rolled. Those data are shown in Table 6.

It is clear from the above data that thorium production at all stages involved very high air dust levels at several plants. Even on a daily weighted average, air dust levels were many times the MAC. General air concentrations also exceeded MAC. At Fernald, very high dust levels continued well into the 1960s. Finally, data for the 1970s appear to be very sparse. It is interesting to note that even some wet area dust levels were found in the surveys to be above the MAC of 70 dpm/m^3. This is an indication that all thorium production operations should be considered high dust operations, unless reliable measurements are available to the contrary. Furthermore, in view of the high dust levels, areas in the proximity of production operations would also be likely to experience considerable thorium dust.

Table 6: Lindsay Light and Chemical Company and Simonds Saw Thorium Air Dust Data

Lindsay data	MAC
Charging and milling ore	8.0
Rotary dryer operation	12
Pot area (loading ore into sulfuric acid)	114
Pot area (loading ore into sulfuric acid)	44
Pot area (loading ore into sulfuric acid)	186
Pot area (loading ore into sulfuric acid)	29
Average for pot area (loading ore into sulfuric acid)	93
Simonds data (1952?)	
Rolling Th daily weighted average	15
Average General air during rolling	12
Passing billets through rolls (roughing average)	67
Passing billets through rolls (finishing average)	193

Source: Klevin, 1954.

It is important to note in this context that even 1 MAC exposure to thorium for certain organs yields a committed dose much higher than exposure to uranium, the main material processed and produced at Fernald for certain organs. (At the time, 1 MAC for thorium and uranium was defined as being the same number—70 dpm/m^3 until 1970 and 100 dpm/m^3 thereafter.) SC&A has pointed out the critical importance of this fact for dose reconstruction in other reports (see SC&A 2006, for instance). We reproduce Table 4 from SC&A 2006 for convenience (Table 7).

Table 7: 50-Year Organ Dose Conversion Factors for U-234 and Th-232 – Inhalation (in sieverts per becquerel and ratios)

Organ	U-234 Type M, Sv/Bq	U-234 Type S, Sv/Bq	Th-232 Type S, Sv/Bq	Ratio Th S/U M	Ratio Th S/ U S
Bone Surface	3.90E-06	5.03E-07	2.86E-04	7.33E+01	5.69E+02
Breast	1.37E-07	1.63E-08	8.29E-07	6.05E+00	5.09E+01
Liver	5.34E-07	6.93E-08	5.05E-06	9.46E+00	7.29E+01
Red Marrow	4.03E-07	5.21E-08	1.00E-05	2.48E+01	1.92E+02
Testes	1.37E-07	1.63E-08	2.62E-06	1.91E+01	1.61E+02

Source: Federal Guidance Report 13, U.S. EPA, published on CD in 2002.
Reproduction of Table 4, SC&A 2006.
Note: DCFs are based on AMAD = 1 μm

Table 7 shows that a 1-MAC level of air contamination with Type S thorium-232 is equivalent to 569 MAC of Type S uranium-234 for bone surface dose. Thus even ~0.1% Th-232 dust in the air (in terms of dpm/m^3) mixed in with uranium can make a significant contribution to bone surface dose. The dose conversion factors (DCFs) show that a few tenths of 1% can make a significant contribution to dose to the testes and red bone marrow. When assessed against these facts, the TBD is particularly deficient in regard to its attention to thorium air concentration data. As noted, NIOSH has stated that it is revising the TBD and incorporating more thorium data.

5.1.3 Thorium Fugitive Emissions

Finding 3: Thorium intakes due to fugitive emissions and resuspension in production areas may have been significant in some locations and during some periods. The TBD does not address the issue of fugitive emissions in production areas. Furthermore, the TBD does not provide a method to estimate resuspension intakes in the pre-1986 period and for those without lapel air sampling in the post-1986 period.

There is clear evidence of significant problems with fugitive emissions of thorium from production areas. These problems were not confined to early production. A 1970 memorandum on "Thorium Metal Production Housekeeping" is worth quoting at length in this regard:

> 1. *Probably the worst housekeeping problem in the facility is the Ball Mill. This equipment leaks excessively at practically every joint. All horizontal surfaces have a thick covering of dust. In operation, this dust becomes airborne and adds to the dust coming from the leaks. Since the ventilation is inadequate and there is no proper enclosure, a bucket was placed under the largest leak to help contain the spilled dust. This is not adequate. It is recommended that Engineering Division be requested to inspect the Ball Mill and associated equipment and recommend methods of improving both the dust problem and the housekeeping problem.*
>
> 2. *During the operation of removing the calcined ThF_4 and CaF_2 from the retorts, the stack of trays is left standing on a skid near the south annex door. The door is left open to aid in cooling the trays. The wind coming through the door blows the loose powder from the trays and spreads it generously through the annex. Removing the trays from the support requires heavy effort and this dislodges more powder to be spread by the wind. It is recommended that this stack of trays be put inside the enclosure used for grinding, weighing, and blending their contents.* [Ross 1970]

It is unclear how long the problem of high fugitive dust existed prior to the 1970 memorandum, or for how long afterwards it persisted, but the document indicates that the levels of thorium dust were high both indoors and outdoors, and that industrial hygiene measures were poor. Moreover, the same memorandum makes it clear that significant residual contamination from the poorly controlled processes was present in many locations. They included the following:

> *…the drying oven area, the bottom of the blending enclosure, the saws and the saw area, the entrance to the furnace room when used to remove dezinced derbies from their holders, the top deck of the furnace room, the ThF_4 enclosure and the area surrounding it, and others.* [Ross 1970]

These circumstances indicate that both thorium production workers as well as those who did not directly work with thorium may have experienced significant thorium intakes due to faulty equipment, lack of adequate ventilation, and poor location of the equipment. Maintenance workers who repaired the equipment may also have had large exposures due to resuspension of dust from the heavily contaminated surfaces. In view of the high DCFs of thorium relative to uranium for several organs, it is essential that dose reconstructors have explicit guidance on how these doses are to be estimated.

Resuspension of thorium would also be an issue in the post-1986 period. The TBD does not document the protocols for Th-232 lapel sampling in this period. Given the conditions described above, the exposure potential for those who were not provided with such monitoring should be evaluated. The resuspension model suggested by SC&A as part of the evaluation of Bethlehem Steel might be considered in this context (SC&A 2005e).

5.1.4 Exposures from Thorium Redrumming

Finding 4: The guidance in the TBD regarding exposures from redrumming thorium is not well founded and is not claimant favorable.

There were extensive thorium redrumming, packaging, and shipping operations in the 1980–1986 period. Such operations were also carried out during the period of thorium processing. For instance, a 1965 "Request for Engineering Services" began as follows:

> *The thorium residue drums are disintegrating. Mr. Costa started redrumming these residues but was stopped by the IH&R Department due to high dust levels of contamination arising from dust generated by the redrumming operation. Prior to the IH&R shutdown of the redrumming operation, the sump cake had been redrummed in 900 drums and 100 drums of floor sweepings had been redrummed.*
>
> *…About 30% of the drums are so corroded that they cannot be lifted off their pallets without falling apart.* ***This is the fourth time this material has been redrummed. There are approximately 2000 drums of this material.*** [DeFazio 1965, emphasis added]

The inference from the engineering request for ventilation system design is that the prior redrumming operations were carried out at least three times without such ventilation and that half the job in question (redrumming of 1,000 out of 2,000 drums) was also similarly carried out without ventilation. SC&A has not found air dust data relating to the redrumming operations referred to in DeFazio 1965.

The TBD has only a brief discussion of doses arising from thorium storage operations (Section 2.3.2.1, TBD Vol. 2, pp. 50–51). This section does not discuss redrumming operations in the pre-1990 period at all. It considers corrosion only as one of four possible "Events" that could lead to airborne thorium contamination ("Fork impact," "Fork drop," "Physical degradation," and "Miscellaneous"). Only 0.69 grams of thorium are assumed to be released during an event involving "Physical degradation," and only 42 such events are assumed to take place each year (Table 2-22, p. 51, TBD, Vol. 2). The number of drum puncture events is very small compared to the 30% rate of greatly degraded drums in the 1965 assessment quoted above.

It is possible that many of them were included in the "miscellaneous" events category. However, in that case, the estimate of the amount released is even smaller—0.162 grams per event.

NIOSH's thorium intake estimates are based on estimated "dispersible thorium" per drum and a fraction of the dispersible thorium that would become airborne. Dispersible thorium per drum was estimated at between 683 grams and 79.1 kilograms (TBD Vol. 2, Table 2-21, p. 51). No references were provided for any of the data and no analysis was provided for the estimates of fractional airborne thorium that was applied to each event. No references were provided about event frequency. The context of the estimates indicates that they apply to the period of decontamination in the 1990s:

> *During the 1990s, drums of thorium stored in various plant locations, including those in Building 65 and 67, were overpacked and transferred to Buildings 64 and 78 for interim storage and eventual offsite shipment. Structurally unsound drums were placed inside larger containers by overpacking. The overpacked and structurally sound drums were transferred to Buildings 64 and 78 and subsequently placed in strong tight containers (STCs) suitable for offsite shipment.* [TBD, Vol. 2, p. 50]

Given that the TBD states that workers wore lapel samplers in the post-1986 period and that this would be the basis for thorium intake, it is unclear why Tables 2-21 and 2-22 were included at all, since they seem to apply to the 1990s. They do not apply to the earlier period of redrumming, when the rate of totally deteriorated drums was estimated at 30%. Moreover, the estimated dust concentration is only 1.97 10^{-5} g/m^3 (TBD Vol. 2, p. 51), which is only about 0.07 MAC of Th-232 or 0.14 MAC when Th-228 is also taken into account. This is very likely to be far lower than the air concentrations in the redrumming of thorium in the 1960s and in other periods. This conclusion is based on the record that thorium and uranium were treated more or less on a par in those periods, with the same maximum allowable concentration, and a small fraction of 1 MAC would have been regarded as satisfactory. It is unlikely that an Engineering Request, such as the one from 1965 quoted above, would have been made if an operation were at 0.14 MAC. The very low estimate of airborne thorium appears to be in conflict with the evidence from the redrumming operation. It is unlikely to be correct for the period of production; it should also be re-evaluated for badly deteriorated drums even for the 1990s, using lapel-sampling data that should be available.

A 1968 memorandum identified drumming and dumping as the being responsible for the "most" serious air dust problems:

> *As you well know, most of our air dust at FMPC over the years have resulted from drumming and dumping dry materials. Any time that we can eliminate either of these operations our air dust problems become greatly reduced.* [Starkey 1968]

The guidance for thorium exposure during redrumming needs to be re-evaluated and a new model developed.

5.1.5 Exposures due to Thorium Fires

Finding 5: The TBD has not evaluated exposures due to thorium fires. The TBD has also not evaluated other thorium incidents or failures of industrial hygiene.

There were a number of thorium fires in the 1950s at Fernald, including prolonged ones. A number of problems resulted from these fires. A proposed 1959 project to address the problem stated the following:

> *During the past four years there have been 30 known fires with these materials [thorium residues], some of which burned for several days. Clean up after these fires is a difficult job. In one case, the fire burned through a concrete storage pad. Storage of the drums on soil resulted in a worse situation, when a fire contaminated a considerable area, and much stone and dirt had to be removed. As long as these residues are in the unoxidized state, the hazard and expensive housekeeping problems will exist. Corrosion from prolonged storage of the drums has resulted in oil leaks, and redrumming and clean up problems. Attempts to redrum these materials have resulted in violent reactions exposing personnel to possible serious injury.* [NLO 1959, pp. 1–2]

The TBD does not contain any discussion of these fires and related thorium incidents. The assessment quoted above states that there were "violent reactions," but provides no dosimetric information. The modest discussion of redrumming in the TBD gives no hint of these serious problems in the production era, and how NIOSH proposes to reconstruct doses due to these incidents and to the various types of clean-up operations that followed.

5.1.6 TBD Procedure for Estimating Thorium Intakes

Finding 6: The approach suggested for estimating thorium intakes does not reflect the history of production or the available thorium air concentration data. It is likely to result in significant underestimates of internal dose from thorium.

The TBD has the following formula for annual thorium exposure (Vol. 5, p. 23):

- 100 hours of work at 10 MAC
- 500 hours of work at 0.1 MAC

This amounts to an annual intake corresponding to 1,050-MAC hours. The basis for this approach is described as follows in the TBD:

> *In vivo counting was performed on the workers in the more likely exposed groups at least once each year. There is some evidence of urine analyses for thorium in claimant files as early as 1955, but to date no information has been found regarding how to interpret it. Although urinalysis can offer some information regarding thorium intake, it is not the preferred bioassay technique, since the material is predominantly insoluble. Fecal sampling and in vivo analyses are the*

> *preferred default. This is a difficult default to derive with any degree of technical basis because:*
>
> *1- There was primarily gross alpha and some gross beta air monitoring during thorium operations for the purpose of controlling worker exposures to below MAC levels. A few in vitro analyses for thorium were discovered primarily in claimant file records; only a few in vivo analyses were found. The thorium results are questionable because of the lack of information for readily interpreting them (e.g., there is no information regarding the in vitro separation method or counting procedure/equipment, nor is there information regarding the assumptions made to derive the in vivo results).*
>
> *2- It is known that respiratory protection (both preventative and following MAC-level air sample results) was provided and would have resulted in at least a factor of 10 protection when used properly. However it is also known that workers were exposed to >MAC levels without respiratory protection. Considering this information, standard respiratory protection factors cannot be assumed.*
>
> *3- Limited operation times and smaller volumes and mass (which also would presuppose a more effective ventilation confinement) reduced the exposure potential, all of which would result in an assumption for limited periods of higher-level contamination.*
>
> *4- The MAC of 100 dpm m^{-3} (4.5×10^{-11} $\mu Ci\ cm^{-3}$) is 20 to 100 times larger than the current derived air concentrations for 232Th.* [TBD, Vol. 5, pp. 22–23]

On this basis, the TBD states that the "recommended" approach is "claimant favorable" (Vol. 5, p. 23). These arguments are not compatible with the available data. Historical air concentrations of thorium were far higher than the then-prevailing maximum allowable air concentration for much if not most of the period of thorium production, and for many operations and locations. Historical daily weighted averages were also often above the then-prevailing MAC. It is unclear why the current standard is cited at all in the context of historical thorium intakes. It is not relevant to them.

Thorium production was undoubtedly much smaller than uranium at Fernald; nonetheless, it was an industrial-scale operation and thousands of tons were produced there. As already noted, individual worker exposure is not connected to the level of production or capacity utilization, unless a plant is shut down for some of the time, in which case only resuspension doses are operative.

We know that Plant 9 and the Pilot Plant specialized in thorium work during some periods. There is, therefore, no basis to restrict exposure time to a small fraction of the year for workers engaged solely or mainly on thorium production, as suggested by the dose reconstruction procedure in the TBD. Moreover, production data in the TBD are incomplete.

Furthermore, the memorandum regarding drying of thorium in doorways and leaky equipment quoted above shows that high dust levels likely prevailed for considerable periods, even when actual processing was not going on. The highly degraded condition of the thorium drums caused high dust levels during redrumming operations, and several of these were carried out over time.

Even general air samples indicate thorium dust levels of ~ 1 to several MAC. For instance, the empirical lognormal average of five 1954 general air samples in Plant 9 production areas general air came was about 3 MAC (Plant 9 Survey 1954).[3]

NIOSH's conclusion that its approach is claimant favorable is partly based on its statement that it would assume that respirators were not used. However, this is not necessarily claimant favorable, since there is documentation that respirators were often not used even in the dustiest periods. This is acknowledged in the TBD. It is also implicit in the recommendation that respirators be worn in high dust thorium production areas. For instance a 1960 memorandum from K.N. Ross to J.E. Carvitti states the following:

> *The attached evaluation shows that most of the operations performed in the thorium oxidation area are greater than the MAC…. It is recommended that an air dust survey of these operations be made to determine why the high dust air levels are not controlled. In addition, the results show that the dust levels on the sifting operation (not approved by the Fume & Dust Control Committee) are grossly inadequate and need correction.*
>
> *A dust type respirator should be worn while performing these operations until a new air dust evaluation shows the air dust levels to be less than the MAC.* [Ross 1960]

NIOSH's assumption that respirators were not used is moderately claimant favorable for the population of workers, but in view of the widespread non-use of respirators, it is not clear that that conclusion can be extended to individual workers.

From the data cited above, one can conclude that some fraction of the thorium workers at Fernald were exposed to levels of several MAC, 50 MAC, or even 500 MAC as average exposures, with peaks of exposure running as high as 1,000 MAC to 3,500 MAC (see data tables above). The highest measurement of 1,260 MAC in Plant 6, for instance, attributed to manual raking of thorium residue into the Plant 6 furnace in 1962 (see Finding 1 above), would produce an intake in a **single hour** that would be **greater than NIOSH annual** estimated intake of 1,050 MAC-hours.

SC&A has not come across Type Super S thorium in the literature but it is possible that a highly insoluble form of thorium could be created during fires or machining. This possibility should be investigated. As noted above, thorium residues (including metal residues) were burned in the Plant 6 furnace. There were fires in thorium drums. Site expert interviews indicated that high-fired thorium was present at Fernald (Attachment 4). The presence of high-fired (highly insoluble or Type Super S) thorium—that is thorium that is significantly more insoluble than the Type S currently defined in the literature—could make a significant impact on the thorium dose estimation for some organs.

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[3] The arithmetic average was about 22 MAC, due to one high sample.

Finally, there is also evidence of thorium fumes. A Plant 9 Health & Safety Division datasheet from 1954 describes the process as follows:

> *Cutting thorium derbies in half by hacksaw. The operation is done dry and releases a considerable amount of fume in the area. Saw operator was without any type of respirator.* [HSD 1954]

The dust sample taken was a general air sample by the hacksaw and measured 2,544 dpm/m^3 or about 36 MAC. Therefore, it is important to consider inhalation for fumes for metal cutting processes.

In summary, the method for intake estimation suggested by NIOSH is not adequately supported by the data or by scientific analysis, and may not be claimant favorable. The data in the TBD are incomplete and inadequate to make estimates of thorium intakes from 1954 to 1986. A resuspension model is needed for all periods, including the post-1986 period. The completeness and adequacy of lapel sampling data remains to be demonstrated for workers monitored for thorium in the post-1986 period.

5.2 ISSUE 2: HIGH-GRADE ORE PROCESSING WASTE STEAMS

5.2.1 Raffinate Intake Estimation Method

Finding 7: The TBD does not specify a method for estimating doses in the raffinate streams, which are uranium-poor, from ore processing in Plant 2/3. These doses may be very difficult to calculate, especially for high-grade ores, notably pitchblende ore from Congo.

Fernald processed high-grade ores, including pitchblende, which was processed during the 1953 to 1955 period (TBD Vol. 5, p. 7). These ores, being very rich in uranium (up to two-thirds uranium oxide content), therefore also have high concentrations of Ra-226 and Th-230, which are decay products of U-238 generally present at levels close to equilibrium with U-238. Similarly, they have relatively high concentrations of protactinium-231 and actinium-227 (and its decay products, thorium-227 and radium-223), all of which are in the decay chain of uranium-235. Processing of high-grade ores gives rise to waste streams that are high in the decay products of U-238 and U-235, but relatively low in uranium, which is part of the product stream.

Essentially no personnel monitoring for the decay products of U-238 and U-235 was done in the period of production when ores were handled at Fernald. The TBD cites some air concentration data for Plant 2/3 (Vol. 2, pp. 21–22), but these are in production areas, not waste stream areas. Unlike production areas, where uranium bioassay data can provide at least a starting point for internal dose reconstruction, such data are not very useful in determining dose of decay products. Uranium is a minor constituent of the waste streams in terms of its fraction of the total radioactivity per gram of material. This is accentuated by the fact that the DCFs for most organs of the trace constituents are much larger than they are for any of the isotopes of uranium present in natural uranium.

The TBD has data on the isotopic composition of the waste streams as present in an aggregated form in the K-65 Silos, also called Silo 1 and Silo 2. These data can be used to estimate doses in the absence of personnel monitoring data, provided sufficient air concentration data are available. However, no such data are cited for the processing waste streams in Plant 2/3.[4] The TBD cites the decay products that are the radionuclides of concern for Building 3E, where raffinates were processed. However, there are no data that would be useful for estimating doses due to these radionuclides in the TBD.

The problem of estimation of doses for production workers who worked at the filter presses and other locations where the waste streams were handled was dealt with by SC&A at length during consideration and review of the MCW SEC Petition (1949–1957 period). NIOSH also considered it in detail as part of that same process. The analyses and reviews can be found in SC&A 2005a and SC&A 2005c. The dose reconstruction procedures suggested by NIOSH as well as illustrative examples are in the attachments to SC&A 2005c. A review of those procedures can also be found in SC&A 2005c.

While some of the analysis in the MCW-related reports is specific to that site, given that residues sent to storage were brought back to the site and reprocessed for uranium extraction, the primary discussion relating to pitchblende waste streams applies here and will not be repeated. Suffice it to say that uranium bioassay data provide an uncertain basis for estimating internal dose, due to the trace constituents in pitchblende processing waste streams. For such data to be used at all, knowledge is needed of the fraction of uranium relative to the other radionuclides at various points in the waste stream. Furthermore, these data need to be rather reliable, because the dose depends greatly on accurate (or upper-bound) knowledge of the ratio of trace radionuclide activity to uranium activity. No relevant data specific to Fernald are provided in the TBD, and SC&A has not come across any in the course of this review.

One alternative approach that NIOSH suggested in the context of Mallinckrodt was to use radon breath data. Such a dataset was available for a subset of Mallinckrodt workers. The Fernald TBD mentions that "a series of radon breath samples" were located in the context of a discussion of the composition of the K-65 silos (TBD Vol. 5, p. 26); however, the data are not provided, nor is it clear whether any of the workers who processed the waste streams in Plant 2/3 were covered by the sampling program.

As it stands, the TBD has no procedure in place and no data on which to base one for estimating doses to workers involved with ore processing waste streams.[5] It is to be noted in this context that one of the statements made by SC&A in the Mallinckrodt context was that using the general approach for estimating maximum plausible doses using ORAUT-OTIB-0002 may result in doses smaller than the ones actually experienced by some workers.

A check of some completed dose reconstructions for Fernald using a maximizing method where the claim was denied revealed that NIOSH frequently uses the approach of assigning

[4] There are some air concentration data for the period when Silo 1 was loaded with the K-65 residues brought to Fernald from Mallinckrodt Chemical Works. The citation and use of these data has been cited here as one of the strengths of the TBD (see Section 4).

[5] This includes all workers, including maintenance workers and roving trades employees.

hypothetical 12 or 28 radionuclide intakes based on OTIB-0002, as it did in the case of Mallinckrodt. The DCFs for some organs for thorium-230 and protactinium-231 (and in some cases Ac-227) are orders of magnitude greater than those for U-234 or U-238. Although thorium-230 and some other radionuclides of concern here are part of the hypothetical 12 and 28 intake lists, it is not clear that the assumptions in OTIB-0002 are claimant favorable for the more highly exposed workers at Fernald, such as those exposed to certain raffinate and residue materials or to high levels of thorium-232 dust. Hence, NIOSH should verify that the doses using OTIB-0002 (meant only for efficiency purposes in cases that are likely to be denied) are actually higher for organs such as bone surface than would be the case were the intakes estimated from Fernald raffinate operations (including K-65 silo related work).

5.2.2 TBD Guidelines for Estimating Raffinate Exposure

Finding 8: Workers who may have worked with raffinates may be missed by the protocol specified in Vol. 5 of the TBD. The guidelines for determining which workers were exposed to raffinate dusts are too restrictive and place far too great a reliance on completeness of records for job assignments, or in the alternative, place the burden of proof on the claimant. They have not been adequately justified by measurements and are not claimant favorable.

It is argued that internal exposure to K-65 raffinate dust would have been associated with external exposures of several hundred mrem per week:

> *Calculations of internal intakes resulting from exposures to the raffinate dusts generated during dumping operations should be used only for claimants for whom a work history on this specific project can be established. An examination of external penetrating radiation dose for workers who were known to have worked with and handled these drums of raffinate wastes show significant (several 100 mrem per week) penetrating dose accumulation. Therefore a criteria to determine and/or verify that a worker had indeed been exposed to internal intake from raffinate dusts would be a record of penetrating external dose, i.e., no detectable dose would clearly indicate little direct contact or work with the barrels of waste.* [TBD Vol. 5, p. 27]

However, exposure to dust could have occurred at some distance from the drums and would have been strongly dependent on the ventilation conditions, whereas the external dose rate would have fallen off substantially with distance. Although it is agreed that no detectable dose would indicate little direct work with the barrels of waste, how should the dose reconstructor address workers with modest levels of external exposure, say 50 mrem per week, in terms of their potential exposure to dust?

The protocol for assigning internal dose only to those workers whose records show that they worked with the waste and whose records show that they worked with raffinates appears far too restrictive, based on the evidence provided. NIOSH should establish that "several 100 mrem" per week is an appropriate criterion for these workers. The prevailing maximum dose limit from the mid-1950s onward would have been routinely exceeded at any dose averaging over 250 mrem per week (assuming 1 week off every quarter). This seems implausible on the face of it. The criterion appears to be exclusionary. It needs to be better quantified—"several 100 mrem" is far too vague—and justified based on worker external dose records. Furthermore, NIOSH needs to demonstrate that available DOE records have the kind of detail concerning job assignment information that would enable a dose reconstructor to make a determination of work with raffinates in a claimant-favorable way.

A set of criteria that is clear, technically well-founded, and claimant favorable is needed to determine who worked with various raffinate streams and, in particular, who may have been exposed to high Ra-226 and Th-230 raffinates.

The time of the operation—10 weeks maximum per year, with an upper limit for individual work of 6 weeks—is not well justified, given the importance of the topic. To say that the work "could have been limited to a period of 10 weeks per year" seems a rather weak basis for limiting exposure time. NIOSH should provide the data on which these times are based, so that the technical reasoning is more transparent and justifiable.

Furthermore, external exposure guidance for determining who worked with raffinate dusts is only applicable (if suitable criteria can be developed) to waste streams containing high concentrations of Ra-226. It does not adequately address the waste streams arising from RU processing.

Finally, the guidance for the mix of radionuclides to be used needs clarification on two points. The TBD refers to Table 5-16 for the choice of the mix of radionuclides to be used in assigning the 1.3 microcurie estimated intake per year (Vol. 5, p. 25 and p. 27). First, this reference is ambiguous, because it does not specify whether the data for Silo 1 or Silo 2 should be used. Second, the guidance should make it explicit that the intake of beta emitters in Table 5-16 would be in addition to 1.3 microcuries per year, which was developed based on alpha dust data. This is indicated in the present text, but is not explicit.

5.3 ISSUE 3: ESTIMATION OF DOSES FROM RECYCLED URANIUIM

5.3.1 Recycled Uranium Trace Contaminant Data

Finding 9: The data on trace contaminants in RU in the Fernald TBD are incomplete and appear to be incorrect. Different official documents have very different values for various aspects of RU data, including production and contamination. The contradictions have not been sorted out in the TBD.

The TBD cites considerable data on the contamination of RU with trace amounts of plutonium-239, neptunium-237, and technetium-99. However, these data are incomplete. The representation of maximum trace contamination is at variance with other official documents and appears to be incorrect.

Table 5-9 of the TBD (Vol. 5, pp.15–16) provides data on plutonium-239, neptunium-237, and technetium-99 contamination of various source of RU received at Fernald. The data are given in parts per billion of the trace contaminant in uranium, written as "ppb U," which we will abbreviate here simply as ppb. The highest value of Pu-239 contamination, associated with uranium trioxide from tower ash from Paducah is given as 412.177 ppb (TBD, Vol. 5, Table 5-9 and p. 17). Several values of Pu-239 contamination are between 10 and 100 ppb, and the rest are below 10 ppb, which was the specification limit for Pu-239 contamination at Fernald.

However, other documents are at variance with the maximum value of 412.177 ppb. For instance, a 1985 compilation of RU feed materials above 3 ppb U received at Fernald, prepared by National Lead of Ohio (NLO), gives the highest total plutonium contamination in "ash" for 1980 as 1,122.553 ppb (Spenceley 1985, Attachment D). Plutonium isotopes other than Pu-239 would not contribute significantly to the ppb values; hence, it is safe to interpret the "Total plutonium ppb" in Spenceley 1985 as approximately equivalent to a Pu-239 ppb value. This reference does not provide details of other radionuclides.

It is quite possible that both sources are incorrect. The TBD appears to be based on a DOE report on RU (DOE 2000). This DOE report states that the total uranium receipts at Fernald amounted to 362,581.8 metric tons (DOE 2000, p. ES-2). This appears to be inconsistent with materials accounting reports from Fernald. For instance, the cumulative receipts until the end of FY 1986 were stated by Westinghouse to be 606,931.9 metric tons (Bogar 1986, Table V). This materials account is consistent with others produced during the period of production and submitted to the AEC and the DOE. Hence, it is likely that the DOE 2000, which is the basis for the data on RU, is incorrect even for the basic value relating to uranium receipts at Fernald.

We note here that the TBD also appears to have an incorrect value for uranium production at Fernald. Volume 1 of the TBD estimates the shipments of uranium metal at 170,000 metric tons and intermediate products at 35,000 metric tons. The materials account cited above provides a value of 594,699 metric tons cumulative shipments to the end of FY 1986. Furthermore, the total shipments of 205,000 metric tons in Volume 1 of the TBD are less than the estimate of 246,683 metric tons of RU alone that the TBD states were received at Fernald (TBD Vol. 5, p. 13). The total amount of RU of 246,683 metric tons in DOE 2000 appears rather large. In contrast, the amount estimated in Spenceley 1985 is only 7,183.6 metric tons, cumulative through 1985. This is almost 30 times less than the value in DOE 2000. Finally, Volume 6 of the TBD contains an entirely different number for RU compared to Vol. 5. Citing a DOE 2003 report on RU, it states that the receipts of RU at Fernald amounted to 17,966 metric tons. This matter is further discussed in Chapter 7.

Since the last mentioned report (DOE 2003) was prepared in order to correct "some inconsistencies between quantities of RU shipped and the quantities received" (DOE 2003, p. v) in the DOE 2000 report, it is surprising that NIOSH did not employ the corrected report. The figures from this report are shown in Vol. 6 of the TBD (Table 6-2, p. 8); they indicate an overall average Pu contamination of the RU received at Fernald of 4.14 ppb. This is greater than all the average contamination values for enriched, natural, and depleted RU shown in Table 5-10, Vol. 5 of the TBD (3.5 ppb, <0.1 ppb and <0.1 ppb, respectively), where the basis for the RU dose reconstruction is developed. Volume 5 of the TBD gives the overall average Pu contamination of RU as 0.9 ppb, which is only about 22% of the value in DOE 2003.

The overall average values for Np-237 and Tc-99 in Table 5-10 are also at variance with DOE 2003 (Table A-9, p. 60, which is reproduced as Table 6-2 in Vol. 6 of the TBD). The concentrations of Np-237 and Tc-99 calculated from the DOE 2003 data are 319 ppb and 7510 ppb, respectively, compared to 104 ppb and 1,346 ppb given in Vol. 5 of the TBD.

Another contradiction emerges from the comparison of the values in Volume 5 of the TBD and DOE 2003. Since the overall value for RU receipts given in Volume 5 of the TBD is so much larger than that in DOE 2003 (246,683.1 metric tons versus 17,966 metric tons), the total contaminant content of RU estimated in Volume 5 of the TBD is much larger than that in DOE 2003. Table 8 shows the comparison.

Table 8: Comparison of Total Fernald RU Contamination, TBD, Vol. 5 vs. DOE 2003

	Total Pu, grams	Total Np-237, grams	Total Tc-99, grams
TBD Vol. 5, Table 5-10	217.7	25,742.1	331,998.1
DOE 2003, Table A-9	74.3	5,735	135,000
Ratio, TBD/DOE 2003	2.93	4.49	2.46

Volume 5 of the TBD is not only in contradiction to Vol. 6 of the TBD, but it is also at variance with what DOE claims is a more definitive DOE report on RU (DOE 2003), since that report was designed to correct earlier problems. SC&A has not done a review of the underlying data that led to the correction, since that would involve a major effort to review RU data across the complex. It is unclear at the present time how reliable the various figures for plutonium, neptunium, and technetium contamination (both as totals and in terms of concentrations) might be.

An evaluation by Bechtel of RU shipped to Fernald from Paducah provides yet another set of values for RU contamination for a specific batch that do not match the values in Volume 5 of the TBD. This document provides a range of values of Pu-239 in "Feed Plant Ash" shipped to Fernald in 1980 from Paducah as 37 to 3,118 ppb (Bechtel 2000, Table 4-2.2, p. 51). The various containers of Feed Plant Ash were not mixed at Paducah, because the reported values were "calculated from results of 16 hoppers analyzed by FMPC" (Bechtel 2000, footnote to Table 4.2-2, p. 51). Hence workers handling and measuring the hoppers would have been exposed to concentrations of trace radionuclides during some time periods when the concentrations were far higher than the largest value reported in the TBD, especially if they worked with raffinate streams. Finally, the same table in Bechtel 2000 notes that data for plutonium contamination are not available for "Filter Cake" shipped to Fernald. Three other items have only blanks in the column for plutonium contamination. The higher trace contamination levels may adversely affect some workers, who were mainly in contact with them due to their work assignments or periods of employment. For others, long-term exposure to RU may mean that the values suggested by NIOSH are claimant favorable (see below).

In summary, the contradictions and conflicting values in the RU data need to be investigated, before a reliable set of values for RU amounts and contamination can be established.

5.3.2 Recycled Uranium Trace Contaminant Radionuclide List

Finding 10: The radionuclide list for RU in the TBD is incomplete. Furthermore, the concentrations of trace radionuclides in the raffinates, which are much higher than those in the feed material, are not adequately discussed.

The TBD focuses on Pu-239, Np-237, and Tc-99 in its evaluation of RU. Other radionuclides, such as americium-241 and thorium isotopes (228, 230, and 232) are mentioned, but no data are provided (see Section 5.2.2, Vol. 5, pp. 13–18). The omission of thorium isotopes, and in particular thorium-230, may be of considerable significance. Furthermore, when RU is processed for its uranium content, the raffinates tend to accumulate the plutonium and other trace contaminants, including thorium-230. The raffinate stream contains little uranium. Hence the problem of dose reconstruction for workers who handled the raffinates is analogous to that of the workers who handled the waste streams from pitchblende ore processing. This problem was recognized at Fernald at least by the mid-1980s. For instance, a 1988 evaluation stated the following:

> *The uranium feed would contain the trace of TRU impurity that was typical of recycle uranium. A portion of the TRU impurities would end up in the uranium product and a portion in the byproducts. The vast majority of uranium goes into the uranium product, but a small amount does end up in the byproduct. The end result is that the ratio of TRU to U is slightly lower in the product than it was in the feed, but that ratio is* ***much higher in the byproduct than it was in the feed****.* [Hinnefeld 1988, emphasis added].

This problem of concentration of trace radionuclides in the raffinate stream is also recognized in the TBD, which cited an expert evaluation done in 1989 (Bassett 1989). In the case of magnesium fluoride feed, a note to Table 5-9 in the TBD states the following:

> *Though the results in the table are all reported in ppb U, this measure is meaningless in subgroups in which there is very little uranium, such as subgroup 8, in which the MgF_2 did accumulate some isotopes, but was low in uranium by design.* [Vol. 5, TBD, p. 15]

Despite the fact that the TBD states that trace contaminant values are “meaningless” when there is very little uranium present, the quantitative discussion in the TBD of RU dose estimation is focused primarily on the trace contaminant values of uranium feed material, rather than raffinates or magnesium fluoride.

Thorium-230 has also been recognized as a specific problem in this regard. For instance, the DOE-commissioned evaluation of radiation doses due to trace contaminants in RU for the Paducah plant indicates that thorium-230 doses were among the highest in some circumstances. In that case, the maximum bone surface dose estimated for “ash receivers” was estimated as 110 rem, about the same as that for Pu-239 and much higher than Np-237 (PACE/University of Utah 2000, Tables 7.10 and 7.11, pp. 76–77). As with the processing of ores, thorium-230 will tend to concentrate in the raffinate stream as well, exacerbating the problem.

A complete evaluation should also consider thorium-232, uranium-232, and uranium-236 as potential contaminants of RU. Specifically, U-232 is created as a neutron activation (decay) product of protactinium-231, and the DOE recommends that it be taken into consideration in RU assessments. This is both an internal and external dose issue, because U-232 decays into thorium-228 with a 70-year half-life. According to DOE-STD-1136-2004, the *Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities*, U-232 presents the greatest external dose hazard in RU:

> *The isotope in recycled uranium presenting the greatest potential radiological hazard from external sources is ^{232}U. ^{232}U is a daughter product of neutron activation of ^{231}Pa. The health hazards of ^{232}U are primarily due to the rapid buildup of gamma activity of its decay products, particularly from ^{228}Th. The gamma activity buildup is both time and process-dependent.* [DOE 2004, p. 2-15].

Given that the highest values of trace contamination with plutonium received at Fernald could be in the thousands of ppb, Table 5-9, which gives the values for plutonium in the various RU streams at Fernald, is incomplete and inadequate. The highest value of Pu-239 in this table, 412.177 ppb, corresponds to feed material (ash) from Paducah. There is no discussion in the TBD of the specific batches of RU and the waste streams arising from them. Such an analysis is necessary for individual internal dose reconstruction for at least some groups of Fernald workers.

5.3.3 TBD Guideline for Recycled Uranium Dose Estimation

Finding 11: The suggested approach for RU dose estimation in the TBD is claimant favorable for many RU workers, but is not claimant favorable for others and for some periods; it is not based on an evaluation of the available data.

The TBD proposes to use 100 ppb of Pu-239, 3,500 ppb of Np-237, and 9,000 ppb of Tc-99 as the trace contaminant concentrations to be added to uranium dose (TBD Vol. 5, p. 17). The basic approach is to use uranium bioassay data and add the doses from the assumed trace contaminant concentration. There are a number of problems with this approach. No personnel monitoring data are available for the pre-1986 period; bioassay and in-vivo data exist for the post-1986 period. Of those data, the in-vivo data are not of much use, since the detection limits for plutonium are very high. These issues are discussed in the RU section of the TBD (Section 5.2.2).

First, a one-size-fits-all method of estimating doses due to trace contaminants in RU is not appropriate. Over the decades, shipments of RU appear to have varied in Pu-239 content from well below the specification limit of 10 ppb to orders of magnitude larger than that (possibly to several thousand ppb). Concentrations of Np-237 would tend to be 1 to 2 orders of magnitude larger. Hence, the suggested values would be very claimant favorable for some workers handling RU, while they may not be favorable for others.

Second, the list of radionuclides in RU needs to include all important contributors to **dose** and not just intake. Very small proportions of Th-230, or Pu-239, or Np-237 can become the main contributors to dose for certain organs (bone surface dose for instance), because their DCFs are orders of magnitude higher than the corresponding ones for uranium. Hence, it is important to know the trace contaminant concentrations with some precision. Alternatively, a value that can be **demonstrated** to be scientifically sound and claimant favorable may be used. This must be on the basis of a comprehensive evaluation of the data, which has not been done in the TBD.

Third, the raffinate streams are not considered adequately in the TBD, which notes that these are known to concentrate the trace contaminants in RU. In the absence of more detailed data on trace contaminants in waste streams, uranium bioassay cannot be reliably used to reconstruct doses for RU raffinate workers.

Other workers in some specific jobs not involving raffinate streams may have been exposed to TRU concentrations at much higher levels relative to uranium than those handling feed material. For instance, workers manually cleaned out crucibles in which uranium tetrafluoride was reduced to metal, according to SC&A site expert interviews:

> *Chemical Operators had a wide variety of responsibilities. Some of the high exposure jobs included manning the dumping stations, cleaning equipment (i.e., dust collectors, reduction pots, crucibles, furnaces, reaction vessels, etc.), inventorying the rabbit hutches, and decontaminating areas when needed. Graphite molds were cleaned with a broom handle and steel wool. After the removal of the MgF_2 from the uranium,* ***individuals would stick their heads down as far as they could to clean the slag out of the pot. During this operation there was no respiratory protection worn****.* [from Attachment 4 of this report] [Emphasis added.]

Uranium bioassay data would not be adequate to estimate trace contaminant doses in such cases without a very specific knowledge of the contaminant ratios for that particular operation. The TBD acknowledges as much in the note to Table 5-9 and provides one value of nearly 100 ppb plutonium-239 in magnesium fluoride slag. However, it provides no analysis to show that the recommended values for trace contaminants would be consistently claimant favorable for such workers or for others who worked with RU waste streams.

Finally, the TBD correctly notes that dose reconstructors should assume the most claimant-favorable solubility type for RU contaminants (TBD Vol. 5, p. 17). It should be noted that these contaminants will often occur as traces in a uranium compound matrix. Thus, the full range of solubility classes for uranium should be considered; i.e., plutonium should be considered to be potentially in Class F form in this context, even though only Class M and Class S would normally be considered for compounds of plutonium.

5.4 ISSUE 4: INTERNAL DOSES DUE TO URANIUM

5.4.1 Enrichment of Uranium Processed at Fernald

Finding 12: The TBD notes that uranium batches with enrichment greater than 2% were processed at Fernald. NIOSH's assumption of 2% enriched uranium is claimant favorable

most of the time, but not for periods and batches when uranium of higher enrichments was processed.

Uranium urinalysis at Fernald was done using the fluorometric method, which yields results in mass of total uranium per liter (TBD Vol. 5, Table 5-9, p. 30). This method is, therefore, unable to provide data on the enrichment of the uranium that was inhaled.

Natural uranium, depleted uranium, and uranium enriched up to 10% were processed at Fernald. The TBD states that enriched uranium processing began in 1964, and adopts the following recommendation for default values for uranium dose reconstruction:

> *In the absence of specific enrichment information, and considering the above available data related to processing experience of uranium enrichments at FEMP, the default assumption for time periods after 1964 is 2% enrichment for bioassay data in milligram quantities of uranium. Prior to 1964 natural uranium should be assumed.* [TBD Vol. 5, p. 10]

An assumption about uranium enrichment is necessary to derive the intake in terms of radioactivity from bioassay data. In so far as depleted and natural uranium and uranium of any enrichment less than 2% was processed after 1964, this default assumption is claimant favorable. However, there are two areas where it is not.

First, Fernald materials accounts show that some enrichment uranium was processed there from 1953 onward, though it was in relatively small quantities until 1958, when over 500 metric tons were processed (Bogar 1986). The TBD appears to be incorrect, both about the starting date of enriched uranium processing and about the amounts. In regard to the latter, the TBD states the following:

> *Of the total quantity of uranium received and processed at FEMP <25% was enriched above normal (60,181 MTU of the total 246,683 MTU). Approximately 95% (208 gms of the total 218 gms) of the Pu-239 which was received at the Site came in the enriched uranium receipts. (DOE 2000)* [TBD Vol. 5, p. 10]

This statement appears to confuse enriched uranium that came to Fernald as RU with all enriched uranium. DOE 2000, the report cited in the TBD paragraph quoted above, gives the total production at Fernald as 363,582 metric tons (rounded), of which 246,683 metric tons are stated to be RU (DOE 2000, p. ES-2). As previously discussed, the production figures in DOE 2000 appear to be incorrect—at least they do not match the detailed materials accounting data submitted annually by Fernald management (both NLO and Westinghouse) to the DOE. For instance, Bogar 1986, which was the account up to and including FY 1986, gives the cumulative enriched uranium shipments up to that date of 126,317 metric tons (rounded), or just over double the amount cited in the TBD. The materials accounting data from 1986 show that enriched uranium was about 21% of the total shipment amount of 594,699 metric tons of all types of uranium (Bogar 1986).

Lack of knowledge of the enrichment may prevent accurate or claimant-favorable dose reconstruction in the case of incidents. For instance, the TBD suggests using an enrichment of 2% for the February 14, 1966, incident, even though the enrichment was unknown. It does not provide any evidence that it was not more than 2%. It is difficult to see how such a dose reconstruction for this incident could be regarded as resolving the uncertainty in favor of the claimant.

Finally, the TBD acknowledges that uranium enrichments up to 5% or even 10% were processed at Fernald, starting in 1965:

> *In 1965, the FEMP became the official receiving station for uranium compounds of up to 5% ^{235}U furnished by licensees. With the startup of enriched uranium operations in the refinery in 1966, more than 1,500 safe mass batches of up to 10% ^{235}U feed materials were prepared for drum digestion. This recycled uranium was known to contain traces of ^{237}Np, ^{238}Pu, and ^{239}Pu.* [TBD Vol. 2, p. 15]

The difficulties arising from a lack of claimant favorability in the choice of an enrichment value that is too low for some workers and periods would be compounded in the case of recycled enriched uranium. This is because the uranium intake value is the basis for estimating the intakes of trace radionuclides. Hence, an underestimate of uranium radioactivity by a factor of 2 would lead to a corresponding underestimate of trace radionuclide intakes. Given that the latter may be the most significant parts of internal dose in some situations, a modest underestimate for uranium could result in a large problem in the overall final result of internal dose.

In summary, the following problems need to be corrected before a choice of enrichments can be considered claimant favorable:

- The TBD needs to be revised to show the correct periods of enriched uranium processing.
- The amounts of enriched uranium processed need to be corrected, presuming the annual materials accounts reports filed by the contractor were correct.
- The dates and amounts of uranium over 2% enrichment need to be established, so that an appropriate adjustment can be made for workers in those years (and Plants, if needed).

5.4.2 Doses to Unmonitored Female Employees

Finding 13: Female employees were not monitored for long periods at Fernald even though they were at some risk of internal intakes of radionuclides.

Vol. 5 of the TBD does not discuss whether female employees were provided with bioassay monitoring. However, Vol. 6 of the TBD notes that there was no external dose monitored for female employees from 1951–1960 and again from 1969–1978. For instance, women who worked in the laundry or as laboratory technicians were at some risk of exposure. However, there are no data in the TBD as to when women worked there. NIOSH should also establish that there were women that were not assigned production work during periods that they were not monitored. There is a photograph of a female employee taking a sample from an ingot in a production area that dates from the 1980s (del Tredici 1987, Plate 18). While this is from an era when women were monitored, according to the TBD, it is not far from the time (1978) when none were. A closer look at the frequency of bioassay monitoring for women employees in production work is also warranted.

Furthermore, the above discussion on fugitive emissions for thorium indicates a work environment that had considerable ground-level radioactive dust from production, at least during some periods of operation. Female employees and other unmonitored workers may have inhaled such fugitive dust, which would also not be captured in the environmental dose (see Section 5.7). The TBD needs to take explicit account of the various categories of work done by female employees in order to develop a suitable model for internal intake estimation. SC&A has not been able to address the feasibility of development of such a model, because there is no overall database where bioassay data and in-vivo counts have been collected.

5.4.3 Periodic Extremely High Uranium Dust Concentrations

Finding 14: The TBD does not address the extremely high uranium dust concentrations, which were present at Fernald under a variety of circumstances, and their effect on dose reconstruction. Particle size and solubility assumptions for workers who experienced chip fires should be examined.

There is ample documentation of very high dust levels at Fernald at least in the initial two decades in several of its plants and a variety of operations. Some of the documents are provided in the Fernald SEC Petition (2005) and will not be cited here.[6] Some of the highest dust levels occurred during periodic maintenance or repair operations. For instance, the recovery of parts of a broken main screw in a Plant 4 reactor (where UF_4 was made) in 1967 produced dust levels as high as 171,770 dpm/m^3; the averages for the various operations that were needed for the repair work ranged from 40 dpm/m^3 (12 feet from the reactor where “no work [was] being done”) to over 45,000 dmp/m^3 (“[r]aking loose oxide into catch pan, vacuuming talc & shoveling oxide into drums”). No overall average is provided. (Jones and Keim 1967).

A periodic maintenance operation in Plant 5, cleaning out uranium oxide under a conveyor, produced an average of 359 MAC (about 25,100 dpm/m^3) over the 5-hour operation. This meant that almost an entire working-year’s intake (at 1 MAC) would be accumulated in that single operation (assuming a 2,000-hour work year). Some workers who did the most hazardous jobs likely accumulated higher intakes. The average dust level faced by the “[o]perator cleaning out under [the] burnout conveyor” was 18,000 MAC. This was reported as a significant improvement over the prior year, when the same operation averaged 97,000 MAC, which would give an annual intake at 1 MAC in just about one-and-a-quarter minutes of exposure. (Klein 1960).

[6] The law firm of Waite, Schneider, Bayless, and Chesley in Cincinnati, which represented Fernald workers in a class action lawsuit in the 1990s, has a large archive of documents regarding working conditions at Fernald. The Fernald SEC Petition (2005) has evidently drawn on this archive. This archive contains both air dust data and individual worker bioassay data. It may be useful in validating whether the bioassay data are sufficient to provide a claimant-favorable dose reconstruction for internal dose.

Some routine operations, like grinding and machining of uranium metal in Plant 6, produced dust levels in the hundreds to thousands of times MAC in 1952. High dust levels in routine operations often triggered investigations and ventilation improvements, however. The same operations showed lower dust levels in 1953, but still in the range of 39 MAC to 154 MAC (Heatherton 1953). These 1953 levels apparently persisted through most of the year and possibly beyond, since Fernald was not "scheduled to do any further checking at this time [November 1953] in the machining section unless it is believed absolutely necessary." (Heatherton 1953a)

NIOSH has informed SC&A that there are ample uranium bioassay data for Fernald. These data have not been compiled for the site, so SC&A is unable to make a judgment of the sufficiency of the available data for claimant-favorable dose reconstruction, notably in the context of certain conditions prevailing at Fernald, such as the very high episodic dust levels discussed above. Furthermore, an assumption of a mid-point intake in such a case may be more claimant favorable than assuming a chronic intake (Puncher et al. (in press); Strom 2003). NIOSH should explicitly investigate the choices for claimant-favorable assumptions in case of episodic high intakes when the date of intake is unknown. If urinalysis was not done following such high episodic intakes, much of the uranium could be excreted prior to the next routine sampling. Frequency of sampling and sampling after work in unusually dusty conditions are, therefore, an important consideration in the use of bioassay data.

The TBD does not provide guidance to the dose reconstructor on the problem of factoring in high episodic intakes (as distinct say from large daily variations in exposure that are typical of a job). If the time of an acute intake is unknown, the most claimant favorable approach is to consider an acute intake on the day following the last monitoring result. This should be specified as part of the dose reconstruction procedure for infrequent, high acute intakes. The issue of whether the DOE files of the claimants contain sufficient data to determine whether such intakes also need to be assessed.

Furthermore, uranium monitoring at Fernald was done mainly for its heavy metal toxicity to the kidney (TBD, Vol. 5, p. 12). The MDL for uranium using fluorophotometry was high—14μg/L. With such a high MDL, rather high exposures from Type S uranium would not have been detected. In addition, urine samples were submitted after at least a 2-day work break (TBD Vol. 5, p. 28); this allows elimination of uranium to be cleared rapidly via the GI tract, a procedure that makes the detection of uranium contamination even more difficult. Finally, when using bioassay data, Type S solubility may be more claimant favorable than Type M for non-metabolic organs. The dose reconstruction procedure for using the available bioassay data should consider these factors carefully. Some examples will illustrate these points.

Consider the following description of a uranium fire in 1956:

> *Specifically, a drum of fines located under the chip crusher ignited. By the time the burning drum was removed from the building (approximately 2 to 3 minutes later), the machining bay air was heavily laden with smoke and fume. Personnel did not evacuate immediately but remained in the area 7 to 8 minutes after the fire started. No one was observed wearing a respirator until several minutes later and then only a few. When evacuation was made it was for a very short duration,*

> *perhaps 18 minutes, and when re-entry was made the room air was still visibly contaminated.* [Stefanac 1956]

This fire may have created submicron-size fumes. The TBD acknowledges frequent uranium metal fires (Vol. 5, p. 9), but provides no guidance on the particle size distribution to be used for chip fires. If they are considered among the principal sources of exposure for certain workers due to the frequency of fires, then the issue of exposure to fumes could have considerable significance for them.

Similarly, the question of exposure to high-fired uranium needs explicit guidance in the TBD. The TBD acknowledges the presence of high-fired uranium as one of the chemical forms present at Fernald (TBD Vol. 5, p. 11), but provides no guidance regarding the dose reconstruction procedure or model to be followed.

The issues of extremely high episodic exposures in certain jobs (such as those noted above), particle size (notably as a result of fires), the presence of high-fired uranium together could make a substantial difference in the dose reconstruction protocol, especially routine sampling was infrequent for workers with high potential for episodic intakes and sampling was not done after such intakes. The TBD does not provide guidance for dose reconstructors to address these problems.

Finally, the availability of a significant amount of air dust data from various parts of Fernald could enable NIOSH to partly validate its approach to estimating uranium intakes from bioassay data.

5.5 ISSUE 5: INGESTION DOSE

5.5.1 Ingestion Doses and the TBD

Finding 15: Ingestion doses are not considered in the TBD.

NIOSH proposes to use bioassay data for estimating internal doses due to uranium. Urinalysis data would capture the inhalation as well as ingestion pathways. However, the TBD proposes to use air concentration data for thorium dose reconstruction (see above). Whenever air concentration (rather than bioassay) data are used, it is also important to consider ingestion dose separately, since this is an additional pathway that is not captured by inhalation assumptions. Fernald had heavy air dust loads, including from thorium-232 production. Therefore, ingestion doses from thorium-232 need to be explicitly considered, unless sufficient personal monitoring data are also found for thorium.

The dust at Fernald would be expected to be a mixture of uranium and thorium, with the former predominating. An approach for considering mixtures was suggested by SC&A as part of its review of the Bethlehem Steel Site Profile (SC&A 2005e, p. 21). NIOSH may want to consider a similar approach for estimating thorium-232 ingestion intakes for Fernald.

5.6 ISSUE 6: EXTERNAL DOSE

5.6.1 External Dose Reconstruction Protocols

As a prefatory remark to external dose findings, SC&A notes that Findings #16 through #20 are largely concerned with skin/shallow dose. The findings are made as technical arguments, but their impacts on potential claims may be modest. For example, while skin dose to the palm of the hand is likely to be underestimated, there may be few, if any, claims of skin cancer located in that area. However, since the procedure in the TBD is not adequate for estimating such doses, in case there are any claims, SC&A concluded that a technical review of the matter was necessary as part of this TBD review.

Finding 16: Protocols for reconstructing shallow external dose during the operations at FEMP need to be further developed.

The deep dose Hp(10) evaluation was made within the uncertainties of the dosimetric systems available at the time, and a large underestimation of Hp(10) appears to be unlikely. The TBD argues that the correction factor for the loss of low-energy photons in the shielded filter proposed in the TBD could be under 10% (Vol. 6, p. 13). It suggests a factor of 10% should be used to correct for this lost dose (Vol. 6, p. 23). Any uncertainty or underestimation resulting from this factor is likely to be small when compared to the Hp(0.07) lost dose.

The evaluation of the shallow dose Hp(0.07) for the calculation of the POC for skin cancer should take into consideration the substantial missed skin dose due to beta-gamma emitters that were not registered by thorax or wrist extremity dosimetry.

The reconstruction of the beta dose to other shallow organs (gonads, breast) for the evaluation of the POC for cancer formation should also take into consideration the geometry of exposure. There is considerable potential for missed dose due to high-energy beta emitters that arises due to the location of the source relative to the organ that would not be adequately registered in Fernald thorax or wrist dosimetry.

5.6.2 Estimation of Extremity Doses

Finding 17: Extremity doses appear to be underestimated.

From the nature of the work at Fernald, the hands and forearms of the workers received the highest external doses. The TBD details the dosimetry performed to estimate these extremity doses; however, the calculation procedures given in the TBD will substantially underestimate the extremity dose.

For Fernald work with open sources, beta radiation was the highest contributor to extremity dose. Information is given in the TBD on measured beta dose rates at the surface of uranium metal ingots—around 240 millirem per hour. All open sources of uranium and thorium products showed high beta dose rates. Where uranium and thorium decay products accumulated in a part of the process, the beta dose rates were considerably higher. The TBD acknowledges this fact (Vol. 6, p. 14), but provides no guidance to the dose reconstructor on this point.

The higher dose rates in areas and job types where the beta-emitting daughters of U-238 are concentrated could be a considerable problem in dose reconstruction. The DOE's *Guide of Good Practices for Occupational Radiological Protection at Uranium Facilities*, DOE-STD-1136-2004, makes the following observations on this point:

> *Processes that separate and sometimes concentrate beta-emitting uranium daughters are not uncommon in DOE uranium facilities. Surface beta dose rates on the order of 1 to 20 rad per hour have been observed in such circumstances. Exposure control is complicated by the fact that considerable contact work takes place in facilities that process uranium metal. Beta particles are shielded by rubber gloves or other protective devices or are usually absorbed within the dead layer of skin. The actual beta dose to live tissue would depend on the energy of the beta particles and the thickness and types of intervening shielding.* [DOE 2004, p. 6-7]

In view of the above information, it is safe to say that some areas of Fernald were likely to have contact shallow dose rates between 4 and 80 times the contact dose rates for massive uranium ingots where the decay products have not been concentrated. The TBD identifies these as follows:

> *The forms of radiation encountered at FEMP varied from plant to plant with Plants 5 and 9 exhibiting the highest potential workplace dose rates. These plants were involved with metal reduction, casting, and rolling, and these processes generated the separation and migration of daughter products ^{234}Th and ^{234}Pa (UX-1 and UX-2). As stated above, ^{234}Pa contributes approximately 95% of the total beta dose rate; therefore, any location in the process where this material accumulated resulted in the potential for higher exposure rates. Other areas of potential high radiation exposure included areas where daughter products contaminated other materials (i.e., crucibles, saws, and rolling mills), or where large quantities of the parent material were present.* [TBD Vol. 6, p. 15]

External beta radiation is important at Fernald, especially in areas where there would be direct contact with concentrated decay products of uranium, Th-234 and Pa-234m, with the latter being the main source. Completeness of extremity monitoring or estimation methods that can derive extremity doses in claimant-favorable ways are, therefore, very important. SC&A's review of the TBD, as well as some claimant files, indicates that there are a number of ways in which the extremity doses would be underestimated if the guidance in the TBD were followed.

Completeness of Extremity Monitoring

No finger monitoring was conducted at Fernald. Wrist monitoring was conducted for some workers, but did not cover all workers. A review of the DOE records in the files of about 15 claimants working during various periods from 1952 onwards into the 1980s did not reveal a single case of wrist badge data in the claimants' DOE files. The job types included chemical operator, laborer, pipefitter, machinist, carpenter's helper, electrician, degreaser, supervisor, and millwright. The shallow wrist doses recorded for these workers per year or over their work period ranged from a few rem up to 60 rem, with many well over 10 rem. Wrist monitoring appears to have begun around 1970. SC&A could find no wrist badge data on the NIOSH Site Research database prior to that time. No such data were found in a very limited search of the DOE files in claimant records.

The TBD does not discuss the problem of missed extremity doses. This is a significant gap, because it is clear from the available data that in certain areas, the exposure potential for extremity doses was high. For instance, the compilation of beta plus gamma wrist badge results for October 1972 shows a range of wrist badge readings between 535 and 6,700 millirem for the month.[7] The data for November indicate most wrist doses in the several hundred-millirem range.[8] At these rates, wrist doses could reach hundreds of rem over the course of decades-long employment. The hand and finger doses would be even higher.

The TBD needs to discuss how the problem of gaps in the data that appear to be substantial will be filled to estimate wrist dose.

We now turn to the problem of connecting wrist dose with finger or hand dose.

Finger-to-Wrist Dose Ratios

The TBD mentions that finger-to-wrist ratios (correction factors) of 2.06 had been used at Fernald after 1988, and that a correction factor of 3 might have been used previously (Vol. 6, p. 10). It then goes on to say that as the fingers are shielded behind gloves (shielding factor of 20%), and the extremity dosimeter was not, the values of Hp(0.07) would overestimate the dose to the fingers, and therefore are claimant favorable. However, the following requirements for beta dosimetry are necessary before such an assumption can be made:

- There must be no material between the beta emitter and the detector (film emulsion or TLD).
- The distance between the beta emitter and the finger, and the beta emitter and the detector has to be very similar in order for the measured dose to correspond to the real dose to the extremity.
- The angle of incidence of the beta radiation to the detector has to be close to normal (90^o). This applies to film dosimeters and also to calcium sulfate TLDs, which are usually formed into thin cylindrical or square wafers. The plastic shielding on the side of the dosimeter will also absorb most if not all the beta particles.
- The wrist dosimeter must always be worn on the palm side of the hand. If it were worn on the back of the hand, no beta dose would be registered.

When all these factors are taken together, the following conclusions can be drawn:

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[7] The document has no title, but is a compilation of datasheets. It is numbered 1713 on the NIOSH Site Research database with the title "Wrist and Film Badge Data (October 1972)," and has 6 pages. The data referred to are on page 1 of the file, with the notation that the badges were worn between September 12 and October 10, 1972.

[8] NIOSH Site Research database document number 1704: "Wrist and Film Badge Data (November 1972)."

- Case A: When holding a beta source in the gloved hand, essentially no dose will be recorded on the wrist dosimeter. It is not possible to estimate a correction factor.
- Case B: When cleaning or polishing a beta source (such as a uranium metal bar) with a gloved hand, the wrist dosimeter will be close to the surface. The dose recorded will provide a reasonable estimate of the real dose to the fingers. The correction factor would be close to one.
- Case C: For other geometries, the correction factor will be between one and such a large number that the use of a correction factor is inappropriate.

The correction factor lies between 1 for case B and some high number for case A. In the latter case, the correction factor is not meaningfully defined, since the recorded dose on the wrist dosimeter will be very low or zero. Such considerations make the use of correction factors for hand and finger doses unreliable and impractical. A better and more consistent way of approaching the problem would be to estimate the finger and hand doses on a case-by-case basis in case of skin cancer of the hand. For workers that operated or performed maintenance on equipment with high concentrations of decay products of U-238 or Th-232, the annual beta dose to the skin of the hand could be as high as a few hundred rem. For other workers, handling metallic U products, the dose to the skin of the hand could be estimated as follows:

240 mrem/hour × 2000 hours per year × the fraction of time the uranium was handled

A similar approach can be developed for thorium-232.

It can be seen from the above that an analysis of exposure geometry of the problem during the actual work performed is essential to the determination of a scientifically reasonable and claimant-favorable extremity dose.

Contaminated Gloves or Non-Issuance of Gloves

A second factor that can lead to an order-of-magnitude underestimation of the extremity dose is the question of glove contamination. The TBD refers to the problem of contaminated gloves only in the context of potential for exposure to Tc-99 beta dose (TBD Vol. 6, p. 9). However, even in this context, it does not provide guidance as to how the problem is to be addressed. In other contexts, the TBD only cites gloves as an element of clothing that provides a 20% shielding factor for beta radiation (TBD Vol. 6, p. 10).

From the FEMP document on the decontamination of gloves (Wunder 1955), a sample of the gloves was monitored, and around 35% of the gloves measured showed a beta-gamma dose rate above 20 mrep/h, where 20 mrep/h was the maximum dose rate of the dose rate meter. As the gloves were not intended for contamination control, it may be assumed that the dose rate inside was the same as that outside. Some gloves continued to show above 20 mrep/h even after decontamination, which was estimated to have removed around 90% of the radionuclides. Using a conversion factor of 1 mrep = 1 mrem, this dose rate is equivalent to 20 mrem/h. Assuming that the workers would use the gloves around 2000 hours/year gives an annual dose rate to the fingers and palm of the hand for the users of these gloves at around 40 rem. Even if one considers actual time of wearing gloves to be 1,000 hours, the annual missed dose to the hand and fingers would be 20 rem. The maximum doses in a few cases would be much higher.

An interesting detail in the Fernald documentation was the proposed burning of used gloves for uranium recovery. This indicates generalized glove and workplace contamination. The beta radiation (the predominant part) on the gloves would not be detected by the wrist dosimeter. This would imply that for the workers who used gloves, the skin of the hand received an undetected dose, which can be considered around 20 to 60 rem/year, with a possible maximum being much higher. This dose should be considered as "background" and added to the beta dose to the hand received from the routine work with the uranium and thorium compounds.

There is also some evidence, provided as a statement in the Fernald SEC petition, that the clothing issue record of an employee who routinely handled uranium metal for testing shows that he was never issued gloves (Fernald SEC Petition, Part 1, p. 19).

The above discussion has been in the context of shallow extremity doses from uranium-238 decay products. Similar considerations apply to external dose from Th-232 decay products and the process streams that concentrate Ra-228 and its decay product, Ac-228, with which it can be expected to be in equilibrium (due to the short half-life of 6.15 hours of Ac-228). In the case of Th-232, there is the additional problem of geometry of deep exposure when thorium-bearing materials were handled due to the higher contact gamma dose in this case (see below).

5.6.3 Beta Dose to the Rest of the Body

Finding 18: Beta dose to the rest of the body would also be underestimated, based on the TBD guidance.

It appears from the supporting documentation of Fernald that the workers passed much of the working day with a substantial coverage of radioactive dust. Various documents provide some examples:

- Dust samples from the chip furnace area showed contamination ranging from 0 to 92,984 dpm/m^3, with averages at particular work locations ranging from 22 to 25,676 dpm/m^3 (0.3 to 366 MAC) (Heatherton 1953). Workers in such areas would likely have a heavy coating of dust.
- In 1953, a worker was observed having "[h]is body covered with black dust, and the worker volunteered that this material was black oxide, U_3O_8, which he had encountered in cleaning the Bag House" (Durkin 1953).
- A 1954 letter from W.B. Harris of the Health and Safety Laboratory noted "a general disregard on the part of the operators of the toxicity of the material. This is evidenced by…dust on desk tops, hood tops, and so forth; careless and sloppy handling of equipment containing uranium powders….spillage on the floors of small heaps of uranium salts" (Harris 1954).
- Dust continued to be a problem into the 1980s. As discussed below, many TLDs were so coated with dust that an attempt to correct the external dose for this resulted in large

correction factors, often in excess of 50%, and sometimes in excess of 100% (yielding negative radiation doses).

The work in the dusty conditions is, of course, a very important input for internal dose calculations. However, dusty work conditions also mean that the worker was almost continuously externally irradiated with beta-gamma emitters. This contamination would have contributed to the Hp(0.07) dose to the skin without being registered on the thorax or extremity dosimeters. This irradiation condition is not mentioned and quantified in the occupational external dose TBD.

This generalized contamination led to beta doses to the rest of the body, which would not necessarily have been recorded by the thorax or wrist dosimeters. However, the TBD acknowledges the potential for significant beta dose to the skin:

> *After reviewing the tables in this TBD it is possible to determine that the preponderance of the radiation consists of beta particles, and while this form of radiation can deliver substantial doses to bare skin in proximity it does not penetrate deeply into the body. The dose rate from the photon component associated with the radioactive decay of uranium is "minor compared to the beta dose rate" (Alvarez et al. 1984). In addition, protective measures such as distance, shielding, clothing, gloves, etc., reduce beta dose rates appreciably without excessive bulk by approximately 20%.* [TBD Vol. 6, p. 10]

This appears to imply the following:

(1) The recorded values of Hp(0.07) as measured by the dosimeter located on the thorax are claimant-favorable

(2) Only the beta dose to the skin should be considered. The beta dose to other body organs, notably the breast and the gonads, need not be considered

Neither of these considerations is correct or claimant favorable. As to point (1) above, the Hp(0.07) dose recorded on the thorax dosimeter will be a small fraction of that actually delivered to the skin. Data on Hp(0.07) dose obtained from the thorax dosimeter in the following cases may be difficult to interpret in the following cases, if it can be done at all:

(a) Dose due to directly handling uranium, as in the ORAUT-OCAS-001 example (OCAS-001, p. 46), or directly handling other beta/gamma emitters

(b) Dose due to a hot particle

(c) Dose to the legs and hands while standing, sitting, or kneeling on all fours on a contaminated surface (in this case, the dosimeter being more or less perpendicular to the contaminated surface)

(d) Dose when standing facing a uniformly contaminated surface if the distance of the dosimeter from the contaminated surface is significantly higher than around 50 cm.

There are some geometries where the dose of record would be useful; for instance, working in a confined contaminated space such as a pipe, vessel or duct, or lying face down on a contaminated surface. In these cases, the beta dose to the thorax dosimeter approximates the dose to the skin, if the beta energy spectrum is similar to the beta calibration spectrum. This presumes that the front of the thorax dosimeter was facing the contaminated surface.

Evaluating the irradiation geometries above suggests that, unless the employee spent most of his day doing maintenance work in confined spaces or supervising a contaminated control panel, the Hp(0.07) dose to his or her thorax dosimeter due to beta radiation may have little relation to the real beta skin dose.

The suggestion in the TBD (Vol. 6, p. 17) that the recorded external doses are claimant favorable over a wide range of angular variation of the incident radiation is generally not correct for the following reasons (apart from the geometry of the source relative to the organ exposed, discussed above):

- The Hp(10) response for horizontal rotation goes down as the irradiation angle increases. There is a modest reduction of the response for the TLD dosimeter. However, this problem is much more serous for film dosimeters.

- The dose recorded by TLD and film dosimeters goes down very quickly as a function of angle. It will fall to almost zero for side-on irradiations. This angular dependence is not at all claimant favorable, and will lead to considerable underestimation of Hp(0.07) dose.

Considering organs other than the skin, the maximum beta energy emitted by some radionuclides (notably Pa-234m with E_{max} = 2.29 MeV) is high enough to cause a dose to the gonads, breast, or lens of the eye. Hence, an assessment of shallow dose is not only important for skin cancer cases, but also for other near-surface organs. SC&A has previously suggested that the thyroid also be considered as a candidate for shallow dose assessment (SC&A 2005a, p. 14).

It is clear from the same arguments used above that the use of Hp(0.07) as measured with the thorax dosimeter to estimate the beta dose to the gonads or to the eye lens is appropriate only in some geometries. For all other geometries (for example, sitting on a uranium metal ingot), the Hp(0.07) dose recorded on the thorax dosimeter does not represent the real dose to the gonads. It is to be noted that sitting on ingots to stamp ID numbers was a practice followed at Fernald sufficiently frequently for an employee to allow himself to be photographed that way.[9] Other examples of the problem of geometry, such as sitting on derbies, are provided in the Site Expert Interview Summary (Attachment 4).

As a final note, the unreliability of the thorax dosimeter for beta dose and the lack of egress monitoring until the late 1980s would make it more difficult to reconstruct skin dose for personnel such as security guards, who would enter the site for a variety of reasons, such as escorting visitors.

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[9] Photograph by Robert del Tredici, taken in 1987. The photographs at Fernald, some of which were published in del Tredici 1987, were taken with the permission of management. NIOSH has agreed to evaluate the geometry issues connected with this example. See Attachment 3.

For the case of a claimant with cancer of the breast, gonads, or thyroid, a specific investigation should be made to estimate the relevant organ dose due to beta radiation.

5.6.4 Geometry of Exposure

Finding 19: The TBD does not analyze the special problems associated with geometry of the source relative to the exposed organ and dosimeter in thorium handling and production.

In the case of Th-232, the problem of shallow and deep dose geometry is even more complex. Unlike uranium, both gamma and beta dose are significant for Th-232. Special exposure geometries, such as handling thorium metal, shoveling thorium chips into a furnace or withdrawing ash from a furnace, and handling drums containing thorium have considerable implications for interpretation of deep dose. A 1955 survey done at Fernald found the following:

> *An attempt was made to compare the radiation from thorium with that of [sic] uranium, in which the surface dose is known. These measurements indicate that a gamma radiation level from thorium is approximately 10–20 times that from uranium, while the beta radiation from thorium is approximately 25% of that from uranium. Assuming a surface dose of 5 mr/hr gamma and 240 mreps/hr beta from uranium metal, I think we can say that the contact dose from thorium is in the neighborhood of 50–100 mr/hr gamma and 75 mreps/hr beta.* [Heatherton 1955]

These estimates of contact dose from thorium would be considerably increased in the process streams, where the decay products of thorium were concentrated. In the case of thorium, the external dose problem extends into deep dose. The geometry of exposure and the relationship of hand dose, wrist dose, and the dose recorded on the main badge worn at the chest or lapel level becomes critical to a sound dose evaluation. The TBD contains no evaluation of this problem.

5.6.5 Correction Factors during Initial Period of TLD Use

Finding 20: Correction factors used during an initial period of use of TLDs at Fernald are not scientifically appropriate.

Table 6-3 (Vol. 6, p. 9) states that the use of TLDs at Fernald began in 1985. However, the Westinghouse transition report on Environment Safety and Health indicates that film badges were used "prior to 1983" and that "the multi-element Panasonic badges were first used" in 1983 (Westinghouse 1986, p. 14 and p. 16.) It appears therefore that TLDs began to be used at Fernald in 1983.

In its response to SC&A questions, NIOSH/ORAU stated that the initial use of the TLD was experimental, and that these doses were not entered into worker dose records:

> *The TLD model in question was one under development and was not the dosimeter of record. The TLD model that was finally put into service in 1985 was the first to be DOELAP certified.* [Attachment 2]

SC&A cannot determine when the TLD measurements were first used as the dose of record. However, the Westinghouse transition report indicates that they had been in use for sometime by October 1985, and that until that date, correction factors were being used to adjust the dose to account for the dust deposited on the dosimeters:

> *After an interval of one to several days, each tray of badges is surveyed for contamination. A beta-gamma survey instrument is used to screen the badges as they lay flat in the trays. If the badge reads more than 200 counts per minute on contact, it is taken out of the tray and deconned with alcohol and paper wipes. Badges which can be successfully deconned to below 200 c/m are returned to service. A record is kept of all badges found to be contaminated in excess of this 200 c/m limit….*
>
> *According to Bioassay Department personnel, about 100 badges per month are found to be contaminated above the 200 c/m limit. Most of these contaminated badges come from workers in Plants 5 and 4. Up until about 1 month ago (October 1985) an attempt was made to correct individual dosimeter results for contributions from contamination on the badge. A correction factor (derived from a study using 90 contaminated badges) was applied as a function of the level of contamination observed. Documentation of this correction is seen in Attachment 3. Any corrections which led to more than a 50% reduction [in dose] were brought to the attention of the Health Physics Department for their evaluation and approval.* [Westinghouse 1986, p. 15]

This indicates the routine use of TLDs, though the starting date of such use cannot be definitively determined. If the Westinghouse transition document is correct in stating that the use of film badges only occurred "[p]rior to 1983," then it is likely that the TLDs began to be used routinely in 1983. It is possible that their use began later. This is a matter of some importance, since the correction factors were evidently incorrect. Their use actually sometimes resulted in negative radiation doses. Table 9 shows some examples of TLD measurements, corrections, and corrected result from the attachment mentioned in the above quote.

Table 9: Some Examples of Corrections to Measured TLD Dose

Badge #	Gross [1]	Net	Correction mrem	Correction %	Uncorrected mrem	Corrected mrem
A	2,000	1,900	532	65	821	289
B	500	400	112	14	802	690
C	1,200	1,100	308	41	759	451
D	2200	2100	588	86	687	99
E	700	600	168	114	147	-21
F	1000	900	252	663	38	-214

Source: Westinghouse 1986, Attachment 3. Badge numbers have been replaced by letters.
[1] - Survey meter reading.

The use of a formula to generate correction factors that resulted in negative radiation doses was obviously faulty;[10] the practice was apparently discontinued in October 1985. It is unclear when it began. Hence, even if the dust had deposited very close to the time of submission of the badge, the number of days would be half the period. Thus, the correction would be too large in this case. The reverse was also possible, of course, in case most of the dust settled on the badge early in the wear period.

It is unclear what was actually entered into the dose records when large percentage corrections were referred to the Health Physics Department. Moreover, the use of this correction factor was also inappropriate for those badges with less than a 50% correction factor.

In the conference call of August 18, 2006, NIOSH/ORAU stated that they would investigate the issue. SC&A believes that the integrity of the external dose record from 1983 to October 1985 is open to question until this issue is resolved.

As a final point, SC&A notes that the high dust levels on many TLDs are indicative of inadequate industrial hygiene conditions even in the 1980s. This fact reinforces the discussion in Finding 18 above regarding the potential at Fernald for significant unrecorded beta dose to the skin in areas other than the hands and fingers.

5.6.6 Female Employees – External Dose

Finding 21: The method for estimating external dose to unmonitored female employees is incomplete and its claimant favorability has not been appropriately demonstrated.

The TBD states that the approach it describes for unmonitored employees, including women in the times they were not monitored, should only be applied to non-compensable cases. The guidance is to assign an external dose of 500 mrem/year. NIOSH states that this dose "is several times above the mean doses observed for monitored workers" and that, therefore, this value is claimant favorable (TBD Vol. 6, Table 6-14, p. 24). The TBD does not specify how the mean dose for monitored workers was estimated, since no database for such monitored workers has been compiled. Furthermore, it is not clear that the mean dose for all periods is a relevant figure to use for unmonitored female employees, because the lack of monitoring was in specific periods (1951 to 1960 and 1969 to 1978). The validity and claimant favorability of the suggested approach, especially for the early period, needs to be established by estimating the distribution of monitored worker dose in those periods.

The problem of extremity doses for female employees who handled clothes contaminated with uranium-238, thorium-232, and some of the radionuclides in their decay chains is not addressed. This could be particularly important for beta exposures. No procedures for estimating such exposures are specified in the TBD.

Finally, the TBD provides no guidance as to the procedure to be used for estimating doses to female employees or men who were not monitored in cases that may be compensable. There is

[10] A part of the problem was that the number of days that the dust was assumed to be on the badge was always taken as the days worn divided by 2.

explicit guidance that the 500 mrem per year is to be applied only to cases that are likely to be non-compensable:

> *For unmonitored workers, 500 mrem per year will be assigned as an upper bound limit. This is several times above the mean doses observed for monitored workers. Since this dose is considered an overestimate, this upper bound will only be used in cases that will likely result in a Probability of Causation (PC) less than 50%. The applicable years this dose may be assigned are shown in Table 6-14.* [TBD Vol. 6, p. 24]

NIOSH should specify a procedure for estimating doses for cases where best estimate doses are to be done. Furthermore, SC&A notes that Table 6-14 does not contain any entry for the period 1969–1978; presumably this was an oversight and 500 mrem was intended, based on the discussion in the text.

5.7 ISSUE 7: OCCUPATIONAL ENVIRONMENTAL DOSE: INTERNAL – NON-RADON

The fundamental approach used in the TBD for reconstructing environmental internal exposures of workers for 1951 to 1988 was to use published information regarding the annual atmospheric release rate of uranium, thorium, radon, and radon progeny from various point and area sources on the site, along with the application of standard Gaussian dispersion models, to reconstruct the airborne radionuclide concentrations at potential receptor locations onsite. Given these derived airborne concentrations, internal exposures were derived using conventional ICRP methodologies. The following presents a review of the methods used in the TBD to derive the source terms, followed by a review of the methods used to derive the atmospheric dispersion factors between the sources of the releases and the receptor locations, followed by the methods used to derive inhalation doses at receptor locations.

5.7.1 Uranium Emissions Source Term

Finding 22: The source term for atmospheric uranium emissions from Fernald is significantly underestimated.

The site profile refers to Boback et al. (1987) as updated by Dolan and Hill (1988)[11] and RAC (1995) as the bases for the estimated annual atmospheric releases. The Boback et al. report, as updated in 1988, was used for the uranium and thorium source terms, while the RAC report was used for radon emissions. SC&A notes that there was yet another update of this report that was done in 1989 that NIOSH did not use, even though it was part of the same series of contractor/DOE documents (Clark et al. 1989).

[11] The TBD erroneously refers to this publication as Dolan and Dolan 1988 (TBD Vol. 4, p. 9). The reference list for this publication should also be corrected from "Dolan, L.C. and C.A. Dolan…" to "Dolan, L.C. and C.A. Hill…"

According to Boback et al. (1987) as updated by Dolan and Hill (1988), the total uranium emissions for the time period 1951–1988 were 175,130 kg.[12] However, this source term, and the annual emissions estimates that comprise it, were incomplete and based in part on incorrect assumptions. The RAC (1995) study estimated uranium emissions to be about 310,000 kg (50th percentile) with a 90% confidence interval from 270,000 kg to 360,000 kg (RAC 1995, p. xii). The RAC estimates based on stack and scrubber data are in good agreement with soil data as shown in Appendix C (RAC 1998).

A review of Boback et al. (1987) and Dolan and Hill reveals (1988) reveals a number of deficiencies, such as an assumption of manufacturer-specified efficiency for Plant 8 scrubbers and underestimation of unmonitored discharges. The problems with the official estimates in Boback et al. (1987) and Dolan and Hill (1988) are well documented and should be evaluated by NIOSH.[13] In view of the fact that the CDC commissioned a study to review the Fernald source term and estimate offsite radiation doses, and that the best estimate in this study is about 75% larger than the estimate cited in Dolan and Hill (1988), it is surprising that NIOSH did not review the NLO and Westinghouse source terms more critically.

The RAC study did not have estimates of thorium emissions. However, in view of the documented problems with the DOE and contractor estimates with the uranium source term, NIOSH should subject the Dolan and Hill (1988) thorium source term to a similar critical analysis. For instance, the thorium source term lists only Plants 8, 9, and the Pilot Plant as being sources (TBD Vol. 4, Table 4-3, p. 12); however, we know that Plants 4 and 6 were also sources. The emissions estimates need to reflect the full production history of thorium at Fernald; they also need to carefully consider issues such as baghouse and scrubber efficiencies in various periods.

5.7.2 Modeling Environmental Dose

Finding 23: The TBD has not adequately considered various aspects of internal environmental dose, including the applicability of the Gaussian model, episodic releases, and particle size.

Episodic Releases

Boback et al. (1987) states that the results of continuous stack sampling of each of the buildings were reported as monthly values, and then were summed to produce annual source terms. In view of the fact that releases were highly variable, the TBD would benefit from a discussion of variability in the source terms in order to address the issue of the effect of episodic releases on the dose reconstruction. For example, page 14 of the Boback report refers to an episodic release of 1,195 kg of UF_6 on February 14, 1966.

Data compiled by Weldon Adams in 1985 indicate that more than one-third of the then-estimated source term was attributable to relatively short-term releases (Adams 1985). Furthermore, data

[12] Clark et al. 1989 give an estimate of just over 179,000 kilograms, which is about four metric tons larger than the estimate in the TBD.

[13] See RAC 1995 and Makhijani and Franke 1989.

for the early years are missing or incomplete. Some of these releases may have occurred over extended periods of days or weeks, in which case they may be modeled as continuous releases; but others may have been more truly episodic in the sense that they occurred in periods shorter than a day. Furthermore, the episodic nature of the releases needs to be assessed in the context of the RAC source term.

Given that the episodic releases in at least some of the early years were likely to have been large, it is possible that significant environmental dose may have been received by unmonitored individuals in unfavorable weather conditions that would not be adequately captured by annual average dose. If a large portion of the emissions in a year came from a few short-term releases, then the environmental dose from episodic releases may dominate the intake for many workers. Details of timing and magnitude of the episodic releases, notably in the early years, may be important in developing a claimant-favorable approach to unmonitored environmental internal dose.

The Gaussian Model

For the purpose of deriving the environmental doses to workers outdoors on site, NIOSH divided the site into a grid consisting of 11 locations (see Figure 4-2 on page 14 of the TBD). Each point and area source is assigned a location within one of the 11 grid locations, and average annual atmospheric dispersion factors were derived for each receptor location within each of the 11 grid locations. Hence, the product of the average annual source term for a given plant (expressed in Ci/sec) with the average annual atmospheric dispersion factor (i.e., X/Q, expressed in sec/m^3) yields the average annual airborne radionuclide concentration (Ci/m^3) at any of the 11 grid locations due to atmospheric releases from any of the emission sources.

In principle, this approach is conceptually valid. However, the report is silent regarding episodic releases, which would not be well represented by average annual Gaussian modeling. The application of average annual atmospheric dispersion factors could result in gross overestimates or gross underestimates of the doses associated with episodic releases. If the episodic releases were numerous and random, then the use of average annual dispersion factors is appropriate. The TBD would benefit from a discussion of this possible issue.

The equation used to derive average annual atmospheric dispersion factors includes a term for elevated releases. Again, in theory, this is appropriate under some circumstances. However, as indicated in the TBD (Vol. 4, p. 17), a release height of 10 meters is used as input to the equation used to model elevated releases, resulting in near field (<500 meters between the source and receptor) atmospheric dispersion factors for elevated releases that range from about 2-fold lower to 9 orders of magnitude lower than ground-level atmospheric dispersion factors (see Table 4-6 on page 18 of the TBD), depending on the distance between the source term and the receptor. The problem is, when the release heights are relatively low, as compared to the height of the buildings and structures in the vicinity of the releases, building wake effects negate the benefit of the elevated releases. Under these conditions, which appear to be the case for many locations at the site, ground-level atmospheric dispersion factors should be employed. The implications are that, for the close-in locations delineated in Table 4-7 on page 18 of the TBD, the atmospheric dispersion factors may be significantly underestimated, resulting in significantly underestimated doses to workers at those locations.

The TBD (Vol. 4, p. 17) states that atmospheric dispersion factors (X/Q values) were derived assuming a wind speed of 3.2 m/sec and stability Class F. Once the X/Q values were derived for a given distance between the release point and receptor (using the sigma y and sigma z values in Figures 4-3 and 4-4 of the TBD), an adjustment factor is applied to account for the frequency the wind blows toward a given receptor from a given source. This is a very crude method for deriving X/Q values. In one respect, it could be considered conservative, because stability Class F is assumed; however, this conservatism is offset by the use of an elevated release. By using stability Class F, the plume is assumed to have minimal vertical and lateral spread as it moves downwind. As a result, when the plume touches down to the ground (at about 500 meters downwind from an elevated source), the concentration of radionuclides in the plume is likely to be overestimated, because typical average annual meteorological conditions are not represented by stability Class F (i.e., one would expect that average annual conditions would reflect greater dispersion than those associated with stability Class F). However, before the plume touches the ground downwind, the ground-level radionuclide concentrations will be essentially zero (see the differences in the X/Q values between 100 meters and 500 meters in Table 4-6 of the TBD). Hence, for much or most of the site and for many or most workers, the approach chosen will likely result in significant underestimates of intakes.

Tables 1 and 2 of the Boback et al. (1987) report provide stack heights and roof heights, respectively. It appears that the heights of the buildings are comparable to the stack heights. The implication is that these releases should be treated as ground-level releases for the purpose of atmospheric dispersion modeling, because, as a general rule, credit for elevated releases is only appropriate if the stack is 2.5 times higher than the nearby buildings, in which case building wake effects become unimportant.

The entire approach used to derive X/Q values in the TBD could be substantially improved by simply using annual joint frequency data, which couples wind speed, direction, and stability class. This modification and the assumption of ground-level releases for deriving X/Q values will likely increase the doses to receptors within about 500 meters of a source, and reduce the doses to receptors greater than about 500 meters from a source.

Enrichment of Emissions

The annual emissions would tend to reflect the weighted average of the enrichment of uranium processed in that year. The specific activity of uranium of the enrichments handled at Fernald varies by more than an order of magnitude between depleted uranium and 10% enriched uranium. Shipment and receipts data on normal, enriched, and depleted uranium are available by year (e.g., Bogar 1986). These could be used to roughly assess the enrichment of emissions for any particular year. This does solve the problem of what enrichment to use for the enriched uranium production stream. However, that is an issue with broader implications for internal dose reconstruction, as discussed above. The research needed to more accurately assess internal dose in a claimant-favorable way in regard to the enrichment of the uranium being processed can also be used to improve the environmental dose. SC&A notes that the question of enrichment may be more important for occupational internal dose than for environmental dose.

Other Radionuclides in Emissions

Boback et al. (1987, p. 17) discusses the sampling and analyses that were performed in 1985 to determine the radionuclide-to-uranium ratios in stack emissions for other radionuclides. The statement is made that "no information is available that would permit ratio adjustments for materials processed in earlier years." This raises the question of the reliability of the ratios used in the TBD for the early years. That report indicates that, beginning in 1956, uranium concentrates from Canada were processed that contained Ra-226 (p. 19). The report states that the ratio of Ra-226 to U ranged from 0.037 to 10.3 µCiRa/kgU, and that, for the purpose of estimating Ra-226 emissions, the average ratio of 1 µCiRa/kgU was used. Pitchblende was also processed at Fernald from 1953 to 1955 (TBD Vol. 2, p. 54).

The TBD does not discuss how the environmental dose from the decay products of uranium, notably Ra-226 and Th-230, will be estimated. NIOSH should establish a range of ratios for Ra-226 and Th-230 to uranium for Plant 2/3 operations, as well as any other ore-handling operations. Given that the Ra-226 and Th-230 content of the ores processed at Fernald varied, it will be important to establish a period-specific distribution of ratios of these radionuclides to uranium. For each period, NIOSH may wish to consider using the **95th percent confidence level on the mean**[14] of the distribution of ratios in order to provide a reasonable upper bound on the average ratio. It is probably not necessary to use the 95th percentile value of the full distribution of the ratios, since there does not appear to be any reason to believe that an individual could have repeatedly experienced the 95th percentile ratios. However, if it turns out that, during a given time period or at a given facility, the ratios were consistently at the high end of the distribution, then a high-end ratio may be appropriate. Some discussion and guidance regarding this possibility should be provided in the TBD.

Similar comments apply to Th-232 decay products.

5.7.3 Exposures from Diffuse Emissions

Finding 24: Diffuse emissions of uranium and thorium may have produced significant internal exposures for some personnel.

The TBD has partly addressed the diffuse emissions from the waste pits caused by wind erosion, but has not addressed more important sources of diffuse emissions at Fernald. As has been discussed, the working environment at Fernald was often very dusty. Some of the dust in the workplace was vented through windows or doors. There is evidence included in the TBD of

[14] It should be emphasized that the 95th percentile of the mean is a very different parameter than the 95th percentile of the distribution. The former should be used when the mean is the proper parameter for use in a dose reconstruction, but a level of assurance is needed that the mean is not underestimated. The latter is used when it is possible that a worker or group of workers consistently may have experienced the high end of a distribution of values because of uncertainties regarding where they worked and the type of work they performed, and, as a result, it is plausible that they in fact experienced chronic exposures to the high end of the distribution.

very high dust concentrations outdoors. For instance, the TBD documents *average outdoor* air concentrations for 1956 and 1957 from about 31 MAC to more than 130 MAC. These high dust concentrations were in the following work areas (TBD, Vol. 2, Table 2-14a, p. 40):

- "Outside Williams Mill" (General Air, 44.3 MAC)
- "Breaking Salt at outside mill" (Breathing Zone, 30.8 MAC)
- "Shoveling onto conveyor at outside mill" (Breathing Zone, 137.80 MAC)
- "Changing drums at outside mill" (Breathing Zone, 122.90 MAC)

Given that these are averages over 2 years, the episodic air concentrations outdoors can be expected to be much higher. The environmental exposures of any unmonitored personnel coming in the vicinity of such high air concentrations for even modest periods of time (a few hours per week), even if one takes the general air sample average, may greatly exceed the environmental dose from stack releases. This is even more likely to be the case for the model of internal environmental exposures suggested. We note here that exposure to 30 MAC, even for a few hours, would easily result in a greater intake than any claimant-favorable model for intake from the diffuse emissions suggested in the TBD. Hence it is critical that evidence for diffuse emissions from production operations, as well as from handling and redrumming operations, be compiled.

As noted already, there is evidence for large outdoor diffuse emissions of thorium, but SC&A has not come across quantitative data characterizing them. This is an important gap in the estimation of environmental exposures that NIOSH should try to plug.

The use of a Gaussian plume model for diffuse emissions would be, of course, entirely inappropriate. Such exposures will have to be assessed from direct evidence of outdoor air concentrations **in working areas** during various periods of time. Air monitoring stations at the periphery will not be able to provide adequate data for this purpose.

5.8 ISSUE 8: RADON

There are two major estimates of radon emissions available that could be used as the source term for radon emissions from the K-65 silos (also called Silos 1 and 2). These are silos where waste with high radium content was stored, including waste from MCW in St. Louis, as well as waste generated from high-grade ore processing at Fernald. The first was estimated by Boback et al. (1987), which was 60 curies per year. The second was from the RAC 1995 report, which was part of a series of reports on Fernald commissioned by the CDC.

Boback et al. (1987) employs conventional steady-state diffusion transport equations as codified into the computer code UDAD. That code was developed for use in modeling radon emanations from uranium mill tailings; it was applied to the silos by incorporating into the calculations information regarding the radiological and physical characteristics of the K-65 residues and the barriers to the radon emissions from the silos. The results of the Boback calculations are as follows:

(1) Radon flux from open tank = 2E5 pCi/m^2-sec
(2) Radon flux from a tank covered with 4 inches of concrete = 2400 pCi/m^2-sec

Measurements made directly above the tanks with 4 inches of concrete yielded results ranging from 13 to 2.8E7 pCi/m^2-sec. The Boback report states that the high values are at locations above areas of the dome with cracks in the concrete. However, the fact that measurements from these cracks are much higher than the radon flux estimated from an open tank by the model would leave the use of the Boback et al. estimate open to question. NIOSH chose to use the RAC 1995 estimate; SC&A concurs with this choice.

The RAC report estimates the radon emissions from the silos from 1951 through 1988 to have been 170,000 Ci (about 4,500 curies per year), with a range of 110,000 to 230,000 Ci (5% to 95% confidence interval) (RAC 1995, p. xii). Figure 4-1 of the TBD presents the radon releases from the K-65 silos. The peak of the releases was about 6,000 curies per year from 1959–1979.

RAC 1995 acknowledges the considerable uncertainty associated with estimating radon emissions from the silos due to uncertainty in the diffusion coefficients. As a result, RAC employed a variety of models and modeling assumptions, along with Monte Carlo techniques, in order to characterize and quantify the magnitude of the uncertainty. Notwithstanding this acknowledgment by NIOSH, the TBD used the average annual emission rates to model the airborne radionuclide concentration, including radon, for the purpose of dose reconstruction. It would seem that this is not a claimant-favorable assumption. It may be more appropriate to use the 95th percentile values of the mean. However, since the differences between the median and 95th percentile values are less than a factor of 2, the potential for a significant underestimate of the radon source term seems to be relatively small, and perhaps accounted for by the conservatism inherent in using a progeny equilibrium fraction of 0.7; i.e., the TBD cites evidence that radon progeny only achieved a 1% to 27% equilibrium, but assumed 70% equilibrium. This is a reasonably conservative assumption that will tend to place an upper bound on inhalation exposures to radon progeny, given the validity of the radon source term and atmospheric dispersion factors.

Given the derived radon concentrations, exposure to radon progeny, in working level months (WLMs), assumes 70% equilibrium and 100 pCi corresponds to 1 WL. This is a correct conversion (see page 20 of the TBD). In the background information, the concept Working Level is defined as follows:

> *…working level (WL) was introduced by Holaday et al. (1957) as a convenient one-parameter measure of the concentration of radon progeny in uranium mine air that can be employed as a measure of exposure. They define 1 WL to be any combination of Po-218, Pb-214, Bi-214, and Po-214 (the short-lived progeny of radon) in 1 liter of air under ambient temperature and pressure that results in the ultimate emission of 1.3e5 MeV of alpha particle energy. This is about the total amount of energy released over a long period of time by the short-lived daughters in equilibrium with 100 pCi of radon.* [Schleien et al. 1998]

The TBD (Vol. 4, p. 20) indicates that exposure in WLM for thoron progeny is based on an equilibrium fraction of 0.1 and the assumption that 7.47 pCi of thoron corresponds to 1 WL. The implication is that the total alpha energy emission from the complete decay of 7.47 pCi of each of the short-lived progeny of thoron corresponds to 1.3E5 MeV. An independent check confirms that 7.47 pCi of thoron corresponds to 1.3E5 MeV of short-lived progeny. The basis for the assumed equilibrium fraction of 0.1 should be provided.

Check on Radon Dose

This section presents a hand calculation to check on a radon and progeny exposure calculation in the TBD. As indicated in Figure 4-1 (page 12) of the TBD, the highest median radon emission rate was about 6000 Ci/yr from 1958 through 1979. According to Figure 4-2 on page 14 of the TBD, the silos were located in grid number EA-6, and workers worked in that area about 250 meters from the silos (see Table 4-7 on page 18). In addition, according to Table 4-8 on page 19, the wind blew 19% of the time from the silos toward workers at EA-6. Using Figures 4-3 and 4-4, the σ_y and σ_z values for stability Class F at 250 meters are about 10 m and 3 m, respectively. For radon progeny, equation 4-3 (page 15) of the TBD is used to derive the X/Q value, as follows:

$$X/Q = 1/(2\pi\sigma_y\sigma_z u)\ \exp[-1/2(y^2/\sigma_y{}^2 + H^2/\sigma_z{}^2)]$$

Where:

$\sigma_y = 10$ m
$\sigma_z = 4$ m
u = 3.2 m/s
H = 10 m
X/Q = 5e-5 sec/m3 for particulates
X/Q = 1e-4 sec/m3 for gases (radon)

These values are in agreement with the value listed in Table 4-6 on page 18 of the TBD.[15] These are the atmospheric dispersion factors for particulate and radon emissions 250 meters downwind from the silos, assuming a 10-meter release height, and the wind was blowing 100% of the time toward the receptors at a wind speed of 3.2 m/s under stability class F. Applying a correction factor for wind direction of 19%, the X/Q is 9.5E-6 sec/m^3 and 1.9E-5 sec/m^3 for radon progeny and radon, respectively.

The radon concentration would be as follows:

$$C_{Rn} = 6000 \text{ Ci/yr} \times 10^{12} \text{ pCi/Ci} \times 1.09\text{E-4 sec/m}^3 \times 0.19/3.15\text{E7 sec/yr} = 3{,}944 \text{ pCi/ m}^3$$
$$\approx 3.9 \text{ pCi/liter}$$

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[15] The atmospheric dispersion factors for gases are twice those for particulates due to reflection. When a plume containing gases, such as radon, touches down to the ground, gases "reflect" off the ground and remain airborne. However, when a plume containing particles touches down, the particles deposit onto the ground; hence, the two-fold difference in atmospheric dispersion factors for gases versus particulates.

This value is consistent with the values reported in Table 4-9a of the TBD. When expressed in terms of exposure to radon progeny with an equilibrium of 0.7, this amounts to about 0.027 WL, or about 0.32 WLM per year exposure. The TBD's estimate for a similar situation and the same assumptions is slightly lower at 0.27 WLM per year.

5.8.1 Environmental Radon Dose Modeling

Finding 25: NIOSH's modeling of radon dose is not claimant favorable and does not take actual working conditions into account.

There are several ways in which the NIOSH estimates of radon dose are likely to be underestimated, and, hence, not claimant favorable.

While the check on NIOSH's calculations above yields values consistent with those in the TBD, SC&A is not in accordance with the NIOSH assumption that dose and dispersion coefficients should be calculated at a distance of 250 meters, with a release height assumption of 10 meters. NIOSH should use an assumption of ground-level exposures, for which the X/Q values and the associated exposure estimates would be 25-fold higher. Another important observation is that, at closer locations, the difference between the ground level and elevated X/Q values are even greater. For example, the closest distance analyzed in Table 4-7 is 150 meters. For this distance, and a ground-level release, the radon dose would be more than 4 orders of magnitude greater than that obtained using the NIOSH assumptions. Hence, the individuals located close to the silos, even if only a small part of the time, could have experienced exposures much larger than those reported in the TBD.

Site expert interviews indicate that workers were in close proximity to the silos under many circumstances (Attachment 4); for instance, they took breaks next to the silos. There were attempts to control environmental radon dose, but these appear to have been instituted in the 1990s. SC&A site expert interviews indicated the following:

> *The Communication Center received real-time radon concentration data. If this exceeded a trigger point (100 pCi/Liter), security made an announcement asking individuals to stay indoors. A technician was dispatched to the area to verify the conditions. These announcements didn't typically occur during the work day. This was a more current practice and did not occur in the 1950s, 1960s, 1970s, and 1980s.*

Workers also had assignments relating to the silos. In these circumstances, there were attempts to control the dose, but the quantification of dose in some cases appears to be difficult. For instance, SC&A's interviews indicated the following:

> *When individuals had to take samples or enter the silos, a glove bag was used to control exposure. The manhole on the top of the silo is opened and the sample is taken through the in and out port. There were attempts to measure radon in the glove bags, but these were not successful.*

In summary, the NIOSH source term for radon appears to be claimant favorable, though there will remain considerable uncertainties about the actual emissions history. However, the modeling of the radon dose is not claimant favorable.

5.8.2 Radon Dose from Pitchblende Ore Storage

Finding 26: NIOSH has not considered a major source of radon dose—the storage source of pitchblende ore on site, near Plant 1.

A University of Cincinnati study concluded that there was another major source of radon at Fernald—the Q-11 silos near Plant 1 where pitchblende ore was stored from 1952 to 1958 (Pinney and Hornung 2006). Since this source was much closer to working areas than the K-65 silos, it was likely a large source of exposure during the time that Q-11 ores were stored there. The TBD has not considered this issue.

Pinney and Hornung (2006) also estimated the annual exposure per year due to the K-65 silos alone. Their estimate of mean exposure is about 1 WLM from the late 1950s to the end of the 1970s. This is almost 4 times the estimate based on NIOSH's assumptions. Their maximum estimate is about 2 WLM for most of this period, but with a peak of almost 2.5 WLM in the late 1950s and early 1960s. Their estimates are based on assessing cumulative radon exposure from tracks in window glass calibrated by C-39 plastic film taped to the glass for 3 weeks.

5.9 ISSUE 9: OCCUPATIONAL ENVIRONMENTAL DOSE – EXTERNAL

The primary source of external environmental radiation exposures was direct radiation from Ra-226 and its progeny in the K-65 silos. According to the TBD, prior to 1975, the radiation fields were monitored with hand-held survey meters, and after 1975, external radiation exposures were monitored with TLDs and aerial surveys. Other contributing sources of ambient external radiation addressed in the TBD include the waste pits and the production facilities.

Equation 4-5 of the TBD (Vol. 4, p. 46) presents the method used to estimate the external radiation dose rates at each of the 11 grid locations. The basic approach is to use the actual measured dose rates at the locations where measurements were made, and then derive the dose rates at the grid locations based on adjustments that take into consideration the distance from the source and the distance to the grid location using the inverse square law. One concern with this approach is that it only applies to point sources. For sources whose dimensions are large relative to the distance to the measurement location and/or the grid location, this approach could either significantly underestimate or overestimate the exposure rates at the grid locations. The TBD would benefit from a discussion of this issue. This approach, however, is not unreasonable for time periods when extensive survey data are available; i.e., the post-1976 period.

5.9.1 Outdoor Diffuse Emissions and External Environmental Dose

Finding 27: The TBD does not consider outdoor diffuse emissions in production areas as a source of external environmental dose.

Given the documentation regarding high diffuse emissions and high uranium and thorium concentrations outdoors (discussed above), it is possible that the external environmental dose, other than that from the K-65 silos, may have derived mainly from deposition of uranium and thorium dust on workers. For thorium dust, this could involve considerable deep dose as well as shallow dose, while for uranium it would mean mainly the latter. NIOSH should evaluate the extent of the problem, which may have been significant in some outdoor production areas.

5.9.2 External Environmental Dose near the K-65 Silos

Finding 28: External environmental dose for workers near the K-65 silos needs to be better evaluated.

The TBD is silent on how external doses to workers from the silos were derived for persons that may have spent time in the area of Fernald containing the silos (i.e., EA-6). This is of particular concern for the early years before additional shielding was provided for the silos. It is also of concern for those unmonitored workers who may have taken breaks near the silos. For instance, it may especially affect female employees during the years when they were not monitored.

5.9.3 Occupational Radon Exposure

Finding 29: Occupational internal exposure to radon is estimated based on just two radon data points from 1953. This is an inadequate basis to reconstruct occupational radon dose.

Volume 5 of the TBD describes the procedure for estimating radon dose to those workers who opened the K-65 waste drums and loaded Silos 1 and 2:

> *From a single radon sample data sheet on which the analyses of two samples were recorded on 10/29/53, the higher of the two samples indicated a result of 230 pCi/L radon gas, which verifies the logical assumption that radon gas was released as the drum lids were removed. In addition to the default particulate intake (determined as previously stated), a conservative/bounding analysis of possible radon plus daughter product exposures can be derived:*
>
> > *• Assume 230 pCi/L (2.3 WL) with 100% daughter product equilibrium for 1304 hrs. (163 day x 8 hr/day)/74 months of the dumping operations = 17.6 average hours/month exposure. Then 2.3 WL 17.6/167(the fraction of a full working month) x 12 months = 2.9 WLM exposure per year.*

It is not clear why a measurement of 230 pCi/L would verify that it was associated with the opening of the drum. It is also not clear why that would be assumed to be the highest exposure to radon. Choosing the higher of only two samples is a rather weak basis for parameter value assignment. NIOSH should better justify its assignment of radon dose to these workers or develop a procedure for estimating a demonstrably claimant-favorable value.

5.10 ISSUE 10: OCCUPATIONAL MEDICAL DOSE

5.10.1 Possible Use of Photofluorography

Finding 30: The possible use of PFG at Fernald in the early years was ruled out in the TBD without adequate documentation. This is contrary to NIOSH general guidance and is not claimant favorable.

The TBD states (Vol. 3, Section 3.2) that no PFG equipment was ever used at FEMP. This conclusion is attributed to communications with Ms. Betty Smith and Ms. Diane Jacobowski. Ms. Jacobowski's statement is included as part of the Luther Brown 2002 transmittal, which is referenced in the TBD (Brown 2002). However, she worked from the mid-1980s onwards, and her opinion may therefore not be reliable for procedures relating to the 1950s. Ms. Smith was the only person interviewed who worked there during the period when PFG may have been used, but NIOSH could provide no documentation on statements by Ms. Smith. This was affirmed by NIOSH/ORAU during the August 18, 2006, conference call:

> *ORAUT/NIOSH: There are no formal records of those conversations. They were just documented in the TBD and that is all there is.* [Attachment 3]

Even so, the statement by Ms. Jacobowski indicates no records on x-rays were found prior to 1961. NIOSH should further verify that PFG units were not in use at FEMP during the period of 1951–1958. If no positive evidence can be found that x-rays were the method used, the PFG should be assumed for this period. This is in accordance with the general guidance on medical x-rays provided in Revision 3 of ORAUT-OTIB-0006 (Kathren and Shockley 2005, pp. 20–21).

5.10.2 X-ray Retake Rate

Finding 31: The assumption that there was a 15% retake rate for x-rays is not adequately documented or analyzed.

The TBD (Vol. 3, Section 3.2) states that a review of claimant files showed that 15% of the claimants reported that retakes occurred. Further review of the TBD shows that there is no documented attempts to establish retake rates for x-ray units in use at Fernald. During the conference call, NIOSH/ORAU referred to ORAUT-OTIB-0006 guidance on retake rates. That document states the following:

> *The incidence of defective films necessitating retakes is not known, but it is likely to have been very small and certainly no more than a few percent and probably much less.* [Kathren and Shockley 2005, p. 14]

Retakes can occur either because the technician is not satisfied with the quality of the picture or as a result of a request by a physician. Furthermore, as SC&A noted in the conference call with

NIOSH ORAU, it is rare that retakes end up in the medical record. NIOSH should re-evaluate the potential contribution to dose that is attributable to retakes resulting from improper techniques or poor performance of processing equipment.

5.10.3 X-ray Collimation

Finding 32: The assumption that there was collimation is not technically justifiable based on the evidence provided in the TBD and is not claimant favorable.

The TBD (Vol. 3, Section 3.1.4) concludes that, based upon a survey of selected radiographs from 1952–1980, it was determined that collimation was always used from the inception of x-ray use at the site. This conclusion is based upon the observation of a dark line at the bottom of the selected radiographs:

> *...the current FEMP records manager, Mr. Brian Devir, who (as a request of the TBD investigation) selectively examined radiographs from chest X-rays taken from 1952 to 1980. He confirmed that a clearly distinct darkened area existed at the lower edge of each radiograph, which is specifically indicative of the use of collimation. Also noted was that all of the radiographs examined from the years 1952 to 1980 exhibited the same unexposed area at the edges.* ***A well-collimated beam would have left a small, unexposed area or penumbra effect at the edges of the radiograph****, while a poorly collimated beam would have produced a radiograph that was exposed over the entire area. Based on the discussions with Mr. Devir and the correlated evaluation of the radiograph files, it is possible to reach the conclusion that the X-ray beams used at FEMP were collimated from the beginning of the medical X-ray processes at the site, and should be treated as such when estimating the contribution of an individual due to medical X-ray exposure.* [TBD, Vol. 3, p. 9, emphasis added]

Collimators are made of very dense materials (e.g., lead, etc.), and their use should appear as a lightened or unexposed area on the film. Also, any evidence of collimation should occur on all sides of the film, not just the bottom. Mr. Devir noted both of these facts in his communication with NIOSH (see bolded text above). Therefore, it is unclear why NIOSH concluded from this communication that “the darkened area at the lower edge of each radiograph” was evidence of collimation throughout the period in question. NIOSH should re-evaluate its conclusion. It does not appear to be based on the cited evidence and is not claimant favorable, in that it would underestimate doses relative to an assumption of no collimation.

5.10.4 Occupational Lumbar Spine X-rays

Finding 33: NIOSH has prematurely concluded that lumbar spine x-rays for laborers and construction workers were not conditions of employment. Based on the evidence provided, this assumption is not sufficiently documented and is not claimant favorable.

The TBD acknowledges that Fernald construction workers and laborers received lumbar spine x-rays (Vol. 3, p. 11), but NIOSH has ruled out the possibility that lumbar spine x-rays were used as a condition of employment at Fernald:

> *It also was noted in reviewing claimant files that lumbar spine X-rays were taken primarily for construction worker and laborers. In a telephone communication with Mr. Louis C. Bogar, the former Vice President of ES&H for FEMP, on October 28, 2003, he clearly stated that lumbar spine X-rays and any X-rays other than chest were not taken as occupational or pre-employment requirements.*

A contemporaneous interview is not a sufficient basis to rule out the possibility that the lumbar spine x-rays were taken as a condition of employment. Such x-rays could easily have been a condition of employment in the 1950s and 1960s. Fernald, after all, was a site where heavy labor was involved for many workers, including construction workers and laborers. The TBD provides no evidence from claimant files or other sources that the lumbar spine x-rays that were done were as a result of injuries or medical conditions unrelated to employment. Unless there is definitive evidence that lumbar spine x-rays were unrelated to employment or were the result of injuries, their presence should be assumed to be a condition of employment for construction workers, laborers, and any others who may have received them.

6.0 OBSERVATIONS

6.1.1 Internal Inconsistencies in the TBD

Observation 1: The TBD has not been checked for internal consistency and there are internal contradictions in it; some of the basic facts in it are incorrect.

Several examples of inconsistencies and factual problems have been discussed in the findings above. For instance, the estimate of production of 205,000 metric tons is less than the figure provided for RU receipts of over 246,000 metric tons. One of these numbers is wrong. There are two quite different estimates of RU receipts, one more that 200,000 metric tons less than the other.

Another important inconsistency relates to the decontamination factor due to the use of respirators. Volume 2 of the TBD provides intake estimates in certain jobs with the use of respirators. Volume 5 of the TBD provides guidelines that do not assume the use of respirators. Furthermore, SC&A notes that in Table 2-1a and subsequent tables, decontamination factors are cited, but this is done without reference to actual respirator efficiencies or the adequacy of any program of fit tests. This is not relevant to dose reconstruction if the decontamination factors are not used, but it would be helpful if the citation of specific performance characteristics that relate to intake could be accompanied by a reference.

A third example of incorrect statements relates to thorium air concentrations:

> *The same air sampling procedures were followed for thorium processing as for uranium processing. Some records have been recovered that indicate that basic air activity levels were recorded in fractional MAC (70 dpm m^{-3} prior to 1970 and 100 dpm m^{-3} thereafter) for thorium processing. The thorium air sampling results are similar to the uranium air sample results.* [TBD Vol. 5, p. 21]

As has been discussed in Chapter 5, there is a great deal of evidence of high thorium air concentrations at Fernald.

As a final example, the production estimates in the TBD are not only internally inconsistent, they appear to be at variance with the materials accounting documents generated during the production phase of Fernald.

SC&A discussed this issue of inconsistencies and factual problems with NIOSH/ORAU during the August 18, 2006, conference call. NIOSH and ORAU are cognizant of the problem and will correct them when a new revision of the TBD is published. It is currently under revision.

6.1.2 Intakes and Plant Production Capacity Utilization

Observation 2: Individual intakes should not be linked to plant production capacity utilization.

The TBD suggests that air concentrations of radioactivity for periods for which there are no data can be derived by reference to production capacity utilization:

> *The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.* [Vol. 2, Table 2-3b footnote]

The same concept is applied in Table 2-1b. A similar concept is applied to estimating in-plant thorium concentrations, except here, atmospheric emission ratios are used. In Table 2-1c (Vol. 2, p. 14), in-plant thorium concentrations were obtained by multiplying the uranium concentration estimates for a particular year by the thorium/uranium emission ratio.

Air concentrations experienced by an individual worker would not be expected to vary with the throughput or capacity utilization, but rather with the working conditions, equipment, ventilation, and other industrial hygiene measures prevalent while the work is being done. It is quite possible for low throughput rates to have high workplace contamination and vice versa. There is no necessary relationship or even a tendency for throughput or capacity utilization to be related to air concentration. Similarly, in-plant air concentrations cannot be assumed to scale with emissions, as much depends on the details of the air flow patterns within the plant, the size distribution of the aerosol, the positions of the ventilation extraction ducts, and the degree of filtration imposed on the extraction. Such assumptions should not be used as a basis for intake estimation. The only factor related to production that can be usefully taken into account, if all other factors are known to be the same, is if plants were completely idle for entire shifts or longer. Note that this is not necessarily the same as partial capacity utilization. For instance, partial capacity utilization could still mean that some lathes or drills or reduction furnaces may be operating each day and the entire plant operated with fewer workers, creating similar exposure conditions to full capacity utilization, but for fewer workers. Hence, the time of exposure may be reduced only if there are data showing that there was no work during certain periods, all other things, such as industrial hygiene measures, being equal.

6.1.3 Bioassay Frequency and Incidents

Observation 3: NIOSH dose reconstruction procedures should ensure that the bioassay samples were frequent enough to capture incidents such as chip fires, or that the plant procedures themselves as carried out in practice ensured that samples would be taken after fires or blowouts.

Chip fires were common at Fernald. Sometimes these incidents could involve intense exposure to fumes, as occurred during in 1956:

> *Specifically, a drum of fines located under the chip crusher ignited. By the time the burning drum was removed from the building (approximately 2 to 3 minutes later), the machining bay air was heavily laden with smoke and fume. Personnel did not evacuate immediately but remained in the area 7 to 8 minutes after the fire started. No one was observed wearing a respirator until several minutes later and then only a few. When evacuation was made it was for a very short duration, perhaps 18 minutes, and when re-entry was made the room air was still visibly contaminated.* [Stefanac 1956]

There was considerable contamination even after visible dust had cleared. The incident was analyzed to try to set procedures for such chip fires, which were frequent (refer to interviews), perhaps even daily in some periods. TBD does not provide any procedure to check for bioassay frequency, as well as who was monitored using such data on incidents and air contamination as a check.

6.1.4 Uranium Isotopic Ratios

Observation 4: The uranium isotopic ratios in some of the data in the TBD are incorrect.

The isotopes present in uranium (U-238, U-235, and U-234) appear in certain ratios that are characteristic of the enrichment of the uranium. This implies certain mass ratios, which are also characteristic of the enrichment level. The ratios of U-238 to U-235 and U-238 to U-234 must be consistent with each other for a given enrichment of the sample. Some values in the TBD are incorrect, because they represent ratios that cannot arise in practice or are inconsistent.

For instance, the Waste Pit 2 uranium isotopic composition is incorrect. The U-238/U-234 ratio suggests slightly depleted uranium (close to natural uranium), but the mass ratio of U-235/U-238 suggests about 7% enriched uranium. Furthermore, U-235 is almost 20% of the radioactivity. This is impossible, since U-235 never represents more than 5% of the radioactivity at any enrichment of uranium. (At higher enrichments, U-234 dominates the specific activity. For DU, it is U-238.)

The same problem is present in the data for Waste Pit 6 (TBD Vol. 2, p. 65) where the U-234/U238 ratio suggests depleted uranium, but the U-235/U238 ratio suggests enriched uranium. SC&A has not tried to check all such basic problems, but it is important that isotopic compositions be physically plausible and consistent. NIOSH should examine whether there are errors in the underlying data as well.

6.1.5 Frequency of Events in Thorium Overpacking Operations

Observation 5: The number of "events" listed for thorium overpacking operations is very high, but the TBD provides no detail on the nature of most of the events, the data on which the estimates of event frequency and intakes were based, or how the intake estimates were derived.

Table 2-22 (Vol. 2, p. 51) gives the expected number of events during thorium overpacking operations. It lists three specific types of events—fork impact, fork drop, physical degradation of the drums—and miscellaneous. For the first three, the annual event frequencies are given as 17, 17, and 42, respectively. For miscellaneous, the event frequency is given as 1,358 per year, or almost 4 every day (assuming 365-day operation). The nature of these events is not specified; the method of estimating emissions is also not specified. This is an inordinately large frequency of events, whose implications for dose reconstruction need to be explored in greater detail.

6.1.6 MDLs for Beta Extremity Monitoring

Observation 6: The MDLs for beta extremity dosimeters should be provided for missed dose estimation.

The values for the MDLs for the extremity beta dosimeters should be provided. The exchange frequency of the extremity dosimeters is also required to calculate the missed extremity dose.

6.1.7 X-ray Unit Survey Data

Observation 7: NIOSH should review the calculated data for the Bennet x-ray unit and the Keleket unit survey to determine if the dose estimates in Table 3-13 are appropriate.

The TBD states that the earliest recorded survey of x-ray equipment (Keleket) occurred in November 1961. Review of available historical memos suggests the purpose of this survey was to ascertain exposures to film badges, if badges were inadvertently worn during annual chest x-rays given to workers. Difficulties encountered included not being able to operate the x-ray unit in the full diagnostic range, and the Victoreen R-meters were not being read on the same day as exposures. Consequently, many assumptions were applied as being derived from NCRP guidelines, such as the half-value layer (HVL) of 2.5 mm Al. It appears the intent of the survey was to determine any undue contribution of "Grenz" radiation to skin dose, as measured on the film badge. NIOSH should re-evaluate the assumptions being applied; this could lead to substantial changes in Table 3-13 (*Organ Dose Estimates to FEMP Chest Radiographs from 1951–1977*) of the TBD.

The TBD does not detail or provide substantial evidence that equipment survey data reported for the period March 1977 to February 1988, as evidenced in Tables 3-10 and 3-14, are related to an actual survey of the output of the Bennett 300 unit, which was put into service in March 1977. During the August 18 conference call, NIOSH/ORAU clarified that the data for this unit are calculated from a Hanford unit. SC&A has requested a copy of the survey of that unit.

6.1.8 Miscellaneous Observations

- In Table 5-6 (Vol. 5, p. 12), it is unclear why the radiation exposure limit for the 2% enriched soluble form is more than an order of magnitude lower than the limit for the natural form, whereas for the insoluble form, the limits for the natural and 2% enriched forms are identical at 3.0E-10. The basis of these figures should be clarified.
- Table 5-8 (Vol. 5, p. 15) reports derived air concentrations from 1989; however, the table lists results in terms of inhalation Type S, which was not introduced by the ICRP until 1994. A clear statement of how the original results were derived and how they subsequently have been interpreted would be helpful. This is of importance, as Type S does not correspond exactly in biokinetics to the Class Y that was formerly used.
- In Figure 5.1 (Vol. 5, p. 19), should 'Th-23' at the top of the figure read 'Th-228'?
- In Table 5-14 (Vol. 5, p. 20), the entries for oxalate are associated with the chemical formula for nitrate.
- On page 28, it is misleading to state that urine samples were provided after a 2-day break to allow elimination of uranium cleared rapidly via the GI tract. Urinalysis only evaluates uranium that has been taken up and subsequently excreted. What a 2-day interval does is ensure that the early kinetics of uptake and retention, which can be very variable, do not unduly influence the results obtained.
- At the end of Section 5.3.4 on page 31 (Vol. 5), it is stated that uranium results that are within a factor of 10 of the Decision Level (DL) should be adjusted for full dose reconstructions. What does 'adjusted' mean in this context? Furthermore, it seems inequitable to assign a DL for Fernald at 5 times that for INEL (0.8 vs. 0.16 micrograms/L).
- As lung counting began in 1968, why does Table 5-24 (Vol. 5) show only data from 1974 onward? In the paragraph following that table, it appears that the reference to percent body burden should be to percent lung burden?
- On page 36, it is noted that no system performance characteristics of the Mobile In Vivo Radiation Monitoring Laboratory (MIVRML) have been found to date. As this was the Y-12 instrument, these characteristics should be in the various papers published by Cofield. Only one journal and one 'grey literature' publication are cited in the reference list. A more thorough search is indicated.
- In Vol. 2 on page 24 in the second line of Section 2.2.4.2, 'UF_6' should read 'UF_4.'
- Table 5-5, Vol. 5, does not contain any rating for Plant 6, where machining of U was done. This should be rated as high.
- In Vol. 5 in Table 5-6, the heading of the second column ("mg intake = approx. 0.337 mg kidney – toxicity limit") needs explanation and a better connection to the values listed in the column.
- The energy given on page 6 of the TBD (Vol. 6) should be written as 0.300 ± 0.005 MeV.

- On page 7 of the TBD (Vol. 6), the text “Figures 6-1 and 6-2” should be changed to “Figures 6-3 and 6-4.”
- On page 24 of the TBD (Vol. 6) the calculation of the total missed photon dose should be $400 + 30 \times 3 \times 0.5 = 445$ mrem and not 449 mrem as given.
- Page 15 of Vol. 4 refers twice to a RAC 1988 report that does not exist. The document RAC 1998 that is in the reference list does not contain the information about particle sizes in Appendix E
- In Table 6-7, Vol. 6, the values of Hp(10) and Hp(0.07) for Sr-90/Y-90 have been interchanged. It is probable that this also happened to these values for the other DOELAP energies. The table shows the “angular response,” not the “annular response.” Furthermore, the 9 values between the energies of M30 ± 60 V and M150± 40 H are given twice in the table.

7.0 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.

7.1 THE FIVE OBJECTIVES

The SC&A review procedures, as approved by the Advisory Board, require that each site profile be evaluated against the five measures of adequacy; (1) completeness of data sources, (2) technical accuracy, (3) adequacy of data, (4) consistency among site profiles, and (4) regulatory compliance. Each of these is discussed below.

7.1.1 Objective 1: Completeness of Data Sources

The TBD is incomplete in a number of ways. Possibly the most notable of these for the purposes of dose reconstruction is the incompleteness of the thorium-232 production and air concentration data. Therefore, the research into thorium production done by NIOSH is incomplete and inadequate. Much documentation indicating high dust levels of thorium was missed. Production periods were also missed. The thorium data in the TBD are insufficient to arrive at defensible estimates of thorium exposure.

The section on "Cited References" in Volume 5 of the TBD (internal dose) does not contain any citations of 1950s documents for any material, including uranium. There is a section called "Other References," which are presumably not cited. There are only three documents with 1950s dates in that section, and none of them contain thorium data. Volume 2 of the TBD, Site Description, where thorium is also discussed, contains no references to documents from the 1950s.

The temporal coverage of the data sources is also incomplete. The section on "Cited References" in Volume 5 of the TBD does not contain a single citation for any document from the 1950s for any material, including uranium. This is strange, in view of the rich documentation available for that period. There is a section called "Other References," which are presumably not cited. There are only three documents with 1950s dates there, but none involve thorium data. Volume 2 of the TBD, Site Description, where thorium is also discussed, contains no references to documents from the 1950s.

Recycled uranium data are incomplete and also internally inconsistent. The characterization of fugitive emissions is also incomplete in essential respects. As a result, some of the most important sources, and possibly the most important sources, of environmental exposure have been missed. Original x-ray records are available. These were not checked to determine whether PFG was used at Fernald in the early years. Finally, the documentation of the interviews that were used in the TBD is also incomplete or unavailable.

NIOSH/ORAU stated during the August 18, 2006, conference call that this was an early TBD, which may account for the gaps. At present, there is considerable data on NIOSH's Site Research database. There is also a large archive with legal counsel who participated in the various Fernald-related legal proceedings. It is to be noted that some of the exhibits from Fernald litigation are on the NIOSH Site Research database (e.g., HSD 1954), though they are not cited in the TBD. These and other sources can be tapped for revising the TBD. (NIOSH has stated that the TBD is currently being revised.)

7.1.2 Objective 2: Technical Accuracy

The TBD has a number of problems with the lack of internal consistency between one volume and the next. There are numerous important errors in the TBD in regard to isotopic ratios of waste, including material that could become resuspended and inhaled.

The model adopted for estimating environmental dose is, by and large, not appropriate for workers outdoors but close to buildings. Since important sources of environmental exposure, such as fugitive emissions in production areas, have been missed, the accuracy of the resulting dose reconstruction is open to question.

Apart from chronic exposure to uranium or exposure to frequent incidents, the internal exposure approaches in the TBD are unlikely to result in accurate dose reconstruction results.

The protocol for assessing finger and hand doses is inadequate. Furthermore, there are no correction factors for situations where workers sat astride ingots to stamp numbers on them or just sat on ingots at other times. A more accurate approach needs to be developed for external beta dose to areas other than the extremities. Finally, the issue of what data were entered into worker dose records in the 1983 to October 1985 period needs to be settled, since inappropriate correction factors were applied to TLDs during some or all of this period.

7.1.3 Objective 3: Adequacy of Data

The data in the TBD appear inadequate for best-estimate and bounding dose reconstruction for a number of situations and worker groups. Areas of particular concern include the following:

- Thorium dose reconstruction
- Workers exposed to raffinates, including RU-related raffinates
- Workers exposed to RU
- Maximum dose reconstructions for which ORAUT-OTIB-0002 is now used to provide an upper limit for dose

- Situations where chip fires or the machining of metal (thorium or uranium) may produce fumes with very small particle size
- Radon exposure in the environs of Plant 2/3, and of workers who received K-65 waste and loaded Silos 1 and 2
- Environmental dose for unmonitored workers, including women, who were not monitored even for external dose during 1951 to 1960 and 1969 to 1978

NIOSH has stated that it is revising the TBD and that more data have become available, especially for thorium. These data have not been published (as of the end of September 2006) and SC&A has not reviewed them.

If the correction factors for uranium dust that were used in the initial TLD period were actually entered into the dose records of workers, there would be a problem of external dose reconstruction during this period (1983 to October 1985). It is unclear whether this was done and what values were entered into worker dose records when negative doses resulted from the application of correction factors.

The extent of the data available to estimate extremity doses is unclear. There was no use of finger badges at Fernald. The TBD guidelines suggest reliance on wrist badge records, but these data appear to be rather limited and may not cover the entire period of Fernald operation.

Data on episodic releases for the early years appear to be limited.

7.1.4 Objective 4: Consistency among Site Profiles

The overall approach of using bioassay data, when available, for internal dose reconstruction is consistent with the approach in other site profiles, and with 42 CFR 82. The approach suggested for environmental dose reconstruction at Fernald is about the same as that for several other sites. The TBD proposes to use estimates of stack emissions to estimate dose to unmonitored workers. The procedure, which raises concerns at other, larger sites, such as the Savannah River Site, is even more problematic at Fernald, given the much smaller site and the many buildings on it. Fugitive emissions may be more important at Fernald for unmonitored workers than at very large sites like Hanford, Savannah River Site, or INEL.

The approach suggested for exposure to raffinates in terms of the radionuclide lists and concentrations is much more defensible than the one in the MCW TBD. The use of the radionuclide ratios from the K-65 Silo sampling provides a sound basis for estimating intake. Also, the criteria for deciding which workers were actually exposed appear to be specific to Fernald. The screening level of "several 100 mrem" external exposure per week is rather high and has not been justified by comparison with other sites that handled similar materials, including MCW, which was the source of much of the K-65 material.

The Fernald external TBD (Vol. 6) recognizes that a correction factor is necessary to compensate for the loss of information due to the low-energy photons being absorbed in the shielded filter:

> *It is estimated that a correction equal to 10% of the <250 keV values given in Table 6-8 be added to the Hp(10) dose due to the contribution of these low energy photons to penetrating dose but are absorbed in the thick filter.* [TBD Vol. 6, p. 23]

For comparison, the correction factor for the Nevada Test Site (NTS) is larger—25%—for the period 1961 to 1966. Until 1966, only gamma dose was measured. In that year, a multi-element dosimeter that measured shallow dose was introduced [ORAUT-TKBS-0008-6, p. 40].

Table 10 below compares the procedures proposed in different TBDs for different DOE sites that compensate for the absorption of low-energy photons in the shielded filter of the film dosimeters.

Table 10. Correction Factors for Hp(10) Dose in Various TBDs

Parameter	FEMP	NTS (1961-1966)	INEEL	SRS
Compensation for loss of information of Hp(10) dose due to low-energy photons due to use of only the shielded filter to measure the Hp(10).	Multiply the E < 250 keV values by 1.1 and add to the Hp(10)	Multiply the Hp(10) by 1.25 for 30< E 250 KeV	No compensation	Add the open window dose to Hp(10)

The differing correction factors in Table 10 are not consistently linked to the energy spectrum of the photons present; hence it is difficult to determine whether the approach is similar across sites and consistently claimant favorable.

7.1.5 Objective 5: Regulatory Compliance

NIOSH needs to verify that its use of ORAUT-OTIB-0002 actually represents worst-case assumptions relative to some conditions at Fernald, such as work with K-65 residues and other raffinate streams. This is important for demonstrating that its use of the efficiency procedure for some groups of Fernald workers conforms to 42 CFR 82.

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ATTACHMENT 1: SC&A QUESTIONS ON THE FERNALD TBD SENT TO NIOSH

QUESTIONS FOR NIOSH REGARDING THE TECHNICAL BASIS DOCUMENT FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT (FEED MATERIALS PRODUCTION CENTER)

A. GENERAL QUESTIONS AND QUESTIONS RELATING TO VOLUMES 1 AND 2 OF THE TBD

1. Could NIOSH provide SC&A with the notes of its interviews with site experts?

2. NIOSH states that there were a “relatively small number of production workers” at Fernald (TBD, Vol. 1, p. 8). What is the documentary basis for this statement? In the same paragraph, the TBD states that “it seems likely that few workers routinely exceeded established exposure limits.” What is the documentary basis for this statement?

3. The TBD provides cumulative production figures of nearly 170,000 metric tons of uranium metal and 35,000 metric tons of intermediate products (Vol. 1, p. 5). Please provide the reference(s) for these figures.

4. Was the ore processing flowsheet similar to that used at Mallinckrodt with the various stages of filtering and concentration of Ra-226, Th-230, Pa-231 and Ac-227?

5. Would the ratios of radionuclides in the K-65 Silo 1 or Silo 2 be applicable to specific waste streams, or do they represent mixtures of actual waste streams that were all discharged into the silos? The question relates only to Fernald waste streams and not the Mallinckrodt materials in the silos.

6. What is the scientific justification for using the ratio of Th-232 to U atmospheric emissions to determine in-Plant thorium contamination?

B. QUESTIONS RELATING TO MEDICAL DOSE (VOL. 3)

1. On page 11 of Vol. 3, NIOSH cites a number of telephone communications on the basis of which the possible use of PFG at Fernald was ruled out. Could NIOSH provide SC&A with the records of these communications?

2. The TBD does not detail the evidence that equipment survey data reported for the period March 1977 to February 1988, as shown in Tables 3-10 and 3-14, are related to an actual survey of the output of the Bennett 300 unit, which was put into service in March 1977. Could NIOSH clarify whether the data are from an actual survey?

3. Section 3.1.4 of the TBD concludes that, based upon a survey of selected radiographs from 1952–1980, it was determined that collimation was always used from the

inception of x-ray use at the site. This conclusion is based upon the observation of a dark line at the bottom of the selected radiographs. Since collimators are made of very dense materials (e.g., lead, etc.), their use should appear as a lightened or unexposed area on the film. Also, any evidence of collimation should occur on all sides of the film, not just the bottom. Did NIOSH examine other explanations for the black line at the bottom of the radiographs?

4. Are doses from x-rays taken after workplace accidents going to be included in dose reconstructions?

5. The TBD in Section 3.2 states that a review of claimant files showed that 15% of the claimants reported that retakes occurred. Could NIOSH provide SC&A with the data compilation used to determine the retake rate?

C. QUESTIONS RELATING TO ENVIRONMENTAL DOSE (VOL. 4)

1. Why did the TBD use the source term developed by Boback 1987 and the 1988 supplement for uranium, rather than the source term developed for the Radiological Assessments Corporation by the CDC, which is much higher (about 310,000 kilograms compared to about 175,000 kilograms used by NIOSH)? Did NIOSH take into account the consideration that the RAC source term has been shown to be in accordance with soil data in Appendix C (RAC, 1998)?[16]

2. Why did the TBD use the thorium source term from Boback 1987 and the 1988 supplement rather than the RAC 1995 source term?

3. Table 4-4 lists annual airborne thorium emissions at Plants 8 and 9 and the Pilot Plant. This estimate is claimed to be conservative because of the assumptions used for scrubber and dust collector efficiency. What were the values of efficiency used? Did the procedure take into account documentation indicating that scrubber efficiency, notably in Plant 8, was sometimes far below the manufacturer-specified range?

4. According to a tabulation by NLO,[17] a significant fraction of the uranium releases from Fernald were of an episodic or accidental nature, influencing the environmental doses. How is NIOSH going to account for episodic releases in estimating environmental internal dose for individual dose reconstructions?

5. Tables 4-2 and 4-3 (TBD, Vol. 4) summarize annual fugitive uranium and thorium emissions. Please provide methodological details as to how the numbers were derived.

6. Could information be provided that demonstrates that the trace radionuclide-to-uranium ratios observed in 1985 apply to the earlier years? Specifically, what about the

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[16] RAC (Radiological Assessments Corporation), 1998, *The Fernald Dosimetry Reconstruction Project, Task 6 Radiation Doses and Risk to Residents from FMPC Operations from 1951-1988*, RAC Report No. 1-CDC-Fernald-1998-FINAL Vols. I and II.

[17] Adams W.J. (1985), letter to Vincent Fayne, Oak Ridge Operations, Cincinnati, March 21, 1985.

radionuclide ratios for (a) ore processing, including pitchblende processing, and (b) waste stream handling, processing, and dumping?

7. In developing the radionuclide-to-uranium ratios, the TBD used average observed values. Has NIOSH considered using the 95th percent confidence level of the mean, as opposed to the true mean, as a more claimant-favorable strategy?

8. Are there time periods when a given facility may have experienced radionuclide-to-uranium ratios that were chronically at the high end of the distributions?

9. Given that Tables 1 and 2 of the Boback report cited in the TBD reveal that the release heights were comparable to the heights of the nearby buildings, what is the basis for taking credit for an elevated release of 10 m when deriving atmospheric dispersion factors? How were building wake effects taken into consideration?

10. For the purpose of deriving the radon and radon progeny releases from the silos, the TBD used the median values derived in the RAC 1995 report. Wouldn't this approach be considered claimant-neutral as opposed to claimant-favorable?

11. Page 17 of the TBD states that atmospheric dispersion factors (X/Q values) were derived assuming a wind speed of 3.2 m/sec and stability class F. Once the X/Q values were derived for a given distance between the release point and receptor (using the σ_y and sigma σ_z values in Figures 4-3 and 4-4 of the TBD), an adjustment factor is applied to account for the frequency the wind blows toward a given receptor from a given source. Why didn't NIOSH employ the conventional joint frequency approach to deriving average annual atmospheric dispersion factors? Furthermore, the selected wind speed of 3.2 m/s does not appear to be claimant favorable. Please provide a justification as to why NIOSH is using this value for wind speed.

12. Table 4-8 contains the estimated distances for receptors from contributing emission sources. For EA-6, the distance from the K-65 silos is given as 250 m, even though the geographic center of EA-6 appears to be at a distance of about 100 m. The distance from the K-65 silos to EA-9 is given as 2,000 m, even though the most distant point in EA-9 appears to be about 1,500 m away from the K-65 silos. The distance to Plant 7 to EA-3 and EA-8 is 250 m in both cases, even though Plant 7 is located inside EA-7. Please explain the basis for the assumptions.

13. The TBD states on page 16 that the respirable fraction (<10 μm) of uranium particles was determined to be 65% on the basis of RAC (1995), Table E-1. It appears that for this calculation, the simple arithmetic average of data from 15 dust collector stacks was used. Table E-1 does not provide data on particle sizes from scrubber emissions (Plant 2/3 and Plant 8). Table E-8 of RAC (1995) indicates that the composite of U_3O_8 releases indicate that more than 75% of the emissions in the outlet had a particle size of less than 10μm. Please explain how the fraction of 65% respirable particles is representative for the total of all uranium emissions.

14. Has NIOSH considered the contribution to the internal dose associated with the resuspension and inhalation of deposited Pb-210?

15. Has NIOSH attempted to compare the pre-1989 derived atmospheric dispersion factors with the actual empirically determined atmospheric dispersion factors obtained using the actual monitored emissions and airborne radionuclide concentrations at monitored locations?

16. The footnote to Table 4-7 on page 19 suggests that the dispersion coefficients were multiplied by a factor of 0.5 for U and Th particulate aerosols, presumably to account for plume depletion, as explained in the paragraph below equation 4-3 on page 17. For most distances, plume depletion will be less than 50%. Please explain how it can be claimant favorable to apply a uniform plume depletion factor of 50% for all releases of particulates.

17. Equation 4-5 on page 35 of the TBD presents the method used to estimate the external radiation dose rates at each of the 11 grid locations. The basic approach was to use the actual measured dose rate at the locations where measurements were made, and then derive the dose rate at the grid locations, based on adjustments that take into consideration the distance from the source and the distance to the grid location using the inverse square law. One concern with this approach is that it only applies to point sources. Has NIOSH evaluated the degree to which this approach works for sources whose dimensions are large relative to the distance to the measurement location and/or the grid location?

18. For the purpose of deriving the external environmental exposure pre-1976, when there were no measurements, the doses were derived by comparing the uranium throughput in those years with the years for which there were external environmental dose measurements. What is the relevance of uranium production to external environmental dose in outdoor areas? Why did NIOSH not use uranium emissions instead, for instance? Were uranium isotopes the main external environmental dose problem throughout the Fernald site? Has NIOSH evaluated the degree to which the controlling factors remained unchanged over the years?

19. The TBD does not discuss the methods used to derive pre-1976 external environmental doses from the silos. How does NIOSH plan to reconstruct these doses?

20. How does NIOSH propose to reconstruct doses for the K-65 workers involved in handling Mallinckrodt K-65 residues, including the unloading of these residues and their loading into Silo 1?

D. QUESTIONS RELATING TO INTERNAL DOSE (VOL. 5)

1. What is the reference for the decontamination factor of 50 used for some Th-232 production activities?

2. Table 2-1a assumes respirator-based decontamination by a factor of 50 for some operations (Vol. 2, pp. 12–13). But in Vol. 5, "at least a factor of 10" is given for decontamination, and it is said that respirator use was not consistent and a decontamination factor cannot be assumed (Vol. 5. pp. 22–23). Is a decontamination factor being assumed for uranium when air concentrations are used for intake estimation? If so, for which jobs and periods? And what is the value being used?

3. Has NIOSH taken into account the dose reconstruction implications of the finding that respirators were judged at one point (1953) to be the "epitome of filth?"[18] Specifically, if respirators were stored in places or were worn so that they were susceptible to contamination on the inside, the intake could possibly be even higher than for those who did not wear respirators. Has NIOSH done interviews regarding jobs and periods during which respirators were worn and on the condition of the respirators? If so, SC&A requests the records of these interviews. Has NIOSH determined whether a central service (recommended in the memo quoted in the footnote) was implemented, and if so, when?

4. On page 11 (TBD, Vol. 2), it is not clear why thoria gel production for 1964 and 1965 was estimated based on a linear extrapolation of the quantity produced in 1966 through 1970. Can some justification for this assumption be provided?

5. Could NIOSH provide the flowchart of thorium processing? Was it similar to the Ames Laboratory flowchart?

6. How has NIOSH taken into account localized high concentrations of uranium dust in areas such as dust collector baghouses?

7. Is NIOSH developing an internal dose co-worker model? If so, what periods would this apply to, and what data are being used?

8. Has NIOSH compiled internal dose data into a database? If so, could it be made accessible on the Advisory Board's section of the O Drive?

9. How is NIOSH going to reconstruct internal dose prior to 1953, since there do not appear to be data before 1953, as implied by the sentence, "A urinalysis program was administered at FEMP starting in 1953 or possibly before" (p. 30 of Vol. 5). The table on the same page states that there are uranium bioassay data for 1952. Are there data for 1952?

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[18] Dr. Quigley to Charles Dees, "Industrial Case Study," October 12, 1953, p. 3, on which Dr. J. W. Durkin appears to be quoted. The full quote, which has the name of one person (perhaps two) deleted from the document is as follows: "The other problem that became apparent in this situation is the poor care being given to the dust respirators. The ones observed by [blank] and myself near the Chip Burner were the epitome of filth. Apart from this, it would have been a perfect fomite [?] for the transfer of respiratory infection between employees. This simply corroborates the reiteration of [blank] that something should be done about the respirator situation – either the men must take better care of them, or central service must be provided." An earlier part of the document notes that "there were two Dust-Foe respirators hanging on hooks" in the "shack-type office in the [Chip Burner] area."

10. Since no bioassay data for thorium are available prior to 1990 – that is for the entire production period – how is NIOSH going to validate the dose estimates for thorium-232, as well as for its decay products, notably radium-224?

11. Since much of the thorium data is lost and many documents have apparently been destroyed (p. 18, Vol. 5), and since there are hardly any bioassay data or other data specific to thorium in the workplace, how is NIOSH going to ensure that the dose reconstructions are claimant favorable? How is NIOSH going to ensure that all plants where thorium was processed are included in its list? Could NIOSH provide all the interviews on which its analysis of thorium production and related issues is based?

12. Given that thorium-232 DCFs are orders of magnitude larger than uranium for some organs, how is NIOSH going to address doses to uranium workers in the plants listed for thorium production (Plants 8 and 9, the Pilot Plant, and possibly Plant 4) (a) during thorium production periods, and (b) due to resuspension of thorium dust during non-thorium production periods?

13. Could NIOSH provide the records that have been recovered in relation to thorium described at the bottom of page 21, Vol. 5?

14. On page 22, Vol. 5, NIOSH states that "Therefore, the three Plants mentioned [Plants 8 and 9, and the Pilot Plant] should be considered the primary processing sites, although there is some evidence that a few isolated thorium operations occurred in other locations." There seems to be no guidance for dose reconstruction at these other locations (such as Plant 4), and how the periods or workers who were exposed would be determined. How is NIOSH addressing the issue of thorium work in Plants other than Plant 8, Plant 9, and the Pilot Plant?

15. On page 22, NIOSH states that it is using BZ samples from lapel samplers to conservatively estimate thorium exposures. How is NIOSH taking into account the Y-12 study indicating that this is not a reliable way to make intake estimates, and that BZ-estimated intakes could be significant underestimates when compared with bioassay estimated intakes?

16. Since enrichments of uranium-235 up to 20% were processed at Fernald, how does NIOSH justify the use of 2% enrichment as the default value after 1964? Given the large difference in specific activities and the fact that the fluorometric method was used for determining uranium content of urine, this would appear to be an assumption that would not be claimant favorable for some groups of workers at some times. Would it be possible to use a range of enrichments with a suitable distribution (or distributions for different time periods) instead?

17. In Table 5-11, RU contaminant concentrations are given for plutonium-239, neptunium-237 and technetium-99. Although plutonium-239 is likely to have dominated the plutonium component of the contamination in mass terms, plutonium-238 could have been more important in activity terms. Has NIOSH given

consideration to the possibility of specifying a default mass concentration for plutonium, together with a default partitioning between plutonium-238, plutonium-239, and plutonium-240, to allow intakes of activity by radionuclide to be assigned?

18. In Table 5-16, is there any explanation why Pb-210 and Po-210 activity concentrations in Silo 1 measured in 1993 are substantially less than would be expected based on the secular equilibrium concentrations that would be supported by the Ra-226 present? It is noted that this effect is much less marked in Silo 2.

19. How can the Rn-222 concentration of 2.3 WL given on page 27 of Volume 5 be justified as claimant favorable when it is based on the higher of only two samples from a single radon sample data sheet?

E. QUESTIONS RELATING TO EXTERNAL DOSE (VOL. 6)

1. Is NIOSH developing an external dose co-worker model? If so, what periods would this apply to and what data are being used?

2. Page 23 of the external dose volume mentions the use of co-worker data for missed doses? What criteria are being used to choose the co-workers for the missed doses?

3. Page 23 also mentions lost dosimeter results. What proportion of the data has been lost?

4. Has NIOSH compiled external dose data into a database? If so, could it be made accessible on the Advisory Board's section of the O Drive?

5. The TBD discusses adjustments to dosimeter readings. In regard to radioactive dust settling on the dosimeter, the TBD states that dosimeters were in plastic bags "at times" (p. 11, Vol. 6).[19] However, Volume 4 of the set of transition reports in the handover from NLO to Westinghouse discusses the application of adjustment factors to TLDs for a period between 1983 and October 1985. The use of this correction factor sometimes resulted in negative radiation dose estimates. The correction factors resulted in changes (according to the calculations shown in the datasheets) of 6% to 663%. In the examples given in the report, the largest magnitude correction of 1,652 millirem was applied to a dose of 1,291 millirem, resulting in a net negative estimated dose equal to -361 mrem.[20] The practice was used from 1983 (when TLDs were introduced) to October 1985, when its regular use was discontinued. However, it appears to have been continued in an

[19] "An additional radiological concern at several locations at FEMP occurred when workers were subjected to high levels of radioactive material-bearing dust. This widespread source of contamination was a concern for personal dosimeters, so at times the dosimeters were enclosed in plastic bags for protection against dust contamination. The manner in which these contaminated dosimeters were handled was not identified; however, this should not be an issue in dose reconstruction because the dosimeters were calibrated in plastic bags and no adjustments were made to the dosimeter results for either Hs(0.07) or Hp(10)." (TBD, Vol. 6, p. 11)

[20] Feed Materials Production Center, Final Phase-in Report, Vol. 4 of 15, Environment, Safety and Health, Westinghouse Company of Ohio, January 17, 1986. See Attachment 3 for the datasheets.

ad hoc fashion after that date.[21] While doses with high percentage corrections (more than 50%, therefore including negative dose estimates) were not automatically entered into the dose record, it is unclear what exactly was done. The TBD does not discuss this problem, although it indicates some difficulties in the initial period of TLD testing due to a problem in the algorithm, notably for shallow dose (p. 12, Vol. 6). Has NIOSH investigated this problem and how the resultant doses might be interpreted? Since the TBD acknowledges that plastic bags were used only "at times," has NIOSH investigated the periods when this was not the practice? Were correction factors applied during such periods? Does NIOSH have documentation indicating the periods when dosimeters were in plastic bags? Section 6.5 on adjustments to dose does not discuss the use of the correction factors described above. How is NIOSH going to take them into account?

6. Vol. 6 of the TBD discusses correction factors for geometry. Has NIOSH taken adequate account of some jobs where the badge readings were unlikely to have any systematic relationship to the organ dose? One such job, stamping numbers on ingots, was photographed by Robert del Tredici in 1987. The photograph shows the worker sitting astride an ingot stamping an ID number on its flat face; it can be provided upon request. His film badge is dangling from his coverall pocket parallel to the face of the ingot. His body shields the radiation from behind. The use of wrist badges is evident. The angular response correction factors (Table 6-7) do not address this problem.

7. On page 22 of Vol. 6, NIOSH states that "Corrections to the FEMP-reported dose are required, due to uncertainties in the recorded data and lack of significant data, especially prior to 1980." How much pre-1980 data is missing? What happened to the individual external dose records for the pre-1980 period that caused a significant amount of data to be missing?

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[21] Ibid. p. 15.

ATTACHMENT 2: ANSWERS TO SC&A QUESTIONS ON FERNALD SITE PROFILE

FINAL ORAUT DRAFT
08/16/2006

A. GENERAL QUESTIONS AND QUESTIONS RELATING TO VOLUMES 1 AND 2 OF THE TBD

1. Could NIOSH provide SC&A with the notes of its interviews with site experts?

   The Site Profile development team only interviewed four former Fernald workers. Unfortunately, there were no comments from interviewees that related directly to issues or assumptions in the TBDs, so documentation of these interviews was not retained.

2. NIOSH states that there were a "relatively small number of production workers" at Fernald (TBD, Vol. 1, p. 8). What is the documentary basis for this statement? In the same paragraph, the TBD states that "it seems likely that few workers routinely exceeded established exposure limits." What is the documentary basis for this statement?

   ASI (Advanced Sciences Inc.) prepared a document (date unknown) for Westinghouse Materials Company of Ohio (Fernald, Ohio) which states that there were almost 2900 employees, some of whom were production workers. This is relatively small when compared to other AEC sites such as Hanford and SRP.

   The basis for stating that it seems likely that few workers routinely exceeded established exposure limits is the many letters and notes [Dugan (1981) and Noyes (1968)], as well as lists of individual exposure results in the early production years.

3. The TBD provides cumulative production figures of nearly 170,000 metric tons of uranium metal and 35,000 metric tons of intermediate products (Vol. 1, p. 5). Please provide the reference(s) for these figures.

   The original figures were calculated and extrapolated from available data. Other data was received from mass balance reports. The site descriptions and other TDB sections will be revised to reflect updated information, which will include references for the information.

4. Was the ore processing flowsheet similar to that used at Mallinckrodt with the various stages of filtering and concentration of Ra-226, Th-230, Pa-231 and Ac-227?

   The two facilities' flow sheets have not been reviewed together. We currently understand that there were similarities with the Mallinckrodt Destrehan process, but the process adopted at Fernald would have included modifications and upgrades.

5. Would the ratios of radionuclides in the K-65 Silo 1 or Silo 2 be applicable to specific waste streams, or do they represent mixtures of actual waste streams that were all discharged into the silos? The question relates only to Fernald waste streams and not the Mallinckrodt materials in the silos.

The isotopic ratios were determined in the early 90s by taking core sample of the accumulated sludge. Thus the analyses represent results of mixtures of actual waste streams that were discharged to the silos, including the Mallinckrodt waste.

6. What is the scientific justification for using the ratio of Th-232 to U atmospheric emissions to determine in-Plant thorium contamination?

   The footnote to Table 2-1c indicates that the basis for the ratios would be found in Appendix 2B, but it appears that there is a typographical error somewhere. We will either provide the basis for these numbers or delete them, as they are superseded by information in the internal dose TBD.

B. QUESTIONS RELATING TO MEDICAL DOSE (VOL. 3)

1. On page 11 of Vol. 3, NIOSH cites a number of telephone communications on the basis of which the possible use of PFG at Fernald was ruled out. Could NIOSH provide SC&A with the records of these communications?

   No other information regarding telephone conversations beyond that included in the TBD, is available.

2. The TBD does not detail the evidence that equipment survey data reported for the period March 1977 to February 1988, as shown in Tables 3-10 and 3-14, are related to an actual survey of the output of the Bennett 300 unit, which was put into service in March 1977. Could NIOSH clarify whether the data are from an actual survey?

   It appears the data for the Bennett unit were calculated, not measured. The exposure data reported in a memo dated February 24, 1977, presumably associated with the Bennett X-ray machine, were not measurement data. Instead they represented calculations of exposure for various projections based on the nominal technique (including tube potential and mAs) in use at Fernald at that time and nominal dose factors extracted from a graph on page 159 of the Radiological Health Handbook. The dose factors, in units of mR per mAs, were selected to match the tube potential and Source to Skin Distance for the projection of interest. The footnote below Table 3-10 which refers to the "the measured *data from 02/77" [emphasis added] is an error, and will be changed in the next revision.*

3. Section 3.1.4 of the TBD concludes that, based upon a survey of selected radiographs from 1952–1980, it was determined that collimation was always used from the inception of x-ray use at the site. This conclusion is based upon the observation of a dark line at the bottom of the selected radiographs. Since collimators are made of very dense materials (e.g., lead, etc.), their use should appear as a lightened or unexposed area on the film. Also, any evidence of collimation should occur on all sides of the film, not just the bottom. Did NIOSH examine other explanations for the black line at the bottom of the radiographs?

   No other information is available other than that presented. The fact that evidence of visible collimation is not seen on all edges of the film does not mean that collimation is not applied. Preparing to expose a radiograph includes an attempt to "cut the four corners" and precisely align the film and x-ray beam boundary. See SRDB Ref ID 22720 for a documented communication with a Brookhaven National Laboratory X-ray technician who used that technique. However, the ORAUT will attempt to look at actual radiographs from Fernald again to resolve the question about the "black line".

4. Are doses from x-rays taken after workplace accidents going to be included in dose reconstructions?

   In accordance with 42CFR 81 and 82, only medical exposures that were performed for medical screening and required as a condition of employment are included in the occupational medical dose. Diagnostic and therapeutic procedures not required for medical screening are not included." X-rays taken after workplace accidents are diagnostic and so are not included in dose reconstruction.

5. The TBD in Section 3.2 states that a review of claimant files showed that 15% of the claimants reported that retakes occurred. Could NIOSH provide SC&A with the data compilation used to determine the retake rate?

   No other information regarding X-ray retake rate, beyond that included in the TBD, is available.

C. QUESTIONS RELATING TO ENVIRONMENTAL DOSE (VOL. 4)

1. Why did the TBD use the source term developed by Boback 1987 and the 1988 supplement for uranium, rather than the source term developed for the Radiological Assessments Corporation by the CDC, which is much higher (about 310,000 kg compared to about 175,000 kg used by NIOSH)? Did NIOSH take into account the consideration that the RAC source term has been shown to be in accordance with soil data in Appendix C (RAC, 1998)?

   The original revision of the Fernald Occupational Environmental Dosimetry Technical Basis Document (OEDTBD) used the Boback data to estimate exposure to site releases because it was believed that its use would be sufficiently conservative and the resulting exposures would represent exposure estimates that would be favorable to the claimant. Use of the release data compiled by RAC (1995) would simply add to the existing conservative estimate.

2. Why did the TBD use the Th source term from Boback 1987 and the 1988 supplement rather than the RAC 1995 source term?

   See response to C.1 above.

3. Table 4-4 lists annual airborne Th emissions at Plant 8 and 9 and the Pilot Plant. This estimate is claimed to be conservative because of the assumptions used for scrubber and dust collector efficiency. What were the values of efficiency used? Did the procedure take into account documentation indicating that scrubber efficiency, notable in Plant 8, was sometimes far below the manufacturer-specified range?

   For the Th emission calculations, the efficiency assumed for the scrubber was 85% and the efficiency assumed for the dust collector was 95% (Dolan and Hill 1988), and although Dolan and Hill were aware that efficiencies varied, they thought their chosen values compared reasonably to the NRC's 95% estimate for a venturi-type scrubber and the typical rating of 99%+ for dust collectors, as well as made allowances for "operational upset."

   The RAC 1995 document provides a description of the scrubber efficiencies at both Plants 2/3 and 8 that differs from the Dolan and Hill (1988) assumptions. Updates to the TBD are warranted based on the differences in the efficiency estimates.

4. According to a tabulation by NLO, a significant fraction of the U releases from Fernald were of an episodic or accidental nature, influencing the environmental doses. How is NIOSH going to account for episodic releases in estimating environmental internal dose for individual dose reconstructions?

   Episodic (and operational) stack releases are included as annual integrated emissions within the tables in the TBD. Over extended periods of time, these integrated emissions provide means of estimating internal exposures for individuals who were not monitored and who would not have required monitoring because of their low potential for exposure during their employment. In accordance with program guidance given in ORAUT-PROC-0031, the derived maximum site-wide annual median intakes via inhalation and ingestion will be used to estimate doses for these unmonitored individuals when other dose-estimating information is not available.

5. Tables 4-2 and 4-3 (TBD, Vol. 4) summarize annual fugitive U and Th emissions. Please provide methodological details as to how the numbers were derived.

   For fugitive emissions, EPA guidelines were used to calculate emissions from the waste storage and production areas. Reference: Method for Estimating Fugitive Particulate Emissions From Hazardous Waste Sites. U. S. Environmental Protection Agency, Cincinnati, Ohio, August 1987. EP/600/2-87/066 PB87-232203.

6. Could information be provided that demonstrates that the trace radionuclide-to-U ratios observed in 1985 apply to the earlier years? Specifically, what about the radionuclide ratios for (a) ore processing, including pitchblende processing, and (b) waste stream handling, processing, and dumping?

   Yes. The values represent the earlier years. These values are also given within the Fernald Internal Dosimetry Technical Basis Document.

7. In developing the radionuclide-to-U ratios, the TBD used average observed values. Has NIOSH considered using the 95th percent confidence level of the mean, as opposed to the true mean, as a more claimant –favorable strategy?

   Use of the mean values is reasonable for estimates of exposures to unmonitored workers, unless there is additional information that indicates that other values should be used. The mean ratios are to be applied to the maximum annual median uranium values, so they would tend to be favorable to claimants.

8. Are there time periods when a given facility may have experienced radionuclide-to-U ratios that were chronically at the high end of the distributions?

   Ratios of uranium to other radioactive contaminants varied among plants and even among areas within plants due to operational conditions and/or chemical processes being conducted. It would be expected that the non-uranium radionuclide to uranium ratios would be much larger in plants 1, 2/3, and 4; but becoming more weighted to uranium after initial reduction of UF_4 into metal within the Plant 5 "A" area.

9. Given that Tables 1 and 2 of the Boback report cited in the TBD reveal that the release heights were comparable to the heights of the nearby buildings, what is the basis for taking credit for an elevated release of 10 m when deriving atmospheric dispersion factors? How were building wake effects taken into consideration?

Many of the stack heights given in Table 1 indicate that they are only a few feet above the roof peak heights provided in Table 2 of Boback et al (1987), however the previous calculations need to be reviewed and consideration will be given to issues including stack heights and effective stack heights. No building wake effects were taken into account in estimating downwind concentrations from Fernald releases.

10. For the purpose of deriving the Rn and Rn progeny releases from the silos, the TBD used the median values derived in the RAC 1995 report. Wouldn't this approach be considered claimant-neutral as opposed to claimant-favorable?

    Best estimates (neither giving favor to the claimant, but not denying the benefit of doubt) are the preferred method of dose reconstruction. Regarding releases of Rn and associated progeny, a recent University of Cincinnati study has become available and the values in the TBD will be reconsidered in light of the new information.

11. Page 17 of the TBD states that atmospheric dispersion factors (X/Q values) were derived assuming a wind speed of 3.2 m/sec and stability class F. Once the X/Q values were derived for a given distance between the release point and receptor (using the σ_y and σ_z values in Figures 4-3 and 4-4 of the TBD), an adjustment factor is applied to account for the frequency the wind blows toward a given receptor from a given source. Why didn't NIOSH employ the conventional joint frequency approach to deriving average annual atmospheric dispersion factors? Furthermore, the selected wind speed of 3.2 m/s does not appear to be claimant favorable. Please provide a justification as to why NIOSH is using this value for wind speed.

    The wind speed of 3.2 m/s is from the environmental report and the choice of stability class "F" came from the Safety Analysis report for the thorium overpack operation.

12. Table 4-8 contains the estimated distances for receptors from contributing emission sources. For EA-6, the distance from the K-65 silos is given as 250 m, even though the geographic center of EA-6 appears to be at a distance of about 100 m. The distance from the K-65 silos to EA-9 is given as 2,000 m, even though the most distant point in EA-9 appears to be about 1,500 m away from the K-65 silos. The distance to Plant 7 to EA-3 and EA-8 is 250 m in both cases, even though Plant 7 is located inside EA-7. Please explain the basis for the assumptions.

    The estimated downwind distances will be reviewed and revised or justified as necessary.

13. The TBD states on page 16 that the respirable fraction (<10 μm) of U particles was determined to be 65% on the basis of RAC (1995), Table E-1. It appears that for this calculation, the simple arithmetic average of data from 15 dust collector stacks was used. Table E-1 does not provide data on particle sizes from scrubber emissions (Plant 2/3 and Plant 8). Table E-8 of RAC (1995) indicates that the composite of U_3O_8 releases indicate that more than 75% of the emissions in the outlet had a particle size of less than 10 μm. Please explain how the fraction of 65% respirable particles is representative for the total of all U emissions.

    Upon review, we believe that the higher fraction of respirable particles should be considered in determining the total respirable uranium particulate from at least Plants 2/3 and 8. The TBD will be revised accordingly.

14. Has NIOSH considered the contribution to the internal dose associated with the resuspension and inhalation of deposited Pb-210?

No, at this time NIOSH has not considered emissions of Pb-210 separately from the emissions of radon, because it is likely that assumed Rn intakes and the associated assumed equilibrium ratio of progeny are sufficiently large to account for intakes and associated doses from Pb-210 environmental releases.

15. Has NIOSH attempted to compare the pre-1989 derived atmospheric dispersion factors with the actual empirically determined atmospheric dispersion factors obtained using the actual monitored emissions and airborne radionuclide concentrations at monitored locations?

    The atmospheric dispersion factors have not been compared, but since the TBD was originally written, additional data have been received and comparisons are now possible.

16. The footnote to Table 4-7 on page 19 suggests that the dispersion coefficients were multiplied by a factor of 0.5 for U and Th particulate aerosols, presumably to account for plume depletion, as explained in the paragraph below equation 4-3 on page 17. For most distance, plume depletion will be less than 50%. Please explain how it can be claimant favorable to apply a uniform plume depletion factor of 50% for all releases of particulates.

    Although the Pasquill-Gifford Equation used for gases in Equation 4-2 should be divided by two for application to particulate, and thus results in Equation 4-3, the footnote to Table 4-7 appears to indicate that it's possible the numbers were divided in half again. The calculations will be checked and the numbers in Table 4-7 of the TBD will be updated if needed to reflect the appropriate values..

17. Equation 4-5 on page 35 of the TBD presents the method used to estimate the external radiation dose rates at each of the 11 grid locations. The basic approach was to use the actual measured dose rates at each of the locations where measurements were made, and then derive the dose rate at the grid locations, based on adjustments that take into consideration the distance from the source and the distance to the grid location using the inverse square law. One concern with this approach is that it only applies to point sources. Has NIOSH evaluated the degree to which this approach works for sources whose dimensions are large relative to the distance to the measurement location and/or the grid location?

    For most locations the distances compared to the source sizes are sufficiently large that a point source methodology is reasonable. For the few sources that might not be best approximated as point sources (e.g., the pits), the results are sufficiently close to actual measured results using these equations that the method appears reasonable.

18. The purpose of deriving the external environmental exposure pre-1976, when there were no measurements, the doses were derived by comparing the U throughput in those years with the years for which there were external environmental dose measurements. What is the relevance of U production to external environmental dose in outdoor areas? Why did NIOSH not use U emissions instead, for instance? Were U isotopes the main external environmental dose problem throughout the Fernald site? Has NIOSH evaluated the degree to which the controlling factors remained unchanged over the years?

    The environmental occupational exposures were ratioed to the U production rates. The primary environmental external exposure would have been due to the radium-bearing material (Ra-226) in the K-65 silos and the thorium (Th-232) stored within several warehouses on the Fernald site. Uranium's short-lived progeny, Pa-234m, contributes to the non-penetrating dose. This exposure *would have represented a baseline external exposure and would have incrementally increased based upon the throughput of uranium being processed within the process area.*

19. The TBD does not discuss the methods used to derive pre-1976 external environmental doses from the silos. How does NIOSH plan to reconstruct these doses?

    The method for extrapolating doses back to the pre-1976 periods is described in the TBD beginning with the last paragraph on p. 35. The method includes the dose from the silos, although the silo dose rates are not specifically called out in Table B-1 for pre-1976 periods. This is easiest to see by comparing the 1971–1975 and 1976 values in Table B-1, because the production rates were the same during these periods.

20. How does NIOSH propose to reconstruct doses for the K-65 workers involved in handling Mallinckrodt K-65 residues, including the unloading of these residues and their loading into Silo 1?

    This is not considered environmental exposure that would be used to address unmonitored worker doses, rather it is part of the exposure in a radiologically controlled workplace and so is covered in Section 5.2.4 of the Fernald Internal Dosimetry Technical Basis Document.

D. QUESTIONS RELATING TO INTERNAL DOSE (VOL. 5)

1. What is the reference for the decontamination factor of 50 used for some Th-232 production activities?

    A review of this TBD resulted in no locating of a decontamination factor of 50 in the document. Please clarify this question.

2. Table 2-1a assumes respirator-based decontamination by a factor of 50 for some operations (Vol. 2, pp. 12–13). But in Vol. 5, "at least a factor of 10" is given for decontamination, and it is said that respirator use was not consistent and a decontamination factor cannot be assumed (Vol. 5. pp. 22–23). Is a decontamination factor being assumed for uranium when air concentrations are used for intake estimation? If so, for which jobs and periods? And what is the value being used?

    To date, we are unaware of respiratory protection factors being used for Fernald dose reconstructions, and currently have no plans to apply these factors. (It's conceivable that in the future on a case by case basis, where there are no bioassay that can be used to estimate intakes and it can be shown that the worker was included in a respirator fit test program and was wearing a respirator that such factors might be applied). Table 2-1a applies (inappropriately) a respiratory protection factor only to some operations or locations. The last column in Table 2-1a and its associated footnote b., and other similar columns and footnotes in the Site Description TBD tables (e.g., 2-2b) will be deleted.

3. Has NIOSH taken into account the dose reconstruction implications of the finding that respirators were judged at one point (1953) to be the "epitome of filth?"[22] Specifically, if respirators were stored in places or were worn so that they were susceptible to contamination on the inside, the intake could possibly be even higher than for those who did not wear respirators. Has NIOSH done interviews regarding jobs and periods during which respirators were worn and on the condition of the respirators? If so, SC&A requests the records of these interviews. Has NIOSH determined whether a central service (recommended in the memo quoted in the footnote) was implemented, and if so, when?

   The TBD recommends that no credit be taken for respirator usage despite a documented program for respiratory supply and maintenance. Intakes derived from urinalysis results, which are likely to be available for those who handled respirators, would account for intakes that occurred directly from respirators. Ingestion intakes will be added for thorium operational intakes, which currently are based on intakes calculated from air concentrations. CATIs include some information regarding respirator usage, but other specific interviews regarding respirators, their care and their usage have not been assembled, and would unlikely affect exposure assumptions.

4. On page 11 (TBD, Vol. 2), it is not clear why thoria gel production for 1964 and 1965 was estimated based on a linear extrapolation of the quantity produced in 1966 through 1970. Can some justification for this assumption be provided?

   This question belongs in the section for Vol. 2 – the Site Description. Air monitoring and/or effluent release calculations are used to derive internal intakes and so this assumption does not affect dose reconstruction.

5. Could NIOSH provide the flowchart of thorium processing? Was it similar to the Ames Laboratory flowchart?

   Simplified flow sheets are included in the Dolan and Hill (1988 report) report. We are not familiar with the mentioned Ames Laboratory flowcharts. Is a more complete reference to these documents available, so we can review them?

6. How has NIOSH taken into account localized high concentrations of uranium dust in areas such as dust collector baghouses?

   Internal dose reconstruction is performed using uranium bioassay data, even if the intake occurred as a result of working in the high dust levels in the dust collector baghouses.

7. Is NIOSH developing an internal dose co-worker model? If so, what periods would this apply to, and what data are being used?

   So far, there has not been a need to develop a FEMP coworker model for internal dose.

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[22] Dr. Quigley to Charles Dees, "Industrial Case Study," October 12, 1953, p. 3, on which Dr. J. W. Durkin appears to be quoted. The full quote, which has the name of one person (perhaps two) deleted from the document is as follows: "The other problem that became apparent in this situation is the poor care being given to the dust respirators. The ones observed by [blank] and myself near the Chip Burner were the epitome of filth. Apart from this, it would have been a perfect fomite [?] for the transfer of respiratory infection between employees. This simply corroborates the reiteration of [blank] that something should be done about the respirator situation – either the men must take better care of them, or central service must be provided." An earlier part of the document notes that "there were two Dust-Foe respirators hanging on hooks" in the "shack-type office in the [Chip Burner] area."

8. Has NIOSH compiled internal dose data into a database? If so, could it be made accessible on the Advisory Board's section of the O Drive?

   At this point a NIOSH internal dose database is not available. There is a CEDR database, and if the Board Members have filed the appropriate paperwork for viewing CEDR data, access could be made available via the O drive).

9. How is NIOSH going to reconstruct internal dose prior to 1953, since there do not appear to be data before 1953, as implied by the sentence, "A urinalysis program was administered at FEMP starting in 1953 or possibly before" (p. 30 of Vol. 5). The table on the same page states that there are uranium bioassay data for 1952. Are there data for 1952?

   FEMP started to process radiological materials at the Pilot Plant in October 1951.The available data are adequate to estimate intakes from the beginning of radiological operations. In a quick review of the CEDR database for Fernald and some Fernald claims with employment prior to 1953, some uranium urinalysis results from 1952 were observed.

10. Since no bioassay data for thorium are available prior to 1990 – that is for the entire production period – how is NIOSH going to validate the dose estimates for thorium-232, as well as for its decay products, notably radium-224?

    Dose estimates are based on an understanding of the process, some air sampling measurements and default maximum credible intakes, derived from maximum air sample data. If a more comprehensive air monitoring database becomes available, its use will be considered. The concern is not clear about Ra-224, the alpha-emitting, short-lived progeny of Th-228, whose dose appears to be adequately accounted for in the assumption that the alpha activity measured in air only comes from the larger dose contributors Th-232 and Th-228.

11. Since much of the thorium data is lost and many documents have apparently been destroyed (p. 18, Vol. 5), and since there are hardly any bioassay data or other data specific to thorium in the workplace, how is NIOSH going to ensure that the dose reconstructions are claimant favorable? How is NIOSH going to ensure that all plants where thorium was processed are included in its list? Could NIOSH provide all the interviews on which its analysis of thorium production and related issues is based?

    The TBD referred to interviews performed by Dolan and Hill (1988) and that reference is available in the Site Research Database. The dose reconstruction for thorium exposures includes a default assumption that is claimant favorable to the extreme and should address any credible exposure. The TBD recognizes that a few scattered operations with thorium were conducted in plant 4. Any suggestion in the interviews that a claimant could have been involved with thorium operations will have the conservative defaults applied. However, the documented data for the few operations outside the pilot plant, Plant 8 and 9 are few and some additional information search may clarify how to address this question.

12. Given that thorium-232 DCFs are orders of magnitude larger than uranium for some organs, how is NIOSH going to address doses to uranium workers in the plants listed for thorium production (Plants 8 and 9, the Pilot Plant, and possibly Plant 4) (a) during thorium production periods, and (b) due to resuspension of thorium dust during nonthorium production periods?

    The question of addressing possible residual thorium contamination from discontinued thorium operations is under consideration.

13. Could NIOSH provide the records that have been recovered in relation to thorium described at the bottom of page 21, Vol. 5?

    The thorium air sampling records that have been recovered can be found in the SRDB and can be provided.

14. On page 22, Vol. 5, NIOSH states that "Therefore, the three Plants mentioned [Plants 8 and 9, and the Pilot Plant] should be considered the primary processing sites, although there is some evidence that a few isolated thorium operations occurred in other locations." There seems to be no guidance for dose reconstruction at these other locations (such as Plant 4), and how the periods or workers who were exposed would be determined. How is NIOSH addressing the issue of thorium work in Plants other than Plant 8, Plant 9, and the Pilot Plant?

    Perhaps a clarification should be emphasized that dose reconstructions for claims that include evidence of thorium exposure should include thorium internal dose based on the default values in the TBD. This question will receive additional consideration.

15. On page 22, NIOSH states that it is using BZ samples from lapel samplers to conservatively estimate thorium exposures. How is NIOSH taking into account the Y-12 study indicating that this is not a reliable way to make intake estimates, and that BZ-estimated intakes could be significant underestimates when compared with bioassay estimated intakes?

    The TBD statement on page 22 describes the current (modern) methods of controlling and assigning internal intakes – conservatively. If the questioner's Y-12 reference is the Y-12 Uranium Exposure Study (Eckerman and Kerr 1999 [Ref ID 11600]), it is clear that the intake estimation method proposed in the TBD is reasonable; in the Y-12 study the ratios of air concentration to bioassay derived intakes range from 0.11 to 1.38 with an average of 0.49 in Table 11 of the Y-12 study, indicating that if bioassay is the gold standard, Y-12 intakes derived from bioassay might be low in some cases by up to a factor of 9. However, the intakes in the Y-12 study were reduced to account for respiratory protection factors ranging from 1 (no respirator) to 50, but typically in the 25 to 50 range. For FEMP claims there is no proposal to apply a respiratory protection factor to the FEMP BZA derived intakes. In addition, currently the more claimant-favorable missed intakes from bioassay rather than air concentration derived intakes have been used to estimate FEMP doses. Assigning intakes based upon breathing zone air sampling data collected in current day programs with appropriate collection and measurement techniques is recognized as a reasonable way to estimate intakes.

16. Since enrichments of uranium-235 up to 20% were processed at Fernald, how does NIOSH justify the use of 2% enrichment as the default value after 1964? Given the large difference in specific activities and the fact that the fluorometric method was used for determining uranium content of urine, this would appear to be an assumption that would not be claimant favorable for some groups of workers at some times. Would it be possible to use a range of enrichments with a suitable distribution (or distributions for different time periods) instead?

    The amount of U of enrichments above 2% at FEMP was trivial (a few 55 gal drums compared to MTU). Also the exposures to these enrichments were less due to increased value, small amounts, need for additional criticality controls, etc.

17. In Table 5-11, RU contaminant concentrations are given for plutonium-239, neptunium-237 and technetium-99. Although plutonium-239 is likely to have dominated the plutonium component of the contamination in mass terms, plutonium-238 could have been more important in activity terms. Has

NIOSH given consideration to the possibility of specifying a default mass concentration for plutonium, together with a default partitioning between plutonium-238, plutonium-239, and plutonium-240, to allow intakes of activity by radionuclide to be assigned?

The Pu-238 was not a significant internal dose factor, as a result of processing primarily DU and low LEU. The method used to account for the dose from recycle uranium contaminants tends to be claimant favorable and uses the larger mass ratios to estimate intakes and it is likely that this worst-case method is sufficiently bounding to account for a small fraction of the higher specific activity Pu-238 in the mixture.

18. In Table 5-16, is there any explanation why Pb-210 and Po-210 activity concentrations in Silo 1 measured in 1993 are substantially less than would be expected based on the secular equilibrium concentrations that would be supported by the Ra-226 present? It is noted that this effect is much less marked in Silo 2.

There are a number of possible explanations for the less-than-equilibrium ratios, but the most likely one is that at some point during the ore processing much of the Pb-210 (21 year half-life) was separated from the Ra-226. Much (if not all) of the K-65 residue in Silo 1 came from Mallinckrodt's Destrehan facility, and some of the residues had been reprocessed in 1949 to extract additional uranium, which could have removed more lead. Silo 2 contained K-65 from Fernald beginning in 1952 and from Mallinckrodt in 1953 to 1956, when Mallinckrodt was no longer processing pitchblende. One would guess that there was less emphasis in "getting the lead out" by the time Silo 2 came into use (or perhaps there was more emphasis in controlling lead waste or releases to the environment). It is not clear how this would affect dose reconstruction, because it seems reasonable to use the measured ratios.

19. How can the Rn-222 concentration of 2.3 WL given on page 27 of Volume 5 be justified as claimant favorable when it is based on the higher of only two samples from a single radon sample data sheet?

Based on reviews of radon concentrations at sites that processed African as well as domestic ore and handled or stored its residues, such as Mallinckrodt and Linde Ceramics, the value of 2.3 WL appears favorable to the claimant. More information on radon at Fernald has become available and will be reviewed and incorporated into the site profile as necessary.

E. QUESTIONS RELATING TO EXTERNAL DOSE (VOL. 6)

1. Is NIOSH developing an external dose co-worker model? If so, what periods would this apply to and what data is being used?

No external dose "co-worker model" is currently under development.

2. Page 23 of the external dose volume mentions the use of co-worker data for missed doses? What criteria are being used to choose the co-workers for the missed doses?

The term "co-worker" as used in the TBD referred to someone who worked "side-by side" or did exactly the same job as the worker who either lost his dosimeter or whose dosimeter results were lost or was not monitored for some unknown reason for that exchange period. It was not intended to imply anything other than that.

3. Page 23 also mentions lost dosimeter results. What proportion of the data has been lost?

Dosimeter results have not been tabulated to estimate the proportion(s) of unavailable (because of dosimeter loss, record unavailability, etc.) results. The current sense is that the proportions are not likely to be large.

4. Has NIOSH compiled external dose data into a database? If so, could it be made accessible on the Advisory Board's section of the O Drive?

    Fernald external dose results were not compiled by ORAUT. To our knowledge the only databases that may be available are DOE's REMS database and ORAU's CEDR database. If the Board Members have filed the appropriate paperwork for viewing CEDR data, access could be made available via the O drive. Summary data from REMS are in the Site Research Database.

5. The TBD discusses adjustments to dosimeter readings. In regard to radioactive dust settling on the dosimeter, the TBD states that dosimeters were in plastic bags "at times" (p. 11, Vol. 6).[23] However, Volume 4 of the set of transition reports in the handover from NLO to Westinghouse discusses the application of adjustment factors to TLDs for a period between 1983 and October 1985. The use of this correction factor sometimes resulted in negative radiation dose estimates. The correction factors resulted in changes (according to the calculations shown in the datasheets) of 6% to 663%. In the examples given in the report, the largest magnitude correction of 1,652 millirem was applied to a dose of 1,291 millirem, resulting in a net negative estimated dose equal to -361 mrem.[24] The practice was used from 1983 (when TLDs were introduced) to October 1985, when its regular use was discontinued. However, it appears to have been continued in an *ad hoc* fashion after that date.[25] While doses with high percentage corrections (more than 50%, therefore including negative dose estimates) were not automatically entered into the dose record, it is unclear what exactly was done. The TBD does not discuss this problem, although it indicates some difficulties in the initial period of TLD testing due to a problem in the algorithm, notably for shallow dose (p. 12, Vol. 6). Has NIOSH investigated this problem and how the resultant doses might be interpreted? Since the TBD acknowledges that plastic bags were used only "at times," has NIOSH investigated the periods when this was not the practice? Were correction factors applied during such periods? Does NIOSH have documentation indicating the periods when dosimeters were in plastic bags? Section 6.5 on adjustments to dose does not discuss the use of the correction factors described above. How is NIOSH going to take them into account?

    The dose of record during the period in question, 1983–1985, was from the same film dosimeter in use from 1954–1985 and not from the bagged TLDs (see Table 6-12, pg.22). The TLD model in question was one under development and was not the dosimeter of record. The TLD model that was finally put into service in 1985 was the first to be DOELAP certified. As for correction factors, none were needed because plastic bags did not cover the dosimeter of record prior to the 1985 service date and no data was found that indicated the use of plastic bags after this date. However in discussions with ex-Fernald employees involved with the dosimetry program the use of plastic bags did occur and the same calibration practices prevailed.

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[23] "An additional radiological concern at several locations at FEMP occurred when workers were subjected to high levels of radioactive material-bearing dust. This widespread source of contamination was a concern for personal dosimeters, so at times the dosimeters were enclosed in plastic bags for protection against dust contamination. The manner in which these contaminated dosimeters were handled was not identified; however, this should not be an issue in dose reconstruction because the dosimeters were calibrated in plastic bags and no adjustments were made to the dosimeter results for either Hs(0.07) or Hp(10)." (TBD, Vol. 6, p. 11)

[24] Feed Materials Production Center, Final Phase-in Report, Vol. 4 of 15, Environment, Safety and Health, Westinghouse Company of Ohio, January 17, 1986. See Attachment 3 for the datasheets.

[25] Ibid. p. 15.

6. Vol. 6 of the TBD discusses correction factors for geometry. Has NIOSH taken adequate account of some jobs where the badge readings were unlikely to have any systematic relationship to the organ dose? One such job, stamping numbers on ingots, was photographed by Robert del Tredici in 1987. The photograph shows the worker sitting astride an ingot stamping an ID number on its flat face; it can be provided upon request. His film badge is dangling from his coverall pocket parallel to the face of the ingot. His body shields the radiation from behind. The use of wrist badges is evident. The angular response correction factors (Table 6-7) do not address this problem.

   The stated situation, while against all company rules, regulations and procedures, happened frequently. Instructions were given describing how dosimeters were to be worn so that they would measure the highest exposure to the body. The time spent in conducting this activity, e.g. stamping an ID number on an ingot, is a very small fraction of the individual's total working time and therefore of the individuals total exposure. Any individual claim involving a situation as depicted by the photo will be evaluated on a case-by-case basis. No generic correction factor is available or thought necessary for this particular situation.

7. On page 22 of Vol. 6, NIOSH states that "Corrections to the FEMP-reported dose are required, due to uncertainties in the recorded data and lack of significant data, especially prior to 1980." How much pre-1980 data is missing? What happened to the individual external dose records for the pre-1980 period that caused a significant amount of data to be missing?

   The "lack of significant data" referred to the information provided thereafter in the TBD regarding external dosimeter response-related details, and was not meant to imply that individual external dose records were missing. The corrections to pre-1985 data are due to the responses of the dosimeters and their inability to measure the contribution to the total dose from those photon radiations of less than several hundred keV and in particular the L-x-rays of both U and Th. The standard error for film dosimeters of this period and for these low energies is estimated to be+/- 30%, a value given in several TBD's, (Y-12, Hanford, IAAP). Since a portion of the total doses lie in these lower energy ranges, a correction is suggested in order to maintain a "favorable to claimants" position.

ATTACHMENT 3: SUMMARY OF THE CONFERENCE CALL OF AUGUST 18, 2006, ON THE FERNALD SITE PROFILE REGARDING SC&A QUESTIONS SENT TO NIOSH

For NIOSH and ORAUT: Mark Rolfes, Mel Chew, Cindy Bloom, Bryce Rich, Liz Brackett, Bob Morris, Elyse Thomas, Tom LaBone, Jack Fix, Karen Kent, Mutty Sharfi, Kenny Fleming

For SC&A: John Mauro, Harry Pettengill, Arjun Makhijani

These notes are a complement to the written answers provided by NIOSH to SC&A, which are reproduced in Attachment 2. Those answers are not repeated here, unless necessary to provide context for the notes of the discussion. The questions submitted by SC&A to NIOSH are shown in Attachment 1. Only those questions on which there was substantive discussion beyond the written replies provided by NIOSH are summarized here. NIOSH written responses reproduced here from Attachment 2 are indented and italicized. Furthermore, a full list of NIOSH actions to revise the TBD has been extracted from the Attachments in this review and provided in the text of the review in Section 5.0. The conversational style is retained to provide a flavor of the nature of the technical exchanges. This summary is not verbatim.

A. GENERAL QUESTIONS AND QUESTIONS RELATING TO VOLUMES 1 AND 2 OF THE TBD

1. Could NIOSH provide SC&A with the notes of its interviews with site experts?

> *The Site Profile development team only interviewed four former Fernald workers. Unfortunately, there were no comments from interviewees that related directly to issues or assumptions in the TBDs, so documentation of these interviews was not retained.*

SC&A: Are there any e-mail exchanges of the interviews?

ORAUT/NIOSH: There were e-mails, but the interviews were casual in nature. They focused on thorium. They were done in the context of preparation of the Dolan report (1988). We do not have any thing more than the reference to the interviews in the Dolan report, nor do we know if those interviews were documented.

SC&A: Did the interviews play a role in the thorium section, and if so, could NIOSH ask Dolan whether the documentation is available?

ORAUT/NIOSH: Yes, the interviews did play a role. Much more documentation is becoming available on thorium. When we did the TBD, information on thorium was limited, but we have received and are expecting more thorium information, which will be considered and incorporated in a revision of the TBD.

SC&A: Are you revising the TBD, and what is the schedule – is it within the next 30 days?

ORAUT/NIOSH: We are going through the bi-annual TBD review and revising it. We are behind schedule. We are not going to publish the revised TBD in the next month. We could respond to your TBD review as part of the revision.

SC&A: Are the new documents, especially regarding thorium, on the O Drive?

ORAUT/NIOSH: We are placing the documents on the Site Research database. Reference numbers will be sequential, so you can find the latest documents easily.

ORAUT/NIOSH action: Place thorium documents on the Site Research database as they become available. NIOSH will also prepare a brief summary of where ORAUT/NIOSH is in the TBD revision process as soon as possible, so it can be reflected in the SC&A TBD review. SC&A will make a list of the major revisions that are now planned or being produced.

2. How many workers were there at Fernald?

ORAUT/NIOSH: The TBD reflects at specified times the size of the workforce and SC&A was considering the total number of workers over time. Both are smaller than at some large DOE sites, hence the use of the term "relatively small."

SC&A: Yes, that seems right; we agree.

3. Regarding cumulative production.

SC&A: The production numbers in the TBD seem low. There are shipment and receipt data that indicate production of uranium (all types) of around half a million metric tons.

ORAUT/NIOSH research was centered on some material balance reports and the recycle uranium work. The mass balance mainly for RU is in OTIB-53 in final review.

SC&A action: Arjun will send data and/or references to Mark Rolfes.

4. Are the uranium ore processing flowsheets similar to that developed by NIOSH for Mallinckrodt showing the various stages of filtering and concentrations of Ra-226, Th-230, Pa-231 and Ac-227?

ORAUT/NIOSH: The Fernald flow sheet was similar to Mallinckrodt, but would have incorporated better designs. There were some differences. There is a text that talks about the differences.

ORAUT/NIOSH action: Look at flowsheet for Fernald and compare to Mallinckrodt. At Fernald, the waste that went into Silo 2 is the main concern, since that was the waste from processing of relatively high-grade ores at Fernald. The first step would be to create the Fernald flowsheet and try to benchmark that with MCW.

5. Would the ratios of radionuclides in the K-65 Silo 1 or Silo 2 be applicable to specific waste streams, or do they represent mixtures of actual waste streams that were all discharged into the silos? The question relates only to Fernald waste streams and not the Mallinckrodt materials in the silos.

ORAUT/NIOSH: Comprehensive radionuclide-specific analyses for Silo 2, like those reported in the 1990s, have not been located at this time.

6. What is the scientific justification for using the ratio of Th-232 to U atmospheric emissions to determine in-plant thorium contamination?

ORAUT/NIOSH: Those ratios are not being used in dose reconstruction. The internal dosimetry part of the TBD specifies how thorium doses are estimated. The uranium-to-thorium ratio was used as a sanity check. The TBD is being revised to reflect the extensive data on thorium that is becoming available, including more results from thorium air samples and thorium lung count data.

SC&A: The assumptions in the Site Description are not the same as those in the environmental and internal dose sections of the TBD. This is confusing.

ORAUT/NIOSH: Vol. 2 was developed early on. It will be made consistent with Volumes 4 and 5, the environmental and internal dose sections.

SC&A: This would be useful and clear up this confusion by making the needed changes.

B. QUESTIONS RELATING TO MEDICAL DOSE (VOL. 3)

1. This question was about records of telephone communications as the basis for which the possible use of a PFG unit at Fernald was ruled out.

> *No other information regarding telephone conversations beyond that included in the TBD is available.*

SC&A: Are we to take the response to mean that no record of these conversations is available? Specifically, we are looking for documented information as to why the use of a PFG unit is ruled out. The only person who worked in the period of interest and who was interviewed was Nurse Smith, so validating that conversation is central to this issue. Relying on people who joined in the 1980s may not be viewed as reliable for determining whether there were PFG units in use in the 1950s.

ORAUT/NIOSH: There are no formal records of those conversations. They were just documented in the TBD and that is all there is.

SC&A: Who helped determine and therefore rule out PFG use as concluded in the TBD?

Mel Chew: I helped with this. I don't remember the specific conversation about the PFG unit. It came up, but I just don't recall it.

SC&A: If you look at the [NIOSH] guidelines, especially OTIB-0006, there is an appreciation of the need to consider the use of PFG units as a fast and efficient screening tool for the high employee volume being hired at new DOE facilities built during the 1940s and 1950s. PFG was in common use at most DOE facilities in the 1950s, so you should not default to x-rays as opposed to PFG units without validation.

SC&A: In my review of the TBD medical section, I don't recollect any discussion of film size. If you find smaller than 14" by 17" film, that is usually a dead giveaway that there was use of a PFG unit. I don't recall that there was anything stated about the size of the x-ray film in the TBD.

SC&A: Also of concern is whether there is any indication that x-rays of employees may have been taken offsite or outside the Fernald medical clinic.

ORAUT/NIOSH: We have no reason to think that that was the case. How would we look at that?

SC&A: If you look a number of x-ray films, you can see if you have different levels of definition (contrast, etc.), film sizes, and such. Specifically, any PFG film will be smaller in size. So you can infer whether they were made in one location or more, and whether a PFG unit was used.

NIOSH/ORAUT action: Elyse will go to the Fernald records center, look at the some of archived records, including films, and try to resolve some of these questions.

SC&A: If there are the actual films to review and not just the medical interpretation, it will be easy to check if PFG was used.

2. Were data for Bennett unit calculated or measured?

ORAUT/NIOSH: The data were calculated. There were also data from Hanford. The calculated values were higher than the measured Hanford values, so this appears to be claimant favorable.

SC&A: We suspected that early survey information [Tables 3-10 and 3-14] was calculated. In our records search, we were unable to find an actual survey attributable to the Bennett unit. I understand that has been done. How about the Keleket unit? Have you looked at that again? They assumed a half-value layer of 2.5 mm of Al.

ORAUT/NIOSH: We're not yet ready to answer the question about the Keleket unit. Can you clarify the question you want answered?

SC&A: The TBD states that the Keleket unit was surveyed in 1961 and the results of that survey help to validate the dose calculations for that unit. Our review shows the purpose of the survey was to establish whether unwarranted external doses resulted from workers inadvertently wearing their dosimeter during annual x-ray exams. There were problems also with the unit not operating in the full diagnostic range and the use of 2.5 mm of Al as added filtration, which appears to be assumed rather than measured. Can NIOSH demonstrate with actual survey data that the HVL of Keleket was empirically measured and output was later measured in the full diagnostic range of the unit?

Follow-up post-discussion question from Harry for NIOSH: "Can NIOSH provide SC&A with a copy of the actual Bennett unit survey that clearly identifies the date and unit number?"

3. Did NIOSH examine other explanations for the black line at the bottom of the radiographs, other than assuming that collimation was always used at Fernald from the earliest days?

SC&A: This assumption is not defensible without an actual examination of the film by a technician to determine the reason for the black line at the bottom of the film. Such a single line at the bottom of the film alone is unlikely to be due to collimation.

ORAUT/NIOSH action: NIOSH will review this issue again, and look at the actual films in the record center during a forthcoming visit and will report back to SC&A its findings.

Supplementary post-discussion question from Harry for NIOSH: NIOSH, in Section 3.1.4 of the TBD, concludes that from 1952–1980, collimations were always utilized. Can NIOSH show by actual documentation that the Keleket and Bennett units had collimators installed, and do any studies exist to show they were routinely checked for alignment error or leakage of the collimators?

4. Are doses from x-rays taken after workplace accidents going to be included in dose reconstructions?

> *In accordance with 42 CFR 81 and 82, only medical exposures that were performed for medical screening and required as a condition of employment are included in the occupational medical dose. Diagnostic and therapeutic procedures not required for medical screening are not included." X-rays taken after workplace accidents are diagnostic and so are not included in dose reconstruction.*

SC&A: The rationale for this question was not so much intended to cover whether a person was rolled in for x-ray because he had a workplace injury. Perhaps a clarification is in order. The question should state: Were some of the prescribed and often repetitive screening x-rays, which occurred outside the routine physical exam schedule also considered as a "condition of employment?" So far it has not been stated in the TBD that they were.

ORAUT/NIOSH: Pelvic and lumbar spine exams were also required [in the DOE complex] and those would be covered. They were typically given on an annual basis or more often for periods in the 1940s and in the 1950s. However, we asked about these x-rays for Fernald and were told that they did not do them there.

SC&A: My understanding is this resulted from a conversation you had with a manager in 2003. So the question remains whether there is documentation to establish whether screening exams of all types were included if they occurred. Is there a basis for knowing what happened in the 1950s?

Elyse: Usually what we tried to do was to determine whether x-rays were screening or not, whether they were performed on a large number of people who were asymptomatic, or, for instance, for tuberculosis screening. The clue usually is in the data submitted by the DOE site. If you see an exam just on a few people, then it is likely that this was not a screening. But if there were a large number of lumbar spines, for instance, then there is a good chance that was a screening method. Sometimes we have the [x-ray] records, but not the protocol for taking the x-rays. For Fernald, we may have seen lumbar spines in just one of the claimant files. But I am not sure of that right now. For an individual dose reconstruction, they count up the number of x-rays in the file and decide whether the file is complete. If it seems that there were routine annual x-rays, then they assign that, even if records for some years are missing. We usually have a list of x-rays taken for the individual employee. Some sites use forms that make it clear if an exam was for screening. But at most sites, at least in the early years, this was not clear.

SC&A: Was there a numerical criterion for how many people had to be x-rayed before one would conclude that it was screening that would be considered as a condition of employment?

ORAUT/NOISH: No. You get a feel for it as you go through the claimant cases; there is no hard and fast rule.

SC&A: Fernald was a uranium metal foundry from its earliest days. So it seems reasonable that it would have been important to establish whether new workers had a pre-existing back injury. Can NIOSH further validate that routine screening exams for respirator users, asbestosis workers, food handlers, etc., were included in medical dose estimates, even when they occurred at different times than when routine physical exams occurred?

ORAUT/NIOSH action: Elyse will look for evidence of lumbar spine x-rays and other screening exams that might have been a requirement for employment, and if it appears that these exams were performed at Fernald, she will look for the period of applicability. She will also look for information to address the Fernald PFG issue.

5. The TBD states that a review of claimant files showed that 15% of the claimants reported that retakes occurred. Could NIOSH provide SC&A with the data compilation used to determine the retake rate?

   No other information regarding X-ray retake rate, beyond that included in the TBD, is available.

SC&A: But what is the 15% rate based on? Was it a default value?

ORAUT/NIOSH: As best as I recall, it came from Ron Kathren, and was taken from OTIB–0006. We don't know whether it was a default value. If it was, then we will correct the language and say so.

SC&A: Retakes happen if the technicians decide they have a poor picture, or they may be ordered by the doctor to do it again, if he wants more detailed information. One is a retake and the other is really a new exam. Actual retakes hardly ever end up in the medical record. As such, it is very hard to estimate retakes unless you do a facility-specific study. Overall, an assumed 15% retake rate for Fernald—given the equipment and timeframe—might be borderline or low.

ORAUT/NIOSH: A 30% uncertainty is applied to the organ dose. It is from OTIB-0006 and presumably includes consideration of retakes.

SC&A: The 30% uncertainty does not have to do with retakes and does not include them, as the 30% uncertainty only covers systematic or measurement error. The retake rates would vary a lot. The reason it stood out to us was that the TBD indicated the 15% came from a "review of claimant files."

ORAUT/NIOSH action: Is it a Fernald statement or a generic statement? Clarify where the assumption of a 15% retake rate comes from.

C. QUESTIONS RELATING TO ENVIRONMENTAL DOSE (VOL. 4)

1. Why did the TBD use the source term developed by Fernald and not by the Radiological Assessments Corporation by the CDC, which is much higher (about 310,000 kg compared to about 175,000 kg used by NIOSH)?

   The original revision of the Fernald Occupational Environmental Dosimetry Technical Basis Document (OEDTBD) used the Boback data to estimate exposure to site releases because it was believed that its use would be sufficiently conservative and the resulting exposures would represent exposure estimates that would be favorable to the claimant. Use of the release data compiled by RAC (1995) would simply add to the existing conservative estimate.

SC&A: The RAC source term is not a conservative one; it is their median estimate. The Fernald 1987 and 1988 source terms were flawed, for instance, because they did not take into account that scrubber efficiencies in Plant 8 were very low sometimes; far below the lowest manufacturer-specified efficiency of 70%. CDC spent $6 million on the RAC study, whose source term is more scientifically sound than the Dolan and Hill source terms.

ORAUT/NIOSH: We felt that the values documented in the Boback report were conservative and claimant favorable. We can change it. It would be claimant favorable to use a higher RAC number.

SC&A: The use of RAC is not about what is claimant favorable. We believe that the RAC source term is much more technically defensible, and it specifies uncertainties. Note that the 5th percentile value of the RAC source term is about the same as the upper bound of the Westinghouse source term. So there are non-trivial differences here.

ORAUT/NIOSH action: NIOSH will look at this issue again.

2. Why did the TBD use the Th source term from Boback 1987 and the 1988 supplement, rather than the RAC 1995 source term?

   See response to C.1 above.

SC&A: This question was in error. The RAC study does not have a thorium source term.

ORAUT/NIOSH: The RAC Report indicates in Table L-13 relative concentrations of Th to U based upon liquid waste discharges. The Boback report also provides airborne Th release data. Both information sources will be assessed, and the TBD revised as necessary.

3. Table 4-4 on thorium emissions may not be conservative as stated in the TBD, for instance, due to low scrubber efficiency.

   The RAC 1995 document provides a description of the scrubber efficiencies at both Plants 2/3 and 8 that differs from the Dolan and Hill (1988) assumptions. Updates to the TBD are warranted based on the differences in the efficiency estimates.

ORAUT/NIOSH action: Both the RAC and Boback Reports provide information sources concerning airborne thorium emissions that will be assessed and the TBD revised as necessary.

4. According to a tabulation by NLO, a significant fraction of the U releases from Fernald were of an episodic or accidental nature, influencing the environmental doses. How is NIOSH going to account for episodic releases in estimating environmental internal dose for individual dose reconstructions?

   Episodic (and operational) stack releases are included as annual integrated emissions within the tables in the TBD. Over extended periods of time, these integrated emissions provide means of estimating internal exposures for individuals who were not monitored and who would not have required monitoring because of their low potential for exposure during their employment. In accordance with program guidance given in ORAUT-PROC-0031, the derived maximum site-wide annual median intakes via inhalation and ingestion will be used to estimate doses for these unmonitored individuals when other dose-estimating information is not available.

SC&A: There are really three issues in regard to estimating internal environmental doses that could affect the use of the annual average Gaussian plume model; episodic releases, ground level vs. elevated releases, and building wake effects. The NIOSH approach is claimant favorable for using stability Class F, but it is not for the other assumptions. For example, the building wake problem is important onsite for the radon emissions from the silos.

ORAUT/NIOSH: We did not have a lot of data when the TBD was prepared, so this was one of the approaches to use. If there were a large number of episodic releases, then they can be treated in an annual average release model.

SC&A: We agree with that. NIOSH has drawn upon the work of RAC, which was for offsite dose estimation for onsite purposes. This is not appropriate. This is a problem we have found across the board.

ORAUT: Are you suggesting another model?

SC&A: You used puff advection at Hanford. There should be some guideline as to when an annual average Gaussian approach can be used and when the more complex approaches should be used. If releases are frequent and random, then you can use annual average, but for large releases every few months, you want to use puff advection. It could make a lot of difference in that case.

(This discussion also covers questions 9, 11, 12, and 15, which are omitted from this summary.)

SC&A action item: SC&A will communicate some preliminary work to NIOSH, and at the same time, finish its site profile review.

5. How were fugitive U and Th emissions calculated?

> *For fugitive emissions, EPA guidelines were used to calculate emissions from the waste storage and production areas. Reference: Method for Estimating Fugitive Particulate Emissions from Hazardous Waste Sites. U. S. Environmental Protection Agency, Cincinnati, Ohio, August 1987. EP/600/2-87/066 PB87-232203.*

SC&A: This generic estimate does not seem appropriate. There are Fernald data from the 1950s or earlier where fugitive emissions were estimated. The fugitive emissions from some practices appear to have been substantial. For example, there were leaks in outdoor equipment, dust escaping from doors and windows opened during blowouts, and dust being blown about from keeping thorium trays in doorways. These data should be used. Also the EPA equations give very low values for dust loadings compared to empirical values for dust loadings. The EPA approach gives 1 to 2 micrograms per cubic meter; empirical data show that this is low by 2 or 3 orders of magnitude.

Mel Chew: We should review this as a generic approach. This was an early approach, and it should be reviewed generically. Is that what you are asking?

SC&A: SC&A will look at the dust loading, but it may not be the most important environmental source term. The other items we've mentioned above may be more important.

SC&A action: Arjun will try to dig up documents on fugitive emissions and send them to NIOSH for use in revising the site profile.

7. In developing the radionuclide-to-U ratios, the TBD used average observed values. Has NIOSH considered using the 95th percent confidence level of the mean, as opposed to the true mean, as a more claimant-favorable strategy?

ORAUT/NIOSH: Remember that environmental doses are for unmonitored workers. For other workers, the approach is specified in Vol. 5 of the TBD. Coverage of Fernald workers in terms of monitoring for both external and internal dose was quite thorough. NIOSH experience with claims shows that this was the case.

10. For the purpose of deriving the Rn and Rn progeny releases from the silos, the TBD used the median values derived in the RAC 1995 report. Wouldn't this approach be considered claimant-neutral, as opposed to claimant-favorable?

Best estimates (neither giving favor to the claimant, but not denying the benefit of doubt) are the preferred method of dose reconstruction. Regarding releases of Rn and associated progeny, a recent University of Cincinnati study has become available and the values in the TBD will be reconsidered in light of the new information.

ORAUT/NIOSH: Again, the environmental dose TBD is for unmonitored workers. A separate protocol is used for monitored workers, as specified in Vol. 5. For these workers, the dose assignment is higher. We are re-evaluating all this in light of new information. Specifically, NIOSH has new information from the University of Cincinnati.

14. How about resuspension of Pb-210 that has built up in the soil from deposition?

ORAUT/NIOSH: This will be minor, since lead-210 has a long half-life relative to radon. The radon blows offsite to a large extent, and most of the lead-210 build-up will be there. Also, the lead-210 component of resuspension dose would be much smaller than the other components like uranium, due to high environmental releases.

SC&A: But there is a disequilibrium for lead-210 in the silos, indicating that there is a deficit, which must be somewhere.

ORAUT/NIOSH: We don't expect to see lead-210 in equilibrium, because the K-65 residues were reprocessed at Mallinckrodt in 1949 before being shipped to Fernald. The lead-210 may have been stripped at Mallinckrodt in the barium sulfate process.

SC&A: In that case, it would be perhaps two half-lives of lead-210, and that may be part of the explanation for the Silo 1 measurements.

SC&A action: SC&A will do a sample calculation of Pb-210 deposition to estimate build-up and see if this is an issue.

17. What about the validity of the inverse square law for external radiation for areal sources?

For most locations the distances compared to the source sizes are sufficiently large that a point source methodology is reasonable. For the few sources that might not be best approximated as point sources (e.g., the pits), the results are sufficiently close to actual measured results using these equations that the method appears reasonable.

SC&A: What measurements were used?

ORAUT/NIOSH: The external dose values were from aerial survey data.

SC&A: This appears appropriate.

18. For pre-1976 period, there are no external dose environmental data. Why did NIOSH use production rather than emissions as the key variable for estimates?

SC&A: The external dose factors are not mainly production-dependent, since we know that emissions per unit of production emissions were bigger in the 1950s than later on. Hence, production should not be used to back-extrapolate any dose parameter.

ORAUT/NIOSH: This is unmonitored for workers.

SC&A: Why not scale it according to emissions? SC&A indicated they will revisit this issue and see if they still have a question.

20. How does NIOSH propose to reconstruct doses for the K-65 workers involved in handling Mallinckrodt K-65 residues, including the unloading of these residues and their loading into Silo 1?

ORAUT/NIOSH: This is really an internal dose issue and is addressed in Section 5.2.4 of the Internal Dose TBD, which includes information for allocating intakes from associate radionuclides. This question is not an environmental dose issue.

D. QUESTIONS RELATING TO INTERNAL DOSE (VOL. 5)

1. What is the reference for the decontamination factor of 50 used for some Th-232 production activities?

A review of this TBD resulted in no locating of a decontamination factor of 50 in the document. Please clarify this question.

SC&A: There are many references to such a decontamination factor in Vol. 2, for instance in the footnotes to Tables 2-1a, 2-2a, 2-3a, etc.—about 10 instances in all.

ORAUT/NIOSH: This is actually a respirator protection factor used in Vol. 2 and is not being used in dose reconstruction. We will fix Vol. 2, so it is compatible with Vol. 5. Fernald was an early TBD and needs revision. This also clears up question 2 in this section.

2. Vol. 2 and Vol. 5 are not consistent in regard to respirator decontamination factors. Explain.

See answer to question 1 in this section. Assuming no respirator was used takes care of question 3 as well.

7. Is NIOSH developing an internal dose co-worker model? If so, what periods would this apply to, and what data are being used?

   So far, there has not been a need to develop a FEMP coworker model for internal dose.

ORAUT/NIOSH: The reason that a co-worker model is not needed is that essentially everyone was monitored.

8. Has NIOSH compiled internal dose data into a database?

   At this point a NIOSH internal dose database is not available. There is a CEDR database, and if the Board Members have filed the appropriate paperwork for viewing CEDR data, access could be made available via the O drive).

ORAUT/NIOSH: At the time of TBD, the data was in two archives. Now data are available. Bioassay data are the primary data, and there is really no need to go back and do this, since everyone essentially was monitored.

9. How will internal doses before 1953 be calculated, given that there might be no bioassay data?

ORAUT/NIOSH: Don't know how many claims include only exposures in late 1951 through 1952, but for claims that include later bioassay, chronic intakes can start on the day of employment. There are also some 1952 bioassay records.

10. How will pre-1990 thorium doses be estimated? And how about radium-224?

ORAUT/NIOSH: Ra-224 dose is small relative to the other radionuclides.

SC&A: We agree regarding Ra-224. But the TBD is not on the mark regarding thorium. The suggested method would be an underestimate, at least for the early years. Also, processing was done in more plants than indicated in the TBD.

ORAUT/NIOSH: We are getting more information. We have been able to get lung counting data for thorium. There are thorium chest counts from the late 1960s and early 1970s. The data are being developed, but they do not have them at this point; the DOE has them. Thorium chest counts were done on everyone who had uranium counts. They reported only thorium-232 and thorium-228. [Thorium-230 was not included.] The current default assumption typically results in a determination that a chest count would be positive, but the claims processed to date indicate that the default assumption typically results in an overestimate of intake. There is a box of records for everyone who was monitored at Fernald.

SC&A: How do you know if the people who worked on thorium in the 1950s and 1960s were monitored? You have to be careful to back-extrapolate both, because it may not be the same people who were exposed. We did not see that maximum air concentration data were cited or used in the TBD. Rather, there is the 1050-MAC recommendation for thorium intake that seems rather arbitrary.

ORAUT/NIOSH: We believe it is claimant favorable, but we are re-evaluating the thorium exposures. Thorium records will continue to be added to the Site Research database as they become available.

11. What is NIOSH doing to ensure that all periods and plants where thorium was processed are covered, since much of the thorium data is lost and many documents have apparently been destroyed (Vol. 5, p. 18)?

SC&A: There are data showing it was processed in Plant 6, for instance.

ORAUT/NIOSH: We are looking at where it was processed again.

12. Question about thorium resuspension doses to uranium workers during thorium production and after it.

    The question of addressing possible residual thorium contamination from discontinued thorium operations is under consideration.

SC&A: How about thorium exposure in the 1980s?

ORAUT/NIOSH: We are looking at residual contamination in general. This is a program-level issue, for which we are trying to develop generic approaches for these estimates. There may also be data available to address this.

SC&A: Since the residual contamination was a mixture of uranium and thorium contamination, the model suggested for Bethlehem Steel may be useful.

SC&A action: Arjun will send Bethlehem Steel reference to Mark Rolfes for Cindy.

13. Could NIOSH provide the records that have been recovered in relation to thorium described at the bottom of page 21, Vol. 5?

    The thorium air sampling records that have been recovered can be found in the SRDB and can be provided.

ORAUT/NIOSH: NIOSH is uploading newly found documents as they go along.

15. On page 22, NIOSH states that it is using BZ samples from lapel samplers to conservatively estimate thorium exposures. How is NIOSH taking into account the Y-12 study indicating that this is not a reliable way to make intake estimates, and that BZ-estimated intakes could be significant underestimates when compared with bioassay estimated intakes?

    The TBD statement on page 22 describes the current (modern) methods of controlling and assigning internal intakes – conservatively. If the questioner's Y-12 reference is the Y-12 Uranium Exposure Study (Eckerman and Kerr 1999 [Ref ID 11600]), it is clear that the intake estimation method proposed in the TBD is reasonable; in the Y-12 study the ratios of air concentration to bioassay derived intakes range from 0.11 to 1.38 with an average of 0.49 in Table 11 of the Y-12 study, indicating that if bioassay is the gold standard, Y-12 intakes derived from bioassay [sic, the original response is miswritten and the word "bioassay" should be replaced with "air concentration."] might be low in some cases by up to a factor of 9. However, the intakes in the Y-12 study were reduced to account for respiratory protection factors ranging from 1 (no respirator) to 50, but typically in the 25 to 50 range. For FEMP claims there is no proposal to apply a respiratory protection factor to the FEMP BZA derived intakes. In addition, currently the more claimant favorable missed intakes from bioassay rather than air concentration derived intakes have been used to estimate FEMP doses. Assigning intakes based upon breathing zone air sampling data collected in current day programs with appropriate collection and measurement techniques is recognized as a reasonable way to estimate intakes.

SC&A: The Eckerman and Kerr study indicates the reverse. Air concentration-derived intakes were lower by up to a factor of 9.

ORAUT/NIOSH: That is because a respiratory protection factor for inhalation intakes was used. Without that, the air intakes are higher.

SC&A action: Revisit the Eckerman and Kerr study.

ORAUT/NIOSH: Post-discussion, it was noted that the ORAUT response erroneously referred to bioassay when air concentration was meant. A correction has now been added in square brackets within the response.

16. Since enrichments of uranium-235 up to 20% were processed at Fernald, how does NIOSH justify the use of 2% enrichment as the default value after 1964?

    The amount of U of enrichments above 2% at FEMP was trivial (a few 55 gal drums compared to MTU). Also the exposures to these enrichments were less due to increased value, small amounts, need for additional criticality controls, etc.

SC&A: Some quantitative justification of "trivial" would be useful. It would provide some assurance that this is not a problem assumption for some workers. It would be desirable to document and give some quantitative expression to the term "trivial." We are surprised that there is not a careful materials account for uranium enriched to more than 2%, given that other sites seem to track even natural thorium down to kilogram quantities.

ORAUT/NIOSH: We are sure that it was small. It was not a requirement to do materials accounts for uranium enriched to less than 20%. Other sites did materials accounts for lower enrichments and thorium for their own purposes. It was not headquarters telling them to do it.

18. In Table 5-16, is there any explanation why Pb-210 and Po-210 activity concentrations in Silo 1 measured in 1993 are substantially less than would be expected based on the secular equilibrium concentrations that would be supported by the Ra-226 present? It is noted that this effect is much less marked in Silo 2.

    There are a number of possible explanations for the less-than-equilibrium ratios, but the most likely one is that at some point during the ore processing much of the Pb-210 (21 year half-life) was separated from the Ra-226. Much (if not all) of the K-65 residue in Silo 1 came from Mallinckrodt's Destrehan facility, and some of the residues had been reprocessed in 1949 to extract additional uranium, which could have removed more lead. Silo 2 contained K-65 from Fernald beginning in 1952 and from Mallinckrodt in 1953 to 1956, when Mallinckrodt was no longer processing pitchblende. One would guess that there was less emphasis in "getting the lead out" by the time Silo 2 came into use (or perhaps there was more emphasis in controlling lead waste or releases to the environment). It is not clear how this would affect dose reconstruction, because it seems reasonable to use the measured ratios.

NIOSH provided SC&A with a reference where measurements of radon in the head space of the K-65 silos are published. Waste management proceedings WM-4383, Eger, Jacob Engineering, Langner, Grand Junction Field office.

If there is good agreement between head space concentration of radon as estimated by RAC and Langner measurements in the Fernald head space, that would settle this issue.

SC&A action: Check this publication to see if there an issue here (in terms of a discrepancy between measured and calculated radon concentrations).

19. Rn-222 intake assumption of 2.3 WL is the higher of only two samples from a single radon sample data sheet.

ORAUT/NIOSH: Data from other sites show 2.3 WL is claimant favorable. And there are more data available now that are being analyzed.

SC&A: A comparative table for Fernald compared to other sites would be useful.

E. QUESTIONS RELATING TO EXTERNAL DOSE (VOL. 6)

3. Page 23 also mentions lost dosimeter results. What proportion of the data has been lost?

   Dosimeter results have not been tabulated to estimate the proportion(s) of unavailable (because of dosimeter loss, record unavailability, etc.) results. The current sense is that the proportions are not likely to be large.

SC&A: Is there some notion of what "not likely to be large" means?

NIOSH: The individual dose records are pretty complete. The missing or lost data would be well under 5% based on experience. There is no real gap here.

4. Has NIOSH compiled external dose data into a database? If so, could it be made accessible on the Advisory Board's section of the O Drive?

ORAUT/NIOSH: No action is planned. NIOSH will confirm with the Board.

5. The TBD discusses adjustments to dosimeter readings. In regard to radioactive dust settling on the dosimeter, the TBD states that dosimeters were in plastic bags "at times" (p. 11, Vol. 6).[26] However, Volume 4 of the set of transition reports in the handover from NLO to Westinghouse discusses the application of adjustment factors to TLDs for a period between 1983 and October 1985. The use of this correction factor sometimes resulted in negative radiation dose estimates. The correction factors resulted in changes (according to the calculations shown in the datasheets) of 6% to 663%. In the examples given in the report, the largest magnitude correction of 1,652 millirem was applied to a dose of 1,291 millirem, resulting in a net negative estimated dose equal to -361 mrem.[27] The practice was used from 1983 (when TLDs were introduced) to October 1985, when its regular use was discontinued. However, it appears to have been continued in an ad hoc fashion after that date.[28] While doses with high percentage corrections (more than 50%, therefore including negative dose estimates) were not automatically entered into the dose record, it is unclear what exactly was done. The TBD does not discuss this problem, although it indicates some difficulties in the initial period of TLD testing due to a problem in the algorithm, notably for shallow dose (p. 12, Vol. 6). Has NIOSH investigated this problem and how the resultant doses might be interpreted? Since the TBD acknowledges that plastic bags were used only "at times," has NIOSH investigated the periods when this was not the practice? Were correction factors applied during such periods? Does NIOSH have documentation indicating the periods when

[26] "An additional radiological concern at several locations at FEMP occurred when workers were subjected to high levels of radioactive material-bearing dust. This widespread source of contamination was a concern for personal dosimeters, so at times the dosimeters were enclosed in plastic bags for protection against dust contamination. The manner in which these contaminated dosimeters were handled was not identified; however, this should not be an issue in dose reconstruction because the dosimeters were calibrated in plastic bags and no adjustments were made to the dosimeter results for either Hs(0.07) or Hp(10)." (TBD, Vol. 6, p. 11)

[27] Feed Materials Production Center, Final Phase-in Report, Vol. 4 of 15, Environment, Safety and Health, Westinghouse Company of Ohio, January 17, 1986. See Attachment 3 for the datasheets.

[28] Ibid. p. 15.

dosimeters were in plastic bags? Section 6.5 on adjustments to dose does not discuss the use of the correction factors described above. How is NIOSH going to take them into account?

The dose of record during the period in question, 1983–1985, was from the same film dosimeter in use from 1954–1985 and not from the bagged TLDs (see Table 6-12, pg.22). The TLD model in question was one under development and was not the dosimeter of record. The TLD model that was finally put into service in 1985 was the first to be DOELAP certified. As for correction factors, none were needed because plastic bags did not cover the dosimeter of record prior to the 1985 service date and no data was found that indicated the use of plastic bags after this date. However in discussions with ex-Fernald employees involved with the dosimetry program the use of plastic bags did occur and the same calibration practices prevailed.

SC&A: We cannot accept this statement at face value. The datasheet reproduced in the Westinghouse transition report has badge numbers on it and implies that it is part of the workers' records. Some cross-walking of the data in the transition report with individual dose records is essential before it can be assumed that none of these calculated doses were in worker dose records.

SC&A action: Arjun will find Ref. 5 and send it to Mark, since it is not on the NIOSH database.

ORAUT/NIOSH action: ORAUT/NIOSH will review this issue.

6. Question of organ dose versus dose recorded on the badge due to location of the source relative to badge and organ. Example of a worker sitting on an ingot to stamp an ID number on it shown in a photograph taken by Robert del Tredici in 1987.

The stated situation, while against all company rules, regulations and procedures, happened frequently. Instructions were given describing how dosimeters were to be worn so that they would measure the highest exposure to the body. The time spent in conducting this activity, e.g., stamping an ID number on an ingot, is a very small fraction of the individual's total working time and therefore of the individual's total exposure. Any individual claim involving a situation as depicted by the photo will be evaluated on a case-by-case basis. No generic correction factor is available or thought necessary for this particular situation.

SC&A: Given the huge number of ingots made, it seems unlikely that it was a "very small fraction of the time." Furthermore, if you look at the fact that the badge is perpendicular to the floor and more or less to the source, the dose to the gonads is likely to be far greater than the recorded dose, even when some shielding is taken into account. Hence, even if the amount of time is small, the dose to the gonads is likely to be much greater than that recorded on the badge.

ORAUT/NIOSH: This issue may be addressed adequately in OCAS-TIB-013.

SC&A: A modeling of this problem using the ATTILA model that NIOSH used for Mallinckrodt would be useful and should be done for this job.

SC&A Action: Send the Mallinckrodt review reference to Mark.

ORAUT/NIOSH action: ORAUT/NIOSH will assess the geometry issue.

7. On page 22 of Vol. 6, NIOSH states that "Corrections to the FEMP-reported dose are required, due to uncertainties in the recorded data and lack of significant data, especially prior to 1980." How much pre-1980 data is missing? What happened to the individual external dose records for the pre-1980 period that caused a significant amount of data to be missing?

ORAUT/NIOSH: This is not about individual missing data, but about dosimeter response data, for which a correction is suggested.

SC&A: We seem to have misinterpreted the TBD statement as missing individual data.

ATTACHMENT 4: SITE EXPERT INTERVIEWS

Interviews were conducted with 48 former Fernald Environmental Management Project (FEMP), Department of Energy Ohio Field Office oversight personnel, and other individuals having knowledge of site operations. Years represented by those interviewed range from 1952-present. The interviews were conducted by Ed Sensintaffer and Kathryn Robertson-DeMers, members of the SC&A Fernald review team. The purpose of these interviews was to receive first-hand accounts of past radiological control and personnel monitoring practices at Fernald, and better understand how operations were conducted. Interviews were held in person from February 13–17, 2006. Interviewees were selected to represent a reasonable cross-section of production areas and job categories. Interviewees were originally obtained with the assistance of the DOE, the labor union, National Institute for Occupational Safety and Health (NIOSH) worker outreach meeting minutes, worker outreach groups and retiree organizations, and former health physics staff.

Workers were briefed on the purpose of the interviews and the FEMP Site Profile. They were asked to provide their names, in case there were follow-up questions. Participants were reminded that they would be provided the opportunity to review the interview summaries prior to inclusion into this report. Interviewees were told that there were aspects of operations that were classified and that this information could not be divulged. To ensure classified information has not been included in the interview notes, the notes were reviewed by a classification officer prior to release.

Former and current FEMP employees, and subcontractors interviewed worked in various operations throughout the site. Some of the facilities associated with their work included the Pilot Plant, Plant 2/3, Plant 4, Plant 5, Plant 7, Plant 8, Plant 9, the pit area, and the silos. Some individuals had access to all areas of the plant. The job categories represented included the following:

- Bioassay Laboratory Manager
- Carpenter
- Chemical Operator
- Construction Maintenance
- Construction Laborer
- Electrician
- Health and Safety Division Management
- Health Physicist
- Heavy Equipment Operator
- Inspector
- Laborer
- Laundry
- Machinist
- Millwright
- Pipefitter
- Production

- Radiation Monitor/Radiological Control Technician
- Radiological Engineer
- Security
- Shipping and Receiving
- Staff Engineer Environmental Monitoring
- Transportation
- Welder

The information the workers provided to SC&A has been invaluable in providing a working knowledge of the site operations and the safety program. All interviews have been documented and summarized below. This is not a verbatim discussion, but a summary of information from multiple interviews with many individuals. The information provided by the interviewees was based entirely on their personal experience with Fernald. It is recognized that site expert and former Fernald 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. FEMP site expert input is similarly reflected in our discussion. With the preceding qualifications in mind, this summary has contributed to our findings and observations.

General Information

The plant was divided into what was referred to as the Metal Area and the Chemical Area. The movement of the work force was dependent on the job responsibilities. There were individuals who worked throughout the site, as well as individuals who were assigned to a particular plant. At first, maintenance was assigned to cover a particular area. There was a maintenance pool located in Building 12. Eventually, maintenance personnel were used throughout the site. Transportation was deployed throughout the site. Chemical Operators tended to stay in an area, although they could bid on jobs in other areas to get reassigned to another plant. Operation-specific workers were more prone to stay in a single plant in the early years of operations.

Females were not originally allowed to work in the production areas, because Fernald did not have a fertile-female policy. In 1978 or 1979, a woman started work with the Transportation Department. In 1984, another woman went to work in waste treatment. The number of women in production areas increased through the 1980s. When a woman became aware of being pregnant, she advised Medical and was then sent to work on the "clean site."

Workers from Fernald were sent to other sites on occasion. For example, a contingent of six Fernald workers was sent to the Niagara Falls site to retrieve thorium. The thorium drums were not suitable for shipment, so the material had to be repacked (about 150–200 drums of material). Workers involved noticed differences between the RadCon program at FEMP and that at Niagara Falls, with Niagara Falls having the safer program. In addition, Fernald workers were sent to an area near the South Carolina and Georgia border to drum thorium packed material and ship it to Fernald. Two groups of six workers were sent to the area for about 3 weeks. There was a collaborative effort between Reactive Metals, Inc. (RMI), in Ashtabula, Ohio, and Fernald for a period of time. RMI extruded uranium metal billets for Fernald. Security personnel were sent to other DOE sites for training.

There was an abundant amount of overtime for employees that wished to work it. It was determined in accordance with company policy of the time. When an individual accepted overtime, he was required to work an additional 8 hours. Overtime was not broken into increments smaller than 8 hours for the hourly workers. During Uranyl Nitrate Hexahydrate (UNH) operations, work continued 12 hours per day during the week and 8 hours per day on Saturday and Sunday. The guidelines adopted by the union in the mid-1980s allowed an individual to work 2 shifts back to back and up to 84 hours in a week. The company violated this guideline at times. Prior to the 1980s, average overtime ranged from 15–25 hours per week. There was a slowdown in overtime during the 1980s; however, it picked up again during the cleanup, especially at the silos project. The salaried workers interviewed did not report working much overtime.

Operations personnel were under pressure to meet specific quotas. For example, site experts indicated that in the production area, they were required to make 100 derbies per shift. Once an individual met his quota, the individual could work at a more relaxed pace.

Security

National Lead Company of Ohio, Inc. (NLO), maintained tight security control during the production years. When NLO ran Fernald, Security worked under the prime contractor in support of the Atomic Energy Commission and later the Department of Energy. During the production years at Fernald, Security had a great deal of authority. In general, the rule was "Don't Ask" related to processes and types of radioactive material, especially during the years of tight security.

When Fernald first started, there was a fence around each of the individual plants. Employees were required to have authorization to enter a particular plant. In 1961, there was a fence added and the area around the laboratory building became a controlled area. Access was allowed only to those individuals with a need to know. This was about the same time Fernald started to receive recycled uranium. Entrance could only be gained through a manned gate guarded by Security between the Pilot Plant and the Laboratory. The Chemical Warehouse and all production buildings had a 2-person rule. This stopped being enforced during the accelerated cleanup.

There were walking tours within the security fences, and driving tours of the perimeter. The guard would go to the guardhouse and pick up the clock key. For the east clock run, they were required to visit the garage (warehouse), Plant 4, Plant 6, Plant 9, the warehouse near Plant 9, the maintenance building, the service building, and finally the Administrative Building. Many of the plants had multiple Detex clocks that had to be punched. The west clock run covered the remainder of the Fernald site. During these tours, they were looking for evidence of access to unauthorized areas. Dust deposited on their uniforms as they completed their tours. Guards spent up to 5 days in the production areas per week. The off-shift worked the production area.

Security personnel were responsible for providing escorts for visitors and construction employees. The escortee had to be within sight of the Security Guard at all times. As an escort, they could go to any of the areas onsite. At times, escorting would be their only assignment for a week. When the plant first started, there was a requirement for two guards to escort personnel.

There were times during escorting when there were respirators used by production personnel; however, security was not required to wear it. They were not provided with escape respirators.

Security was involved in escorting trucks with incoming and outgoing materials. The truck was escorted onto the site to the building receiving the material. Security was required to verify the seals on the trucks as they came on and went off the Fernald site. They also verified that the paperwork was appropriate. There were a few incidents where the Bill of Lading did not match the material shipped. At times when transport vehicles were onsite, checking the vehicle was a part of their tour. Trucks delivering material came from all over the country. For shipments arriving by train, Security was required to meet the train at the gate, inspect the train cars, and ride the train onto the plant site. Security was not responsible for inventorying the material shipped to and from the site. In 1989, production was shut down and the emphasis at the site turned to remediation. Security no longer had to escort material onsite.

Security would report to the Security Building to obtain their assignment for the day. They then went to the locker room and changed into their uniform. Dosimeters were stored at the Security Building. They were required to wear their uniforms in the production area during their tours. They did not change into coveralls like other employees. The dosimeter was the only difference in their dress between the clean area and the production area. When they went into the production area, they wore a uniform plus a dosimeter. These same uniforms were also worn into clean areas of the plant. Whereas other plant staff had two pairs of shoes (one for the hot side and one for the cold side), security used a single pair of shoes for all areas of the site. They were not provided with shoe covers. Employees had a single locker to store their uniform in. When they were on duty, this is where they stored their personal clothing.

Security logbooks containing job assignments, information on material escorted, and information on events were maintained. Reports were issued for security infractions providing the details of the occurrence. These reports were maintained in a log by the lieutenant or sergeant.

All classified material had to be locked in a safe over night. If Security found a classified document not properly stored, Security Headquarters was notified and the document was confiscated. There were a lot of occurrences at first until the employees learned the consequences. Individuals were required to clean out their records on an annual basis. Classified documents that were no longer needed were put through a shredder. Confidential records and above were burned. Numbered classified documents had to be sent to Central Records when no longer needed. Once the stringent security controls on the site were lifted, there were only limited amounts of material destroyed.

Production Process

Belgium and African ore were received at Fernald starting in the 1950s. Production was responsible for receiving the raw material, which was transported in via railcar or truck. The material shipped by the railcars primarily came in drums. The cars were unloaded and empty containers were reloaded onto the cars. Some of the cars came in loaded with lime and decolite.

The Pilot Plant was used for numerous evaluations and experimental tests. Evaluations included areas such as refinery operations, hexafluoride reduction, derby pickling, and ingot casting. This plant also housed equipment used for other purposes. This plant was used to produce derbies prior to Plant 5 being constructed. Derbies were produced by reducing UF_4 green salt with finely granulated magnesium metal. Most green salt was produced by the refining process versus by UF_6 reduction. The UF_6 reduction process occurred at Fernald until it was taken over by other DOE sites. It involved vaporization of solid UF_6 to produce gaseous UF_6, and reduction of UF_6 to UF_4. Thorium production activities started in the Pilot Plant in 1964 and continued until 1980.

Ore was conveyed to Plant 2/3. This plant was responsible for conversion of uranium material to uranium trioxide, UO_3, or orange oxide. Material was dissolved in nitric acid to produce UNH. UNH was purified and separated from impurities (i.e., raffinate). The UNH was stored for further processing. The solution was boiled down to a concentrate and under went denitrification, converting the material to orange oxide. The orange oxide was removed with a manual suction process known as gulping. The operators did not like to participate in gulping, because it involved heavy labor, work in elevated temperatures, and exposure to fumes. They reported that respirators were not commonly used during this process. Scraps and residues created by the process included metal oxides and radium-bearing sludge.

The orange oxide was transported to Plant 4 using mobile hoppers. At times, Fernald received orange oxide from offsite. UO_3 was converted to uranium tetrafluoride, UF_4, or green salt by reduction and hydrofluorination. The green salt came out in a hopper and was packaged in 100–250 lb cans to be sent to Plant 5. The processes used in Plant 4 involved very high temperatures.

Plant 5 reduced UF_4 to high purity derbies through a process called reduction. Green salt was blended with magnesium metal granules and the charge put into a magnesium fluoride-lined reactor vessel (the charge was also referred to as a bomb). The lining process was referred to as "jolting." The bomb was capped and the lid was bolted on. It was then placed in a Rockwell Furnace and heated to 1400° for approximately 1.5 hours. The bomb remained in the furnace until it had fired. The operators could observe this on a watt meter. The material was allowed to cool. The contents of the bomb were dumped out, and the derby was separated from the MgF_2 and byproducts using manual and mechanical processes. The MgF_2 would have to be chipped off the derby with chisels and hammers, or cleaned with wire brushes. The slag was fed into chutes and recycled. Once separated, the derby was weighed, labeled, and stored on skids until needed. The derbies and scrap metal were melted in crucibles and cast into ingots for shipment to Plant 6.

Difficulties the operators encountered in the Plant 5 process included frequent blow-outs, where a hole would develop in the lid or bottom of the bomb during the firing. The blow-outs resulted in evacuation of the area and sometimes occurred as often as two to three times per shift. Also, during the removal of the derbies, the slag chutes would become plugged. To unplug these chutes, operations would have to use jackhammers and/or manually remove the material.

Plant 6 was responsible for the production of slugs from ingots. The uranium ingots were passed through a blooming mill to produce billets and sheared. The billets were reduced to the final rod dimensions, depending on where the rod was to be used. Some of the machines used in this area included shears, straighteners, automatic screw machines, centerless grinders, lathes, J-L machines, chaffers, cross machines, and rapid boring machines. Initially, the J-L machine was the only self-contained machine in the foundry area. The cast uranium ingots were treated in a neutral salt (NuSal) bath to harden the material. The NuSal bath contained potassium carbonate and lithium carbonate, and were heated to approximately 1300° F. The metal was pickled, and machining chips and tailings compressed into briquettes. If not adequately covered with water and solvents, the chips and sometimes chunks of uranium would catch on fire. The product was then sent to the Inspection Department, where it was inspected for pits, seams, dimensions, and handling defects. Ultrasound testing was used to check for flaws under the surface. If the slug was good, it was packaged for shipment. These machines required a lot of preventive maintenance internal to the units.

Plant 7 operated from 1954–1956 and was shut down in 1956. The plant was responsible for converting UF_6 into UF_4, which was used at Plant 5. There was a high demand for uranium metal during this period. The UF_6 was provided to Fernald by the gaseous diffusion plant at Paducah. This process supplemented the production of UF_4. Other Fernald plants were modified to increase production of UF_4, so Plant 7 was no longer needed. After shutdown, the area was used to store enriched uranium and as a maintenance shop.

Plant 8 received the bomb reduction liner material from Plant 5 in hoppers. It was emptied at an unloading station and moved to a surge hopper through a jaw crusher. The material was fed into an oxidation furnace where the metallic uranium was converted to black oxide (U_3O_8). The material was further ground and fed into digestion tanks, where it was dissolved in hydrochloric acid. The undissolved solids were filtered out and sent to the scrap dump. The uranium filtrate was sent to a precipitation tank, where it was converted to uranyl ammonium phosphate (UAP). The UAP was dried and sent to the refinery. The recovery process was eventually changed to produce ammonium di-uranate.

Plant 9 produced derbies, ingots, slugs, and washers of various enrichments. With the exception of the washer production, the operations were similar to those in Plant 5 and Plant 6. The plant also had a process for chemically decladding unirradiated fabricated fuel elements. In about 1955, Plant 9 was involved in making thorium metal. The thorium started as crystals and created high quality thorium oxide. This was shipped to Hanford and Bettis. The west side of Plant 9 was considered the thorium or chemical processing area. The east side was where the machining operations took place. There was a large incinerator outside to the southwest used to burn chips and tailings.

The raffinate was sent to the Hot Raffinate Building, where it went through a process to separate the Ra-226 and uranium. Hot barium sulfate was used as a precipitate. Portions containing radium and uranium were drummed and sent out. Some of the filter cake slurry was pumped out to Silos 1 and 2.

Remediation/Waste

The U.S. government obtained ore from the Belgium Congo for use at Fernald. The ore belonged to Belgium, who had planned to extract radium and precious metals from the waste stream. An agreement was eventually made between the Belgium and U.S. governments for Fernald to take on the responsibility for the waste.

Operable Unit 3 (OU3) was the Environmental Protection Agency's designation for the former production area at Fernald. Chips and paint were the primary samples collected from OU3 structures for characterization. The general approach to sampling remedial action sites is to survey and find the highest amount of activity. The sample was taken from this area. The raffinate stream was characterized in the mid-1980s. Analyses included evaluation of transuranics. The raffinate was pumped from the process area into Pit 5 for disposal. These waste pits were also characterized.

The site maintained six engineered pits. Pits 1–3 were really one pit. Materials were either pumped to the pits or transported by truck out to the pits and dumped in. All sorts of material, including slurries, solid waste, depleted uranium, etc., were added to the pits. During the remediation of the pits, derbies, ingots, graphite molds, and other radioactive materials were found. The uranium chips would periodically catch on fire.

Remediation of the pits involved pulling the water off, removing the contents to a predetermined depth, and performing soil sample analysis. If the soil samples did not meet the cleanup criteria, additional digging was required. During remediation, there were general assumptions made about what each pit contained. Pits 1–4 and Pit 6 contained U-238, debris, small pieces of metal, crucibles, cold traps, drums, building material, bags of asbestos, and other garbage from the production areas. Some of the radioactive material found in the pits was in pure form. Pit 5 contained raffinates. There was a Burn Pit at Fernald, which was used to burn just about anything. Residue still remained in the pit until it was remediated. A berm was built from the west side of Pit 3 to the Burn Pit, but the berms were not well defined.

The Clear Well Pit was used to decant water from the waste pits and other areas of the site. It was essentially used as a settling pond. This pit contained any radionuclide found onsite. Water was processed out and eventually released. During remediation, 30 feet of sludge was found in this pit. On the east side of the site, radium ash that had settled out from the Sewage Treatment Center was found.

There were areas of the site that were expected to be clean that were found contaminated during remediation. For example, during excavation in the former Administration area of the site, air sample results showed up 850,000 times the permissible limit. There was a holdup of radioactive material in the piping and ductwork, including thorium in the process piping at the Pilot Plant, black oxide in ducts at Plant 5, radioactive material in the duct work in the Administrative Building, radioactive material in the ventilation ducts and the dishwasher vent stack in the cafeteria area, and dried UNH in pipe alley.

The Plant 1 Storage Pads, located outside, held about 125,000–180,000 drums in 1989. The outdoor environment would sometimes cause the drums to rot. At times, the bottom would fall out of the drums. Many drums required overpacking. Other plants also had storage areas.

Construction Trades

Several of the construction trade personnel were temporarily assigned by their company to Fernald. Many of them left and returned several times. They provided construction and demolition support for the Fernald contract, as defined under the Davis-Bacon Agreement.

Maintenance and similar support services were provided by onsite employees. The construction trades were involved in activities site wide. Some of the construction trade jobs included the following:

(1) Removal and installation of asbestos and insulation from buildings

(2) Construction of railroad tracks to support K-65-related work

(3) Building demolition, including removal of hoods, flooring, walls, dust collectors, ductwork, tanks, furnaces, etc. (Plant 1, Plant 2/3, Plant 5, Plant 6, Plant 8, the Administration Building, the Production Laboratory, etc.)

(4) Transfer Tank Area (TTA) Remediation

(5) Pouring concrete

(6) Removal of brick and piping in pipe alley

(7) Equipment setup and take down (e.g., scaffolding)

(8) Removal of the Old Tank Farms

(9) Building the airlock for the thorium overpacking project

(10) Soil remediation throughout the site, including remediation of Silos 1 and 2

(11) Waste pit drudging and other related work

(12) Labor support

(13) Installation or renovation of areas within production buildings

(14) Installation of the Bentonite on the silos

Construction trades workers moved from site to site as work became available. Some of the other DOE and Atomic Weapons Employers facilities that site experts worked at included Portsmouth Gaseous Diffusion Plant (Piketon), the Mound Plant, and the General Electric Evendale Plant. As subcontractors moved around the complex, they noticed the differences in radiological control implementation at the various sites. For example, Piketon implemented Personnel Contamination Monitors (PCMs) prior to Fernald.

Tools used at the facility were surveyed by Fire and Safety and sometimes confiscated, due to contamination. This was especially true of wood-handled tools.

Radiological Hazards

The radiological hazards associated with the plants are summarized below.

Plant or Building	Concerns for Field Radiological Control
Plant 1 (Ore Assay and Milling)	All uranium isotopes, Ra-226, beryllium
Pilot Plant (Ore Silos)	Th-230-contaminated material, enriched uranium, handled Paducah material
Pilot Plant Annex	U-238
Plant 2/3	Uranium ore, Ra-226, and Th-230 in the raffinate stream
East End Plant 2/3	U-238
Plant 4	Natural uranium, depleted uranium, and enriched uranium, UF_4
Plant 5 (Metals Production Plant)	NU and DU, beryllium
Plant 6	Uranium and thorium-contaminated material and furnaces
Plant 8 (Recycle Plant)	Uranium (all isotopes) and Th-230
Plant 9 (Special Projects Plant)	EU metal, thorium metal, beryllium
Building 54A	U-238, depleted uranium
Building 13A	U-238, U-235, Th-230, Th-232, trace contaminants of Pu-238, Pu-239, Pu-241
Building 64	Thorium storage
Building 65	Thorium storage
Building 61 (Quonset Hut 2)	ThO_2
Quonset Hut 1 (Q-1)	Thorium storage after overpack
Building 67	Thorium storage
Building 68	Thorium storage
Building 69	Decontamination Facility - Uranium, Th-230
Silo 1	Rn, Th-230, Ra-226 (full list is on EDESK)
Silo 3	Th-230 + D, Ra-226 + D
Pits including Burn Pit and Clean Well	U-238, derbies, small pieces of metal
Pit 5	Raffinates; Th-230

Fernald had real-time radiography devices. There was a Co-60 source kept in a vault in the south warehouse of the Pilot Plant. This system was complete with interlocks. In the 1980s, additional soil had to be dumped and distributed around a portion of the building to increase shielding. The source had been in place long before this was done. There were also Phillips Constant Potential X-ray Units used for drum inspections. These units were used in an interlocked area. The integrity of welds was routinely checked with dyes or by visual inspection. When x-rays of welds were required, the objects were sent to the drum inspection booth in the Plant 1 Chemical Warehouse.

Red drums and black drums were stored separately. In the warehouse, small cylinders of material were stored on a wooden pallet. These cylinders were red and were spaced appropriately to prevent a criticality. Security personnel remember seeing Fissile Material signs associated with this material.

Chemical Operators had a wide variety of responsibilities. Some of the high-exposure jobs included manning the dumping stations, cleaning equipment (i.e., dust collectors, reduction pots, crucibles, furnaces, reaction vessels, etc.), inventorying the rabbit hutches, and decontaminating areas when needed. Graphite molds were cleaned with a broom handle and steel wool. After the removal of the MgF_2 from the uranium, individuals would stick their heads down as far as they could to clean the slag out of the pot. During this operation, there was no respiratory protection worn. These job responsibilities provided opportunities for exposure to high concentrations of radioactive material. A Chemical Laborer performed the same type of jobs, and was in training to become a Chemical Operator.

There were both building-specific maintenance crews and a general maintenance pool. The general maintenance pool could be sent anywhere on the Fernald site. Although an individual may be assigned to a particular plant, he may be assigned to another plant during overtime. There were shop areas near the production buildings and a central shop area for handling maintenance on equipment. There were areas in the plants accessed by maintenance that were not routinely occupied (e.g., tanks, entry into pots). Contamination was present in these areas.

Tools in the production area were generally contaminated. Some maintenance workers had "hot-side tools" and "cold-side tools." Maintenance personnel also had tool boxes, which they took from area to area. When they started to monitor tools in these tool boxes, they were found to be contaminated.

Laborers stamped the cores, shipped materials on conveyors, packaged products, and loaded transport vehicles. They had to strap the material down, bringing them in close proximity to uranium. Supervisors, clerks, and administrative support personnel had offices in the production area. The ventilation system in production buildings was recirculated air, potentially exposing those in the administrative areas of the building. The offices tended to be dusty. A clerk was responsible for tracking the uranium as it was received and shipped.

Transportation Labor was responsible for a wide range of duties, including unloading rail cars, hauling waste to the disposal pits, transporting material (e.g., samples, orange oxide, green salt, uranium metal, molds, drums, etc.) between plants with fork trucks and tow motors, and loading and banding offsite shipments of ingots, slugs, and derbies. When using the Tow Motor, the drums were not always secured adequately, so the drums would fall off and break open. This was a fairly routine occurrence. When transporting red drums, a Radiological Control Technician (RCT) had to accompany the Tow Motor operator.

Uranium Characteristic

Enriched uranium, depleted uranium, and natural uranium were all handled. The maximum allowed enrichment at the site was <20% U-235. Small quantities of enriched uranium (>1%) were stored in red drums. This material was used as a sweetener to increase the enrichment in the product. Standard production was 0.95% and 1.25% for Hanford. Special production orders for higher enrichments were made for other facilities, as requested and approved by DOE. The feed uranium compounds sent to Fernald were not chemically pure. Fernald products, however, were of excellent purity in order to meet strict requirements of the managers of the AEC production reactors at various sites throughout the U.S. The product was evaluated by the collection of samples from the process stream.

Fernald also received materials from the Savannah River Site (SRS), Hanford, Paducah Gaseous Diffusion Plant (Paducah), and Y-12 Plant in various forms. Fernald was responsible for taking the intermediate product and creating a final product. Cores returned from SRS came back containing crystallized material. Fernald became the repository for surplus uranium. They stored cladded uranium carbide and uranium alloys.

The chemical forms of uranium handled at Fernald included uranium ore, UO_3 (orange oxide), U_3O_8 (black oxide), UF_6 (uranium hexafluoride), UF_4 (green salt), diuranates (e.g., calcium or ammonium diuranate), UNH, UO_2 (brown oxide), and uranium metal. The oxides were extremely insoluble.

The Fernald site did not process U-233 or have it in pure form in any production processes. It was present in trace amounts in some of the uranium or thorium feeds. If present in thorium feeds, the concentration of U-233 could have increased in extraction liquids reused in the Pilot Plant. Material Accountablity kept track of the quantity of U-233 onsite.

Recycled uranium introduced fission products and transuranics to the site. Fernald was not authorized and not set up to process plutonium materials. Trace amounts of plutonium (<10 ppb) were found in recycled uranium processed at the site, especially green salt. The Fernald process was not designed to handle plutonium. Engineering controls were based on uranium hazards and dust. There was plutonium embedded in the uranium that went airborne. The T-hopper operation filtration created a situation where there was a plutonium buildup. Plutonium Out of Specifications (POOS) was received and stored at Fernald for a period of time. NLO, Inc., did not attempt to maintain accountability for this material. Analyses for plutonium were made only on special occasions when the specific receipts of recycle material warranted such analyses.

Thorium

Thorium was associated with the Pilot Plant, Plant 9, the storage warehouses (Buildings 64 and 65), Building 61, and some raffinate streams. Plant 9 was referred to as the Thorium Plant from the initiation of its operations. If this accurately described the operations in the plant, thorium work was probably here from the beginning of operations. Building 61 (Quonset Hut 2) was a storage area for ThO_2 sintering and machining slugs. Fernald became the Thorium Repository and had the largest inventory of thorium in the United States at one time.

Chemical forms of thorium handled at Fernald included ThO_2 (light oxide), ThF_4 crystals and solution, $Th(OH)_2$ (sol gel); ThC_2O_4 (oxalate), thorium nitrate tetrahydrate, and thorium metal. There was high-fired thorium oxide created in the processes. Thorium gel was shipped in via railroad and pumped to the Pilot Plant when thorium operations were underway.

Most of the stored thorium was located in Building 64 in white drums with blue rings. Site experts indicated the drums had noble gas labels on the outside. These drums eventually deteriorated and white powder, similar to soap powder, was seeping out of a subset of these drums. An over-packing campaign was initiated in the early 1990s to place the disintegrating drums into burial boxes. The drums were dropped into a burial box and a lid bolted on the box. Cleanup of the loose thorium powder was also done. This campaign involved over 5600 drums. The thorium redrumming project involved remote handling of material with the use of fork lifts to put lids on the overpack containers. The Co-60 vault was also used for thorium storage.

Radon

There were roughly 4,000 grams of radium placed in the silos. This equates to 4,000 Ci, plus a similar amount of each of the daughters. This was the largest concentration of radium in the country. The majority of this radium was included in the K-65 residue; however, it is distributed throughout the silos.

Health and Safety (H&S) was aware of the radon and thoron issues from very early on. Radon measurements were initiated for the dumping of drums in the 1950s, although the measurements were not routinely collected until much later. Radon monitoring started with the development of electronic radon monitoring devices. Eberline radon instruments (WLM-2s) with scintillation tubes were used at Fernald field radon measurements. If there was an inversion, this would cause issues because of the increase in ambient radon present. Later, E-perms and eventually Track-Etch detectors were placed around the silos for radon monitoring.

Individual radon monitoring was done on a job-specific basis and not on a routine basis during the time Westinghouse was the contractor. Time-motion studies were done in the 1990s corresponding to Radon Measurements. The working level (WL) unit was implemented in the later years at Fernald.

When individuals had to take samples or enter the silos, a glove bag was used to control exposure. The manhole on the top of the silo is opened and the sample is taken through the in and out port. There were attempts to measure radon in the glove bags, but these were not successful.

The Communication Center received real-time radon concentration data. If this exceeded a trigger point (100 pCi/Liter), Security made an announcement asking individuals to stay indoors. A technician was dispatched to the area to verify the conditions. These announcements didn't typically occur during the workday. This was a more current practice and did not occur in the 1950s, 1960s, 1970s, and 1980s.

The Radon Treatment System (RTS) was engineered to lower the radon levels in and around the silos. The system was composed of a large charcoal bed, PVC piping, and a fan. The idea was to blow the radon back into the silos. Significant gamma dose rates were measured at the charcoal filter of this system. Shielding was used to minimize exposure to the daughters.

A Radon Control System (RCS) was put online during the remediation of Silos 1 and 2. The function of the system was collection of radon gas to reduce exposures. The systems in the mixer rooms of the treatment facility would become plugged, and they had to be unplugged. It was difficult to tell where the collection line was plugged, because there was no sensing equipment on the mixer line. The sensors available on the system would indicate everything was okay if at least one line was clear. Entry into this area resulted in exposures to radon gas.

Radon cups were placed on the fence line to monitor radon concentration. This began around 1987 or 1988. The track-etch cups were changed out quarterly, and above background annual averages were noted at several locations near the K-65 Silos.

There were two aerial surveys done at Fernald by EG&G. There was detectable gamma shine from the silos. Prior to 1986, the cloud of radon drifting from the silo area could be identified.

General Radiological Control

When Fernald began operation, the Health and Safety Division (H&S) included the Medical Department, the Industrial Hygiene and Radiation Department (IH&R), and the Fire Protection and Safety Department. Later, the Bioassay Laboratory Department was added. The first manager of the NLO H&S department was Dr. Joseph Quigley. He was working with the AEC, and was asked by the AEC to take the job as division manager and set up the health and safety functions at the new plant. The bioassay laboratory was also a part of the H&S Division. In 1958, the site formed a Criticality Safety Department that was added to the H&S Division. The Fernald budget was based on the tons of material produced by the site. Although the budget was as high as 50 million dollars, limited funds were dedicated to safety.

The current Radiological Control Organization consists of a field group matrixed to the projects and a central Radiological Control group that handles the programmatic implementation of the program. The field was matrixed to the project starting in about 1996.

With the implementation of DOE Order 5480.11, the Radiological Control Program became more formalized and the Radiological Organization became centralized. When Westinghouse arrived, there was more communication with the workers and the public in relation to operations and safety hazards. The Radiological Control Program was generally improved. Following their release, Fernald implemented the DOE Radiological Control Manual and 10 CFR 835.

Training primarily consisted of safety meetings held once a month during the NLO era. Workers reported that the meetings did not always focus on safety issues. With the change of contractors to Westinghouse, the first formal radiological worker training was implemented. There were two levels of Radiation Workers (Rad Workers) when the formalized training program was implemented; Rad Worker I and Rad Worker II. Rad Worker I was for workers who had a potential for exposure <2% Derived Air Concentration for U-238. These individuals were exempt from bioassay. Rad Worker II-qualified individuals had the potential to exceed this level and were required to participate in the bioassay program.

Operating procedures contained safety requirements. The procedural requirements were determined by production (process steps) and H&S (safety requirements).

During the NLO time period, there were less than 10 H&S technicians onsite. Initially the technicians served the entire plant. As more technicians were hired, they were assigned to particular areas. The early technicians were responsible for environmental monitoring, industrial hygiene, radiological control, and fire and safety. There was a shortage of technicians, making it difficult to cover both routine work and incident response. In the 1980s, the site started hiring more RCTs. Both project-specific support groups and a site-wide routines group were initiated.

When Westinghouse took over the Fernald site, they brought in more RCTs. All RCTs became subcontractors in February 2005, providing full coverage for all radiological areas. The increase in technician staff occurred in the 1990s after production had shut down and the site's mission changed to environmental cleanup.

Posting

Historically, contamination areas were designated as Zone 1, Zone 2, or Zone 3 prior to the current posting requirements. Zone 1 had the least amount of contamination, while Zone 3 had the most contamination. There were additions and changes to postings starting in about the mid-1980s. Workers started noticing an extensive increase in postings. The high-radiation areas included RTR, Building 65, the area around the dosimeter calibration source, parts of the RCS, parts of the TTA, and historically the silo domes. These locations were posted as a High Contamination Area, an Airborne Radiation Area, and a High Radiation Area. High-radiation logs are maintained.

Engineering and Administrative Controls

The principal engineering control for dust was to use dust collectors or scrubbers to ventilate an operation, and to remove dust before discharging the air out a plant stack. Dust of all sizes was collected; the efficiency for collecting large particles was greater than the efficiency for collecting smaller particles. A great deal of information about actual dust size in stack effluents is available in Fernald records.

Dust collectors were changed when there was a change in the differential pressure or an indication that they were plugged. The bag house contained several bags with a blow ring connected to a vacuum hose. The material passing from the dust collector went into a hopper and then into a drum. Originally, the bags for the dust collectors were made of wool. Teflon eventually replaced wool. This was not very effective, and the seams had to be caulked so they would not leak as much. To replace the bags, the blow ring was removed and the 100-lbs bag was dropped in. During the replacement of the bags, the Chemical Operators would clean the hoppers. For this job, the individual would wear an extra pair of coveralls, but prior to about 1978, they were not using respiratory protection.

Portable shielding was used in the Rockwell Furnace area of the reduction process starting in about the 1960s. Heavy rubber mats were also used to reduce external exposure starting in about the 1960s. Additional shielding was added to the process area in the early 1980s, due to a ramp-up of production at this time.

Several materials were tested as dust collectors to see which would hold up to collection of particulates best. Virgin wool was determined to work most efficiently. The particles deposited in the bags had sharp edges and would damage the bags over time. With significant damage, the dust bags would rupture and material was released from the stack. A lot of the released material deposited on the roof or the ground near the plant. There were two methods to identify reduced efficiency in the dust collectors. First, there was a differential pressure gauge, which was monitored by operations. When the differential pressure was outside acceptable limits, the dust collector was changed. Second, there was stack monitoring with an audible alarm to alert personnel to releases.

Prior to the addition of Bentonite to the silos, a layer of bentonite 2–4 ft thick was added on top of Silo material in about 1991 to prevent radon from escaping through cracks. Prior to this, there were dose rates above 100 mrem/hour. Personnel would burn out when working in the silo areas. After the Bentonite was added, the dose rates dropped to approximately 10 mrem/hour. There were some concerns that the material would lose its effectiveness as the bentonite dried over time.

Starting with the arrival of Westinghouse, there were concerns about overexposure. They implemented a system where an employee was allowed to work a set amount of time per week on a particular job. The time limits were determined from dose rate measurements taken by a Radiation Monitor. When working on two jobs, the time limit for the second job may have to be reduced due to exposure received on the first job. For example, if an individual worked on a job where he received 50% of his allotted exposure, and the second job allowed him to work 20 hours per week, he would have to reduce his time to 10 hours per week. It was the employee's responsibility to keep track of the time limits. There were some individuals who didn't know how to recalculate time limits as they went on to other jobs. Supervisors kept a daily log of work tickets each day. Although they collected the information, there was no formal review of this data. The time restrictions were assigned by job tasks. There was no policing of the time limits set for particular jobs. If an individual was not done with a job, he may keep working until it was completed. Time limits ranged from minutes to days per week on a particular job.

Radiation Work Permits

There were job-specific permits prepared by the IH&R Technicians. If it was felt a job was high risk (e.g., changing out dust bags), a technician would perform a survey and determine time limits for the particular job. These time limits were based on skin dose exposure most of the time. The original permits did not specify protective clothing or bioassay requirements. Respiratory Protection was specified for each task.

Westinghouse initiated the modern version of the Radiological Work Permit (RWP). RWPs were implemented with the issuance of DOE 5480.11. Technicians prepared RWPs on a daily basis. Once per week, the RWPs were rewritten. Supervisors approved the RWPs. The older RWPs were similar to a fire permit. Requirements were based on process knowledge. Areas within the plants required RWPs; however, there was no RWP for general access. In about December of 1992, Work Planning and Radiological Compliance took over the responsibility for RWP preparation. Procedures for RWPs outlined the requirements for RWP issuance. Sign-in sheets were adopted in later years.

Field Instruments

Portable survey instruments that have been used at FEMP include the following:

- Ludlum Model 3 with beta/gamma pancake probes
- Ludlum Model 12 with ZnS
- Ludlum Model 2221 with ZnS in Scalar mode
- Eberline RO-20 Ion Chambers
- Bicron Micro-Rem Meters
- AP2 Radon Discriminator – PIP's detector by SAIC
- HP-210 Frisker Probe
- Portable Working Level Instrument

For the Silos Project, the release criteria were set at 20 dpm/100 cm^2 alpha. Smears were counted on a Ludlum 2221 Desktop Scaler for 5 minutes. The minimum detectable activity for this count is 8 dpm. In the calculation of activity, an area correction factor is applied.

Prior to the early to mid-1980s, there was no particular survey frequency. Routine surveys were first adopted for administrative areas and break rooms. Neutron surveys were started in 4B, due to a request from a DOE Facility Representative. In 1995–1996, a study proved that there was no neutron hazard at the plant. There were criticality specifications implemented to prevent criticality accidents, and criticality safety alarms were present at Fernald.

Air Monitoring

Richard Heatherton was working for Health and Safety Laboratory (HASL) when he was asked to take the position of Manager of the Industrial Hygiene Department at the same time that Dr. Quigley was asked to become the H&S Division Director. Other HASL employees were sent, on loan, to Fernald, and they did much of the initial air monitoring as new operations were tested in the Pilot Plant or brought online. Dust studies of the various plants and jobs within those plants were conducted in the 1950s and 1960s, including Breathing Zone (BZ) and General Area (GA) sampling. Breathing zone air samples were taken based on the methodology implemented at HASL. This is not the same type of sampling as the current day Personal Air Sampler. Radiological Control concentrated their studies primarily on the Chemical Operations, because they were believed to have the highest potential for exposure. Generally, three samples were taken per task. The early method for collecting breathing zone samples consisted of holding an air sample pump with a 1" diameter filter paper as close to the nose of the worker as possible. Later, tubing was used draped over the shoulder and positioned at the lapel. The technician would follow the individual around with a stop watch to capture the exposure from each task. This included walking to the cafeteria. These types of annual air studies were discontinued in about 1968. Formal reports of these dust studies were issued. There was no routine air sampling in the 1950s throughout the facility.

After the reduction in force in the 1970s, air sampling decreased. In 1989, Extensive Air Monitoring Plans were developed. Air sampling increased again in the 1980s, and was extensively used in the 1990s during the remediation of the site. About 1,000 BZ air samples were processed per month. The primary method for detection of isotopes other than uranium was BZ air sampling. The air sampling was used instead of bioassay sampling. One hundred percent of the thorium workers wore BZ air samplers. Derived Air Concentration-hour tracking was implemented at Fernald with the extensive use of BZ monitoring in the 1990s. Air samples underwent a gross alpha/beta count, and if they were elevated, alpha spectroscopy was performed to identify the radionuclide of concern. There was a Personnel Air Sampling Card (Form 602-10-25) used to record internal exposure.

In 1994, Field Radiological Control attempted to do a 12-hour, 24-hour, and 7-day decay count on air filters. An extrapolation was done on the initial counts to determine if there were issues. The filters would then be decayed up to 14 days and counted again. The counting responsibility was centralized, and air samples were forwarded to the Centralized Air Sample Counting group. Prior to this, samples were counted in the area and then results were forwarded to the Central group.

The air monitoring program was required to support the internal dosimetry program. The internal dosimetry program requires 25% personnel air sampling use. This is described in the site Internal Dosimetry Technical Basis Document.

Contamination Control

Contamination control in the production areas was poor. At Fernald, it was common to see green salt, yellow cake, and black oxide on the floor in the production areas or on the plant road. Even though the floor was scrubbed once per shift, it was difficult to clean out the nooks and crannies. Releases and spills from equipment occurred routinely. Spills were commonly cleaned up with brooms. Operations in Fernald plants created a great deal of dust in the area. The production area was divided into a “hot side” and a “cold side.” There were administrative offices in the production areas.

When individuals came to work, they came through the turnstiles, went to the locker room and put on company-issued coveralls and cloth caps, and went to work. At lunch time, employees showered and put on clean clothes. Workers had one pair of shoes that were to be worn in the production area, and another pair to be used in the clean areas. Contaminated shoes were worn into the clean areas (blue areas) of the site. After the work day was over, workers were just required to shower and change clothes before leaving the production areas. Prior to Westinghouse, there were no Radiation Monitors or monitoring machines around to determine if an individual had picked up contamination. Visitors were provided with smocks and shoe covers when entering the production areas. In later years, Personal Protective Equipment (PPE) ranged from none up to Level A protection. The Level A suits were wiped down and reused. PPE requirements were consistent for workers in the same immediate area by plan, but not necessarily enforced.

The company cut the sleeves off the coveralls at one point, leaving their arms bare. Radiological Control found out about this practice and was not pleased. The company could not retrieve the sleeves to have them sewn back on. All these coveralls had to be disposed of and new coveralls procured.

The contamination monitoring improved when Westinghouse took over the site. Hand and foot monitors were introduced in some areas in the late 1980s/early 1990s. These units were not available in all areas. Fernald implemented hand and foot monitors around 1987. Hand and foot monitors were on the clean side of the change room. Personnel Contamination Monitors (PCMs) were put into service about 18 months later. PCMs were stationed at the doors in the locker room. PCMs were on the dirty side of the shower (process area to the service building). The alarm set points were based on the uranium contamination limits on the dirty side. The PCM count times were calculated based on the background radiation, and were determined automatically by the instrument. This made sure the count time was long enough to detect the prescribed alarm limit. There were daily occurrences of external contamination from radon with the initiation of egress monitoring. This was especially true when thermal inversions occurred. The individual was recounted after the radon was allowed to decay. They now use Passivated Implanted Planar Silicon detectors with energy discrimination set >5 MeV for monitoring.

Laundry collected coveralls twice a day. The coveralls were often contaminated with orange oxide, green salt, black oxide, and yellow cake, exposing these workers to radioactive material. These individuals were not required to use respiratory protection. Site experts recollect that there was no airborne monitoring in the laundry area.

Respiratory protection was optional in most cases, and use was intermittent. Initially, half-mask respirators were used. Respirators and/or filters were used more than once. Maintenance, operations, and others would wear their respirators around the neck. Frequently there was visible dust (e.g., green salt) on the respirator. Some individuals put Chem Wipes in the face piece of the respirator until the respirator was needed. When they were ready to use the respirator, they removed the Chem Wipes and donned the respirator. Other individuals just blew their respirators out prior to putting them on. Respirators were carried around in pouches or stored in lockers. It was also common in the early days to hang respirators on the machinery in case they were needed. Respiratory protection was not supplied to all areas. Prior to the implementation of a formal respiratory protection program, some individuals had respirators with a poor fit.

It was common to use respiratory protection to reduce chemical exposure potential. For example, during the removal of radioactive asbestos in the laboratory, an airline respirator was used. Initially, the subcontractors had to supply their own respirators. Other respirators used included full-face respirators (starting in the late 1980s) and Positive Air Purifying Respirators. Initially, there was a multiple-use policy for respirators. It was not uncommon to wear a respirator around the neck in production areas, so it could be slipped on as needed for a particular job. Personnel would simply rinse the respirators out. Respirator surveys were not implemented at the time. In 1989, a single-use policy was adopted for respiratory protection use.

In general, respirators were required during dusty conditions, such as drum dumping and certain maintenance activities (e.g., dust bag changes). It was up to the supervisors to enforce the wearing of respirators. In the case of the thorium overpacking, personnel wore a full-face respirator, a single set of Anti-Contamination clothing (Anti-Cs), and pencils. No respiratory protection was used during the reduction, gulping, cleaning of graphite molds, and machining. Machinists were not required to use respiratory protection, and were prone to exceeding monitoring action levels. Site experts noted that with the same operations where a respirator was not used before, respirators were all of the sudden required. The change seemed to correspond to the arrival of Westinghouse.

Historically, workers were instructed not to eat in the process areas. Some individuals disregarded these instructions and ate there anyway. This was identified by the RCTs as a big issue in the early years. Personnel were allowed to drink water in the area. In fact, there were multiple drinking fountains available. Personnel would chew tobacco or gum in the area. Smoking was allowed in the smoking areas set up in the production areas during NLO management. Employees were supposed to shower before lunch and change into their personal clothing. There was no requirement to shower prior to breaks. As a result, contamination was brought into the break rooms. Facility drinking water came from a deep aquifer of the groundwater. Both the shallow aquifer and the final drinking water were tested for contamination. Eating, drinking, and smoking were not allowed in contamination areas, high-contamination areas, radiation areas, and high-radiation areas after implementation of formal Radiological Control Requirements (e.g., 10 CFR 835).

Truck drivers delivered brickets to the West Coast from Fernald. They would also retrieve empty containers on their way back to Fernald. There was a team of two drivers in the truck. Dose rate measurements were not routinely made in the cab area. Drivers were not directed to wear their dosimeters during transportation. The truck had Radioactive Material placards.

External Dosimetry

Initially, all personnel were assigned a dosimeter. The security and dosimetry badge were separate at the beginning of operations. In approximately 1960, the badges were merged, and everyone on site was monitored. At this time, the badge contained high-dose film, low-dose film, sulfur, and foils. Late in the 1980s, they started separating the dosimeter and security badge. During the period of time when the security credential was merged with the dosimeter, all personnel were monitored for external exposure. When the dosimeter and security credential were separated, all individuals entering the process area were required to wear a dosimeter. Dosimeters were required for the process areas; however, they were not required for the blue areas. With the implementation of 10 CFR 835, anyone who entered a posted area was assigned a dosimeter. If the area was 50 microrem per hour or greater, an area was posted with an insert indicating that a TLD was required.

Dosimeters were taken home during some time periods and stored onsite for other periods. During the 1950s, the security badge was turned into security as an individual went through the turnstile. The employee received an identification card, which he/she would exchange in the morning for their security badge. There were about 8–10 Security Guards at the turnstiles at the time. The storage onsite corresponded to the period of time when dosimeters and the security credential were separate. At one time, badges were left in a rack at the guard post for a period of time. The dosimeter and security credential were retrieved when an individual came into work. Individuals were told to wear their dosimeter between the waist and neck. Dosimetry was worn on the outside of the garment. With the implementation of Anti-C's, employees were instructed to wear their dosimeter inside of the Anti-C's, where skin exposure was not a concern. RadCon did not police the use of dosimeters. Individuals would be questioned about not having the security badge, including the era where the dosimeters were combined with the employee badge.

Fernald was responsible for monitoring subcontractors onsite. Dosimeters (initially visitor badges) were assigned by the Security Department, but not all individuals were monitored. Badges could be assigned to more than one person for the monitoring period. Badges were read, but unless there was a positive reading, the dose was not tied to a particular individual. If the badge received measurable dose, an investigation into who wore the badge and where they worked was completed. Later, subcontractors entering radiological areas were assigned individual dosimeters. Years ago, subcontractors were treated differently than regular employees, and they believe this affected their radiation monitoring.

The use of extremity dosimetry was fairly common with those who handled material. For example, uranium machinists were originally assigned wrist dosimeters, and later ring dosimeters. The site switched from the use of wrist dosimeters to ring dosimeters, which became standard issue for some jobs. When RWPs were implemented, the need for extremity dosimetry was specified in the RWP. Non-uniform exposure badges were not used, to the recollection of the site experts. Dose from surface contamination was calculated with Varskin in more recent years. There was no personnel neutron monitoring at Fernald.

According to some site experts, there was non-uniform exposure to personnel in Plant 6 at the rolling mill area where the ingots were rolled out. There have been no issues with partial body exposure since 1994. Multiple badges were rarely used. The routine dosimeter was moved to the area of the body between the neck and the knee, where the highest dose rates were.

Self Reading Pocket Dosimeters (SRPDs) were used in some areas, such as the thorium area. The field maintained an SRPD Issue Log. The initial and return readings (i.e., reading in and reading out) were recorded in the log. An investigation resulted if there were unusual results with SRPDs. The readings themselves are maintained with the field records. There were specific jobs, such as the roof repair on Plant 1, where individuals were instructed to wear SRPDs on other portions of their body (e.g., lower extremity). A comparison between the SRPDs and the primary dosimeter demonstrated that the results were generally within 30% of one another. Timekeeping was used to control individual external exposure for a particular job.

There was an issue with contamination of badges. Green salt, orange oxide, and other materials would settle on the badge. In general, workers were told just to wipe the uranium off their badge. Badges were wrapped for a period of time to prevent contamination. Badges used in calibration were treated the same way. Baggies were used in cases where wet work was conducted. The dosimeter was surveyed by technicians during the badge exchange to make sure the badges were uncontaminated and could be sent to the processing laboratory.

Dosimeter investigations date back to the 1950s. In cases where the dosimeter was lost, damaged, or showed suspicious results, an investigation was conducted. A temporary badge was assigned in the interim. An investigation form was provided to the individual's supervisor to collect information on the exposure period, such as job task involvement. The average dose for each particular task was determined and the sum of doses from all tasks was determined. The technicians had a field procedure for assigning these doses. There is a code in the electronic system where doses were assigned based on this process. If the original badge were found, this information would be reflected in the dosimetry evaluation. Later, co-worker doses were used to assign dose for lost or damaged dosimeters. If the dosimeter was returned after it was lost, the dosimeter was read; however, the co-worker dose was the dose of record. This was to account for the possibility that the dosimeter was not worn during a part of the monitoring period. If the investigation indicated a zero dose should be assigned, this was the dose of record. Investigation results were placed in the dosimetry file.

There were dozens of investigations conducted on high skin doses. Individuals were asked what they had been doing and who they worked with for the given period of time. There was also an evaluation of the glow curve to determine whether an anomaly had occurred during the reading process. It was very clear from evaluation of the glow curve if reader difficulties had occurred. A hard copy of the glow curve was included in the employee file.

Fernald contracted with the University of Michigan to irradiate badges with pure irradiation sources using low-energy betas and high-energy betas. They thought the two sources would also be representative of intermediate energy betas. At the time, they were using two elements to determine the beta dose at the site. An algorithm was developed and put into use at Fernald. They later discovered issues with the algorithm and hired the Idaho National Engineering and Environmental Laboratory (now INEL) to develop a revised algorithm for them. Upon completion, this algorithm replaced the previous algorithm.

There was an overestimation of beta doses using the 802 TLD badges in the mid-1980s. Initially, this exposure was believed to be caused by contamination of the ledge in the holder adjacent to the E1 chip. As a result of collection of contamination on the badge holder, E1 would be irradiated more than E2. This theory was discounted as the problem once the error in the algorithm was discovered.

Historically, the Bioassay Laboratory Department was responsible for testing new dosimetry systems and processing dosimeters. Fernald was the first DOE site to receive accreditation under Department of Energy Laboratory Accreditation Program (DOELAP). Studies on angular dependence are documented in the DOELAP package created by Fernald. There are no negative dosimetry results in the dose of record.

Fernald implemented an extensive area dosimetry program in the late 1980s/early 1990s. There was a wide distribution of these badges throughout the buildings. Area badges were changed on the same frequency as personnel dosimeters.

Annual Radiation Reports were provided to the workers starting in the 1990s. The annual dose from the annual reports dropped for some workers in about 1996. The reason for this drop was not explained to the workers. [SC&A verified the drop in dose between annual reports.] There was no change in dose calculation methodology that would have resulted in a drop in cumulative exposure.

Internal Dosimetry

Individuals who were thought to have potential for internal exposure (e.g., work in airborne radioactivity areas) were monitored for internal exposure. There was a graded approach to the frequency of bioassay collection (i.e., monthly, bimonthly, or quarterly), based on the particular job title. Bioassay samples were also submitted upon hire and at termination. Radiation workers submitted bioassay samples from the beginning of production. An individual was considered a radiation worker if they received 100 mrem or more of internal and external dose in a year. In general, Fernald erred on the conservative side and monitored individuals who did not need to be monitored. Notification cards were sent out when it was time to leave a urine sample. If they were not cooperative, they could be excluded from radiological areas.

Fernald used the fluorometric technique originally developed by HASL to determine total uranium in urine. To obtain an isotopic analysis, samples were sent to an offsite laboratory. The best detection level achieved for fluorimetry was 0.005 mg/L. When the bioassay laboratory was moved outside the service building in the production area, the decision level was 0.015 mg/L. A trigger point of 0.05 mg/L was implemented for uranium bioassay. Kinetic Phosphorimetry Analysis was implemented in 1993 and Inductively Coupled Plasma/ Mass Spectroscopy in 2002. The method for recording a "less than detection level" bioassay value was era-dependent. Zeros were recorded in the 1950s and 1960s, due to the limitations of the data processing equipment. Later, bioassay results were recorded as less than the detection limit.

A neutron activation method, using the nuclear reactor at Wright Patterson Air Force Base, was eventually developed by NLO personnel for the determination of thorium in urine. However, there was no way to correlate the urine concentration with body burden. This problem went away when the mobile in-vivo counter became available in 1968. There was some breath thoron analysis utilizing the method developed by HASL. This was not a routine monitoring method, and there were no positive results.

The first in-vivo counts were conducted in 1968 with the Y-12 Mobile in-vivo counter. The in-vivo counter visited Fernald twice per year. A permanent in-vivo counter was put into service around 1987. The focus of the in-vivo program was to measure the Maximum Permissible Lung Burden (MPLB). In-vivo counting was the bioassay method of choice for insoluble uranium and thorium. Counters were capable of detecting uptakes in the most exposed workers. Over the period of operation, there was only a single individual restricted for an extended period of time as a result of a high in-vivo count. There were situations where individuals were sent offsite (e.g., Hanford, Argonne National Laboratory) for follow-up counts.

In-vivo counts were conducted after the employee's weekend. The delay in counting was done to reduce the possibility of surface contamination on the individual. There was a tendency for protein-binding of the radioactive material to the body hair, especially in men. An additional reason for performing counts after the employee's weekend was to allow particles deposited in the trachea to work their way up the respiratory system by cilia transport, and be swallowed. Radioactive material in the trachea would create erroneous results when trying to determine the activity in the lungs. There was no delay in the collection of urine samples. Dose was calculated in accordance with internal dosimetry procedures of the time, with any detectable amount on an in-vivo count. If the individual reached 75%–80 % of the MPLB, they were pulled off the job and special counts were completed.

Other types of bioassay data collected at Fernald included chemical, thorium, radium, and later plutonium. Breath analysis was used to try to detect radon in breath. Although this data was collected, there was little faith in the results. These results may be documented in the weekly progress reports. There were two cases where in-vivo counting equipment detected positive plutonium burdens. These individuals were sent to Chicago and Richland for in-vivo counts, which confirmed the uptake of plutonium.

Studies on radon concentrations at Fernald were conducted in the 1999/2000 time frame. Radon Breath Analysis studies were conducted by NIOSH. Individuals were required to be off work for some period of time prior to participating. The results from this study indicated that Cincinnati had the 10^{th} highest radon backgrounds in the nation. Pulmonary function tests were completed as a part of the study. There were a significant number of individuals taking the test that had circulatory or pulmonary health problems.

With a suspected intake, individuals were requested to leave special bioassay samples, which could include urine and/or fecal samples. One sample was collected at the end of the shift and the other was collected the next morning. Follow-up bioassay samples were requested when an individual had a positive urine sample. Historically, trigger levels were used as a basis for requiring special bioassay samples. If anything off-normal occurred, employees were directed to leave a sample at the end of their shift and the beginning of the next shift. Codes associated with specific bioassay samples in the record indicate why the bioassay sample was taken (e.g., routine, special, etc.). After the implementation of DOE Order 5480.11, special bioassays were requested in the case of an incident or when a urine sample had a uranium concentration greater then 0.05 mg/liter. Any employee could initiate an Incident Investigation Form (IIF) if they felt they were exposed. They simply had to document the reason why they felt a Special Bioassay sample was warranted. The employee left a sample at the end of their shift and a second sample at the beginning of the next shift. In the early days, incident reports and urinalysis results were put into the medical record.

Fecal sampling was used primarily as a special bioassay technique or for particular jobs. There was no routine sampling program in the early years. Baseline fecal samples were collected for workers involved in thorium work. Subsequent fecal sampling was incident-based. After the initial bioassay sample, air sampling and in-vivo counting were used as the primary means of bioassay for thorium. A background study using approximately 500 fecal samples was conducted in the mid-1980s to determine the background level of thorium in feces.

Thorium workers were on a routine program to receive an annual in-vivo count. If there was an incident or a suspected intake, a special bioassay sample was taken. The emphasis for determining potential intake was based on BZ air sampling. After the thorium overpacking job, thorium-contaminated material was still handled. For example, work with the silo remediation potentially exposed personnel to thorium. Once the in-vivo counter was shutdown in 2002 or 2003, the capability for thorium monitoring went away. There was also no program for sending individuals to other sites for routine in-vivo counting.

The silos were built in the shape of a hemisphere. Silos 1 and 2 were surrounded by dirt, while Silo 3 was not. Silo 4 never held radioactive material. Each silo had a manhole to allow for continued monitoring and collection of samples. Most of the time, the silos were left alone. There was a sump between Silos 1 and 2 for collection of run-off material. No special routine monitoring requirements were implemented for work at the silos during production. During the remediation of the silos, Fernald implemented a more specialized bioassay for silo workers.

Subcontractors were not thought to be Radiation Workers and may not have had bioassays prior to 1986. Starting in the late-1980s, subcontractors were monitored based on the same criteria as permanent employees. Eventually, urine bioassay was collected bimonthly. Routine bioassay samples were followed with special bioassay samples when there was a positive result. Baseline thorium samples (fecal) were collected from individuals working in thorium areas. If an exposure was confirmed, an individual was moved to the "clean area" temporarily. Subcontractors were given an in-vivo count once per year or when ending work at the site. They were told if the count was positive or negative, but further explanations were not provided. Subcontractors did not participate in radon monitoring; however, there were times they were right on top of the source term. It was a challenge to get subcontractors to submit samples prior to them leaving. In later years, Fernald was required to send subcontractor dose reports to the employer (e.g., Wise, Rust Engineering, etc.) A good source of this information is the RadCon letter log.

Technology shortfalls identified in the personnel-monitoring program were limited to the existence of extremely insoluble material.

A field hearing was conducted with Senator Glenn as chair in about 1985. There was some concern raised over the background of the Y-12 in-vivo counter. During a congressional hearing, an independent Health Hygienist was asked to review the early body counts and explain the results. The reviewer could not understand the data. Former health physics staff indicated that the background of the in-vivo counter was well characterized, as quality control checks, including backgrounds, were completed on a regular basis and documented in logbooks.

Environmental Monitoring

The Environmental program involved air sampling, water sampling, soil sampling, biota sampling, and radon monitoring. Early in Fernald operations, gum papers were distributed to collect uranium fallout, and subsequently analyzed by the Bioassay Laboratory. This included an offsite-monitoring program. Radon monitoring was implemented in the 1980s.

Environmental air monitoring stations were originally located in the four corners of the 100 acre production area. Stations were moved in the 1970s from the four corners of the production area out to the site boundary. Some of the stations at the production area boundary were kept in operation after the boundary fence-line stations were added. Offsite stations were added later. Air samples were collected and analyzed weekly. The number of air sampling stations increased over time, especially when the EPA became actively involved in reviewing the releases offsite. When the existence of trace materials in recycled uranium became an issue, the site shipped composite samples from each monitoring station to Oak Ridge National Laboratory to be analyzed for plutonium and neptunium. The results, published in the annual environmental report, indicated there was no issue with release of these radionuclides.

From 1956–1969, microscopic techniques were used to collect particle size information. Particle size studies of the uranium processes were conducted in the 1980s. The particle size results from this study were consistent with the default value of 1.0 micron assumed by the site for environmental dose calculations. National Emission Standard for Hazardous Air Pollutants made particle size determination a requirement for environmental monitoring. A report was issued on the elimination of nonrespirable particles in the 1960s or 1970s.

The stack monitoring program was developed and initiated by the H&S Division to show the Production Division that uranium was present in some stack discharges, and that routine dust collector inspections by Production were needed. Thorium releases from the Fernald facility were also monitored and are documented in an historical emissions report published around 1986. An accident involving a dust collector in Plant 9 occurred. Prior to the accident, there was little stack monitoring. After the accident, monitors were installed on the stacks on all production buildings. The original stack monitors were designed in-house. Strip charts recorded the releases from the stack to the environment.

Large releases of material were the result of malfunctioning equipment or accidents. Releases were not deliberately made to the environment, although releases did occur. Fernald was investigated several times as a result of releases of dust to the environment. Uranium inventory was under tight control by the Material Accountability personnel at the site.

There was an atmospheric release of UNH from Plant 2/3 over a period of weeks in the late-1980s/early 1990s due to a scrubber failure. There was detectable activity at air monitoring stations, which is documented in the Annual Site Environmental Report for that year. The release resulted in a shutdown of the refinery after the air sampling results were communicated to the Fernald management team. There was a shift in DOE policy on release to the environment. DOE did not effectively inform Fernald of this change.

A release of uranium hexafluoride occurred at an operation in the Pilot Plant on February 14, 1966. The Pilot Plant released approximately of 3,800 lbs of UF_6, carrying it from the Pilot Plant, over the administration building and main laboratory, over the parking lot, and into the cow pasture. The site was not well prepared for this type of emergency at the time. This release was referred to as the Cutter release, and is formally documented. There was a large amount of bioassay samples collected around this time.

Routine sampling of rivers, sumps, wells, etc., was performed. Fernald developed an Advanced Wastewater Treatment System to pump and treat water from the aquifer. Once it is treated, the water is released to the Great Miami River or injected back into the aquifer. The extraction wells were supposed to be free of contamination, although the wells were periodically found to be contaminated. There were indicators of contamination in the groundwater. The rain would fall on contaminated soil and migrate offsite, creating a plume. The source of groundwater contaminated was water that found its way to Paddy Run Creek through a sand lens and eventually down to the aquifer.

Prior to construction of the Fernald plant, soil samples were made for engineering purposes, and groundwater flow rates were determined to evaluate water supply and quantity. In the remediation era, soil samples were conducted under the process buildings. During remediation, individuals were exposed to the contaminated soil after buildings were demolished. During soil remediation at Fernald, there were areas where the contamination went deeper into the soil than anticipated.

During the Shaw Project, soil was located into railcars and shipped to Envirocare. If the maximum acceptable concentration was not met, uranium metal would be thrown into the railcar as well. Site experts were uncertain whether Envirocare was aware of this practice.

Until at least 1991, a Reuter-Stokes High Pressure Ionization Chamber was used for environmental radiation measurements. In addition, micro-R surveys were conducted. Since these measurements were easier to take, more Micro-R measurements were taken at each location. These measurements were taken to compare them with the Reuter-Stokes data. There was usually good agreement. In about 1991, environmental TLDs were also implemented to measure radiation levels in the environment.

Once the radioactive material was placed in the silos, there wasn't much of an issue with exposure to personnel. The silos were left alone, except that the grass around the silos had to be mowed, because there was a snake issue. This exposed individuals to radon from the silos. Individuals also found contaminated animals in the site buildings.

Both episodic and routine releases are documented in the environmental report. There is a separate chapter addressing episodic releases. The most important episodic releases from an occupational standpoint were those that occurred inside the buildings, rather than to the environment. There have been no calculations of environmental dose to onsite workers to the knowledge of site experts.

Dr. Quigley met with a representative of the Ohio Department of Health, and they agreed on limits for uranium, alpha and beta radioactivity, and fluoride in the Greater Miami River. There was also an agreement on how periodic reports would be made to the Ohio Department of Health. The local AEC office followed the lead of the Oak Ridge and Washington AEC offices in their dealings with local and state governmental agencies. If there was compliance with a state or local request, it was usually identified by the local AEC office in written documents as a matter of "comity." The State of Ohio and Fernald periodically did split sampling (e.g., milk from cows grazing on Fernald property). Eventually, the state established a few offsite radon-monitoring locations. They also monitored air pollution parameters throughout the county and region, and did let Fernald co-locate some background radon monitors at one of their stations near the University of Cincinnati for a period of time. There were cooperative studies with Hamilton County. The county established its own radon monitoring locations. Fernald and the county shared data.

Incidents

The Communications Center was notified when there was a safety incident or unusual event. The Communications Center would, in turn, send emergency responders if there was a fire or if individuals were injured. During an incident, Security guarded the area. There were incidents (major and minor) almost on a weekly basis.

There were IIRs that a worker could fill out if an anomaly had occurred. These were self-initiating reports, with which workers could request special bioassay when they suspected an uptake. The technicians could also issue an IIR if they felt there was a possible intake. There were no formal trigger levels for special bioassay. The IIRs were filed in the employees dosimetry file. Samples associated with incidents were analyzed and, if they were positive, there may have been a further investigation. The results of the investigation were communicated to the worker. If an incident resulted in the assignment of dose, a formal report was issued. If an injury occurred, a description of the injury and the treatment were documented in the medical file. If Fire and Safety responded, they also issued a report. Industrial Hygiene incidents were documented in letters to the division director. Other sources of incident information include urinalysis records, in-vivo counting records, and various ancillary records.

Significant incidents had to be reported to the DOE or its predecessor within 24 hours of occurrence. The DOE would do an investigation of the incident. Corrective actions were determined during the investigation. The site also had internal reports, which succinctly described the incidents. Lessons learned were also developed throughout the complex and shared with other sites. Although Fernald per se did not maintain a database of these incidents, they were input into a database by DOE.

Uranium fires occurred in Plants 5, 6, and 9 on a daily basis. When shavings or derbies would catch on fire, personnel would try to extinguish it by placing a shovel full of MgF_2 over it, or by using fire or garden hoses to cool the drums. Type D Fire Extinguishers were added later. If the material continued to burn, a forklift driver would move the drums of burning shavings to a safer area. At times, the derbies continued to burn even after fire extinguishing efforts. At this point, they had to let the material burn. At times, derbies would catch on fire during the off hours. When the day shift came in, they found a pile of black oxide rather than a derby. During welding operations in Plant 8, a fire occurred in the northwest corner.

Other incidents or unusual occurrences mentioned by site experts include the following:

- On January 20, 1992, there was a fire at the Boiler Plant. Offsite emergency personnel were called in to assist with the situation. These individuals had to be escorted by Security.
- Plant 4 shut down for 30 days, due to a spill involving plutonium in the late 1970s or early 1980s.
- In Plant 9, there was an incident where a furnace kiln blew up. There were two fatalities as a result.
- When operations cleaned the scales with a vacuum, there were occasions where the vacuum would blow up.
- There were routine Rockwell furnace blowouts during the reduction process. Material would come out both the top and the bottom of the reaction vessel. Evacuation alarms would sound to alert workers in the surrounding area. Forklift personnel would remove the material immediately from the area and individuals went back to work.
- There was an incident with the early radon treatment system, where they over-pressurized the silo, resulting in a radon release to the environment.

- There was a spill of orange oxide outside the north side of Plant 2/3 by the tank farm.

There was a glove bag failure in Plant 9 in 1984. Workers called management when they noted that there was a release occurring at about 5:25 pm. The official report indicates that the release began at 6:00 pm. During the course of the investigation, witnesses of the release were not interviewed. The formal report indicates that 4 lbs of uranium were released to the atmosphere. Witnesses believe this was an underestimation. Several hundred pounds of black oxide fell out of the bottom of the silo High Efficiency Particulate Air filter, creating a large black mushroom that settled over the South Plant 9 cement pad. An investigation of excessive uranium emissions from Plant 9 was conducted by the Oak Ridge Operations Office.

In 1985, during the night shift, an individual reportedly committed suicide in Plant 6 by immersing himself in a salt bath. There were no night shift operations at the time. The bath was covered with a metal top to keep the heat losses down. He was able to move the cover enough so that he could slide into the bath. Operations noted a blip in the salt bath temperature. On the surface of the salt bath was the outline of a person. The furnace was removed from operation and the contents of the bath were emptied after some cooling. They let the material solidify and crystallize in drums. When the bath had been emptied, they found remnants of metal. This incident resulted in a formal investigation by the local Sheriff's Department.

Poor Radiological Control Practices

Radiation Safety rules were not always followed (e.g., not wearing respiratory protection). RadCon had to correct individuals through supervision when they were not adhering to the safety requirements. They were not allowed to redirect workers themselves. This changed as the Radiological Control Program improved. Some of the poor practices observed by site experts included the following:

- Individuals sometimes turned the sensitivity of the alarms down, so the alarms would readily go off.

- There was a situation where the electrical system was rewired, which affected the ventilation system in the area.

- Badges were overexposed intentionally; however, these could be distinguished from others by the high doses, contamination of the dosimeter, and the darkened clear edges on the film.

- Personnel would commonly sit on stacks of rods, derbies, or ingots. Originally they did not use rubber mats. Eventually they directed employees to put down a rubber mat before sitting on product.

- Workers took breaks next to the silos on the hill.

When unauthorized practices were observed (e.g., failure to wear appropriate PPE) in later years, the technicians were directed to issue a Radiation Deficiency Report or an Event Discovery Report. Depending on the severity of the event, disciplinary action could occur.

Miscellaneous

Individuals were strongly encouraged to sign a form allowing the DOE to take samples post-mortem for analysis. "You signed the form or you did not work," was the reported attitude conveyed at the site. In 1981, a monetary incentive was offered to sign up for the registry. This was not effective with the workers. In 1984, workers were asked to authorize the use of their bodies upon hire for evaluation by the uranium registry. The authorization was not clearly explained, and individuals and their families did not realize the government could take the bodies. Some families would guard the bodies at the corners office to ensure the body or its organs did not disappear. For a period of time in the 1960s, there was a shortage of bodies for evaluation.

When the Health Energy Radiation Branch of NIOSH was conducting a feasibility study on whether they could obtain data for an epidemiologic study, they concluded that the necessary information was not available. There was an absence or gaps in work history, exposure, and medical data at the time, limiting their ability to conduct accurate and comprehensive studies of remediation studies.

The union questioned the integrity of the data at Fernald. Dr. Lynn Wise, a member of John Glenn's staff specializing in environmental issues, visited Fernald with two assistants. On live television, the union presented Dr. Wise with supporting documentation that records had been altered. Examples of records provided were job orders, where stay times had been altered. This was one of the reasons NLO was fired. The situation is documented in congressional reports. The outcome was that some documents were determined to be altered.

Following a congressional hearing in the mid-1980s, there was a change in the film badge program. Workers also question the discrepancies in dose results between themselves and collocated co-workers.

Workers were told by supervisors that "the only way uranium could hurt you was if it fell on your head."

Medical

Medical exam frequencies have changed over time at Fernald. Many site experts remembered receiving an annual physical at one time. During medical exams, individuals submitted urine and blood samples for medical evaluation. Routine bioassay samples were collected at the time of the annual physical. Each individual was seen by a doctor. Initially, subcontractors were not provided with medical exams and x-rays. Later, medical x-rays were provided every other year. According to some site experts, NLO lost some of the worker medical records in the 1970s.

Limited information was known regarding the x-ray units. Medical x-ray units were surveyed by the RCTs in the past. The Food and Drug Administration has also done inspections.

Audits and Assessments

The New York Operations Office Health and Safety Representative conducted annual assessments of the Radiological Control program for the first few years. These audits were ad hoc at first, but became more formal by the end of the 1950s. Fernald fell under the jurisdiction of the Oak Ridge Operations Office, who conducted semi-annual to annual audits of all safety program areas. During the mid-1980s, the site had one audit after another. The Defense Nuclear Facility Safety Board completed a Program Review Audit at this time. Oak Ridge Operations office and DOE headquarters also performed audits of the overall safety program. Eventually, the Ohio Field Office became responsible for conducting assessments of Fernald. Audits included evaluations of Environmental Monitoring, Industrial Hygiene and Radiation, Fire Protection and Safety, and Criticality Safety.

Other Hazards

Radiological hazards were not the only health hazards individuals encountered at Fernald. In addition to radioactive material, beryllium, mercury, asbestos, and lead were also used on the site. Some of the chemicals used in the processes included ammonia, nitric and hydrofluoric acids, degreasers, solvents, magnesium fluoride, etc. There were pounds of Be handled at the Pilot Plant. Beryllium was used as a coating for the ingot mold and crucibles, similar to a nonstick coating on a frying pan. Asbestos was reported as prevalent in many of the plants. There were releases of hydrogen fluoride into the work area and environment. When opening a system, it was not uncommon to get sprayed with hydrofluoric or nitric acid. Workers were exposed to nitric acid and hydrofluoric acid fumes, and sometimes overcome by these fumes. Acid burns were not uncommon, and some workers eventually developed chemical dermatitis. Plant 6, Plant 7, and Building 13 had issues with bird droppings, causing a health hazard.

At Plant 2/3, they would release rust-colored material to the environment. Transportation personnel were asked not to park the trucks in the general area of Plant 2/3, especially at the truck dock. Plant 9 also released nitric acid to the environment. Releases also occurred from the Pilot Plant, the Tank Farms, and Plant 4. Workers indicated that the material would burn their lungs and sometimes their skin.

Hoppers had seals that would breach, releasing hydrofluoric acid and product. This was particularly a problem when the product got low. Alarms for this type of release were not consistent, and at times did not work or did not sound. If the workers visually saw the clouds, they would exit the area. There was no guidance given for re-entry. If they were able to breath, individuals would re-enter the building.

A beryllium surveillance program exists; however, it is not inclusive of all individuals potentially exposed to beryllium at Fernald. There have been positively diagnosed cases of Berylliosis in Fernald workers. Some bioassay sampling was completed prior to and after lead jobs.

There were also industrial safety hazards at Fernald during both the production and remediation era. For example, there were problems a couple of times during remediation with vehicles (dozers and trucks) falling into the pits.

Technical Basis Document Comments

Several comments were made by site experts concerning the NIOSH Fernald TBD.

- The NIOSH TBD is based on urine, air monitoring, and dosimeter results. These values may not be representative of the exposure conditions.

- NIOSH/ORAU has been provided with Plant-by-Plant process information.

- Tables of projected exposures to employees in the NIOSH TBD include a Decontamination Factor (DF) for many operations, based on use of a respirator. There is no indication of when the DF is applied. Workers, particularly those working prior to the mid-1980s, indicate that respirators were rarely used. Consequently, the potential exposures in the TBD may be underestimated.

NIOSH held a worker outreach meeting in November 2003. The TBD was completed March 2004.